

**SHELF-LIFE ENHANCEMENT OF FRESH BENGAL  
GRAM KERNELS**

**शुद्धता और सुरक्षा के लिए खाद्य प्रसंस्करण/संयोजन**

**BY**

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**CERTIFICATE - I**

This is to certify that **Mr. Kushal Pramod Dhake** has successfully completed the comprehensive examination held on **11/04/2012** as required under the regulations for Master of Engineering in Processing and Food Engineering.

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**CERTIFICATE - II**

This is to certify that this thesis entitled “**Shelf-life enhancement of fresh bengal gram kernels**” submitted for the degree of **Master of Engineering** in agriculture in the subject of **Processing and Food Engineering** embodies bonafide research work carried out by **Mr. Kushal Pramod Dhake** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on **07/06/2012**.

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## ABSTRACT

Bengal gram (*Cicer arietinum L.*) is a member of leguminous family. Rajasthan is the second largest gram producing state in the country. The production of bengal gram in the year 2010-11 was 13.86 lakh tons from an area of 16.42 lakh hectares. Premature bengal gram green kernels is used for direct consumption as well as for making other preparation for food items. The fresh bengal gram kernel has very short shelf life at room temperature. The modified atmosphere packaging can be used for enhancing the shelf life of fresh bengal gram kernels.

The uniform size of kernels with crop maturity 70 days of variety “Pratap Chana 01” were selected for the study during November 2011 to February 2012. The study consisted of total 18 treatments comprising of two gases oxygen and carbon dioxide with three combinations (2% O<sub>2</sub> and 8% CO<sub>2</sub>; 5% O<sub>2</sub> and 3% CO<sub>2</sub>; 5% O<sub>2</sub> and 8% CO<sub>2</sub>) and two packaging films viz. LDPE and HDPE. The storage was done at ambient, 5±1, 0±1<sup>0</sup>C. Since respiration rate is dependent on factors like storage temperature and composition of storage atmosphere, a mathematical approach was followed to predict the respiration rate under given conditions.

Some physical properties such as moisture content, colour, density, angle of repose, size and sphericity, thousand kernels mass were determined on the basis of crop maturity i.e. from 50- 100 days. Moisture content of the kernels decreased while size, sphericity and the geometric mean diameter increased as the maturity days increase. Bulk, true density and thousand kernels mass increased with the maturity. The stored bengal gram kernels were examined for physiological, quality, microbial and sensory parameters at 3 days interval till the product fully decayed. Bengal gram kernels stored at ambient lost their quality attributes very rapid, manifested by accelerated color, high respiration, rapidly changes in O<sub>2</sub> and CO<sub>2</sub>, decreases in firmness and hardness, increase in water activity, increase in bacterial and fungal count. Use of MAP retarded these changes with maximum retention of all the quality parameters and sensory attributes at low temperature condition (5±1, 0±1<sup>0</sup>C).

Treatment combination G<sub>1</sub>T<sub>3</sub> (2% O<sub>2</sub> and 8% CO<sub>2</sub> and 0±1<sup>0</sup>C) was found acceptable bases on qualitative and physiological attributes till 15 and 21 days under HDPE and LDPE packaging film, respectively.

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^irki puk 01\*\* fdLe ds l eku nku\$ 70 fnu dh Ql y ifji Dork ij bl v/; ; u grq iz kx uoEcj 2011 l s Qojh 2012 rd bl l mHkZ ea fd; k x; kA v/; ; u ds nkjku nks x\$ ka vkD l htu o dkcZu MkbZ vkD l kbM ds rhuks feJ . kka 1/2% O<sub>2</sub> o 8% Co<sub>2</sub>, 5% O<sub>2</sub> o 3% Co<sub>2</sub>, vks\$ 5% O<sub>2</sub> o 8% Co<sub>2</sub>, 1/2 ds vykok nks i s f t a x i n k F k k D P E o HDPE dh Fksy; ka ea dty 18 mipkj iz kx fd; s x; A budk HkA/kj.k okrkoj.kh; rkieku 5±1°C o 0±1°C ij fd; k x; kA yfdu ; nj HkA/kj.k rkieku o ml ds okrkoj.k ds feJ.k vuq kr vkfn ?kVdka ij fuHkZ djrh gA bl fy; \$ mYyf [kr gkykr ea 'ol u nj ds vuqku grq, d xf.krh; rjhdk dke eafy; k x; kA

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G<sub>1</sub>T<sub>3</sub> mipkj l a kst d 1/2% O<sub>2</sub>, 8% Co<sub>2</sub> o 0±1° l S 1/2 xqkoYkk Lohdfr vks\$ HkkSrd ?kVdka ij HDPE o LDPE i s f t a x ijr ij 15 vks\$ 21 fnu rd Øe'k% l okk'ke ik; k x; kA

## CHAPTER 1

## INTRODUCTION

Bengal gram (*Cicer arietinum L.*) is a member of leguminous family. The name Cicer is of Latin origin and is derived from Greek word 'kikus' meaning force or strength. Different Indian states have different name for Chana (chickpeas) aslike it is called in northern states, *Chhole* in Punjab, *Chola* in west Bengal, *Boot* in Orissa, *Sanagulu* in Andhra Pradesh, *Kadale* in Karnataka, *Kadalai* in Tamil Nadu and *Kadala* in Kerala. Bengal gram is the third most important pulses crop in the world after dry bean and dry peas. Bengal gram is a major pulse crop in the Indian subcontinent and several other countries. It is used as an edible seed as well as for making dhal and besan etc. and is broadly divided into two categories i.e. *Kabuli* and *Desi* according to the colour, seed size and taste.

*Desi* chana has a small dark seed and rough coat and also called as Brown gram, *Desi* gram or Kala chana. It make up 85- 90% of world's production whereas *Kabuli* chana is light, almost whitish cream colour, with larger seeds and a smoother coat as compared to the *desi* chana. It makes up the balance 10-15% of world's production.

India is single largest producer of bengal gram, contributing for about 67% of the global production. Other major producing countries are Pakistan, Turkey, Australia, Iran, Ethiopia and Myanmar. Besides leading producer, India is the biggest consumer of bengal gram in the world. The Indian production is estimated to be between 4-7 million tons per year. Normally bengal gram accounts for 4-7 million tons (40-45%) of India's total pulses crop production of 12-15 million tons. Major producing states are Madhya Pradesh, Rajasthan, Uttar Pradesh, and Maharashtra. More than 75 per cent of gram is consumed as dal and besan flour in India(<http://en.wikipedia.org/wiki/Chickpea>). The production of bengal gram in the year 2010-11 was 8.25 million tons from an area of 9.51 million hectares. Bengal gram production has increased by 36 percent between 2004 and 2011 with 25 percent expansion in acreage and 9 percent improvement in yield ([http://eands.dacnet.nic.in/latest\\_2006.htm](http://eands.dacnet.nic.in/latest_2006.htm)).

Rajasthan is the second largest gram producing state in the country. Rajasthan has the capacity to produce around 25-30 lakh tons chana if rains occur on time and farmers take full interest in its sowing. Mostly *desi* chana is produced in Rajasthan. Sowing starts in November to December which converts in arrival during March. In Rajasthan, bengal gram is cultivated as a rainfed (Barani) crop in most of the districts, therefore production fluctuates year to year. The production of bengal gram in the year 2010-11 was 13.86 lakh tons from an

area of 16.42 lakh hectares  
(<http://www.mpuat.ac.in/images/editorFiles/file/AMIC/Chana%2015-03-11.pdf>).

The fresh bengal gram kernels has 60-65% moisture content, 27-28 % carbohydrates, 8.86% protein and other nutrients like fats, sugars etc. Bengal gram is also considered to have medicinal effects and is used for blood purification. Chana is widely appreciated as health food. It is a protein-rich supplement to all cereal based diet, especially for vegetarians. Pulses proteins are rich in lysine and have low sulfur containing amino acids. It offers the most practical means of eradicating protein malnutrition among vegetarian children and nursing mothers.

Considering the nutrient and food value of fresh bengal gram kernels, there is an immense need to enhance its availability in India and world. It is perishable in nature leading to sensory as well as nutrient loss at very high rate. Still, there is almost no appropriate method to preserve bengal gram kernels in fresh form. The present day consumer prefers the vegetables in fresh form with convenience in use. The fresh produce has a short shelf life at ambient condition.

In today's world of population explosion, the importance of food preservation hardly needs any emphasis. Food preservation has a special relevance to the developing country like India, a heavily populated country. In a tropical country like India varying climatic conditions and seasons of gluts and scarcity, modified atmosphere packaging, cold storage and refrigeration have a very important role to play in shelf life enhancement and preservation of perishables. Freezing of food is well recognized all the world over as the best method of preservation of foods, yielding products in quality very close to that of the fresh ones. Food distribution has undergone two major revolutions in the last century, canning and freezing making easy availability to most type of produce throughout the year. However, energy crisis, ecological awareness and demand for healthy and fresh food have created a need for a technology that allows distribution of fresh produce around the year, based on minimum processing and little energy and maximize retention of nutrition and flavour.

Storage under controlled atmosphere/modified atmosphere is known to extend the shelf life of fresh vegetables by retarding their physiological metabolism (Kader *et al.*, 1989). The shelf-life of perishable foods such as meat, poultry, fish, fruits and vegetables and bakery products is limited in the presence of normal air by two principal factors i.e. the chemical effect of atmospheric oxygen and the growth of aerobic spoilage micro organisms.

These factors either individually or in association with one another bring about changes in odour, flavour, colour or texture leading to an overall deterioration in quality. Chilled storage will slow down the undesirable changes but will not necessarily extend the shelf-life sufficiently for retail distribution and display purposes. The scope of present study is to investigate the effect of MAP at different storage condition for enhancement of shelf life of green bengal gram kernels.

### **1.1 Modified Atmospheric Packaging**

Modified atmosphere packaging (MAP) is an ideal preservation technique (Mangaraj and Goswami, 2009) and is known to have great potential for extending the post harvest life of fruits and vegetables (Thompson, 1998). MAP is used to reduce the amount of oxygen present in the headspace of the product. The oxygen level inside the package limits the shelf life of the product in terms of aerobic microorganisms (Ponte *et al.*, 1993).

The main function of modified atmosphere packaging (MAP) is to change the composition of the atmosphere around the product so that the storage life of the product can be extended. Most fruit and vegetables age less quickly when the level of oxygen in the atmosphere surrounding them is reduced. This is because the reduced oxygen slows down the respiration and metabolic rate of the products and therefore slows down the natural aging process. Use of absorbents (O<sub>2</sub>, CO<sub>2</sub> and ethylene) in MAP as active packaging of fresh fruits and vegetables could help in extending the storage life and maintain the freshness inside MA packages (Thompson, 1998).

### **1.2 Justification**

India has diverse agro-climatic conditions and has a large and diverse raw material base suitable for food processing companies. At present a very small percentage of food production is processed into value added products. Factors like rapid urbanization and rising per capita incomes have caused rapid growth and changes in demand patterns. It is to be noted that an average Indian spends about 50 percent of his household budget on food items. This continues to sustain the demand for processed food. (<http://indianfoodprocessing.blogspot.com/2008/10/free-marketing-report-on-food.html>)

Premature bengal gram green kernels is used for direct consumption as well as for making their preparation for food items. The depodding and shelling is done manually and green fresh kernels are used for making different vegetables, sweet dishes and as a

substitute of pea in rice and pulao etc. Green bengal gram kernels have a good demand as a convenience/ ready to use product, if made available as fresh for long time and increased shelf life. The depodding of bengal gram green plant and shelling of individual pod are cumbersome and time consuming operations. No successful mechanical interventions are available for facilitating these operations; hence fresh bengal gram kernels are still not available round the year in the market like frozen pea or other minimal processed vegetables as ready to use products. The fresh bengal gram kernel has very short shelf life at room temperature. The modified atmosphere packaging can be explored for enhancing the shelf life of fresh bengal gram kernels.

Food packaging technologies maintain freshness, quality and help a lot in extending shelf-life. The physical shelf-life of the packaged products taking into account their fitness for human consumption along with their essential nutrients and bioactive compounds etc. can be enhanced by means of suitable packaging technologies such as MAP. MAP has become a widely used food preservation technique, which minimally affects fresh produce characteristics and hence fit in the recent consumer preference for fresh and additives free food. MAP is being used increasingly for extending shelf life, improving the product image and reducing the wastage of a wide range of whole fresh prepared fruits and vegetables (Day *et al.*, 2001).

Hence, with a view to enhance shelf-life and retain the quality of fresh bengal gram kernels, this study is proposed with the following objectives:

- a. To determine the physical properties of fresh bengal gram kernels.
- b. To study the effect of MAP on the shelf life enhancement of fresh bengal gram kernels.
- c. To study the effect of packaging material and storage temperature on quality of bengal gram kernels.

## **CHAPTER II**

### **REVIEW OF LITERATURE**

A comprehensive review of literature is a must in any research endeavor. It gives an excellent overview of work done in any particular field and helps in keeping up with recent developments. So, this chapter deals with the review of the research work carried out by various researchers related on physical properties of fruits and vegetables, modified atmospheric packaging, and storage of grains, fruits and vegetables. The available review related to the present study has been organized and presented hereunder.

#### **2.1 Physical properties**

Physical properties of kernels are necessary for the design of equipments for harvesting, processing, and transportation, separating and packaging operations.

Mohsenin, N. N. (1970) described methods to determine the important physical parameters like shape size, bulk density, moisture content, true density, specific gravity,

porosity which are important in many problems associated with design of specific machines and analysis of behavior of product.

Balasubramanian, D. (2001) studied physical properties of raw cashew nut as a function of moisture content. The average dimension of three principal axes (*viz.*, length, width, thickness), mass ratio, equivalent diameter and sphericity were measured at a moisture content of 8.46% d.b. The 100 nut mass, porosity, bulk density, true density were determined for moisture contents ranging from 3.15 to 20.05% d.b. It was found that the 100 nut mass and true density of raw cashew nuts increased with increased moisture content. The porosity and bulk density decreased linearly as the moisture content increased.

Nimkar and Chattopadhyay (2001) studied the physical properties of green gram. They determined various properties in the moisture content range of 8.39–33.40% d.b. As the moisture content increases the weight of thousand seeds increases while the bulk density decreases simultaneously. The true density, porosity, sphericity, projected area, terminal velocity increases with moisture content.

Konak *et al.*, (2002) studied the physical properties of chick pea (Bengal gram) as a function of moisture content. The average length, width, thickness, the geometric mean diameter, unit mass and volume of seed were 9.342 mm, 7.722 mm, 7.752 mm, 8.358 mm, 0.324 g and 0.238 cm<sup>3</sup>, respectively, at a moisture content of 5.2% d.b. Studies on rewetted seed showed that as moisture content increased from 5.2 to 16.5% d.b., bulk and kernel density decreased from 800 to 741.4 kgm<sup>-3</sup> and from 1428 to 1368 kgm<sup>-3</sup>, respectively. With increasing moisture content, porosity increased from 43.97 to 45.8%, projected area from 1.16 to 1.42 cm<sup>2</sup>, angle of repose from 24.5 to 27.8 and terminal velocity from 8.3 to 9.8ms<sup>-1</sup>.

Sahoo and Srivastava (2002) studied the physical properties of okra seed were evaluated as a function of moisture content. The average length, breadth and thickness of the seed varied from 5.92 to 7.30, 4.71 to 5.40 and 4.59 to 5.36 mm, respectively, as the moisture content increased from 8.16 to 87.57% d.b. The roundness and sphericity increased from 77.76 to 79.35% and 74.48 to 76.52%, respectively, with increase in moisture content from 8.16 to 19.56% d.b. and then decreased to 72.39 and 70.63%, respectively, with further increase of moisture content. In the moisture range of 8.16–87.57%, the seed volume increased from 0.067 to 0.124 cm<sup>3</sup>, 1000 seed weight from 65.78 to 129.75 g and the angle of repose from 27.60 to 39.478. The bulk density, true density and porosity decreased from 0.592 to 0.558 g cm<sup>-3</sup>, 1.107 to 0.986 g cm<sup>-3</sup> and 46.34 to 43.20%, respectively, in the moisture range from 8.16 to 87.57% d.b.

Tabatabaeefar (2003) evaluated the various physical properties of five varieties of wheat for moisture content in the range of 0 to 22% d.b. The average length, width, thickness

and thousand-kernel weight were 7.08, 3.27, 2.98 mm and 29.6 g at a moisture content of 7.4% d.b. The average length for dry land farming wheat varieties was longer than for that irrigated. The average geometric mean diameter and percentage of sphericity was 4.26 and 60. Studies on rewetted wheat showed that the bulk and true densities decreased from 740 to 538.8 kg m<sup>-3</sup> and 1240 to 847.2 kg m<sup>-3</sup>, whereas the corresponding bulk porosity increased.

Yalcin *et al.*, (2007) studied the physical properties of pea seed (*Pisum sativum*) as a function of moisture content. The average length, width and thickness were 7.80, 6.41 and 5.55 mm, respectively, at a moisture content of 10.06% dry basis (d.b.). As the moisture content increases the weight of thousand seeds increases. The bulk density decreases, simultaneously the true density, porosity, sphericity, and projected area, terminal velocity increases.

Ahmadi *et al.*, (2008) studied the physical and mechanical properties of Apricot fruit, pit and kernels. The physical and mechanical properties were determined at 84.19, 17.01 and 17.46% moisture contents for apricot fruits, apricot pits and apricot kernels respectively. Bulk densities of fruits, pit and kernels were 449.5, 440.78 and 406.79 kg/m<sup>3</sup>, the corresponding true densities were 1037.5, 892.63 and 983.38 kg/m<sup>3</sup> and the corresponding porosities were 56.66, 50.62 and 52.32%, respectively. The volumes, mass and surface area of fruits were larger than those of nuts and kernels. The static coefficient of friction of fruit on all surfaces studied (wood, glass, galvanize sheet and fiber glass sheet) were the highest as the surface is viscous and hardness is less.

Gharibzahedi *et al.*,(2011) evaluated the physical properties of castor seed as a function of moisture content in the range of 6.24 to 12.56% d.b. The average length, width, thickness and one thousand seed mass were 10.24 mm, 6.81 mm, 5.05 mm and 195g, respectively at a moisture content of 6.24% d.b. The geometric mean diameter and sphericity increased from 7.06 to 7.16 mm and 67.62 to 67.84% as moisture content increased from 6.24 to 12.56% d.b. respectively. In the same moisture range, bulk density decreased from 517.64 to 497.65 kg m<sup>-3</sup>, true density increased from 908.99 to 989.65 kg m<sup>-3</sup>, and the corresponding porosity increased from 43.05 to 49.71%. As the moisture content increased from 6.24 to 12.56% d.b., the repose angle, terminal velocity and surface area increased from 31.5 to 34.3°, 5.56 to 5.79 ms<sup>-1</sup> and 131.97 to 136.08 mm<sup>2</sup>, respectively.

## **2.2 Modified Atmospheric Packaging**

Vegetables are highly perishable in nature and if these vegetables are minimally processed then their chances of perishing increases many folds. The quantity of the vegetables influences marketing and processing, on which the return of the grower depend. So, there is a need to handle and store fresh cut vegetables in a more convenient environment. Incorrect

storage practices not only decrease shelf life of vegetables because of increase in respiration rate and metabolic activities but also facilitate the entry of spoilage micro-organism.

Young *et al.*, (1988) defined modified atmospheric packaging (MAP) as the perishable product in atmosphere, which has been modified so that its composition is other than that of air. Modified atmospheric packaging (MAP) is a technique wherein fresh food products are enclosed in gas-barrier material using different gas combinations as per the requirement of the respective food product to prolong its shelf life.

Kader *et al.*, (1989) and Phillips, (1995) proposed the use of low O<sub>2</sub> concentration (1-5%), high CO<sub>2</sub> concentration (5-10%) and balance N<sub>2</sub> in combination with storage at refrigeration temperatures ( $\leq 7^{\circ}\text{C}$ ) as optimal storage condition for fresh-cut vegetables to maintain the sensorial as well as the microbial quality.

Beaudry *et al.*, (1992) investigated the effect of temperature on O<sub>2</sub> and CO<sub>2</sub> in modified-atmosphere packaging of Blueberry Fruit. Fruit sealed in low-density polyethylene packages were incubated at 0, 5, 10, 15, 20, or 25<sup>o</sup>C until O<sub>2</sub> and CO<sub>2</sub> levels in the package reached a steady state. A range of steady-state O<sub>2</sub> partial pressures (1 to 18 kPa) was created by placing a range of fruit weights within packages having a constant surface area and film thickness. The steady-state O<sub>2</sub> partial pressure in packages containing the same weight of fruit decreased as temperature increased, indicating the respiratory rate increased more rapidly (i.e., had a greater sensitivity to temperature) than O<sub>2</sub> transmission through the film. Steady-state O<sub>2</sub> and CO<sub>2</sub> partial pressures were used to calculate rates of O<sub>2</sub> uptake, CO<sub>2</sub> production and the respiratory quotient (RQ). The effects of temperature and O<sub>2</sub> partial pressure on O<sub>2</sub> uptake and CO<sub>2</sub> production and the RQ were characterized. The steady-state O<sub>2</sub> partial pressure at which the fruit began to exhibit anaerobic CO<sub>2</sub> production (the RQ breakpoint) increased with increasing temperature, which implies that blueberry fruit can be stored at lower O<sub>2</sub> partial pressures when stored at lower temperatures.

Meheriuk *et al.*, (1995) studied the effect on stored sweet cherries at 0<sup>o</sup>C under modified atmospheres for 10 weeks. Atmosphere within low density polyethylene bags of 38  $\mu$  thickness equilibrated to 0.8% O<sub>2</sub> and 4.5% CO<sub>2</sub> by the second week of storage. Brightness of the fruit (L values) declined after 6 weeks and firmness decreased after 8 weeks. Acceptability remained high for 46 weeks of storage but decreased appreciably thereafter.

Artés *et al.*, (2000) studied modified atmosphere packaging of pomegranate arils. Sweet pomegranates (*Punica granatum* L.) were stored at 2 or 5 <sup>o</sup>C for 12 week in unperforated polypropylene (UPP) film of 25  $\mu$ m thickness in modified atmosphere packaging (MAP). Perforated polypropylene (PPP) film of 20  $\mu$ m thickness and conventional cold storage (15<sup>o</sup>C and 75% RH) were applied as control treatments. PPP at 5<sup>o</sup>C was the best

treatment for maintaining red skin-color of the arils at the end of storage. All treatments suffered a decrease in total anthocyanins content at the end of shelf life. Arils in UPP had higher values of absorbance at 510 and 446 nm. MAP strongly reduced water loss and chilling injuries without incidence of decay.

Pariasca *et al.*, (2000) determined the effects of precooling, modified atmosphere packaging (MAP) and controlled atmosphere (CA) storage on the storability of snow pea pods at 5°C. The appearance of pods stored under CA conditions was much better than that of air-stored pods (control). Low O<sub>2</sub> (2.5 kPa with 5 kPa CO<sub>2</sub>) and high CO<sub>2</sub> (10 kPa with 5 kPa O<sub>2</sub>) concentrations have a detrimental effect on quality of stored pods.

Chu *et al.*, (2001) conducted the experiment on carrot cv. sixpack. These were cut into sticks, slices (1 cm thick), quarter and whole. Then these carrots were stored in different controlled atmosphere (CA): air; 1.5-2.5% O<sub>2</sub>, 50-200 ppm CO<sub>2</sub> and balance N<sub>2</sub>; and 0.5% O<sub>2</sub>, 50-200 ppm CO<sub>2</sub> and balance N<sub>2</sub>. Cutting style affected the respiration rate of carrots. The highest respiration rate was in those cut into sticks, while the lowest rate was in the whole carrot. Low O<sub>2</sub> atmosphere reduces the respiration rates but might also increase the risk of their incurring low O<sub>2</sub> injury.

Day *et al.*, (2001) Modified atmospheric packaging (MAP) has become a widely used food preservation technique, which minimally affects fresh product characteristics, and hence fits in well with the recent consumer preference for fresh and additive free food. MAP is now being used increasingly for extending the shelf life, improving the product image and reducing the wastage of wide range of whole and fresh prepared fruits and vegetables.

Chang *et al.*, (2002) investigated that the effects of modified atmosphere packaging (MAP) on the storage life of loquat fruit. Fruit in MAP had minimal water loss (0.9–1.5%), while perforated polyethylene (PE) packaged fruit had 8.9% water loss after storage for 60 days at 5°C. Fruit stored at high temperature (20°C) sustained severe decay, and MAP increased the incidence of decay. Loquat fruit packaged under these atmosphere conditions could be stored for 2 months at 5 °C with a higher quality and minimal risk of disorder development.

Jayas and Jeyamkondan, (2002) consumer demand for more natural, minimally processed and fresh food is increasing. Modified atmosphere (MA) storage is a well-proven technology for preserving natural quality of food products in addition to extending the storage life. This technique can be integrated with active or interactive packaging to improve or control the package atmosphere to achieve superior product quality and safety.

Masniyom *et al.*, (2002) investigated the effect of modified atmosphere packaging on the keeping quality of seabass slices stored at 4°C. Seabass slices stored in CO<sub>2</sub>-enriched

atmosphere had lower total volatile base, trimethylamine, ammonia and formaldehyde contents than those stored in air. The increase in lightness and exudates loss were observed for samples packaged in high-CO<sub>2</sub> atmosphere, suggesting the denaturation of both muscle and pigment proteins by carbonic acid formed. The shelf-life of seabass slices packaged in 80–100% CO<sub>2</sub> atmosphere could be extended to more than 20 days at 4°C, compared with 9 days for those packaged in air.

Rai *et al.*, (2002) reviewed that the effect of modified atmospheric packaging on quality and shelf life of fruits and vegetables. Modified atmospheric packaging (MAP) is intended to create an appropriate gaseous atmosphere around a commodity packed in film packages to enhance shelf life and to conserve the quality of packaged produce. One of the most important factors to be considered during design of MAP is the selection of packaging film whose permeability to different gases would help in regulating the gaseous exchange during storage. However, MAP is only a supplement to good temperature and humidity management as any change in storage environment can push up the respiration rate of packed produce to dangerous levels resulting in spoilage. Hence application of MAP to a wide range of fruits and vegetables may help in ensuring maximum returns to the producer and a long-lasting quality product for the consumer.

Rai *et al.*, (2002) reviewed that MAP is intended to create an appropriate gaseous atmosphere around a commodity packaged in film package to enhance shelf life and to conserve the quality of the packaged produce. One of the most important factors to be considered during design of MAP is selection of packaging film whose permeability to different gases would help in regulating gaseous exchange during storage. However, MAP is only a supplement to a good temperature and humidity management as any change in storage environment can push up the respiration rate of packaged produce to dangerous levels resulting in spoilage.

Sandhya (2002) studied the modified atmospheric packaging of peas cv. Pb-87 after packaging in LDPE, HDPE and polypropylene of 25 µm thickness and storing at ambient, -11°C, 5°C and 15°C. The shelf life of shelled peas packaged in different types of films was 4, 45, 17 and 7 days when stored at ambient, -11°C, 5°C and 15°C respectively. At 5°C, with 5% CO<sub>2</sub> in LDPE packages, the shelf life was 20 days.

Moretti *et al.*, (2003) studied the evaluation of different oxygen, carbon dioxide and nitrogen combinations employed to extend the shelf life of fresh-cut collard greens. Collard green leaves were minimally processed (3 mm thick) inside a cold room (13±2°C). These samples were stored under two controlled atmosphere (CA) conditions (3% O<sub>2</sub>, 4% CO<sub>2</sub>; 5% O<sub>2</sub>, 5% CO<sub>2</sub> and balance N<sub>2</sub>), and normal air (control), at 5°C (95±2% RH), for six days.

Daily, minimally processed collard greens were evaluated for total vitamin C, total chlorophyll, total soluble solids content, and titratable acidity. Total vitamin C content decreased for all treatments during the storage period. Storage under CA conditions delayed total vitamin C degradation for both atmospheres studied. At the end of the storage period, fresh-cut collard greens stored under 3% O<sub>2</sub>, 4% CO<sub>2</sub> showed around 25% and 56% more vitamin C than the material stored under 5% O<sub>2</sub>, 5% CO<sub>2</sub> and control, respectively. Total chlorophyll content decreased during the storage period. At the end, fresh-cut collard greens stored under 3% O<sub>2</sub>, 4% CO<sub>2</sub> showed 24% and 45% more total chlorophyll than the product stored under 5% O<sub>2</sub>, 5% CO<sub>2</sub> and control, respectively. CA storage delayed organic acid degradation. On the sixth day, fresh cut collard greens stored under 3% O<sub>2</sub>, 4% CO<sub>2</sub> presented around 44% more organic acids than control. Total soluble solids content were not significantly affected.

Gongnian *et al.*, (2004) studied the impact of modified atmosphere packaging (MAP) with low oxygen & high carbon dioxide on the preservation of strawberry. A combination of 2.5% O<sub>2</sub> with 15% CO<sub>2</sub> was the optimum gas composition for strawberry MAP, which prolonged the shelf-life of strawberry compared to storage in the open air by 4~6 days. When strawberry was pre-treated with a 4.3 mg m<sup>-3</sup> ozone water dip and an edible coating prior to packaging, the shelf-life was extended to 8~10 days.

Davoodi (2005) studied extension of shelf life of tomato using modified atmosphere packaging. He carried out the storage studies at two different low temperatures i.e., 8±1°C and 13±1°C. Ripening and other associated changes in mature green tomato fruits were delayed and their shelf life was extended up to 42 and 35 days at 8°C for varieties. Stored fruits under MAP conditions at 8±1°C and 13±1°C. were taken out and kept at ambient condition for ripening for 5 days. Ripened fruits showed very good overall sensory quality attributes for both the varieties of tomatoes. He also studied that micro perforated poly propylene film packages for storage of tomato could extend the shelf life up to 35 and 28 days for var. Avinash and Madanapally, respectively.

Chauhan *et al.*, (2006) studied textural properties of modified atmosphere packaged banana (var. Pachbale), stored at 13 ± 1°C, followed by ethrel induced ripening at 30 ± 1°C. Modified atmosphere included active as well as passive types involving flushing of polyethylene pouches (100 gauge) with specific gas mixture (3% O<sub>2</sub> + 5% CO<sub>2</sub> + 92% N<sub>2</sub>) at partial vacuum (52.63 kPa), respectively. The MAP applications resulted in varied response of various textural parameters including penetration, shear, force-relaxation, and instrumental texture profile analysis. Both the gas flushed, as well as passive MAP stored samples, followed a trend similar to that for control ones, however, the partial vacuum packaged

bananas showed persistence of overall texture followed by normal ripening under ethrel induction. The ripened fruits from all the three types of MAP applications did not show any impediment to the instrumental textural quality.

Cia *et al.*, (2006) studied the effect of different packaging plastic materials on extending the storage life of 'Fuyu' persimmons kept under refrigeration. 'Fuyu' persimmon fruits were packed in different packaging materials: 58- $\mu\text{m}$  multilayer polyolephynic film (PO); 50- $\mu\text{m}$  low density polyethylene film (LDPE) and 38- $\mu\text{m}$  micro perforated PO. Unpacked fruit stored in corrugated cardboard boxes were used as control. Fruit were stored at  $1 \pm 1$  °C/ $90 \pm 5\%$  RH for 90 days. These results suggest that the 58- $\mu\text{m}$  PO and 50- $\mu\text{m}$  LDPE films are suitable for atmosphere modification and packaging of 'Fuyu' persimmon fruit stored under refrigeration with an additional period of time at ambient temperature.

Martin-Diana *et al.*, (2006) used whey permeate at different concentrations (0.5%, 1.5% and 3%) as natural sanitizing agent in the washing treatment of fresh-cut lettuce and carrots. These treatments were compared with a chlorine 120 ppm widely used in the industry. Microbiological, quality (colour changes, browning-related enzymes, headspace gas composition, textural changes and sensory analysis) and nutritional (ascorbic acid and carotenoids) markers were monitored over 10 days in fresh-cut lettuce and carrot packages stored at 4°C. Whey permeate at 3% resulted in equivalent or better microbial load reduction than chlorine. Although lower concentration of whey permeates produced minor initial reduction, microbial counts at the end of the storage were below the recommended levels (108 CFU/g) for safety of fresh-cut vegetables. Sensory analysis panel considered all the samples of fresh-cut lettuce acceptable. However, in the sensory results the sliced carrots treated with 3% whey permeate and chlorine scored lower acceptability due to higher surface whiteness, although these samples had lower microbial loads. Three percent WP controlled the browning-related enzymes better than 0.5%, 1.5% WP and chlorine and consequently the browning. However, this reduction in browning-related enzymes did not result in a lower browning appearance to visual observation during the 10 storage days. These results suggest that whey permeate could be a promising alternative to chlorine for sanitizing fresh-cut vegetables.

Saxena *et al.*, (2008) investigated the effect of different modified atmosphere packaging techniques for extending the shelf-life of fresh-cut jackfruit. On the basis of sensory quality attributes, the shelf-life of pretreated jackfruit bulbs packaged in gas mixture flushed PE bags, in PET jars with silicon membrane window and in PE bag were 35, 31 and 27 days, respectively.

Tim *et al.*, (2008) studied the effect of modified atmosphere packaging on the quality of strawberries. The Strawberries (cultivars Honeoye and Korona) were stored in perforated polypropylene bags at 5 °C for 10 days. The results indicated that storage in a modified atmosphere (11–14% O<sub>2</sub> and 9–12% CO<sub>2</sub>) can be used to maintain the quality of Honeoye and Korona strawberries for a longer time, than if kept in air in open containers.

Zehra *et al.*, (2008) investigated the effect of modified atmosphere packaging on the quality and shelf life of minimally processed carrots during cold storage. The carrots were packed with passive (in air) and active modified atmospheres at low (5% O<sub>2</sub>, 10% CO<sub>2</sub>, 85% N<sub>2</sub>) and high oxygen concentrations (80% O<sub>2</sub>, 10% CO<sub>2</sub>, 10% N<sub>2</sub>). Minimally processed carrots were packed in polypropylene (PP) trays sealed with PP based film. The carrots packed with high oxygen and passive MAP retained quality properties better compared to low oxygen. According to oxygen level in the headspace and sensory results, shelf life of minimally processed carrots is suggested as 7 days for high oxygen and passive MAP application.

Conte *et al.*, (2009) studied the influence of different packaging systems on quality loss of ready-to-use cherries. In particular, the fruits were packaged in oriented polypropylene-based bag and in a bio-based polymeric matrix under ordinary and modified atmosphere conditions (MAP). Cherries quality during storage was determined by monitoring headspace gas concentration, weight loss, titrable acidity, total soluble solids, maturity index, anthocyanins level, pH, viable cell load of various microbial groups and sensory quality. Results suggest that under ordinary atmosphere conditions, OPP shows the best performances. Otherwise, under MAP, both investigated films exert similar effects on the portioned fruit.

Lal *et al.*, (2009) studied the storage behavior of modified atmosphere packed date fruit stored under different conditions. Fruit of date palm at colour turning stage of maturity were packed and stored at ambient temp (35<sup>0</sup>C and 70% RH) and low temperature (7<sup>0</sup>C, 85%RH) up to 15 days. The results indicated that physiological loss in weight, spoilage and total sugar of fruit enhanced during storage.

Fernández *et al.*, (2009) investigated the effect of natural additives, super chilling, and modified atmosphere packaging (MAP) on the shelf-life of Atlantic Salmon (*Salmo salar*) fillets. The variables analyzed were: gas concentration (CO<sub>2</sub>:N<sub>2</sub>), gas-to-product volume (g/p) ratio and type of natural additive. Experiments were monitored by sensory, chemical, and microbiological analyses. Natural additives did not improve salmon shelf-life. The greatest extension of shelf life was reached by a combination of super chilling and MAP. The samples with the highest CO<sub>2</sub> concentration (90%) and g/p ratio of 2.5 showed the highest shelf-life: 22 days vs. 11 days (control sample). Microbial analysis determined the ultimate shelf-life.

Sothornvit and Kiatchanapaibul (2009) studied quality and shelf-life of washed fresh-cut asparagus in modified atmosphere packaging to determine the effect of chlorinated and ozonated water in the washing process to reduce the microbial load on fresh green asparagus and the effect of modified atmosphere packaging (MAP) on asparagus quality. Washing at 10 °C for 15 min with chlorinated water (100 mg/L free Cl<sub>2</sub>) reduced aerobic plate count which had higher efficiency on microbial reduction than the use of ozonated water (0.1 mg/L O<sub>3</sub>). Chlorine and ozone are effective surface disinfectants depending on the concentration used. Washed fresh-cut asparagus with chlorinated water and storage in an active MAP of oriented polypropylene (OPP) bags containing 8.15 kPa CO<sub>2</sub> and 17.51 kPa O<sub>2</sub> maintained its quality for 23 days at 4 °C. The color change of fresh-cut asparagus was dependent of storage time. The visual quality was used as a key factor to determine the shelf-life of fresh-cut asparagus.

Sandhya (2010) reviewed the current status and need of modified atmosphere packaging of fresh produce. Fresh produce is more susceptible to disease organisms because of increase in the respiration rate after harvesting. The respiration of fresh fruits and vegetables can be reduced by many preservation techniques. Modified atmosphere packaging (MAP) technology is largely used for minimally processed fruits and vegetables including fresh, ‘ready-to-use’ vegetables. Extensive research has been done in this research area for many decades. Oxygen, CO<sub>2</sub>, and N<sub>2</sub>, are most often used in MAP. The recommended percentage of O<sub>2</sub> in a modified atmosphere for fruits and vegetables for both safety and quality falls between 1 and 5%. Although other gases such as nitrous and nitric oxides, sulphur dioxide, ethylene, chlorine, as well as ozone and propylene oxide have also been investigated, they have not been applied commercially due to safety, regulatory, and cost considerations. Successful control of both product respiration and ethylene production and perception by MAP can result in a fruit or vegetable product of high organoleptic quality; however, control of these processes is dependent on temperature control.

Santana *et al.*, (2010) studied modified atmosphere packaging extending the storage life of ‘douradão’ peach. Fruits were packed in polypropylene (PP) trays and placed inside low density polyethylene (LDPE) bags (30, 50, 60, 75 µm thickness) with active modified atmosphere (10 kPa CO<sub>2</sub> + 1.5kPa O<sub>2</sub>, balance N<sub>2</sub>). The control was made with peaches held in nonwrapped PP trays. Fruits were kept at 1 ± 1 °C and 90 ± 5% relative humidity (RH) for 28 days and CO<sub>2</sub> and O<sub>2</sub> within packages was monitored every two days. After 14, 21 and 28 days, samples were withdrawn from MAP and kept in air at 25 ± 1 °C and 90 ± 5% RH for ripening. On the day of removal from the cold storage and after 4 days, peaches were evaluated for weight loss, decay incidence, flesh firmness, woolliness incidence, soluble solids content (SSC), titratable acidity (TA) and juice content. The results showed that MAP had influence on reducing weight loss and prevented postharvest decay. MAP of 1-2 kPa O<sub>2</sub>

and 3-6 kPa CO<sub>2</sub> at 1 °C (from 50 and 60 µm LDPE films) were effective for keeping good quality of 'Douradão' peaches during 28 days of storage, the ripe fruits showed reduced incidence of woolliness, adequate juiciness and flesh firmness. Packages of 30 and 75 µm LDPE films were ineffective for reducing woolliness during cold storage. MAP fruits showed lower SSC and no relevant effect on TA. Control fruits did not present marketable conditions after 14 days of cold storage.

Conte *et al.*, (2011) studied the shelf life of fresh-cut cime di rapa (*brassica rapa* L.) as affected by packaging. Two subsequent experimental were run to investigate first the ability of different packaging materials (an oriented polypropylene, a blend of biodegradable polyesters and a nylon/polyethylene multilayer) in delaying the quality loss and then to assess the efficacy of modified atmosphere packaging (MAP). Two different combinations of gas were investigated, oxygen 10%, carbon dioxide 2% and nitrogen 88%, noted as MAP-1 and oxygen 8%, carbon dioxide 2% and nitrogen 90%, and noted as MAP-2. Headspace gas concentration, weight loss, spoilage microbial growth, pH and sensorial quality were monitored in both sets of experiments. The results demonstrated that the best performances under ordinary atmosphere were recorded with the oriented polypropylene-based film, justifying the choice of this polymeric material in the second set-up. The tested MAPs exerted somewhat different results on product quality: the samples packaged under MAP-1 recorded a shelf life of 14 days limited by visible moulds, whereas, fresh-cut leaves sealed under MAP-2 highlighted a shelf life less than 9 days, due to a high proliferation of total mesophilic bacteria.

Khazaei *et al.*, (2011) evaluate the effect of modified atmosphere packaging (MAP) during storage on some quality parameters of bitter orange. Physical, chemical, and sensory properties were monitored at 4 °C for 20 days. Bitter oranges were sanitized, peeled, segmented and packed under normal (21%O<sub>2</sub> +79% N<sub>2</sub> as passive MAP) and two modified atmospheres (20% O<sub>2</sub>+20% CO<sub>2</sub>+60% N<sub>2</sub> as active MAP1 and 60% O<sub>2</sub>+30% CO<sub>2</sub> +10% N<sub>2</sub> as active MAP2) in polyethylene (PE) trays. In general, there was no significant effect of MAP observed in chemical properties ( $P > 0.05$ ). The firmness values increased at all applications ( $P = 0.05$ ). Bitter orange segments remained viable for 20 days under enriched oxygen (60%) and less than 20 days under active (20% oxygen) and passive MAP applications considering quality parameters. We reported that bitter oranges could be prepared as ready to eat fruits with considerable shelf-life, quality and convenience with using MAP2. The longest shelf-life was obtained with MAP containing 30% of carbon dioxide (MAP2).

Kudachikar *et al.*, (2011) studied the effect of modified atmosphere packaging on quality and shelf life of 'Robusta' banana (*Musa* sp.) stored at low temperature. Banana (*Musa* sp var. 'Robusta') stored under active and passive modified atmosphere packaging

(MAP) at  $12\pm 1^{\circ}\text{C}$  and 85–90% RH for 2 seasons was evaluated for fruit quality and shelf-life. A steady state of about 8.6 and 8.2% of  $\text{CO}_2$  and 2.8 and 2.6% of  $\text{O}_2$  in passive MAP and MAP+GK (Green Keeper) packages, respectively, were established after 3 weeks of storage. Passive MAP and MAP+GK treatments of banana resulted in reduction in physiological loss in weight (PLW) of 0.7 and 0.8% after 5 and 7 weeks of storage, respectively as against 5% PLW in openly kept green banana after 3 weeks. Both MAP and MAP+GK treatments delayed colour, texture, pulp to peel ratio and total soluble solids (TSS) content as compared to openly kept control banana. Results indicated that the shelf life of fruits packed under MAP and MAP+GK could be extended up to 5 and 7 weeks, respectively as compared to 3 weeks for openly kept control fruits. Sensory quality of fully ripe fruits of both passive MAP and MAP+GK treatments, 5 days after ethrel dip was very good. Thus, MAP+GK at  $12\pm 1^{\circ}\text{C}$  and 85–90% RH could be commercially used for long term storage and long distance transportation of banana with maximum shelf-life of 7 weeks.

Li *et al.*, (2011) conducted study to investigate the effect of 1-methylcyclopropene (1-MCP) (650 ppb) and modified atmosphere packaging (MAP) on chilling injuries (CI) of sweet pepper during 30 days storage at  $4^{\circ}\text{C}$ . The results showed that, 1-MCP and MAP reduced chilling injury symptoms which were correlated with decreased electrolyte leakage and malondialdehyde content. The activities of superoxide dismutase (SOD), catalase (CAT) and peroxidase (POD) of sweet peppers were also influenced by 1-MCP and MAP. SOD, CAT and POD activities of sweet peppers were 87.3, 28.97 and 0.248  $\text{U}\cdot\text{g}^{-1}$ , respectively at the beginning of the storage. Treatment with 1-MCP, MAP alone and in combination frequently reduced the activities of those enzymes during storage. These results suggested that, combination of 1-MCP treatment and MAP is a promising treatment for reducing chilling injuries of peppers stored at  $4^{\circ}\text{C}$ .

The benefits of MAP technology along with their drawbacks were reviewed by number of researchers (Kader *et al.*, 1989; Ben-Yehoshua *et al.*, 1994; and Mangaraj and Goswami, 2009) are illustrated below.

Advantages of MAP:

- Increased shelf-life for better use of fresh product along with retention of pigments and antioxidants;
- Convenience to consumer, especially housewife in the era of nuclear family and competition;
- Reduction in retail waste;
- Hygienic stackable pack, sealed and free from product drip and odour;
- Little or no need for chemical preservatives;

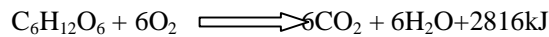
- Increased distribution area;
- Reduced transport cost due to less frequent deliveries;
- Reduced economic loss;
- Appropriate for short and long term storage;
- Improved preservation by clear view of product and all round visibility.

Disadvantages of MAP:

- Temperature and relative humidity control is necessary;
- Potential growth of food-borne pathogens due to temperature abuse by retailers and consumers;
- Benefits of MAP are lost once the package is opened or leaks;
- Cost of quality assurance systems for establishment of product safety;
- Special equipment and training is required;
- Different gas formulations for each product type;
- Increased pack volume which will adversely affect transport costs and retail display space.

### 2.3 Respiration

Respiration can be defined as the metabolic process that provides energy for plant biochemical processes. It is the process by which the stored organic materials (carbohydrates, protein and fats) are broken down into simple end products with the release of energy. Oxygen is used during this process and carbon dioxide is produced. This results in hastening of senescence, reduced food value for the consumer, loss of flavor and salable weight (Kader, 1992). Respiration is accompanied by release of heat according to the following chemical reaction (Lee *et al.*, 1991; Nikhane, 2011);



The significance of respiration in extending the shelf-life of fresh fruit and vegetables stems from the fact that there exists an inverse relation between respiration rate and the shelf-life of the commodity. Respiration rate, which is commonly expressed as rate of O<sub>2</sub> consumption and/or CO<sub>2</sub> production per unit weight of the commodity, reflects the metabolic activity of the fruit/vegetables tissue in the form of biochemical changes associated with ripening/senescence. Because of decrease in respiration rate during storage is beneficial to maintaining the quality, the accurate measurement of respiration rate has become the important factor in food research.

### 2.4 Measurement of Rate of Respiration

The rate of respiration can be expressed either as rate of O<sub>2</sub> consumption or the rate of CO<sub>2</sub> production. It is a temperature dependent parameter and can be estimated by the different method viz

Closed or static system, Flow-through system, Permeable system.

An air tight container of known volume represents a static or closed system to measure the respiration rate of commodity under the selected environmental conditions. The initial atmosphere inside the sealed container containing a known weight of the produce is ambient. The changes in the concentrations of O<sub>2</sub> and CO<sub>2</sub> inside the container are measured over a period of time and the respiration rate in terms of O<sub>2</sub> consumption and CO<sub>2</sub> evaluation is determined (Ratti *et al.*, 1996; Jacxsens *et al.*, 1999; Song *et al.*, 2002; Nikhane 2011), according to the equations 2.1 and 2.2

$$R_{O_2} = \frac{(y_{O_2}^{ti} - y_{O_2}^{tf})V_v}{100 \times M \times (t^f - t^i)} \dots\dots\dots 2.1$$

$$R_{CO_2} = \frac{(y_{CO_2}^{tf} - y_{CO_2}^{ti})V_v}{100 \times M \times (t^f - t^i)} \dots\dots\dots 2.2$$

Where,

$R_{O_2}$  : rate of  $O_2$  consumption,  $ml.kg^{-1}.h^{-1}$

$R_{CO_2}$  : rate of  $CO_2$  evolution,  $ml.kg^{-1}.h^{-1}$

$y_{O_2}^{tf}$  : Final Concentration of  $O_2$ , percent,

$y_{O_2}^{ti}$  : initial concentration of  $O_2$ , percent,

$y_{CO_2}^{tf}$  : Final concentration of  $CO_2$ , percent,

$y_{CO_2}^{ti}$  : initial concentration of  $CO_2$ , percent,

$V$  : void volume of container, ml,

$M$  : weight of produce, kg,

$t_i$  : initial time, h, and

$t_f$  : final time.

Fonesca *et al.*, (2002) reviewed modelling respiration rate of fresh fruits and vegetables for modified atmosphere packages. Respiration rate and gas exchange through the package material are the processes involved in creating a modified atmosphere inside a package that will extend shelf life of fresh fruits and vegetables. Thus, modelling respiration rate of the selected produce is crucial to the design of a successful modified atmosphere packaging (MAP) system.

Conesa *et al.*, (2007) studied the respiration rates of fresh-cut bell peppers under diverse high and low  $O_2$  levels, with or without 20 kPa  $CO_2$ , at 2, 7 and 14 °C. Weight loss and off-odor development were also monitored. A constant respiration rate of pepper dices throughout 3 days under different conditions was found. Fresh-cut peppers exposed to 0, 0.5, 1, 3 and 9 kPa  $O_2$  (all  $CO_2$ -free), and to 0 kPa  $O_2$  +20 kPa  $CO_2$ , had a lower respiration rate than peppers in the range 20–100 kPa  $O_2$  with or without  $CO_2$ . Under high  $O_2$ , 20kPa  $CO_2$  increased the respiration rate by about 20–40% compared to that in free- $CO_2$  atmospheres, this effect being lower at low temperature. High  $O_2$  had little (at 14 °C) or no effect (at 2 and 7 °C) in stimulating both  $CO_2$  reduction and  $O_2$  consumption compared to normal air. High  $CO_2$  in the range 20–100 kPa  $O_2$  increased the respiratory activity of pepper dices, probably because physiological injury occurred at 14 °C. However, 20 kPa  $CO_2$  combined with superatmospheric  $O_2$  neither induced a poor visual appearance nor off-odors. Consequently 50–80 kPa  $O_2$  combined with 20 kPa  $CO_2$  could be used in innovative modified atmosphere packaging of pepper dices to avoid fermentation and inhibit growth of spoilage microorganisms.

Menon *et al.*, (2008) summarized the modelling of respiration rate of green mature mango under the aerobic conditions. Accurate measurement of respiration rate is an important

aspect in designing and operating systems like controlled and modified atmosphere storage. The respiration rate is determined at temperatures 5, 10, 15, 20, 25 and 30<sup>0</sup>C for green mature mango using closed system method.

Dash *et al.*, (2009) suggested that accurate measurement of respiration rate is an important aspect to the success of design and operational features of technique like controlled and modified atmosphere storage. The respiration rate was determined at temperatures 5, 10, 15, 20, 25 and 30<sup>0</sup>C for Sapota fruit using closed system method of calculating respiration rate.

## **2.5 Quality of Modified atmospheric packed product**

Van der Steen *et al.*, (2002) assessed the quality of strawberries and raspberries, packaged in different consumer-sized systems. The consumer-sized packaging systems for strawberries and raspberries were compared: (1) the conventional method of packaging in a macro-perforated high-barrier film (AIR), (2) low O<sub>2</sub> modified atmosphere (i.e. 3–5 kPa O<sub>2</sub> and 5–10 kPa CO<sub>2</sub>-balance N<sub>2</sub>), (3) high O<sub>2</sub> modified atmosphere (HOA, i.e.  $\approx$ 70 kPa O<sub>2</sub>-balance N<sub>2</sub>): HOA in a high-barrier film and (4) HOA in a MA film with an adjusted film permeability. The high O<sub>2</sub> atmosphere in the MA film reached steady-state after 5 days at about 3 kPa O<sub>2</sub> and 5 kPa CO<sub>2</sub>. The O<sub>2</sub> content in the high-barrier film package remained above 21 kPa O<sub>2</sub> during the first 5 days of storage, but then decreased to anaerobic conditions, resulting in off-flavors and odors. To avoid an accumulation of ethylene inside the high-barrier package, an ethylene adsorbing monolayer was added. Shelf life of strawberries and raspberries given the AIR treatment was limited by growth of moulds, rather than by sensory unacceptance. On the other hand, sensory properties limited the shelf life of the fruit packaged under MA. The initial high O<sub>2</sub> atmospheres retarded the growth of moulds. However, when O<sub>2</sub> was depleted and CO<sub>2</sub> had accumulated in the barrier film, sensory quality (odor, taste and firmness) declined. In the MA film, the inhibitory effect on mould growth was maintained, due to the initial high O<sub>2</sub> levels.

Allende *et al.*, (2004) evaluated microbial counts at different steps of the production chain. Following industrial practices, processed lettuce was packaged at 5<sup>0</sup>C in sealed polypropylene (PP) bags with an initial atmosphere containing 3 kPa O<sub>2</sub> and 5 kPa CO<sub>2</sub>. During a storage period of 7 days at 5<sup>0</sup>C, sensory attributes (general appearance, texture, aroma, translucency, initial and persistent off-odors, leaves superficial browning, leaves edges browning, and decay) as well as microbial counts (psychrotrophic and mesophilic bacteria, coliforms and lactic acid bacteria) were monitored. Due to high microbial counts and off-odors evaluation, a shelf life shorter than 7 days should be considered for fresh processed 'Lollo Rosso' lettuce.

Gonzalez-Aguilar *et al.*,(2004) studied the effect of temperature and modified atmosphere packaging on overall quality of fresh-cut bell peppers stored at 5<sup>0</sup>C and 10<sup>0</sup>C were evaluated. In-package atmosphere, overall quality, percentage of leaked juice, texture, ascorbic acid content, ethanol and acetaldehyde, and microbial growth, were evaluated at different intervals of storage. MAP-fresh cut peppers presented better visual quality, less leaked juice and higher firmness than those stored under VP. Microbiological and quality analysis revealed a limit of shelf-life of 14 and 21 days, when fresh-cut peppers were stored at 10<sup>0</sup>C and 5<sup>0</sup>C, respectively. Hence they were conclude that MAP could be used to maintain quality attributes of fresh-cut peppers for up 21 days at 5<sup>0</sup>C

An *et al.*, (2006) studied effects of pretreated ozone and modified atmosphere packaging on the quality of fresh-cut green asparagus. The changes in lignifying, antioxidant enzyme activities and cell wall composition of fresh-cut green asparagus pretreated in 1mg l-1 aqueous ozone and subsequently packaged in modified atmosphere (MAP), were investigated during storage at 3<sup>0</sup>C for 25 days. The enzyme activities in fresh-cut asparagus were inhibited by aqueous ozone treatment and subsequent modified atmosphere packaging. Changes in lignin, cellulose and hemicellulose contents were also monitored during storage. Similarly, the increase of the cell wall composition elements under the aqueous ozone treatment and/or MAP were significantly reduced (P<0.05). Compared to the control group, enzyme activities in MAP and/or group remained high, which means that asparagus in the two latter groups remained a high-ability scavenger of free radicals. It was found that as a result of treatment in O<sub>3</sub> and/or MAP, PAL activity presented a peak at day 10 of storage, but its activities were significantly lower than in the control group.

Liu and Li (2006) studied the microbial proliferation and sensory quality aspects of sliced onions were tested at different temperatures (-2, 4 and 10<sup>0</sup>C) and atmospheric conditions (with or without 40% CO<sub>2</sub> + 59% N<sub>2</sub> +1%O<sub>2</sub>). The results showed that color intensity (yellowness), sensory scores and microbial counts increased, and firmness decreased during storage. The total plate counts (TPC) provided the best indication of the spoilage organism growth capacity under tested temperatures and atmospheric conditions. The microbial shelf lives of the tested onions in 40% CO<sub>2</sub> + 59% N<sub>2</sub> +1% O<sub>2</sub>, or at -2, 4 and 10 °C, were 12.5, 9.5, 7, 12, 9 and 6 days, respectively, and their sensory shelf lives were 12, 8, 5, 10.5, 7 and 5 days, respectively.

Zehra *et al.*, (2008) investigated the effect of modified atmosphere packaging on the quality and shelf life of minimally processed carrots during cold storage. The whiteness index did not significantly change during the 21 days of storage in all applications, indicating the good retention of orange color. The texture values declined for both passive and active MAP applications after 14 days of storage indicating a significant softening.

Lal *et al.*, (2009) studied the storage behavior of modified atmosphere packed date fruit stored under different conditions. Fruit of date palm at colour turning stage of maturity were packed and stored at ambient temp (35<sup>0</sup>C and 70% RH) and low temperature (7<sup>0</sup>C ,85% RH) up to 15 days, resulted into indicated that physiological loss in weight, spoilage and total sugar of fruit enhanced during storage. Simultaneously ascorbic acid and sensory quality score of fruit decrease.

Sothornvit and Kiatchanapaibul (2009) studied quality and shelf-life of washed fresh-cut asparagus in modified atmosphere packaging to determine the effect of chlorinated and ozonated water in the washing process to reduce the microbial load on fresh green asparagus and the effect of modified atmosphere packaging (MAP) on asparagus quality. Washing at 10<sup>0</sup>C for 15 min with chlorinated water (100 mg/L free Cl<sub>2</sub>) reduced aerobic plate count which had higher efficiency on microbial reduction than the use of ozonated water (0.1 mg/L O<sub>3</sub>). Chlorine and ozone are effective surface disinfectants depending on the concentration used. Washed fresh-cut asparagus with chlorinated water and storage in an active MAP of OPP bags containing 8.15 kPa CO<sub>2</sub> and 17.51 kPa O<sub>2</sub> maintained its quality for 23 days at 4<sup>0</sup>C. The color change of fresh-cut asparagus was dependent of storage time. The visual quality was used as a key factor to determine the shelf-life of fresh-cut asparagus.

Arkoudelos *et al.*, (2007) studied the shelf life of fresh eel in various packaging conditions of atmospheric air, vacuum and modified atmosphere packaging (MAP) (40% CO<sub>2</sub>, 30% N<sub>2</sub> and 30% O<sub>2</sub>) at 0<sup>0</sup>C. All raw eel samples received acceptable sensory scores during the first 11 days in atmospheric air, 11 days in vacuum and finally 18 days of storage in MAP conditions. The main spoilage microorganisms under MAP conditions were lactic acid producing bacteria followed by *Shewanella* spp., pseudomonads, Enterobacteriaceae and yeasts. Chemical data revealed that pH, ammonia, glucose and lactate examinations might not be useful for monitoring eel quality differences.

Rahman *et al.*, (2009) conducted experiment to evaluate the effect of packaging materials on the quality and shelf life of country bean (*Lablab niger*) using passive modification of modified atmosphere packaging system. The modified atmosphere was created by making perforation in the packets made by polypropylene. Bean pre-treated with chlorine water and then packaging in selected polypropylene resulted substantial reduction in losses caused by weight loss and rotting/shriveling. These treatment combinations also considerably retained vitamin C,  $\beta$ -carotene, moisture content, etc. Under this condition, the retention of quality and shelf life of bean could be extended upto 8 days at ambient condition as compared to non-treated and without packaging.

Karacay and Ayhan (2010) studied microbial, physical, chemical and sensory qualities of minimally processed and modified Atmosphere packaged “ready to eat” orange segments. Oranges were sanitized, dried, peeled and segmented. Undamaged segments were packed under passive and active MAP with low and high oxygen in PP trays sealed with CPP/OPP film. Overall quality of the segments was monitored for 25 days at 4<sup>0</sup>C. The results showed that orange segments could be stored under passive and active MAP without significant microbial growth. There were slight changes in acidity and Brix ( $p \leq 0.05$ ) with no significant changes in pH and sugar. The hardness increased and color (L, a, b) decreased during storage. Orange segments remained in a commercially viable condition for 10 days under MAP.

Leygonie *et al.*, (2011) studied the protein and lipid oxidative stability of fresh ostrich *M. Iliofibularis* packaged under different modified atmospheric packaging conditions. They investigated the aptness of modified atmospheric packaging (70:30, O<sub>2</sub>:CO<sub>2</sub> (O\_MAP); 70:30, N<sub>2</sub>:CO<sub>2</sub> (N\_MAP)) and traditional overwrap (control) for fresh ostrich steaks, stored at 4 ± 1 °C for 10 days. N\_MAP showed the least oxidation, O\_MAP the highest and the control moderate. Myoglobin (CIE a') was gradually oxidised in all packaging atmospheres, but the O\_MAP oxidised at the slowest rate, remaining significantly more bloomed from day 0 (17.86 ± 1.17) to 8 (9.78 ± 1.12). Free carbonyls were constant in all packaging environments. TBARS remained constant for the N\_MAP (2.39 ± 0.21 mg MDA/kg meat) and the overwrap (3.06 ± 0.29 mg MDA/kg meat), but the O\_MAP increased significantly (9.96 ± 1.02 mg MDA/kg meat) to day 10. The pH increased in the control but remained constant in the MAP treatments. The control also showed the greatest drip loss (>5%).

## CHAPTER III

### MATERIAL AND METHODS

This chapter presents the details of the materials, methodology and the experimental technique used for the study. Investigations were carried out on fresh bengal gram kernels to study the physical properties and effect of modified atmosphere packaging (MAP) and storage on the keeping quality & physiological parameters. Three gas compositions, two types of polymeric film with three storage environments were used to select the suitable polymeric film gas composition & storage temperature for the shelf-life of fresh bengal gram kernels. Detail of the variable materials used and methodology followed to achieve the specific objectives have been discussed in this chapter:

#### 3.1 Physical properties of fresh Bengal gram kernels

Physical properties of bengal gram kernels were determined on the basis of maturity level.

##### 3.1.1 Moisture Content

The moisture content of fresh bengal gram kernels was determined by using the hot air oven method. The flat metallic plate of known weight was taken. Nearly 15 g of sample was spread on the dish. The weight of sample plus dish was noted. The hot air oven was maintained at 100<sup>0</sup>C. The samples were heated at this temperature to 16-18 hr. After drying the samples was immediately placed into the desiccators for cooling and to avoid moisture gain. After cooling the sample was reweighed and the initial moisture content was determined by the following formula (Ranganna, 1986)

$$\text{Moisture content (\%)} = \frac{(\text{Initial Weight of sample} - \text{Final Weight of sample})}{\text{Initial Weight of sample}} \times 100 \quad \dots\dots 3.1$$

##### 3.1.2 Kernel dimensions and sphericity

To determine the average size of the kernels, a sample of 100 randomly selected kernels was drawn and their three principal dimensions were measured using a vernier caliper to an accuracy of 0.02 mm (Nimkar *et al.*, 2001). The geometric mean diameter *D<sub>m</sub>* of the grain was calculated by using the following relationship:

$$D_m = (LBT)^{\frac{1}{3}} \quad \dots\dots 3.2$$

Where L, Band T are the length, width and thickness of the kernel.

The sphericity of kernels was calculated using the formula (Mohsenin, 1986):

$$\phi = \frac{(LBT)^{\frac{1}{3}}}{L} \quad \dots\dots\dots 3.3$$

where  $\phi$  is degree of sphericity

### 3.1.3 Mass of thousand kernels

Thousand grains mass was determined with the standard method as per IS: 4333 Part IV (ISI, 1968b). The one thousand kernels were selected randomly. The mass was determined by means of an electronic balance with least count 0.001 g.

### 3.1.4 True and Bulk Density

The bulk density of kernels based on the volume occupied by the bulk sample was measured using a standard hectoliter as described in IS: 4333 Part III (ISI, 1968a). The true density defined as the ratio between the mass of kernels and true volume of kernels and determined using the toluene displacement method. The volume of toluene displaced was found by immersing a known quantity of bengal gram kernels in the toluene (Sacilik et al. 2003). Porosity of the bulk is the ratio of volume of internal pores within the kernels to its bulk volume and was determined as follows:

$$\epsilon = 100 \left( 1 - \left( \frac{P_b}{P_t} \right) \right) \quad \dots\dots\dots 3.4$$

where:  $\epsilon$  is the porosity in percentage;  $P_b$  is the bulk density in  $\text{kgm}^{-3}$ ; and  $P_t$  is the true density in  $\text{kgm}^{-3}$  (Nimkar et al., 2001).

### 3.1.5 Angle of repose

The angle of repose is the angle with the horizontal at which the material will rest in a pile. This was determined by using an open-ended cylinder of 15 cm diameter and 50 cm height. The cylinder was placed at the centre of a circular plate having a diameter of 70 cm and was filled with bengal gram kernels. The cylinder was raised slowly until it formed a cone on the circular plate. The height of the cone was recorded by using a moveable pointer fixed on a stand having a scale of 0–1 cm precision. The angle of repose  $\alpha$  was calculated using the formula (Fraser et al., 1978; Joshi et al., 1993; Kaleemullah & Gunasekar, 2002; Sacilik et al., 2003; Karababa 2006):

$$\alpha = \tan^{-1} \left( \frac{2H}{d} \right) \quad \dots\dots\dots 3.5$$

where:  $\alpha$  is angle of repose, degrees; H is the height of the cone in cm and d is the diameter of cone in cm.

### 3.2 Time studies on pod stripping and kernels shelling

The time required for the stripping of pods from the plant and also for the shelling the pods to obtain kernels were determined by recording time taken per unit weight of sample. The unit cost of operation was also being calculated.

### 3.3 Respiratory behavior

The closed or static system was used for measurement of respiration rate i.e. to estimate the kinetics of O<sub>2</sub> consumption and CO<sub>2</sub> evolution by fresh bengal gram kernels. Kernels of known weight and volume were placed in a pet jar of 900 ml volume, for each measurement of respiration rate in terms of O<sub>2</sub> and CO<sub>2</sub> gases as shown in Plate 3.1. An impermeable cover was mounted tightly on top of each jar. To prevent gas leakage, the top cover was glued and then adhesive tape was pasted on the joint to make it further tight. Each jar was provided with 5mm diameter opening at center of the top cover of the jar. 10mm diameter septum was plugged on this opening. The sample jars were placed at room temperature, at 5±1<sup>0</sup>C and at 0±1<sup>0</sup>C. The respiration of the fresh bengal gram would change the gaseous concentration inside the containers. These altered concentrations were recorded after specified intervals until a steady state was reached. A steady state is considered when no difference in the gaseous concentration between two successive intervals is observed. For each experiment, the volume of sample (V<sub>s</sub>) filled in the impermeable container was determined using the relation

$$V_s = \frac{W_s}{P_b} \quad \dots\dots\dots 3.6$$

where

V<sub>s</sub>= Volume of sample

W<sub>s</sub>= Weight of sample

P<sub>b</sub>= Mean density of bengal gram

The total inside volume (V<sub>t</sub>) of the impermeable container used for respiration experiment was measured. The density of fresh bengal gram kernels was determined by toluene displacement method through the evaluation of true volume of known mass of fresh bengal gram kernels. The void volume (V<sub>v</sub>) for each experiment was determined by using the relationship

$$V_v = V_t - V_s \quad \dots\dots\dots 3.7$$

The headspace was continuously monitored to determine the O<sub>2</sub> and CO<sub>2</sub> concentrations using a gas analyzer (Quantek Instrument – Model 902D, Dual Trak). The gaseous concentrations obtained in percent are to be required to be converted into partial pressure using the relation that 1atmospheric pressure (101.325kPa) corresponds to 100%

gaseous composition in the atmosphere but as a simplification under the present study has been assumed 100% gaseous composition equivalent to 100 kPa.

The rate of O<sub>2</sub> and CO<sub>2</sub> evolution has been calculated using the following formulae (Rattiet *al.*, 1996; Jacxsens *et al.*, 1999; Fonescaet *al.*, 2002; Song *et al.*, 2002)

$$R_{O_2} = \frac{(p_{O_2}^{in} - p_{O_2}^f)V_v}{100 \times W \times (t^f - t^i)} \quad \dots\dots\dots 3.8$$

$$R_{CO_2} = \frac{(p_{CO_2}^f - p_{CO_2}^{in})V_v}{100 \times W \times (t^f - t^i)} \quad \dots\dots\dots 3.9$$

Where,

R<sub>CO<sub>2</sub></sub>: Rate of CO<sub>2</sub> evolution, ml.kg<sup>-1</sup>.h<sup>-1</sup>

R<sub>O<sub>2</sub></sub> : Rate of O<sub>2</sub> consumption, ml.kg<sup>-1</sup>.h<sup>-1</sup>

p<sub>O<sub>2</sub></sub><sup>in</sup> : Initial partial pressure of O<sub>2</sub> inside film package, kPa,

p<sub>O<sub>2</sub></sub><sup>f</sup> : Final partial pressure of O<sub>2</sub> inside film package, kPa,

p<sub>CO<sub>2</sub></sub><sup>in</sup> : Initial partial pressure of CO<sub>2</sub> inside film package, kPa,

p<sub>CO<sub>2</sub></sub><sup>f</sup> : Final partial pressure of CO<sub>2</sub> inside film package, kPa,

V<sub>v</sub>: void volume of container, ml,

W: weight of fresh Bengal gram kernels inside the container, kg,

t<sup>i</sup> : initial time, h, and

t<sup>f</sup> : final time, h.



**Plate 3.1 Set up for determining respiration rate of fresh Bengal gram kernels**

### 3.3.1 Estimation of Respiratory Behavior

The dependence of the rate of respiration on O<sub>2</sub> concentration has been widely expressed by Michaelis - Menten type equation which is the simplest enzymatic kinetic mechanism. This model is a simplification that tends to fit the experimental data very well, being based on one limiting enzymatic reaction in which the substrate is O<sub>2</sub>. The dependence of the respiration rate on the O<sub>2</sub> and CO<sub>2</sub> concentrations has been described assuming mixed inhibition caused by CO<sub>2</sub> using the enzymatic kinetics model for combined type of inhibition proposed by Peppelens and Van't Leven (1996) for the respiration of fresh produce as follows;

$$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} \left( 1 + \frac{P_{CO_2}^{in}}{K_{mcCO_2}} \right) + P_{O_2}^{in} \left( 1 + \frac{P_{CO_2}^{in}}{K_{muCO_2}} \right)} \quad \dots\dots\dots 3.10$$

Where,

$R_{O_2}$  : Rate of O<sub>2</sub> consumption, ml.kg<sup>-1</sup>.h<sup>-1</sup>

$P_{O_2}^{in}$  : Initial partial pressure of O<sub>2</sub> inside film package, kPa,

$P_{CO_2}^{in}$  : Initial partial pressure of CO<sub>2</sub> inside film package, kPa,

$V_{mO_2}$  : Maximum oxygen consumption rate, ml kg<sup>-1</sup> h<sup>-1</sup>,

$K_{mcCO_2}$  : Michaelis-Menten constant for competitive inhibition of O<sub>2</sub> consumption by CO<sub>2</sub>, %,

$K_{mO_2}$  : Michaelis-Menten constant for oxygen consumption, % and

$K_{muCO_2}$  : Michaelis-Menten constant for uncompetitive inhibition of O<sub>2</sub> consumption by CO<sub>2</sub>, %.

The equation 3.10 is a comprehensive and flexible relationship describing basically all types of inhibition (competitive, uncompetitive and mixed) on the rates of O<sub>2</sub> consumption. When inhibition constant  $K_{muCO_2}$  is infinite, the inhibition is competitive and when inhibition constant  $K_{mcCO_2}$  is infinite then the inhibition becomes uncompetitive. However, when both of the inhibitions constant are infinite, there develops a condition called "No inhibition". Another possibility of finite but unequal values of  $K_{mcCO_2}$  and  $K_{muCO_2}$  has been described as combined or mixed inhibition. Mixed inhibition (Copeland, 2000) encompasses a broad range of behavior and for unambiguous interpretation has been further sub-divided into three types: predominantly competitive, non-competitive and predominantly uncompetitive (Table 3.1).

**Table: 3.1 Types of inhibition based upon the value of inhibition constants**

Values of inhibition constants	Type of inhibition	Equation for estimation of O <sub>2</sub> consumption rate
$K_{mCO_2} = 8,$ $K_{muCO_2} = 8$	No inhibition Michaelis-Menten kinetics	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} + P_{O_2}^{in}}$
$K_{muCO_2} = \infty$	Competitive inhibition	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} \left( 1 + \frac{P_{CO_2}^{in}}{K_{mCO_2}} \right) + P_{O_2}^{in}}$
$K_{muCO_2} = \infty$	Uncompetitive inhibition	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} + P_{O_2}^{in} \left( 1 + \frac{P_{CO_2}^{in}}{K_{muCO_2}} \right)}$
$K_{mCO_2} = K_{muCO_2}$	Non-competitive inhibition	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{(K_{mO_2} + P_{O_2}^{in}) \times \left( 1 + \frac{P_{CO_2}^{in}}{K_{muCO_2}} \right)}$
$K_{mCO_2} < K_{muCO_2}$	Mixed inhibition Predominantly competitive	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} \left( 1 + \frac{P_{CO_2}^{in}}{K_{mCO_2}} \right) + P_{O_2}^{in} \left( 1 + \frac{P_{CO_2}^{in}}{K_{muCO_2}} \right)}$
$K_{mCO_2} > K_{muCO_2}$	Mixed inhibition Predominantly uncompetitive	$R_{O_2} = \frac{V_{mO_2} \times P_{O_2}^{in}}{K_{mO_2} \left( 1 + \frac{P_{CO_2}^{in}}{K_{mCO_2}} \right) + P_{O_2}^{in} \left( 1 + \frac{P_{CO_2}^{in}}{K_{muCO_2}} \right)}$

The experimentally determined respiration rates and partial pressures of O<sub>2</sub> and CO<sub>2</sub> were subsequently used to estimate the enzyme kinetics model parameters. Non-linear regression analysis was carried out using the measured values of R<sub>O<sub>2</sub></sub>, R<sub>CO<sub>2</sub></sub>, P<sub>O<sub>2</sub></sub><sup>in</sup> and P<sub>CO<sub>2</sub></sub><sup>in</sup> to estimate the values of model parameters for O<sub>2</sub> consumption and CO<sub>2</sub> evolution rates of fresh Bengal gram kernels using GraphPad PRISM® Version 5.00.288 software (GraphPad Software, Inc., USA).

### 3.4 Modified Atmosphere Packaging of fresh Bengal gram kernels

#### 3.4.1 Variables under Study

Variables selected for this study were classified in two major categories as independent variables and dependent variables.

##### 3.4.1.1 Independent variables

###### 3.4.1.1.1 Gas compositions for Modified atmosphere packaging

<i>Samples</i>	Composition of gases (%)		
	<i>O<sub>2</sub></i>	<i>CO<sub>2</sub></i>	<i>N<sub>2</sub></i>
G <sub>1</sub>	2	8	90
G <sub>2</sub>	5	3	92
G <sub>3</sub>	5	8	87

#### **3.4.1.1.2 Storage Temperatures**

1. Room temperature ( $T_1$ )
2. In refrigerator at  $5^{\circ}\text{C}$  ( $T_2$ )
3. In refrigerator at  $0^{\circ}$  ( $T_3$ )

#### **3.4.1.1.3 Polythene film**

1. LDPE (L)
2. HDPE (H)

#### **3.4.1.2 Dependent variables**

- 1) Change in head space gas composition
- 2) Physiological loss in weight (PLW)
- 3) Decay (%)
- 4) Quality parameters
  - 1) Colour
  - 2) Firmness
  - 3) Sensory Evaluation
  - 4) Water Activity
  - 5) Microbial parameters

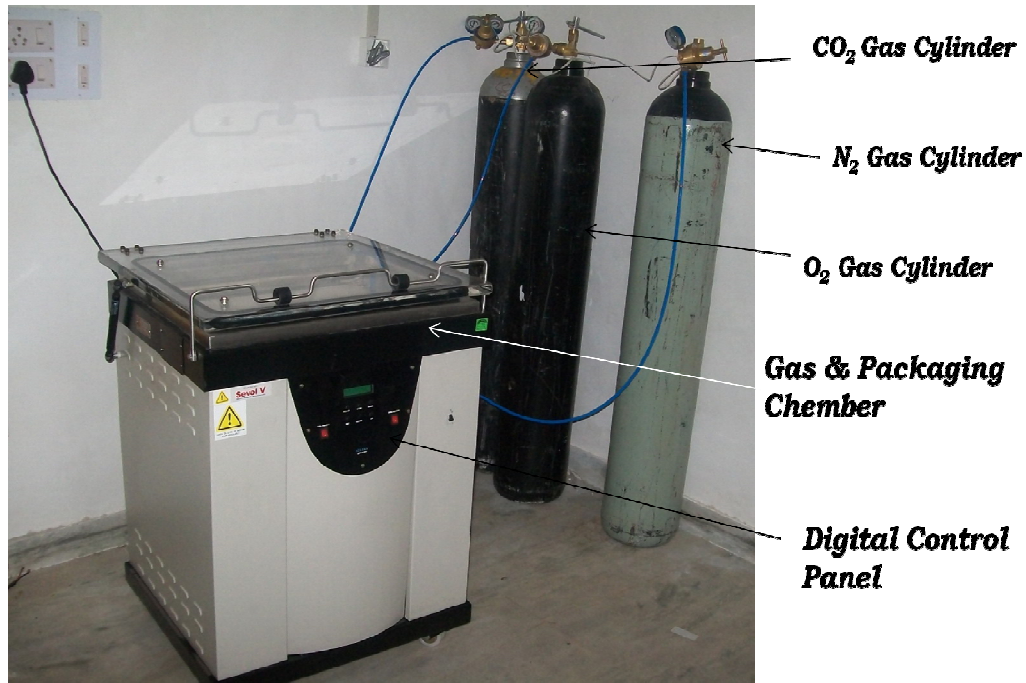
#### **3.4.2 Modified Atmosphere Packaging**

The packages were sealed at room temperature. Modified atmospheric packaging machine plate 3.2 (SEVANA - QS 400 CAP 3G) was used for the experimental work. The machine is having the packaging chamber at the top. There are two different techniques to replace the air: gas flushing and compensated vacuum.

#### **Operational procedure of MAP machine**

The specifications and other details are given in (Appendix C). The gas flush technique is normally accomplished on a form fill-seal machine. The replacement of air inside a package is performed by a continuous gas stream. This gas stream dilutes the air in the atmosphere surrounding the food product. The package is then sealed. Since the replacement of air inside the package is accomplished by dilution, there is a limit on the efficiency of this unit. Typical residual oxygen levels in gas flushed packs are lower than carbon dioxide level. Therefore, if the food item to be packaged is very oxygen sensitive, the gas flush technique is normally not suitable. So when considering a packaging system it is important to consider the oxygen sensitivity of the food product.

The great advantage of the gas flush technique is the speed of the machine. Since the action is continuous, the product rate can be very high. The compensated vacuum technique removes the air inside by pulling a vacuum on the atmosphere inside the package and then breaking the vacuum with the desired gas mixtures. Since the replacement of the air is accomplished in a two-step process, the speed of operation of the equipment is slower than the gas flush technique. However, since the air is removed by vacuum and not simply diluted, the efficiency of the unit with respect to residual air levels is better. Therefore, if the food product is extremely sensitive to oxygen, a compensated vacuum machine must be used.



**Plate 3.2 Modified atmosphere Packaging machine**

### **3.4.2.1 Packaging and storage of fresh bengal gram kernels**

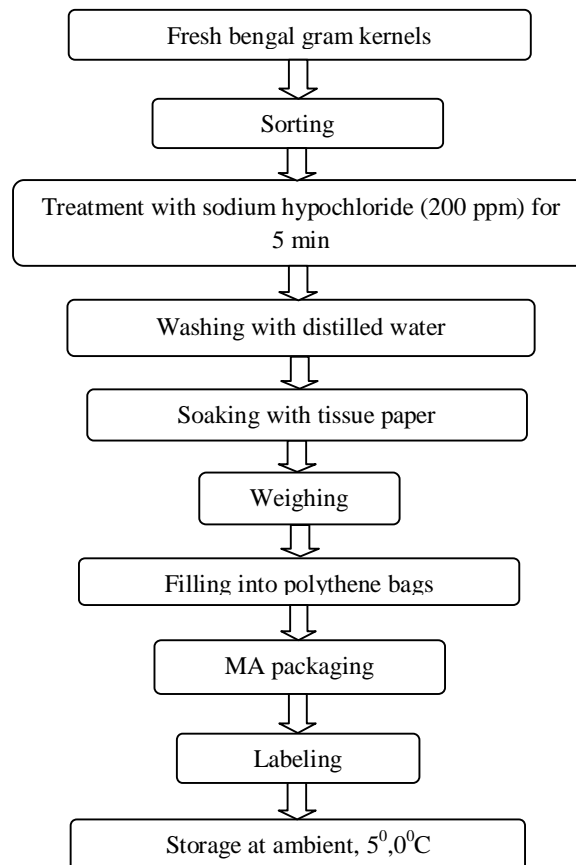
Fresh bengal gram (*Cicer arietinum L.*) was purchased from local market. Damaged, under matured and over matured kernels, foreign matter was discarded from lot of shelled kernels and the remaining uniform size kernels were taken for the experimental purpose.

#### **3.4.2.1.1 Pre treatment**

Chlorine solutions have been widely used to sanitise fresh-cut fruits and vegetables in the industry. However, the possible formation of carcinogenic chlorinated compounds in water has called into question the use of chlorine in food processing plants (Dychdala, 1991; Wei *et al.*, 1999). Moreover, the antimicrobial effectiveness of cold chlorinated water is

limited due to hydrophobic plant surfaces that are believed to limit contact between chlorine solutions and microbial contaminants (Adams, 1991; Beuchat, 1992). There is a real need to find new alternatives for preservation of minimally processed vegetables in order to improve the efficacy of washing treatments. This will lead to increased microbial safety and extend the quality retention of the product. Alternatives or modified methods have been proposed, however, none have yet gained widespread acceptance by the industry. These include organic acids, essential oil treatments, irradiation, heat-shock, ozone treatment, etc. (Loaiza-Velarde *et al.*, 1997; Ponce *et al.*, 2002; Singhet *et al.*, 2002, Diana *et al.*, (2006).

In this study washing treatment of fresh Bengal gram kernels was performed by immersion of the fresh kernels in treatment solution. Chlorinated water was prepared by adding sodium hypochlorite solution (200 g/L available chlorine) to distilled water to obtain 200 ppm free chlorine for 5 min, followed by rinsing with distilled water to remove traces of chlorine. The kernels were then air cooled for 30-45 min at room temperature, before start of experiment. Air cooling helped in surface drying as well as prepared the sample for further experimentation (Nikhane, 2011). The chlorine treated kernels were packed in LDPE and HDPE film packages. The mass of samples was 70 g in each package.



**Fig. 3.1 Process flow chart for modified atmosphere packaging of fresh Bengal gram kernels**

**Table 3.2 Modified atmosphere package nomenclature**

<b>LG<sub>1</sub>T<sub>1</sub></b>	LDPE with G <sub>1</sub> gas composition stored at T <sub>1</sub> condition
<b>LG<sub>1</sub>T<sub>2</sub></b>	LDPE with G <sub>1</sub> gas composition stored at T <sub>2</sub> condition
<b>LG<sub>1</sub>T<sub>3</sub></b>	LDPE with G <sub>1</sub> gas composition stored at T <sub>3</sub> condition
<b>LG<sub>2</sub>T<sub>1</sub></b>	LDPE with G <sub>2</sub> gas composition stored at T <sub>1</sub> condition
<b>LG<sub>2</sub>T<sub>2</sub></b>	LDPE with G <sub>2</sub> gas composition stored at T <sub>2</sub> condition
<b>LG<sub>2</sub>T<sub>3</sub></b>	LDPE with G <sub>2</sub> gas composition stored at T <sub>3</sub> condition
<b>LG<sub>3</sub>T<sub>1</sub></b>	LDPE with G <sub>3</sub> gas composition stored at T <sub>1</sub> condition
<b>LG<sub>3</sub>T<sub>2</sub></b>	LDPE with G <sub>3</sub> gas composition stored at T <sub>2</sub> condition
<b>LG<sub>3</sub>T<sub>3</sub></b>	LDPE with G <sub>3</sub> gas composition stored at T <sub>3</sub> condition
<b>HG<sub>1</sub>T<sub>1</sub></b>	HDPE with G <sub>1</sub> gas composition stored at T <sub>1</sub> condition
<b>HG<sub>1</sub>T<sub>2</sub></b>	HDPE with G <sub>1</sub> gas composition stored at T <sub>2</sub> condition
<b>HG<sub>1</sub>T<sub>3</sub></b>	HDPE with G <sub>1</sub> gas composition stored at T <sub>3</sub> condition
<b>HG<sub>2</sub>T<sub>1</sub></b>	HDPE with G <sub>2</sub> gas composition stored at T <sub>1</sub> condition
<b>HG<sub>2</sub>T<sub>2</sub></b>	HDPE with G <sub>2</sub> gas composition stored at T <sub>2</sub> condition
<b>HG<sub>2</sub>T<sub>3</sub></b>	HDPE with G <sub>2</sub> gas composition stored at T <sub>3</sub> condition
<b>HG<sub>3</sub>T<sub>1</sub></b>	HDPE with G <sub>3</sub> gas composition stored at T <sub>1</sub> condition
<b>HG<sub>3</sub>T<sub>2</sub></b>	HDPE with G <sub>3</sub> gas composition stored at T <sub>2</sub> condition
<b>HG<sub>3</sub>T<sub>3</sub></b>	HDPE with G <sub>3</sub> gas composition stored at T <sub>3</sub> condition

Where

**L and H**-denotes type of packaging material i.e. LDPE and HDPE, respectively

**G<sub>1</sub>, G<sub>2</sub>, G<sub>3</sub>**- different gas composition as stated in section 3.4.1.1.1

**T<sub>1</sub>, T<sub>2</sub>, T<sub>3</sub>**- different storage conditions i.e.at ambient, 5±1 and 0±1<sup>0</sup>C, respectively.

### 3.5 Packaging material

#### 3.5.1 LDPE

Low Density Polyethylene: This is an extremely versatile material and accounts for the biggest proportion of plastic materials used for packaging. This is an inert film with low permeability for water vapour but high gas permeability. Ethylene Vinyl Acetate, a copolymer of ethylene and vinyl acetate has superior sealing qualities. Blended polyethylene can be used with different additives to make a peel able seal, which is strong and gives an adequate barrier. When used with other films for lidding, base webs, preformed trays, bulk packaging or horizontal / vertical form-fill-seal webs, low-density polyethylene can be laminated, extrusion coated or co-extruded.

#### 3.5.2 HDPE

High Density Polyethylene: This film has a higher softening point than LDPE and provides superior barrier properties. It is not suitable as a sealant layer and hence is not used in thermo formable base webs but used as one of the layers in the lidding material in coextruded form. It has better gas-barrier properties than LDPE but poor clarity

**Table 3.3 Input package parameters**

S. No.	Parameter	LDPE	HDPE
1	Length of package, m	0.185	0.184
2	Breadth of package, m	0.130	0.126
3	Thickness of film, micron	40	40
4	Storage temperature	0±1 <sup>0</sup> C, 5±1 <sup>0</sup> C, ambient	0±1 <sup>0</sup> C, 5±1 <sup>0</sup> C, ambient



**Plate 3.3 Storage of modified atmosphere packaged fresh bengal gram kernels at ambient conditions**



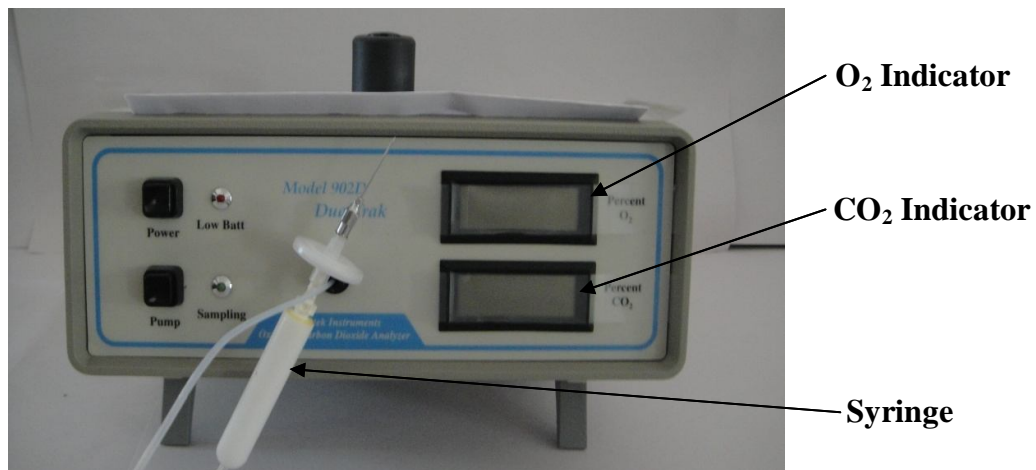
**Plate 3.4 Storage of modified atmosphere packaged fresh bengal gram kernels at low temperature (refrigerator)**

### 3.6 Quality parameters

70 g of prepared/treated bengal gram kernels was packed in polymeric film packages and different gas composition during storage studies. These different bags were then stored under ambient and refrigerator at 5<sup>0</sup>C and 0<sup>0</sup>C and observations pertaining to quality were recorded at regular intervals.

#### 3.6.1 Headspace gas analysis

Package headspace was monitored by means of a portable headspace analyzer (Plate 3.6 Quantek Instrument – Model 902D, Dual Trak). The instrument evaluated the headspace by means of an electrochemical and an infrared sensor (sensitivity: 0.01% O<sub>2</sub>; 0.01 CO<sub>2</sub>, accuracy: 0.01% O<sub>2</sub>; 0.02% CO<sub>2</sub>) for O<sub>2</sub> and CO<sub>2</sub> concentrations, respectively. The instrument was calibrated with the standard O<sub>2</sub> and CO<sub>2</sub> gases; before the actual observations. A sampling probe containing particulate filter and a removable needle having dual side-port holes was used to draw the sample from the package headspace with the help of an electronically miniature pump. The drawn samples were fed simultaneously to the O<sub>2</sub> and CO<sub>2</sub> sensors and concentrations of O<sub>2</sub> and CO<sub>2</sub> were directly read on the digital display panel of the instrument.



**Plate 3.5 Head Space gas analyzer**

#### 3.6.2 Physiological loss in weight (PLW)

Different packages kept under different ambient and refrigerated conditions i.e. 0<sup>0</sup>C and 5<sup>0</sup>C were weighed at 3 days intervals. The PLW at each duration was calculated as:

$$\text{PLW} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100 \quad \dots\dots\dots 3.11$$

During storage, the weight loss due to transpiration and respiration of the fruit was followed (expressed as a percentage of the original weight of the packaged kernels), by weighing the kernels on each three day interval of the experiment by means of a digital precision balance.

### 3.6.3 Decay (%)

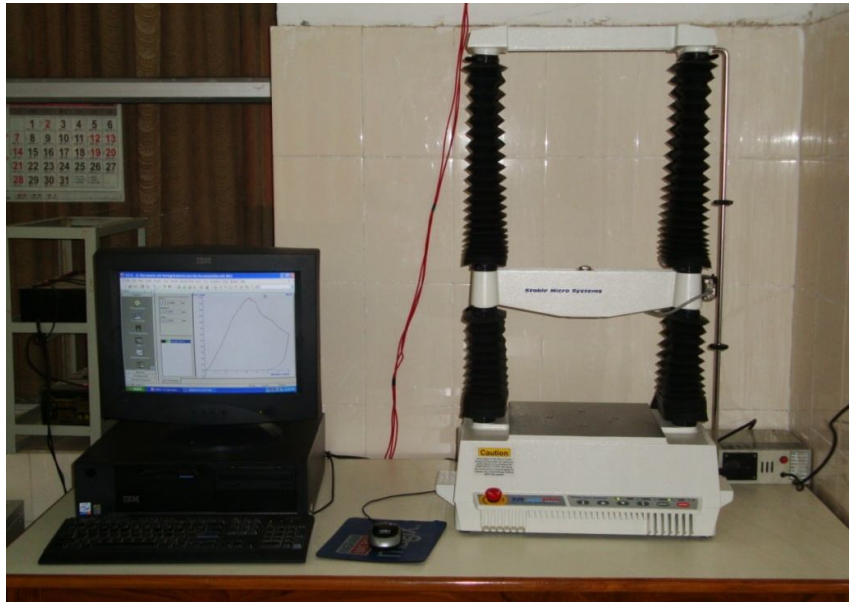
Any form of deterioration in quality was taken as decay. Decay in fresh Bengal gram kernels was observed on weight basis. Here shrinkage was assumed to be zero. Decay for each treatment at each duration was calculated as:

$$\text{Decay (\%)} = \frac{(\text{Initial Weight} - \text{Final Weight})}{\text{Initial Weight}} \times 100 \quad \dots\dots\dots 3.12$$

Here, final weight was noted after removal of decayed material. The sample weight was determined by means of a digital precision balance ( $\pm 0.1$  g)

### 3.6.4 Firmness

TA.XT Plus/TA.HD Plus Textural Analyzer used for measuring textural properties of fresh as well as stored bengal gram kernels is shown in Plate 3.7 and its specifications are presented in Appendix C.1. The texture analyzer (TA) was a microprocessor controlled analysis system, which could be interfaced to a wide range of peripherals, including PC-type computers. The texture analyzer measured force, distance, and time in a most basic test, thus providing three dimensional product analyses. Forces could be measured against set distances and distances may be measured to achieve set forces. The probe carrier contained a very sensitive load cell. The TA.HD plus load cell had electronic overload protection. The TA-XT plus load cell had mechanical overload. The analyzer was linked to a computer that recorded the data via a software program Stable Micro System Exponents software (Stable Micro Systems). Experiments were carried out by different tests that generated plot of force (kg) vs. distance (m), from which texture values for fresh as well as stored bengal gram kernels were obtained. Three replications of each combination were taken for analysis and samples were removed from their packets only a short time before testing.



**Plate 3.6 A view of Texture analyzer**

**Table 3.4 TA Settings used in Textural Analyzer for performing different tests**

<b>TA Settings</b>	<b>Penetration Test</b>	<b>Compression Test</b>
Modes	Measure Force in Compression	Measure Force in Compression
Option	Return To Start	Return To Start
Pre-Test Speed	1.0 mm s <sup>-1</sup>	1.5 mm s <sup>-1</sup>
Test Speed	2.0 mm s <sup>-1</sup>	0.5 mm s <sup>-1</sup>
Post-Test Speed	10 mm s <sup>-1</sup>	10 mm s <sup>-1</sup>
Distance	15 mm	25 mm
Trigger Force	Auto	Auto
Tare Mode	Auto	Auto
Data Acquisition Rate	200pps	200pps

#### **3.6.4.1 Determination of Firmness of fresh bengal gram kernels**

Firmness, hardness or softness textural properties are generally on the same property spectrum. A soft product is one that displays a slight resistance to deformation, a firm product is moderately resistant to deformation and hardness describes a product which displays substantial resistance to deformation. However, it was also found that depending upon the product industry, one of these words may be more favorable or pertinent to a particular product. Firmness is the most commonly evaluated characteristic while determining biscuit texture. Depending upon the type of test conducted, firmness of bengal gram kernels can be obtained by measuring hardness, fracturability and work of shear (Stable Micro Systems).

Hardness is defined as the maximum peak force during the first compression cycle (first bite) and has often been substituted by the term firmness. Units are kg, g or N. Depending on different tests; it can also be measured as area under the curve (kg m) or first peak force (kg). Fracturability is a parameter that was initially called brittleness. The factor that helps determine fracturability is the suddenness (i.e. the distance at fracture) with which the food breaks. Sometimes it can also be given by linear distance. The linear distance function calculates the length of an imaginary line joining all points in the selected region. The greater the linear distance value the easier the sample is fractured.

### 3.6.5 Water Activity ( $a_w$ )

The concept of water activity has a particular importance as an indicator of product quality, safety and storability. It can also indicate the stability of a food product with respect to microbial growth, chemical and biochemical reaction rates and physical properties (Barbosa-Canovas and Vega Mercado, 1996). A reduction of water activity below the optimum delays spores germination and decreases the growth rate. An automated instrument (Novasina – Lab swift- $a_w$ ) as shown in Plate 3.8 was used to determine the water activity of stored bengal gram kernels.

Water activity is measured by equilibrating the liquid phase water in the sample with the vapor phase water in the headspace and measuring the relative humidity of the headspace. The water activity meter is provided with a sample cup, which is sealed against sensor block. Inside the sensor block, there is a fan, a dew point sensor, temperature sensor block and an infrared thermometer. The dew point sensor measures the dew point temperature of the air and the infrared thermometer measures the sample temperature. From these measurements, the relative humidity of the headspace is computed as the ratio of saturation vapor pressure of air to the sample. The purpose of the fan is to speedup the equilibrium process and to control the boundary layer conductance of the dew point sensor.

Water activity is a function of moisture content in the food and the temperature (Ratti and Mujumdar, 1996). Bound molecule of water in food can be defined by water activity such as Tightly bound water  $a_w < 0.3$ ; Moderately bound water  $0.3 < a_w < 0.7$ ; Loosely bound water  $a_w > 0.7$ ; Free water  $a_w \sim 1.0$ .

Most bacteria do not grow at water activities below 0.91, and most moulds cease to grow at water activities below 0.80 (Leung, 1986). By measuring water activity, it is possible to predict which microorganisms will or will not be potential sources of spoilage. Lower water activity of a dried product implies better potential for storage.



**Plate 3.7 Water activity meter**

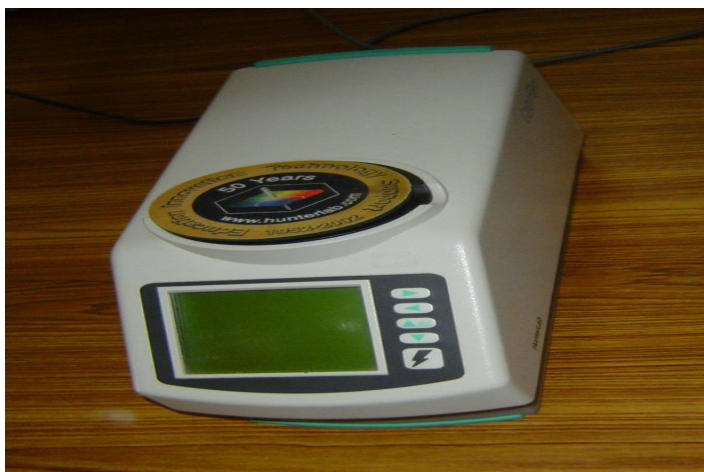
### 3.6.6 Colour measurement

Colour is one of the most important qualities of acceptance for products, reflects sensation to the human eye. Colour is important to consumer as a mean of identification, as a method of judging quality and for its basic aesthetic value. The colorimeter used in the present investigation is shown in Plate 3.9. The technical specifications are presented in Appendix B. Colour of the fresh Bengal gram kernels was measured using a Hunter Lab Colorimeter (Model CFLX/DIFF, CFLX-45). A cylindrical glass sample cup (63.5 mm in diameter x 40 mm height) was placed at the light port (31.75 mm diameter). The instrument was initially calibrated with a black as well as with standard white plate supplied with the equipment. The 3-dimensional scale  $L^*$ ,  $a^*$  and  $b^*$  were used in a Hunter Lab Colorimeter. The  $L^*$  is the lightness coefficient, ranging from 0 (black) to 100 (white) on a vertical axis. The  $a^*$  is purple-red (positive  $a^*$  value) and blue-green (negative  $a^*$  value) on a horizontal axis. A second horizontal axis is  $b^*$ , that represent yellow (positive  $b^*$  value) or blue (negative  $b^*$  value) colour (Plate 3.10). Hunter  $L$ -value, which denotes the degree of whiteness, was chosen to represent the colour value of sample (Anantheswaran *et al.*, 1986). The measured  $a^*$  and  $b^*$  values were converted into chroma values, as follows;

$$C = \sqrt{(a^{*2} + b^{*2})} \quad \dots\dots\dots 3.13$$

$$\text{hue angle} = \tan^{-1} \left( \frac{b}{a} \right) \quad \dots\dots\dots 3.14$$

Hue angles values greater than  $90^0$  correspond to more intense green color while angles to  $90^0$  to yellow. Chroma defines the colour intensity or purity of the hue. Values close to 0 correspond to neutral colors (e.g. grey color), and values close to 60 to bright colours.



**Plate 3.8 Hunter lab colorimeter**

### **3.6.7 Microbial Analysis**

The microbial analysis was mainly done for the bacterial and fungal count. After every three days interval the microbial analysis was done.

#### **3.6.7.1 Preparation of Media**

For bacterial analysis Nutrient agar (Peptone 10gm, meat extract 5gm, NaCl 5 gm) and for fungal analysis Potato Dextrose Agar (Peeled and Boiled potato extract 200gm, Dextrose 20gm, Yeast Extract 1gm) was used. This agar was mixed in the 1000ml of distilled water. The conical flask was used for mixing and this flask was then plugged with cotton plug. The upper portion of the flask was covered with aluminium foil. This media is then put into autoclave at 120<sup>0</sup>C at 15 psi pressure for 18 min.

#### **3.6.7.2 Preparation of Serial dilution**

Firstly the test tubes were filled with 9 ml distilled water with cotton plug on the top. These tubes were then placed in autoclave at 120<sup>0</sup>C at 15 psi pressure for 18 min. 1 gm of sample was crushed into pestle mortar and mixed in a test tube containing 9 ml sterile distilled water. This sample was used as main sample for evaluating microbial quality. Using a sterile pipet to 1 ml of sample was transferred from large tube A to the culture tube labeled A 10<sup>-2</sup>. The content was mixed thoroughly by pipeting up and down several times. Using a sterile new tip cap of pipet every time to transfer 1 ml from tube A 10<sup>-2</sup> to tube A 10<sup>-3</sup> and mixed thoroughly as before. This series of dilutions was continued into tubes A 10<sup>-4</sup>, A 10<sup>-5</sup>, A 10<sup>-6</sup> and A 10<sup>-7</sup>. This series of dilution was repeated for all samples.

#### **3.6.7.3 Preparation of plates**

After removing media from autoclave was then placed into laminar flow. 1 ml sample from each tube was poured into the petriplate. After this media was poured in the petriplate and mixed well with sample. These plates were then cooled into laminar flow for some time. As the media got solidify the plated were transferred into incubator which was set at 37<sup>0</sup>C for 12 hours. For fungal growth the spreader was sterilized by dipping it into a beaker of alcohol.

The excess was then remove and shake off. Then running the spreader through the flame of a Bunsen burner and allowed the alcohol to burn off. The spreader was cool by holding it against the condensation on the inside of the petri dish lid. The liquid culture was gently spread onto the surface of the agar by moving the spreader in a circular manner while rotating the plate. This will ensure an even distribution of sample on the fungal media. This step was then repeated for all dilution. Finally the plates were allowed to absorb the cultures, then turn plates upside-down and incubate overnight at 37 ° C.



**Plate 3.9 Set up for evaluation of microbial quality**

#### **3.6.7.4 Counting and Reporting**

The colony forming units per millilitre (CFU/g) was calculated for plates yielding 30-300colonies. The count was then round off to two significant digits to avoid fictitious precision and accuracy.

$$CFU/g = \frac{\text{Colonies Counted}}{\text{Actual volume of sample in dish (g)}} \quad \dots\dots\dots 3.18$$

#### **3.6.8 Sensory and visual appearance assessment**

The products were served for the evaluation to a five panelists at a time. The score sheet was provided with product and panelists were requested to mark the product according to their liking. The average scores of all the panelists were computed. The independent sample t test was applied to compare between modified atmosphere packed storage bengal gram kernels for various organoleptic characteristics. All sensory tests were performed on basis of organoleptical properties such as taste, odour and firmness. The visual properties (color and general freshness of the kernels, i.e. the first impression the consumer gets about the brightness, the size and the absence of damage) were judged under daylight. Nine points were awarded as like extremely-9, like very much-8, like moderately-7, like slightly-6, neither like nor dislike-5, dislike slightly-4, dislike moderately-3, dislike very much-2, dislike extremely-1. The performa, which was giving to each panelist, is given in Appendix G.

### **CHAPTER IV**

## RESULT AND DISCUSSION

This chapter describes the results obtained for physical properties of fresh bengal gram kernels, Modified atmospheric packaging of fresh bengal gram kernels and its effect on the quality of the stored sample. The quality of the sample was determined with the help of quality parameters, microbiologically and sensory evaluation. The statistical analysis of quality evaluation is presented and discussed in this chapter. Storage stability of sample was also observed for 1month for modified atmosphere packaging and results are also presented in this chapter.

### 4.1 Physical Properties of fresh bengal gram kernels

The physical properties of fresh bengal gram kernels were calculated on the basis of maturity level. The maturity days were considered after sowing of the seed from 50 days to harvesting of crop i.e. up to 100 days. The following properties were determined.

#### 4.1.1 Moisture Content

Fig.4.1 shows variation in moisture content of the bengal gram kernels with the level of maturity i.e. days after sowing. The moisture content decreased from 90.26 to 60.01% wb. The moisture content showed a linear decrease with days of maturity and bears the following relationship with a regression coefficient 0.969:

$$\text{M.C.} = -5.196 D + 93.97 \quad \text{.....(4.1)}$$

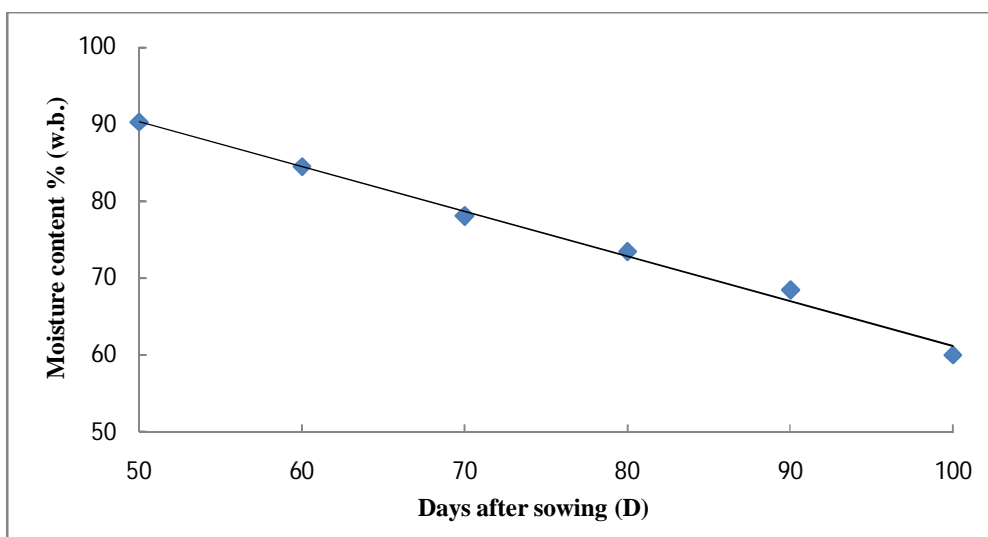


Fig.4.1: Effect of maturity of bengal gram kernels on moisture content

#### 4.1.2 Kernel dimensions and size distribution of kernels

Fig. 4.2–4.4 presents the change in kernel dimensions, sphericity and geometric mean diameter of bengal gram kernels with crop maturity level. It is clear that kernel dimension increases with crop maturity.

A linear relationship exist between the seed dimensions and crop maturity and expressed by the following equations for the length L, width B, thickness T, sphericity  $\phi$ , geometric mean diameter  $D_m$ :

$$L=0.516D + 8.881 \quad (R^2 = 0.976) \quad \dots\dots\dots(4.2)$$

$$B=1.162D + 2.063 \quad (R^2 = 0.977) \quad \dots\dots\dots(4.3)$$

$$T=0.468D + 5.607 \quad (R^2 = 0.988) \quad \dots\dots\dots(4.4)$$

$$\phi=3.719D + 60.84 \quad (R^2 = 0.976) \quad \dots\dots\dots(4.5)$$

$$D_m=0.035D + 0.684 \quad (R^2 = 0.976) \quad \dots\dots\dots(4.6)$$

Where: D is the crop maturity in days.

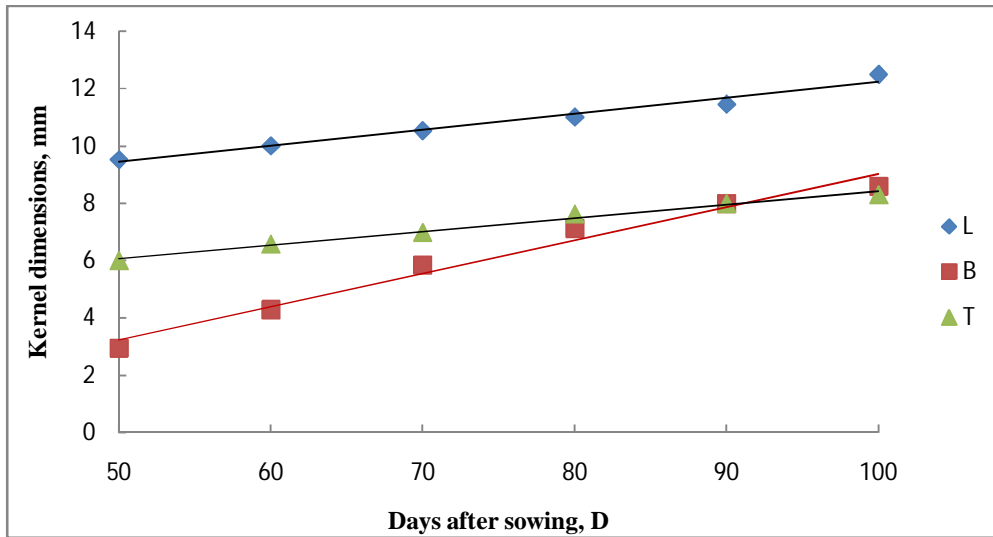
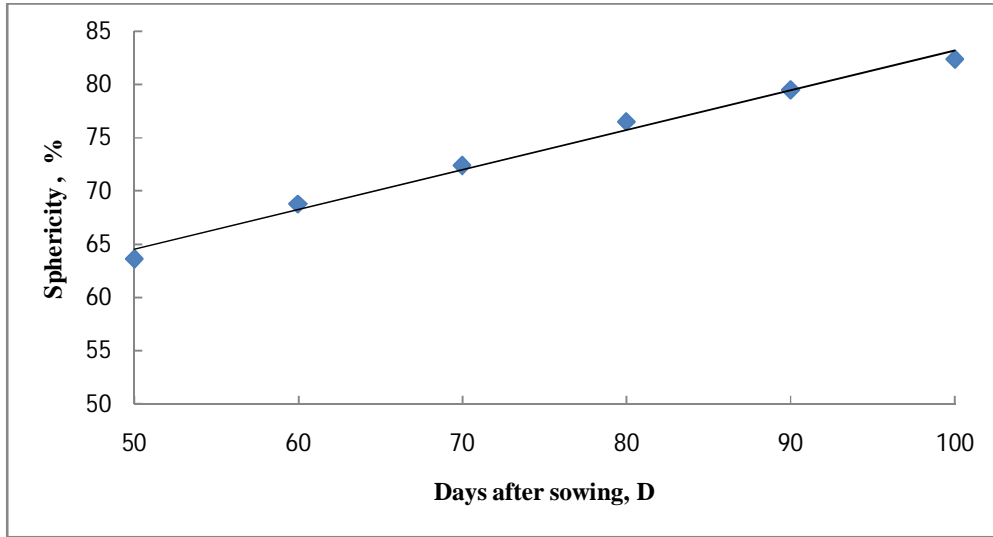
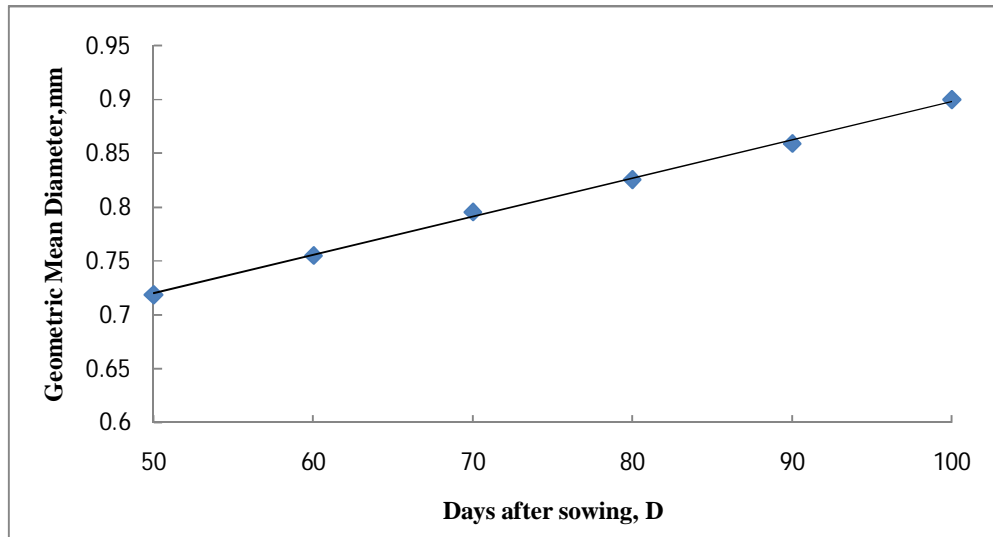


Fig.4.2: Effect of maturity on bengal gram kernel dimensions



**Fig.4.3: Effect of maturity on sphericity of bengal gram kernels**



**Fig.4.4: Effect of maturity on geometric mean diameter of bengal gram kernels**

#### 4.1.3 Colour

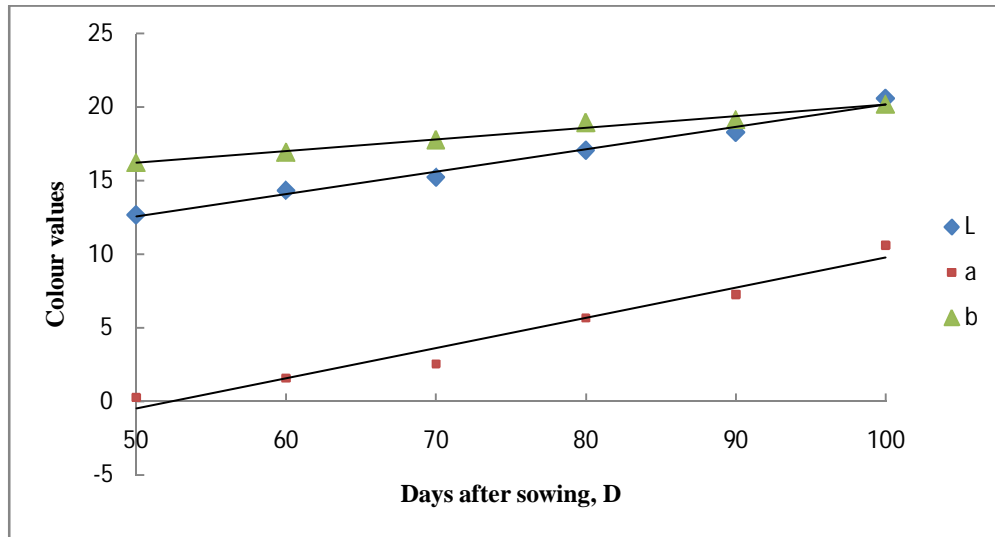
Fig. 4.5 shows the effect of maturity on the colour of the bengal gram kernels. The colour value increases with crop maturity. The relationship between colour values and maturity days was found to be linear and can be expressed by the following equations for the  $L^*$ ,  $a^*$ ,  $b^*$  were obtained.

$$L^* = 1.517 D + 11.04 \quad (R^2 = 0.986) \quad \dots\dots(4.7)$$

$$a^* = 2.05 D - 2.516 \quad (R^2 = 0.965) \quad \dots\dots(4.8)$$

$$b^* = 0.793 D + 15.42 \quad (R^2 = 0.982) \quad \dots\dots(4.9)$$

As the crop matures the green color of kernel diminishes and turns to pale yellow. The 'a' value changes more rapidly with maturity in comparison to 'b' value.



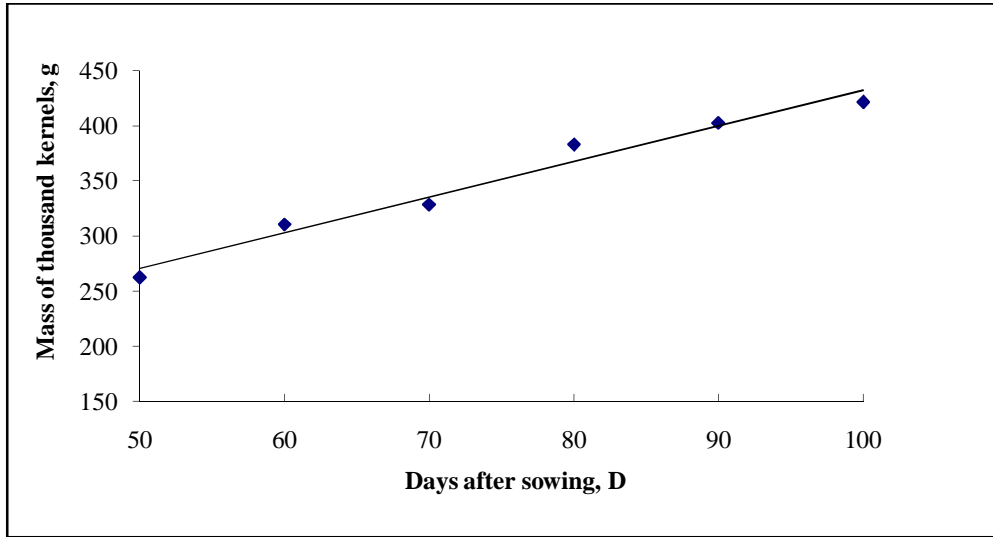
**Fig.4.5: Effect of maturity on colour**

#### 4.1.4 Mass of thousand grain

The average mass of the fresh bengal gram kernels increases linearly with maturity, as shown in the Fig.4.6. This may be attributed to increase in overall dimensions & size of kernel with physiological maturity of crop, which in turns however reduces the moisture content of kernel. The effect of increment in size of kernel is more prominent in comparison to corresponding reduction in moisture content.

The mass of 1000 bengal gram kernels ( $W_t$ ) depicted a linear increase with crop maturity and bears the following relationship with a regression coefficient 0.971:

$$W_t = 32.19 D + 238.5 \quad \dots\dots(4.10)$$



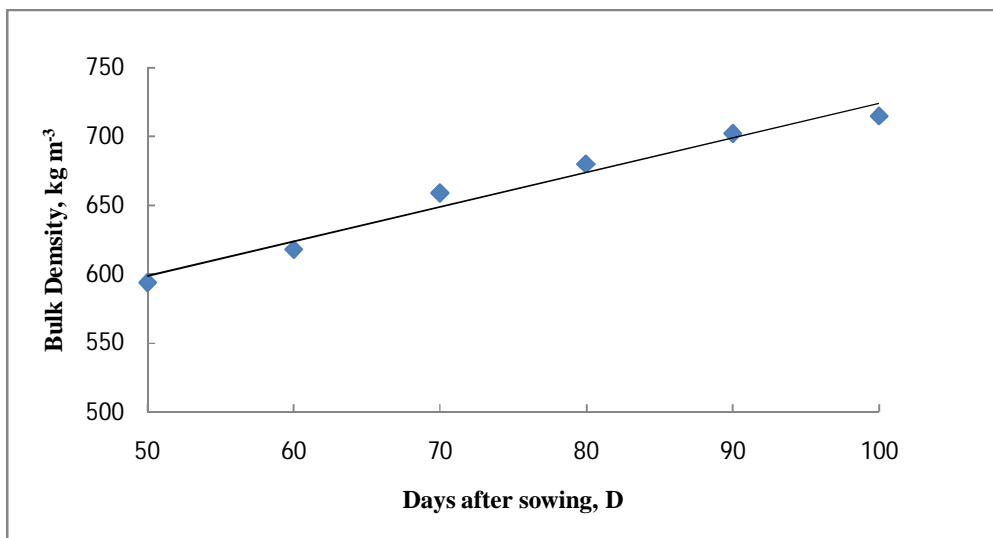
**Fig.4.6: Effect of maturity on thousand kernels weight**

#### 4.1.5 Bulk density

The grain bulk density at different maturity levels varied from 593.90 to 714.86 kg-m<sup>3</sup> (Fig.4.7) and indicated a linear increase with crop maturity. This was due to the fact that increase in mass owing to crop maturity was more for corresponding bulk volume of the kernel (Nimkar & Chattopadhyay, 2001; Yalcin et al, 2007; Konak et al.,2002).

The bulk density of kernels can be mathematically represented as

$$P_b = 25.11D + 573.5 \quad (R^2 = 0.973) \quad \text{.....(4.11)}$$

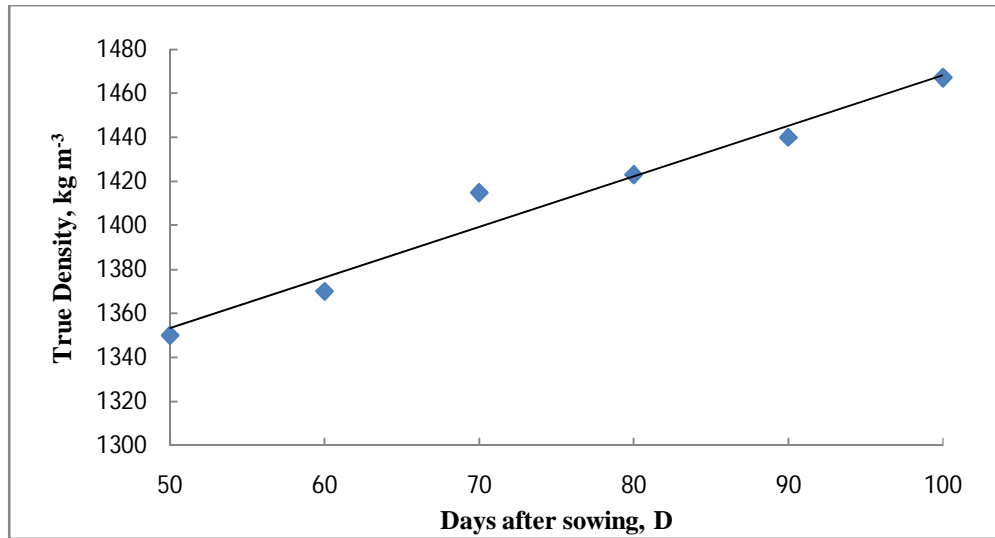


**Fig.4.7: Effect of maturity on bulk density**

#### 4.1.6 True density

The true density varied from 1350 to 1467 kg-m<sup>-3</sup> with crop maturity (Fig.4.8). The increase in true density with maturity might be attributed to the relatively lower true volume as compared to the corresponding change in mass of the kernels with maturity. The results were in conformity with the other researchers (Deshpande et al., 1993; Dutta et al., 1988; Patil, 1977; Shepherd & Bhardwaj, 1986, Nimkar and Chattopadhyay, 2001). The true density of kernels was found to bear the following relationship with maturity days

$$P_t = 22.94 D + 1330 \quad (R^2 = 0.965) \quad \dots\dots\dots(4.12)$$



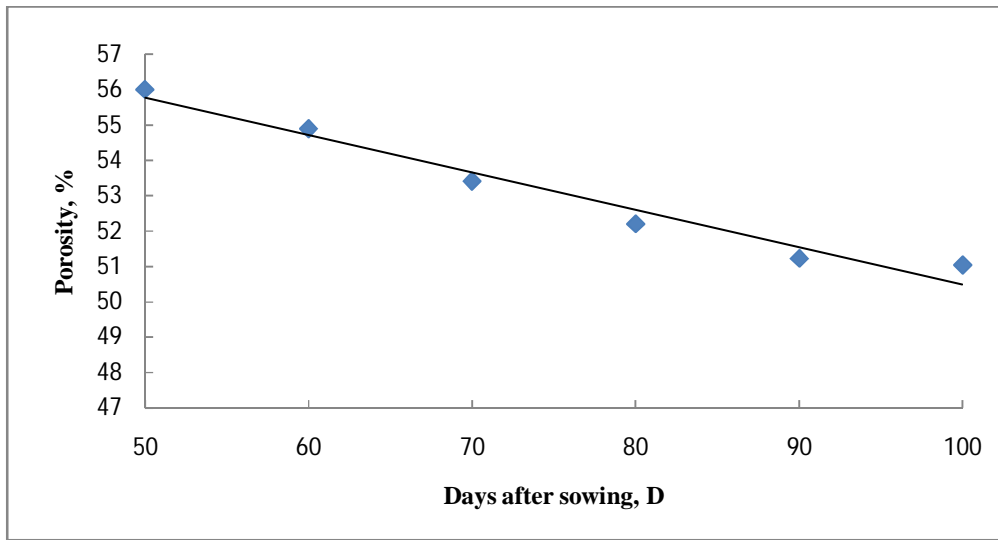
**Fig.4.8: Effect of maturity on true density**

#### 4.1.7 Porosity

Since the porosity depends on the bulk as well as true or kernel densities, the magnitude of variation in porosity depends on these factors only. Fig. 9 illustrates that the porosity of bengal gram kernels decreased with increase in maturity level. The bulk porosity was found to decrease linearly from 56.00 to 51.27% in the specified maturity levels. The trend observed in bengal gram kernels is similar to that of pigeon pea (Shepherd & Bhardwaj, 1986) and lentil (Carman, 1996).

The relationship between porosity and the maturity days of the kernels was linear;

$$\epsilon = -1.059 D + 56.83 \quad (R^2=0.965) \quad \dots\dots\dots(4.13)$$



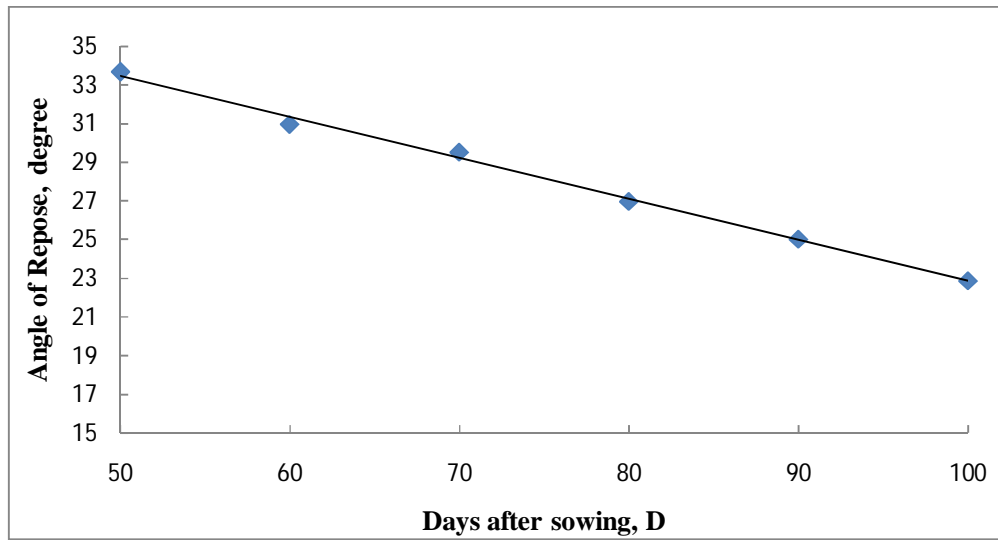
**Fig.4.9: Effect of maturity on porosity**

#### 4.1.8 Angle of repose

Fig.4.10 shows the experimental values of the angle of repose for bengal gram kernels at various maturity levels. The angle of repose decreased from 33.424 to 23.96° with crop maturity of 50–100 days. The value of angle of repose for bengal gram kernels was considerably less than those reported for pigeon pea and fababean seed (Fraser et al., 1978; Shepherd and Bhardwaj, 1986). This is due to the higher sphericity of bengal gram kernels corresponding to maturity allowing them to slide and roll on each other easily.

The values of the angle of repose  $\alpha$  for bengal gram bear the following relationship with maturity days;

$$\alpha = -2.125 D + 35.62 \quad (R^2 = 0.996) \quad \dots\dots\dots(4.14)$$



**Fig.4.10: Effect of maturity on angle of repose**

#### 4.1.9 Statistical Analysis of physical properties of bengal gram kernels:

The statistical analysis was performed on the basis of crop maturity days. The data of physical properties was collected during the maturity days and presented in Appendix H. The statistical analysis was carried out and ANOVA (Analysis of variance) was prepared (Table 4.1). It is evident from the Table 4.1 that all the physical properties were found significant over crop maturity days at 5% level of significance.

**Table 4.1 Analysis of Variance for physical properties of fresh bengal gram kernels**

Particulars	Average	F	Error	SD	Se	CV
M. C. (wb), %	75.7883	358.803**	0.00159	10.2728	0.0231	0.05
Length, mm	10.8483	3.3821293**	0.00040	0.9975	0.0115	0.18
Width, mm	6.1317	14.507689**	0.00040	2.0657	0.0115	0.33
Thickness, mm	7.2467	2.33168**	0.000403	0.8283	0.0115	0.28
Sphericity, %	73.8616	0.1540999**	0.00040	0.0568	0.115	2.03
Geometric mean diameter, mm	0.8117	0.01301**	0.00040	0.0641	0.0115	2.46
Mass of Thousand kernel , g	351.333	11206.4**	9	57.466	1.732	0.850
L	16.3567	24.513**	0.00040	2.685	0.0115	0.12
a	4.665	45.7878**	0.00039	3.670	0.012	0.430
b	18.198	6.729**	0.00039	1.407	0.012	0.110
Bulk density, kg-m <sup>-3</sup>	661.333	6779.6**	4	44.686	1.155	0.300
True density, kg-m <sup>-3</sup>	1410.83	5723.3**	4	41.0627	1.1547	0.14
Porosity, %	53.13	12.232**	0.00039	1.8968	0.0115	0.04
Angle of repose, degree	28.3333	50**	1	3.9258	0.5774	3.53

\*\* Significant at 5% level of significance

#### **4.2 Time studies on pod striping and kernels shelling**

The time required for the striping of pods from the plant and also for the shelling the pods to obtain kernels were determined by recording time taken per unit weight of sample. The recovery of the pods from unit weight of plant and kernels from pod obtained from unit weight of plant was recorded.

Samples of 1.00 kg of plant were given to each labour and the time required, quantity of pods and kernel collection were noted. It was found that on an average 426.8 g of pods could be obtained from one kg of plant, i.e. 42.68% pod recovery was recorded. The kernels collected from one kg of plant were found in the range of 210.2 to 285.7 g i.e. kernel recovery of 21.02 to 28.57%.

The time required for the depoding 1.00 kg of plant was found to vary from 24 to 39 min., depicting that one person can depod approximately 9 to 15 kg in one day (8 hr with 15 min rest after every 2 hr work). The time required for shelling of kernels from pods were found to be in the range of 70 to 120 min for approximately one kg of plant, showing that the

person can shell approximately 1.38 to 2.4 kg of kernels in one day (8 hr with 30 min rest after every 2 hr of work).

The data of time studies on pod stripping and kernels shelling was collected presented in Appendix I. The capacity of one person for depodding of the pods from plat was found to be 1.80 kg/hr while for pod shelling it was 0.276 kg/hr.

### 4.3 Respiratory behavior of fresh bengal gram kernels

The variation in the head space partial pressure ( $p_{O_2}^{in}$  and  $p_{CO_2}^{in}$ ) were measured for the impermeable container containing fresh bengal gram kernels maintained at room temperature,  $0^\circ$  and  $5^\circ C$ . The container containing fresh bengal gram kernels were maintained for 4 h. The  $p_{O_2}^{in}$  value decreases with respect to time in all three cases whereas corresponding  $p_{CO_2}^{in}$  increases with time as shown in Fig. 4.11 to 4.13. Throughout the respiration study, both  $O_2$  and  $CO_2$  partial pressures remained within the aerobic range and no fermentation was observed for fresh bengal gram at all three conditions.

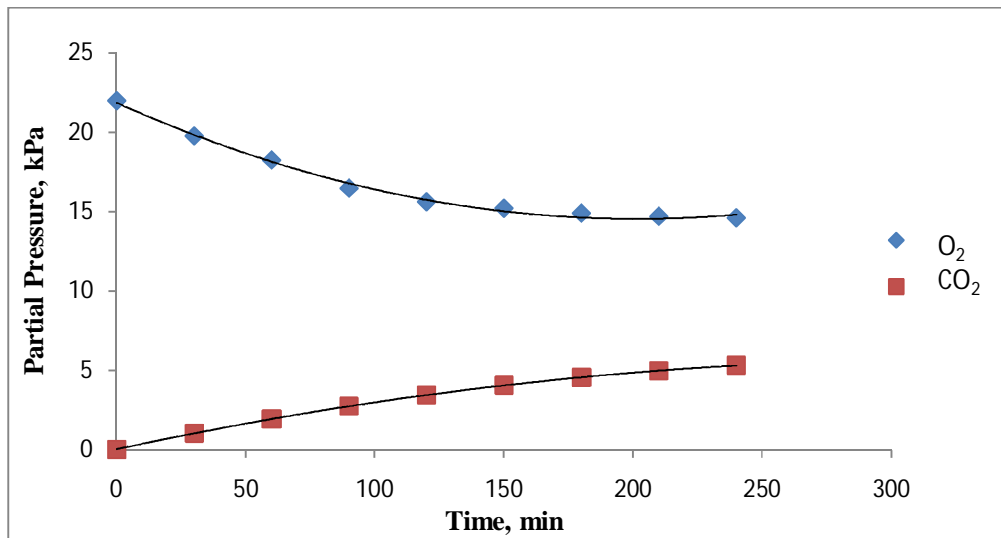


Fig.4.11 Partial pressures of oxygen and carbon dioxide in the container headspace during closed system experiment for fresh bengal gram kernels at ambient temperature.

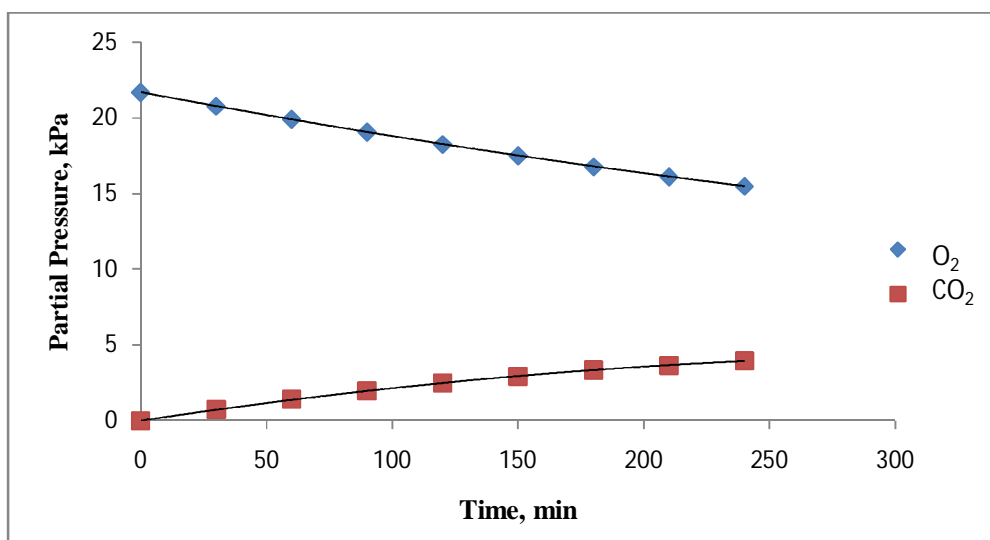


Fig.4.12 Partial pressures of oxygen and carbon dioxide in the container headspace during closed system experiment for fresh bengal gram kernels at 5°C.

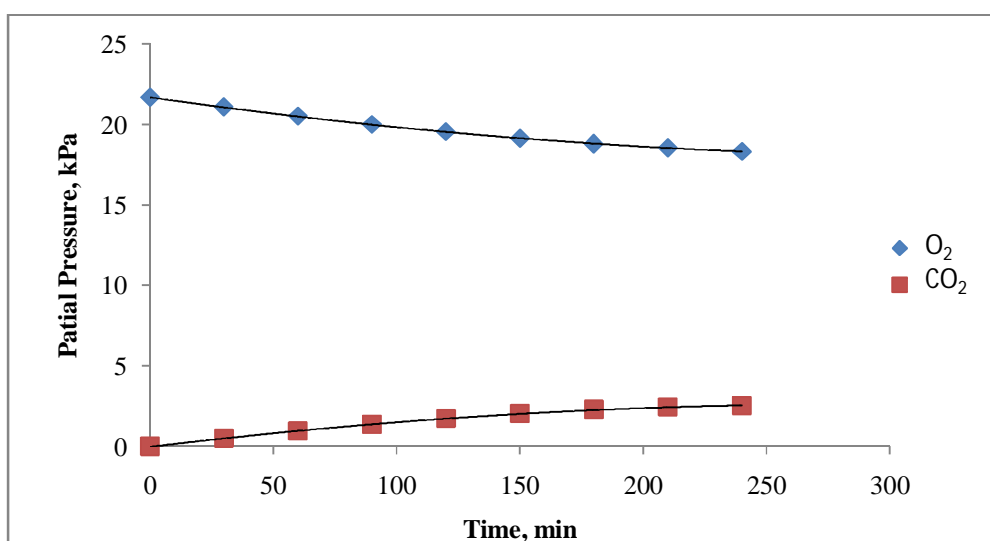


Fig.4.13 Partial pressures of oxygen and carbon dioxide in the container headspace during closed system experiment for fresh bengal gram kernels at 0°C.

Table 4.2 Predicted equations and coefficient of determination for partial pressure

Temperature (°C)	Partial pressure(kPa)	Equation predicted	R <sup>2</sup>
Ambient temperature	O <sub>2</sub>	$y = 0.00018x^2 - 0.07239x + 21.84462$	0.994
	CO <sub>2</sub>	$y = -0.00005x^2 + 0.03517x + 0.00645$	0.999

5	O <sub>2</sub>	$y = 0.00002x^2 - 0.03125x + 21.69202$	0.999
	CO <sub>2</sub>	$y = -0.00004x^2 + 0.02487x + 0.02671$	0.999
0	O <sub>2</sub>	$y = 0.00003x^2 - 0.02178x + 21.69645$	0.999
	CO <sub>2</sub>	$y = -0.00003x^2 + 0.01834x - 0.01197$	0.999

Table 4.3 Steady-rate of oxygen consumption  $(R_{O_2})$  and carbon dioxide evolution  $(R_{CO_2})$  at ambient,  $5 \pm 1^\circ$  and  $0 \pm 1^\circ\text{C}$  respectively

S. N.	Temperature, $^\circ\text{C}$	Respiration rate( $\text{ml kg}^{-1}\text{h}^{-1}$ )	
		$(R_{O_2})$	$(R_{CO_2})$
1	Ambient temperature	$(R_{O_2})$	180.8572
		$(R_{CO_2})$	125.7766
2	5	$(R_{O_2})$	146.1405
		$(R_{CO_2})$	92.2122
3	0	$(R_{O_2})$	79.0596
		$(R_{CO_2})$	59.1104

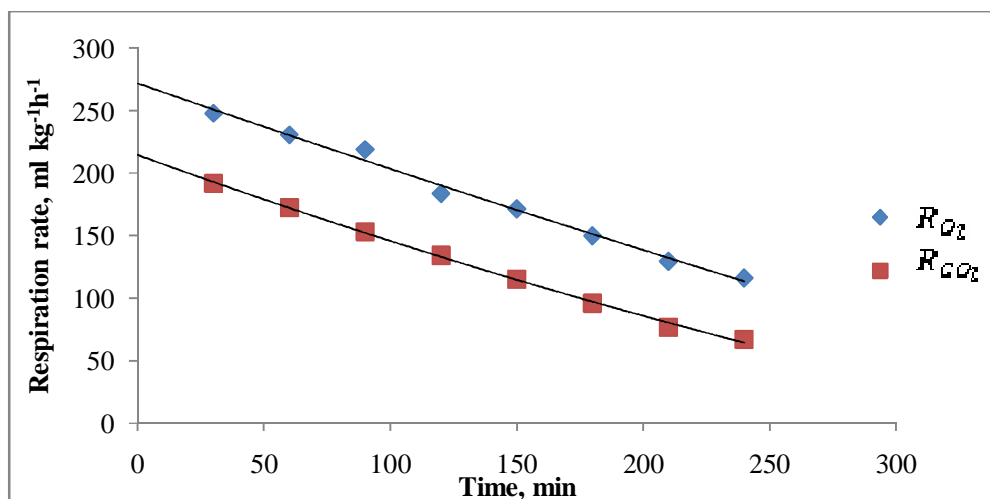


Fig.4.14 Oxygen consumption rate and carbon dioxide evolution rate in the container headspace during the closed system experiment for fresh bengal gram kernels at ambient temperature.

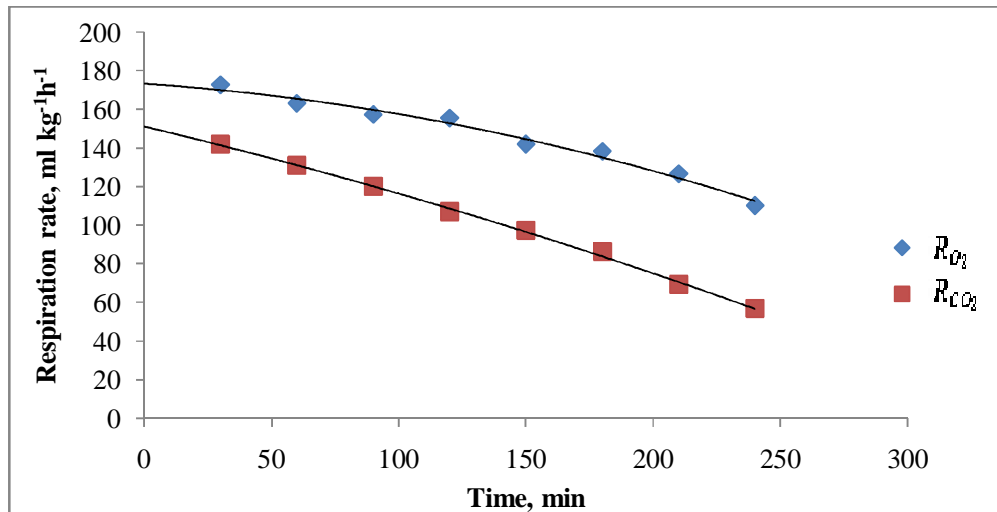


Fig.4.15 Oxygen consumption rate and carbon dioxide evolution rate in the container headspace during the closed system experiment for fresh bengal gram kernels

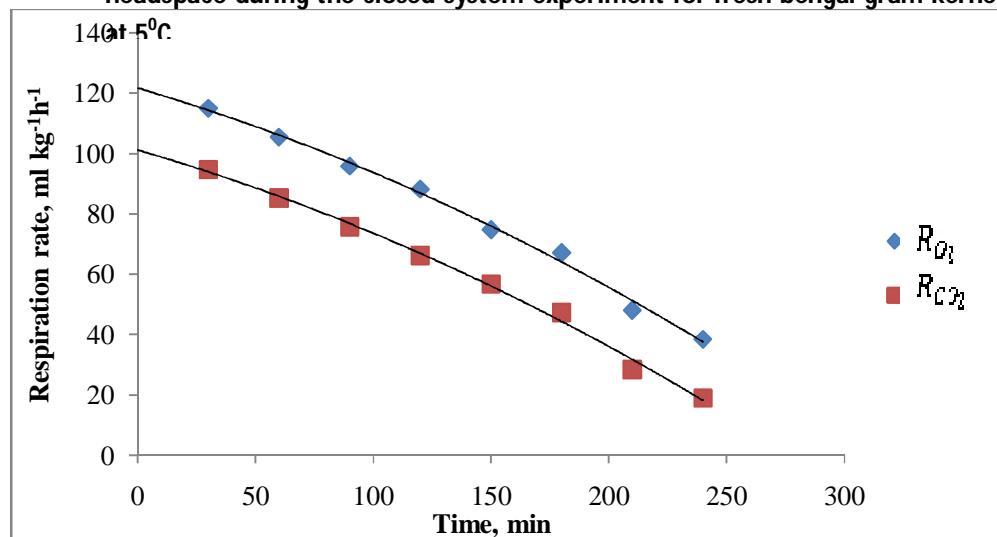


Fig.4.16 Oxygen consumption rate and carbon dioxide evolution rate in the container headspace during the closed system experiment for fresh bengal gram kernels at 5°C.

Table 4.4 Predicted equations and coefficient of determination values for respiration rate

Temperature, (°C)	Respiration rate (ml kg <sup>-1</sup> h <sup>-1</sup> )	Equation predicted	R <sup>2</sup>
Ambient temperature	( $R_{O_2}$ )	$y = 0.00017x^2 - 0.69980x + 271.41080$	0.992
	( $R_{CO_2}$ )	$y = 0.00044x^2 - 0.73203x + 214.41919$	0.998

( $R_{O_2}$ )

5		$y = -0.00046x^2 - 0.13690x + 175.09475$	0.986
		$y = 0.00088x^2 - 0.64177x + 158.75369$	0.987
0		$y = -0.00051x^2 - 0.22969x + 121.70386$	0.994
		$y = -0.00050x^2 - 0.22518x + 100.99437$	0.995

The calculated values of rates of oxygen consumption ( $R_{O_2}$ ) and carbon dioxide evolution ( $R_{CO_2}$ ) (Appendix J-1 to J-3) for the same intervals were plotted for fresh bengal gram kernels. The ( $R_{O_2}$ ) and ( $R_{CO_2}$ ) values remain relatively higher initially, mainly because of initial environmental and respiration adjustments. However as the time progressed, and  $R_{CO_2}$  values kept on decreasing. The partial pressure becomes constant after 3.5 to 4 hr. The respiration rate for  $O_2$  consumption was higher than the rates of  $CO_2$  evaluation as shown in Figure 4.14 to 4.16. The steady state respiration rates for  $O_2$  consumption and  $CO_2$  evaluation for fresh bengal gram kernels are presented as in table 4.3.

The predicted equations for rate of oxygen  $O_2$  consumption and  $CO_2$  evolution have been predicted for all three storage conditions with  $R^2$  value more than 0.99.

#### 4.3.1 Enzyme kinetics model parameters and type of Inhibition

The enzyme kinetics parameters viz,  $V_{mO_2}$ ,  $K_{mO_2}$  and  $K_{muCO_2}$  as determined by the nonlinear analysis of respiration data of fresh bengal gram kernels on the basis of enzyme kinetics equation for mixed or combined inhibition, have been given in Table 4.5.

**Table 4.5 Enzyme kinetics model parameters and type of inhibition for fresh bengal gram kernels at ambient,  $5\pm 1^\circ C$  and  $0\pm 1^\circ C$**

Storage conditions	$V_{mO_2}$ (ml kg/h)	$K_{mO_2}$ (kPa)	$K_{mCO_2}$ (kPa)	Alpha, (a)	$K_{muCO_2}$ = $axK_{mCO_2}$ (kPa)	Types of inhibition	$R^2$
Ambient	306.5	$3.144 \times 10^{-7}$	$9.159 \times 10^{-8}$	$5.104 \times 10^{-23}$	$4.67 \times 10^{16}$	competitive	0.96
$5\pm 1^\circ C$	$8.140 \times 10^{12}$	$9.539 \times 10^{11}$	48.75	$5.644 \times 10^{16}$	$2.75 \times 10^{18}$	competitive	0.95
$0\pm 1^\circ C$	$1.065 \times 10^{10}$	$1.444 \times 10^9$	1.916	$2.582 \times 10^{16}$	$4.94 \times 10^{16}$	competitive	0.97

Alpha determines mechanism. Its value determines the degree to which the binding of inhibitor changes the affinity of the enzyme for the substrate. Its value is always greater than zero. When Alpha=1, the inhibitor does not alter binding of substrate to the enzyme, and the mixed-model is identical to competitive inhibition. When alpha is very small ( but greater than zero), binding of the inhibitor enhances substrate binding to the enzyme, and the mixed model becomes nearly identical to an uncompetitive model.

Since the values of  $K_{muCO_2}$  tends to infinity and alpha is very large in case of fresh bengal gram indicating that the fresh bengal gram kernels exhibits predominantly competitive type of inhibition during its respiration at all three temperatures i.e. at ambient,  $5\pm 1$  and  $0\pm 1^\circ C$ , respectively . As per enzyme theory, during competitive type of inhibition, the inhibitor ( $CO_2$  in this case) binds reversibly to the same site as the substrate ( $O_2$ ), so its inhibition can be entirely overcome by using very high concentration of  $O_2$ . But in case of uncompetitive type of inhibition, inhibitor ( $CO_2$ ) binds with equal affinity to the enzyme, and the enzyme  $O_2$  complex. The inhibition is not surmountable by increasing substrate concentration. Because the enzyme  $O_2$  complex is stabilized, it takes less  $O_2$  to get to half maximal activity. The idea of respiratory inhibition by  $CO_2$  was first supported by simple explanation, i.e., that  $CO_2$  was a sample of the respiration process and, caused simple feedback inhibition. Another hypothesis considered that  $CO_2$  had a controlling effect on mitochondrial activity, including citrate and succinate oxidation. Kader (1989) considered that elevated  $CO_2$  might affect the Krebs cycle intermediates and enzymes. Others considered that  $CO_2$  might inhibit ethylene sampleion rather than having a direct effect on the respiration process.

#### **4.4 Modified atmosphere packaging and storage studies of fresh bengal gram kernels**

The storage studies under ambient,  $5\pm 1$ ,  $0\pm 1^\circ C$  were conducted at Bio-processing laboratory of AICRP on Post Harvest Technology, Department of Processing and Food Engineering, CTAE, MPUAT, Udaipur. Quality parameters such as PLW, decay, firmness, water activity and microbial load of bengal gram kernels along with change in headspace gas composition recorded during storage at 3 days interval till the product became totally unusable. The data collected during experiment was presented in appendix K.

##### **4.4.1 Package headspace atmosphere**

The package headspace composition in terms of  $O_2$  and  $CO_2$  is illustrated in Fig. 4.16 to 4.29. The headspace got modified rapidly and the gas composition in the film package was largely influenced by the packaging materials. The pattern in the level of  $O_2$  and  $CO_2$  gases in

the MA packed fresh bengal gram kernels depicted that there was a gradual decrease in the O<sub>2</sub> level and a gradual increase in the CO<sub>2</sub> level from the beginning of the experiment which could be attributed to transit state of stabilization and equilibrium of the crop with the surroundings. Subsequently, with the progress of storage, the respiration decreased progressively which led to in-pack accumulation of CO<sub>2</sub> under all conditions during later period of storage. Similar pattern of changes in the gaseous atmosphere were reported by numerous researchers (Deily and Rizvi 1981; Smith *et. al*, 1987; Nakhasiet *al.* 1991; Isaaket *al* 2006).

#### **4.4.1.1 Head space O<sub>2</sub>(%)**

The effect of gas composition, storage temperature and combine effect of gas composition and storage temperature and effect of type of packaging films are illustrated in Fig. 4.17- 4.23.

### Effect of gaseous composition

It is clear from data presented in Fig.4.17-4.18 that  $O_2$  decreased with advancement of storage duration, but it is significantly affected by the gaseous composition during the storage.

On 6<sup>th</sup> day of storage, for LDPE minimum  $O_2$  was recorded in  $G_1$  (1.27 %), while maximum in  $G_3$  (3.77 %). On 24<sup>th</sup> day of storage minimum  $O_2$  was recorded in  $G_1$  (0.60 %) and maximum in  $G_3$ (1.30 %). At the end of experiment,0.20%  $O_2$  was recorded in  $G_1$  on 30<sup>th</sup> day of storage.

For HDPE, on 6<sup>th</sup> day of storage the minimum  $O_2$  was observed in  $G_1$  (1.2%), while maximum was recorded in  $G_3$  (3.7%). Similarly on 21<sup>st</sup> day of storage, minimum  $O_2$  was recorded in  $G_1$  (0.6%) and maximum in  $G_2$  (1.4%). At the end of experiment,0.30%  $O_2$  was recorded in  $G_1$  on 27<sup>th</sup> day of storage.

The considerable decrease in  $O_2$  concentration could be explained considering high respiratory rate of product at high storage temperature over low temperature condition (Ares *et al.*, 2006, 2007; Parentelli *et al.*, 2007, Kudachikar *et al.*,2011).

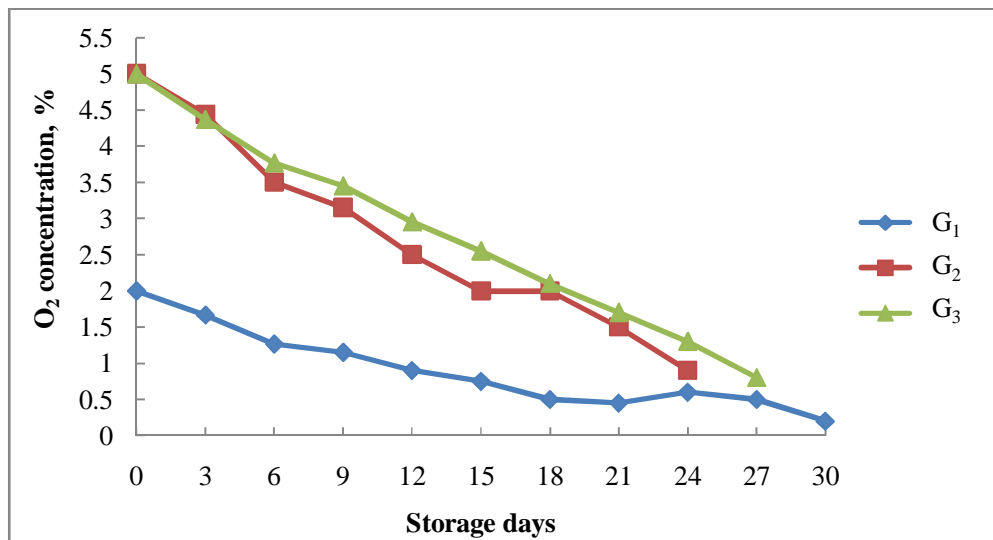
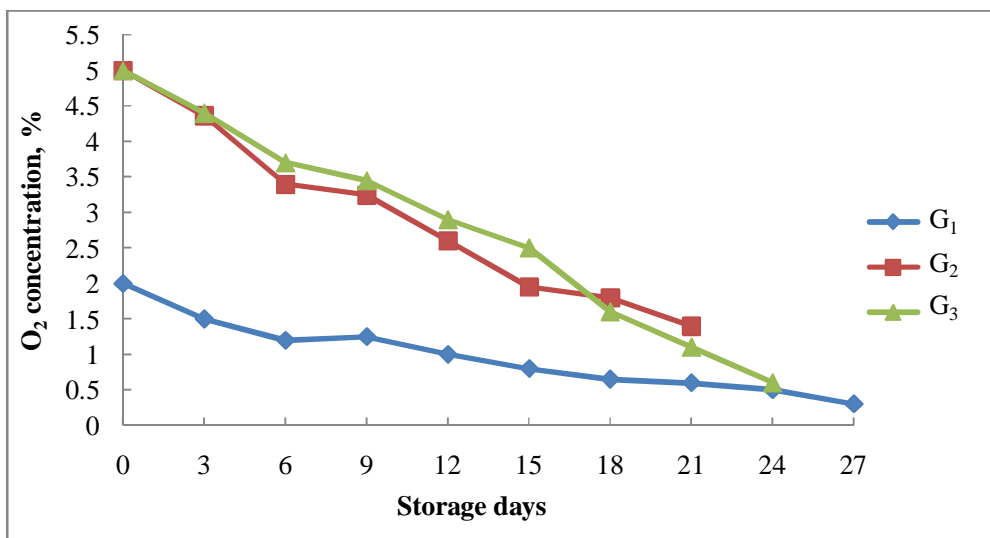


Fig. 4.17 Effect of Gas composition on  $O_2$  concentration in LDPE



**Fig. 4.18 Effect of Gas composition on O<sub>2</sub> concentration in HDPE**

#### Effect of storage temperature

Fig.4.19-4.20 shows that in the sample stored at ambient condition, O<sub>2</sub> decreased rapidly as compared to other storage conditions. Decrease in O<sub>2</sub> of bengal gram kernels stored at low temperature under refrigerated condition was slow as compared to sample stored at ambient temperature.

A critical examination of data reveals that O<sub>2</sub> decreased under all three storage temperature conditions. On 6<sup>th</sup> day of storage, for LDPE, minimum O<sub>2</sub> was recorded at T<sub>1</sub> condition (2.2%) and maximum was recorded at T<sub>3</sub> condition (3.20%). On 21<sup>st</sup> day of storage, minimum O<sub>2</sub> was recorded at T<sub>2</sub> condition (0.2) and maximum was recorded at T<sub>3</sub> condition (1.30%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.2% O<sub>2</sub> was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum O<sub>2</sub> was recorded at T<sub>1</sub> condition (2.2%) and maximum was recorded at T<sub>2</sub> condition (3.1%). On 18<sup>th</sup> day of storage, minimum O<sub>2</sub> was recorded at T<sub>2</sub> condition (0.5%) while maximum was at T<sub>3</sub> condition (1.4%). At the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.3% at T<sub>3</sub> condition.

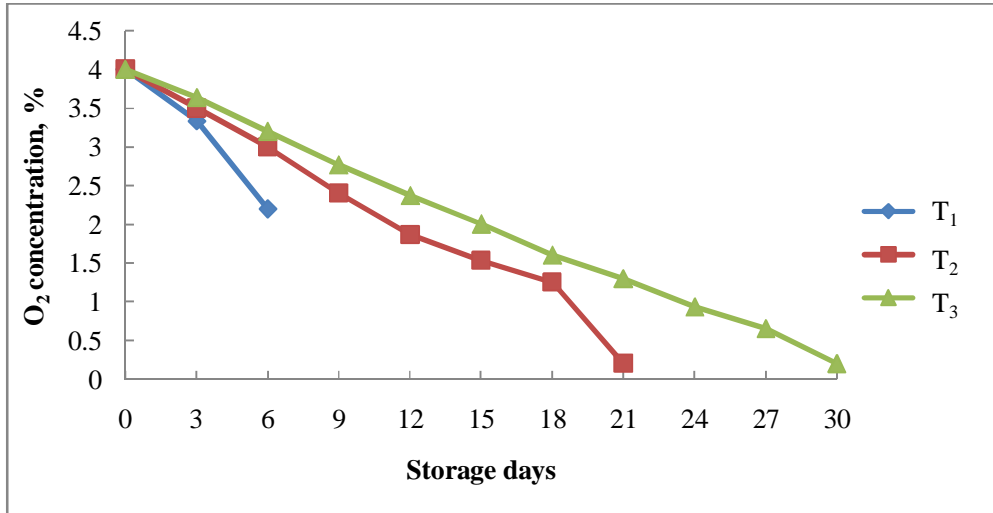


Fig. 4.19 Effect of storage temperature on O<sub>2</sub> concentration in LDPE

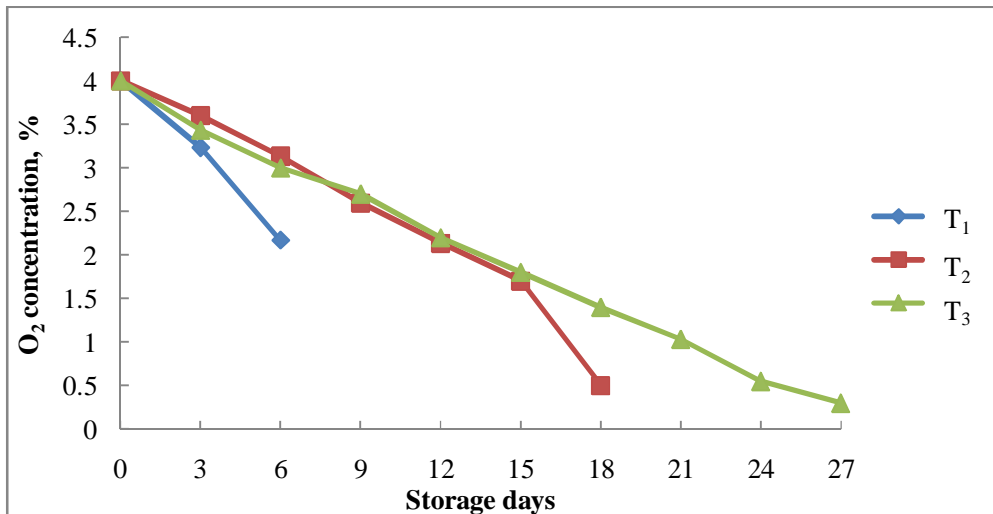


Fig. 4.20 Effect of storage temperature on O<sub>2</sub> concentration in HDPE

#### Combined effect of package gaseous composition and storage temperature

The combined effect of package gaseous composition and storage temperature on bengal gram kernels were shown in Fig. 4.21-4.22.

On 6<sup>th</sup> day of storage minimum O<sub>2</sub> was observed in LG<sub>1</sub>T<sub>1</sub> (0.9%) and maximum was in LG<sub>3</sub>T<sub>3</sub>(4.2%) treatment combination. On 15<sup>th</sup> day of storage, minimum O<sub>2</sub> was recorded in LG<sub>1</sub>T<sub>2</sub> (0.5%) while minimum was in LG<sub>3</sub>T<sub>2</sub> (2.7%). Similarly on 24<sup>th</sup> day of storage minimum O<sub>2</sub> was recorded in LG<sub>1</sub>T<sub>3</sub> (0.6%) and maximum in LG<sub>3</sub>T<sub>3</sub> (0.8%). At the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.2% O<sub>2</sub> was recorded in LG<sub>1</sub>T<sub>3</sub>.

On 6<sup>th</sup> day of storage minimum O<sub>2</sub> was observed in HG<sub>1</sub>T<sub>1</sub> (0.7%) and maximum was in HG<sub>3</sub>T<sub>2</sub> (4.2%) treatment combination. On 15<sup>th</sup> day of storage, minimum O<sub>2</sub> was recorded in HG<sub>1</sub>T<sub>2</sub> (0.6%) while maximum was in HG<sub>3</sub>T<sub>2</sub> (2.9%). Similarly on 21<sup>st</sup> day of storage minimum O<sub>2</sub> was recorded in HG<sub>1</sub>T<sub>3</sub> (0.6 %) and maximum was in HG<sub>2</sub>T<sub>3</sub> (1.4%). At the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.3% O<sub>2</sub> was recorded in HG<sub>1</sub>T<sub>3</sub>.

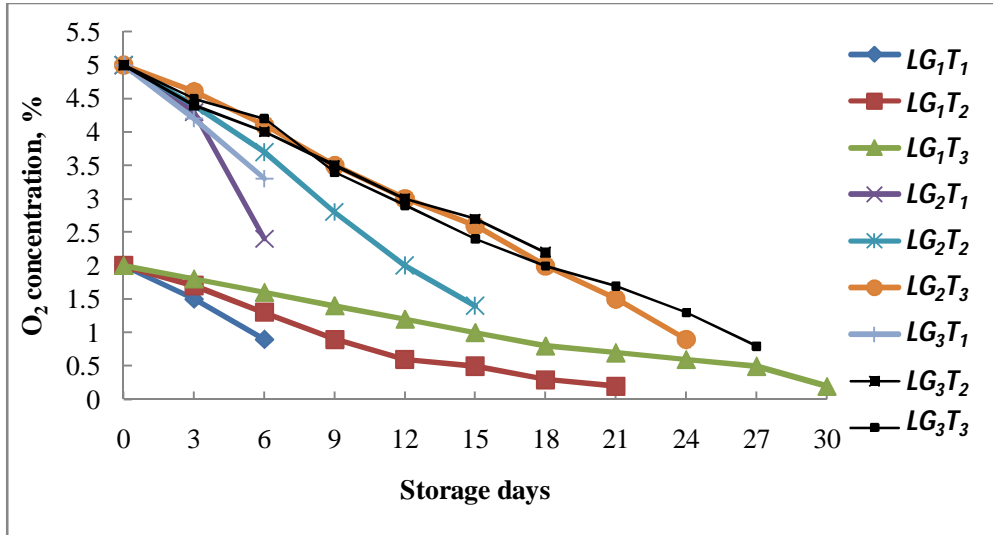


Fig. 4.21 Combined effect of gas composition and storage temperature on O<sub>2</sub> concentration in LDPE

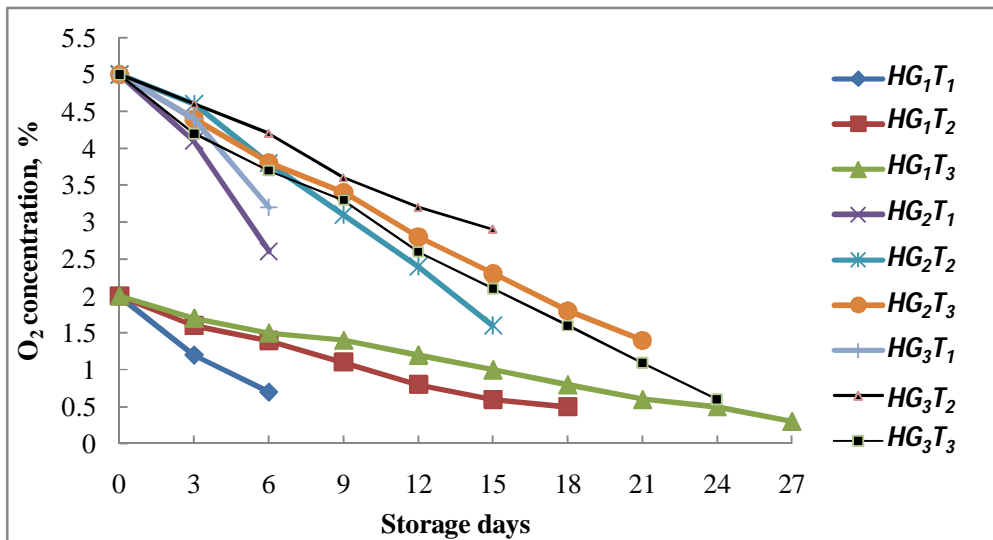
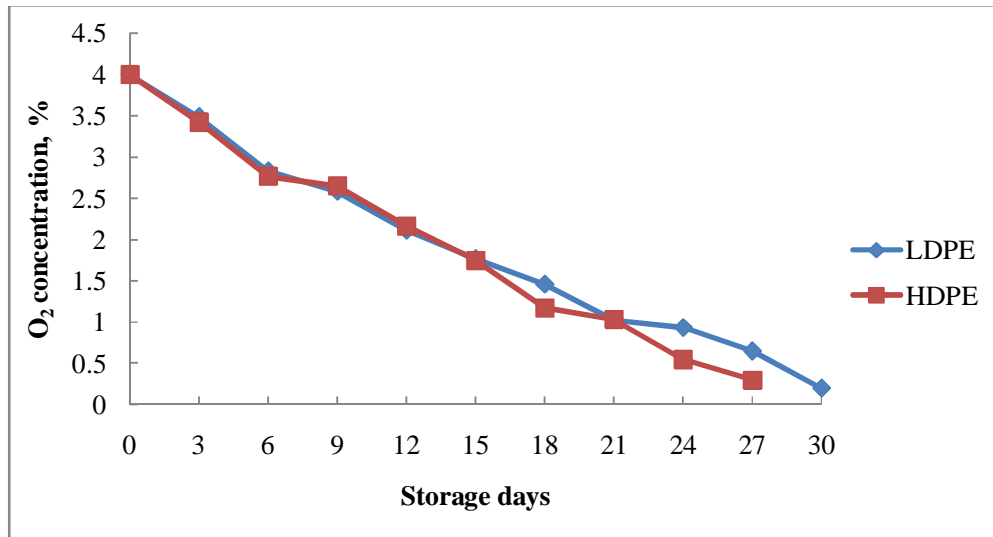


Fig. 4.22 Combined effect of gas composition and storage temperature on O<sub>2</sub> concentration in HDPE

### Effect of polythene film on O<sub>2</sub> concentration



**Fig.4.23 Effect of polythene film on O<sub>2</sub> concentration**

From Figure 4.23 it is clear that the LDPE film retains the more amount of oxygen than HDPE film during the storage period which may be attributed to slow respiration in LDPE than in HDPE. Due to this the sample packed in the LDPE film survived till 30 days as compared to the sample packed in HDPE film (27 days) as the gaseous exchange in LDPE was more slow over HDPE film.

The comparative effect gas composition and storage temperature on O<sub>2</sub> concentration could be observed by F values in the ANOVA (Table 4.6) for both packaging materials i.e. LDPE and HDPE. The F values indicated that gas composition was the more influencing factor than storage temperature. ANOVA also shows that gas composition and storage temperature have significant effect on O<sub>2</sub> concentration at 5% level of significance.

#### 4.4.1.2 Head space CO<sub>2</sub> (%)

The data on head space CO<sub>2</sub> concentration of bengal gram kernels during storage as affected by the different package gas composition and storage temperature are presented in Fig.4.24-4.30.

#### Effect of gaseous composition

It is clear from data presented in Fig.4.24-4.25 that CO<sub>2</sub> increased with advancement of storage duration, but it is significantly affected by the gaseous composition during the storage.

On 6<sup>th</sup> day of storage, for LDPE minimum CO<sub>2</sub> was recorded in G<sub>2</sub> (5.13 %), while maximum in G<sub>1</sub>(9.60 %). On 24<sup>th</sup> day of storage minimum CO<sub>2</sub> was recorded in G<sub>1</sub>(11.00 %) and maximum in G<sub>2</sub> (11.10 %). At the end of experiment, 11.60% CO<sub>2</sub> was recorded in G<sub>1</sub> on 30<sup>th</sup> day.

For HDPE, on 6<sup>th</sup> day of storage the minimum CO<sub>2</sub> was observed in G<sub>2</sub> (5.5%), while maximum was recorded in G<sub>2</sub> (9.8%). Similarly on 21<sup>st</sup> day of storage, minimum O<sub>2</sub> was recorded in G<sub>2</sub> (10.7%) and maximum in G<sub>1</sub> and G<sub>3</sub> (11.7%). At the end of experiment, 11.7% CO<sub>2</sub> was recorded in G<sub>1</sub> on 27<sup>th</sup> day of storage.

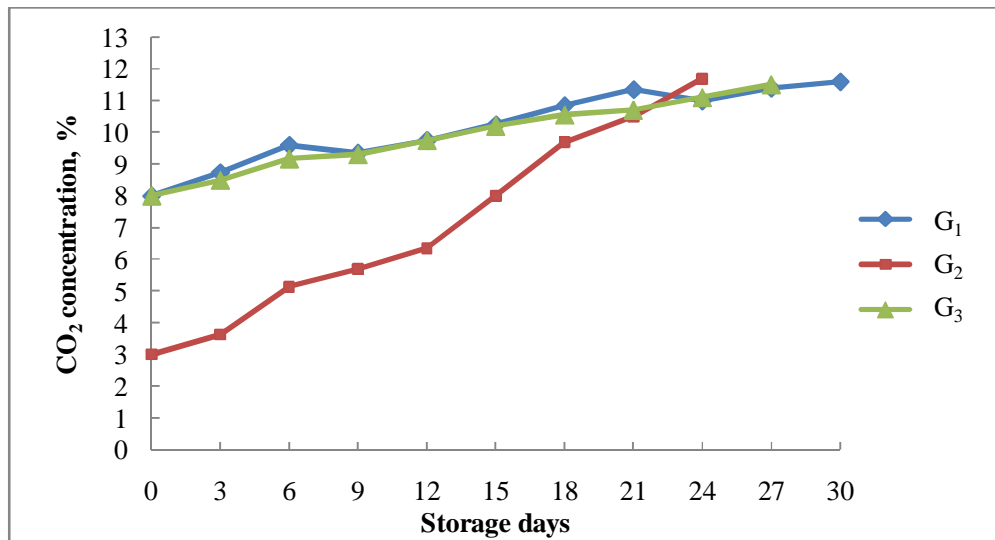


Fig. 4.24 Effect of package gas composition on CO<sub>2</sub> concentration in LDPE

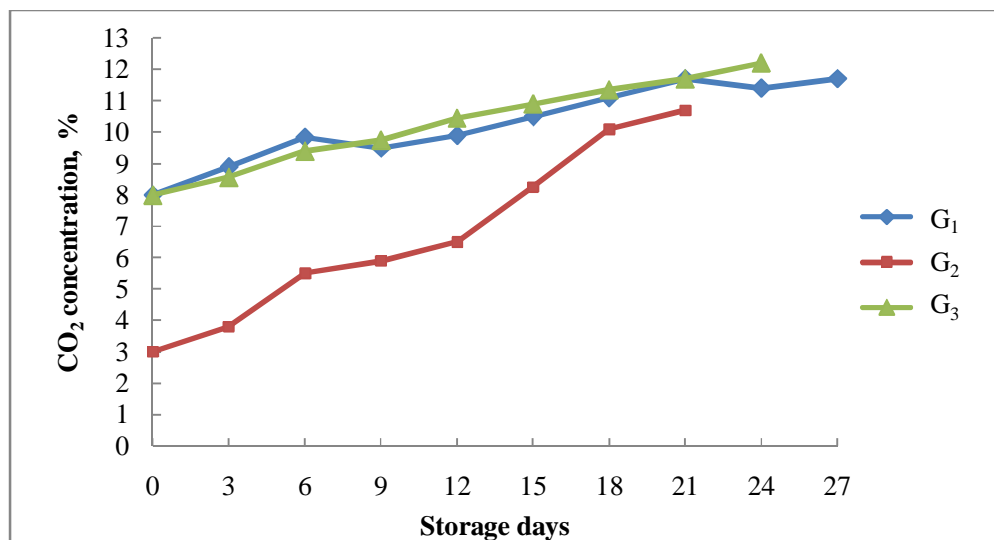


Fig. 4.25 Effect of package gas composition on CO<sub>2</sub> concentration in HDPE

**Table 4.6 Anova of O<sub>2</sub> concentration in LDPE and HDPE**

	Days	3		6		9		12		15	
O <sub>2</sub> LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	5.658	141.45*	4.815	120.375*	7.491	280.90*	5.177	29.90*	3.951	148.15*
gas composition	2	22.423	560.58*	16.230	405.75*	6.253	234.5*	4.224	24.4*	3.403	127.62*
temperature	2	0.203	5.08*	2.520	63*	20.323	762.12*	13.148	75.95*	9.853	369.5*
GXT	4	0.003	0.083	0.255	6.37*	1.693	63.5*	1.668	9.63*	1.273	47.75*
Error	18	0.040		0.040		0.027		0.173		0.027	

	Days	18		21		24		27		30	
O <sub>2</sub> LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	2.868	129.075*	1.426	80.20*	0.746	55.93*	0.263	29.625*	0.013	3*
gas composition	2	2.543	114.45*	0.173	9.75*	0.123	9.25*	0.163	18.37*	0.013	3.000
temperature	2	5.763	259.35*	4.823	271.31*	2.613	196*	0.563	63.37*	0.013	3.000
GXT	4	1.583	71.25*	0.353	19.87*	0.123	9.25*	0.163	18.375*	0.013	3*
Error	18	0.022		0.018		0.013		0.009		0.004	

	Days	3		6		9		12		15	
O <sub>2</sub> HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	6.366	635.583*	4.816	481.583*	7.538	1131*	5.130	769.5*	3.668	550.125*
gas composition	2	24.943	2494*	16.493	1649*	5.920	888*	4.030	604.5*	3.010	451.5*
temperature	2	0.303	30.333*	2.403	240.333*	21.090	3163*	13.870	2080*	9.210	1381*
GXT	4	0.108	10.833*	0.183	18.333*	1.570	235.5*	1.310	196*	1.225	183.75*
Error	18	0.010		0.010		0.007		0.007		0.007	

	Days	18		21		24		27	
O <sub>2</sub> HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.588	357.375*	0.923	277*	0.178	80.25*	0.030	27*
gas composition	2	0.063	14.25*	0.163	49*	0.103	46.5*	0.030	27*
temperature	2	5.263	1184*	3.203	961*	0.403	181.5*	0.030	27*
GXT	4	0.513	115.5*	0.163	49*	0.103	46.5*	0.030	27*

Error	18	0.004		0.003		0.002		0.001	
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### Effect of storage temperature

Fig. 4.26-4.27 shows CO<sub>2</sub> increased rapidly the sample stored at ambient condition, as compared to other storage conditions. Increase in CO<sub>2</sub> of bengal gram kernels stored in at 5 and 0°C was slow as compared to sample stored at ambient temperature.

A critical examination of data in temperature reveals that CO<sub>2</sub> increased under all three storage temperature conditions. On 6<sup>th</sup> day of storage, for LDPE, minimum CO<sub>2</sub> was recorded at T<sub>3</sub> condition (7.30%) and maximum was recorded at T<sub>1</sub> condition (9.17%). On 21<sup>th</sup> day of storage, minimum CO<sub>2</sub> was recorded at T<sub>3</sub> condition (10.63%) and maximum was recorded in T<sub>2</sub> condition (12.00%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 11.60% CO<sub>2</sub> was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum CO<sub>2</sub> was recorded at T<sub>2</sub> condition (6.1%) and maximum was recorded at T<sub>1</sub> condition (9.60%). On 18<sup>th</sup> day of storage, minimum CO<sub>2</sub> was recorded at T<sub>2</sub> condition (10.9%) while maximum was at T<sub>3</sub> condition (11.1%). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 11.7% CO<sub>2</sub> was recorded at T<sub>3</sub> condition.

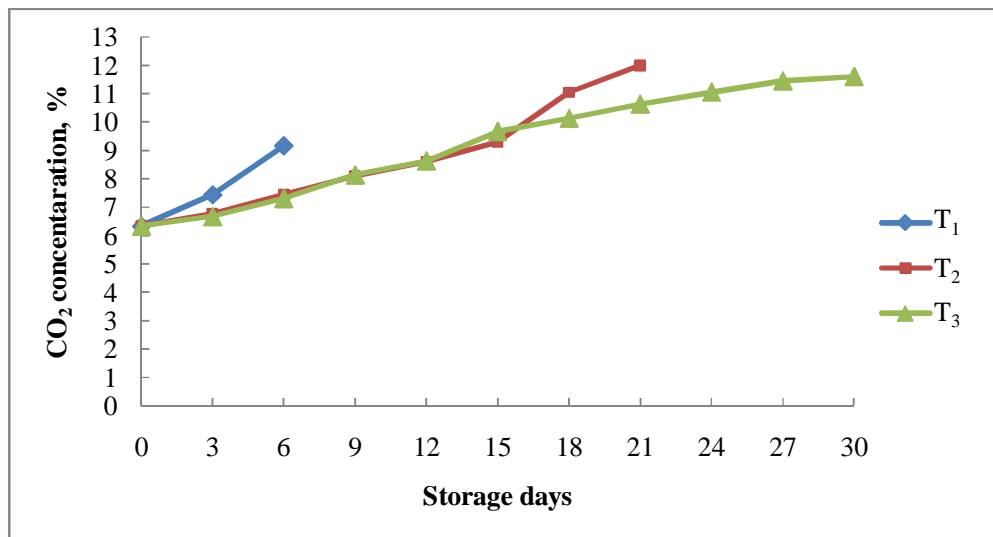
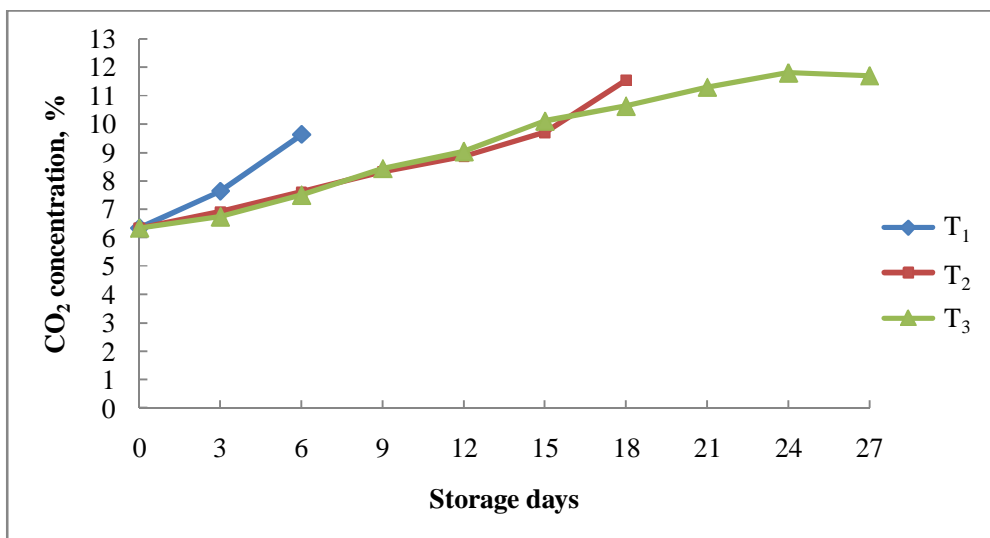


Fig. 4.26 Effect of storage temperature on CO<sub>2</sub> concentration in LDPE



**Fig. 4.27 Effect of storage temperature on CO<sub>2</sub> concentration in HDPE**

#### **Combined effect of package gaseous composition and storage temperature**

The combined effect of package gaseous composition and storage temperature on bengal gram kernels were Fig. 4.28-4.29.

On 6<sup>th</sup> day of storage minimum CO<sub>2</sub> was observed in LG<sub>2</sub>T<sub>1</sub> (6.5%) and maximum was in LG<sub>1</sub>T<sub>1</sub> (11.2%) treatment combination. On 15<sup>th</sup> day of storage, minimum CO<sub>2</sub> was recorded in LG<sub>2</sub>T<sub>2</sub> (6.9%) while maximum was in LG<sub>2</sub>T<sub>2</sub> (10.6%). Similarly on 24<sup>th</sup> day of storage minimum CO<sub>2</sub> was recorded in LG<sub>1</sub>T<sub>3</sub> (11.00%) and maximum was in LG<sub>2</sub>T<sub>3</sub> (11.7%). At the end of experiment i.e. on 30<sup>th</sup> day of storage, 11.60% CO<sub>2</sub> was recorded in LG<sub>1</sub>T<sub>3</sub> treatment combination.

On 6<sup>th</sup> day of storage minimum CO<sub>2</sub> was observed in HG<sub>2</sub>T<sub>3</sub> (4.6%) and maximum was in HG<sub>1</sub>T<sub>1</sub> (11.7%) treatment combination. On 15<sup>th</sup> day of storage, minimum CO<sub>2</sub> was recorded in HG<sub>2</sub>T<sub>2</sub> (7.2%) while maximum was in both HG<sub>1</sub>T<sub>2</sub> (11.00%). Similarly on 21<sup>st</sup> day of storage minimum CO<sub>2</sub> was recorded in HG<sub>2</sub>T<sub>3</sub> (10.7 %) and maximum was in HG<sub>3</sub>T<sub>3</sub> (11.7%). At the end of experiment i.e. on 27<sup>th</sup> day of storage, 11.7% CO<sub>2</sub> was recorded in HG<sub>1</sub>T<sub>3</sub> treatment combination.

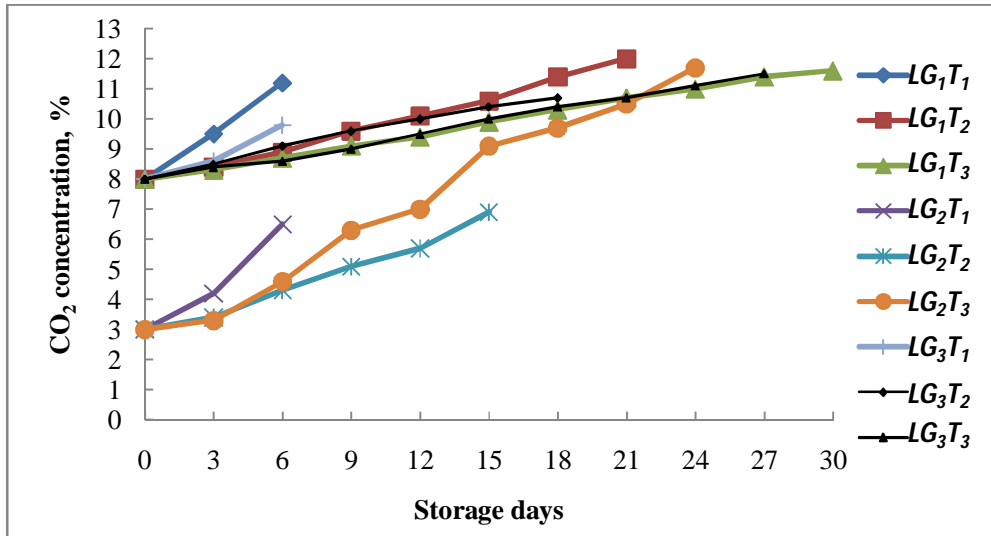


Fig. 4.28 Combined effect of gas composition and temperature on CO<sub>2</sub> concentration

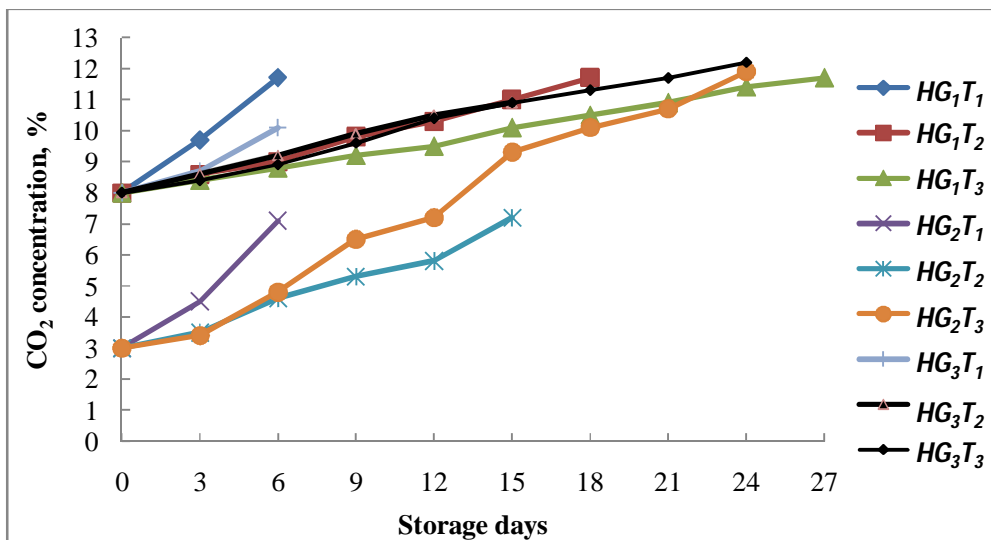
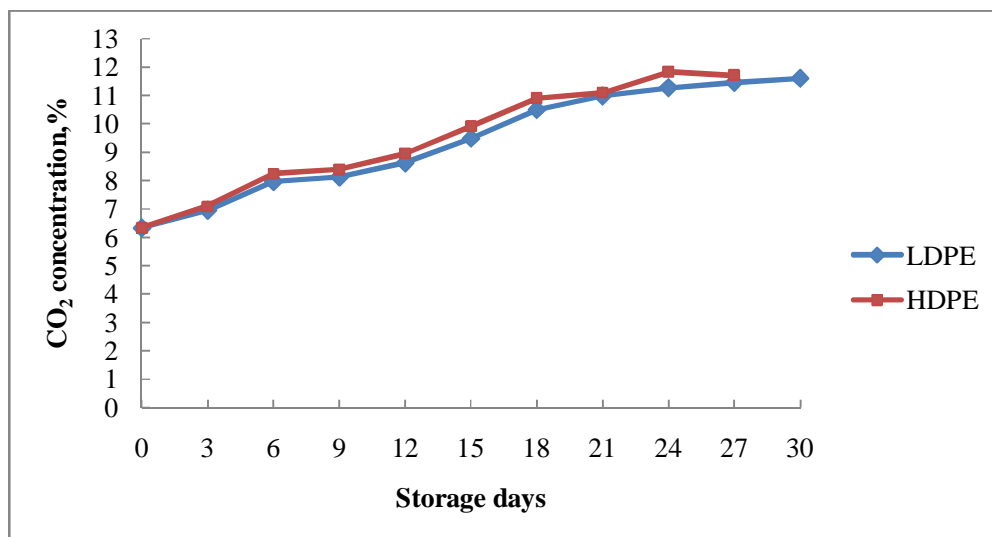


Fig. 4.29 Combined effect of gas composition and temperature on CO<sub>2</sub> concentration

### Effect of polythene films on CO<sub>2</sub> concentration



**Fig.4.30 Effect of packaging film on CO<sub>2</sub> concentration**

From Figure 4.30 it is clear that the HDPE film retains more CO<sub>2</sub> than LDPE during the storage period. The lower retention of CO<sub>2</sub> shows the slow respiration in LDPE than in HDPE. Due to this the sample packed in the LDPE film survived for more days as compared to the sample packed in HDPE film. The package gaseous exchange with storage was more rapid in HDPE over LDPE film.

The comparative effect gas composition and storage temperature on CO<sub>2</sub> concentration could be observed by F values in the ANOVA (Table 4.7) for both polythene films i.e. LDPE and HDPE. The F values indicated that gas composition was the most influencing factor followed by temperature of storage was least effective. ANOVA also shows that gas composition and storage temperature has significant effect on CO<sub>2</sub> concentration at 5% level of significance.

#### 4.4.2 Physiological loss in weight (PLW)

Fig 4.31-4.37 shows the average values of PLW for bengal gram kernels with different gas composition and storage conditions. It was observed that PLW increased at a steady rate with the duration of storage.

**Table 4.7 Anova of CO<sub>2</sub> concentration in LDPE and HDPE**

	Days	3		6		9		12		15	
CO <sub>2</sub> LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	19.178	1917.833*	16.440	1644*	56.178	8988.432*	61.921	9288.125*	70.956	10643.375*
gas composition	2	74.623	7462.333*	54.610	5461*	11.800	1888*	15.413	2312*	6.603	990.5*
temperature	2	1.563	156.333*	9.760	976*	182.820	29251.2*	222.743	33411.5*	270.103	40515.5*
GXT	4	0.263	26.333*	0.695	69.5*	5.093	814.917*	4.763	714.5*	3.558	533.75*
Error	18	0.010		0.010		0.006		0.007		0.007	

	Days	18		21		24		27		30	
CO <sub>2</sub> LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	92.453	16641.45*	100.911	22704.937*	95.311	28593.25*	76.478	34415.25*	44.853	40368*
gas composition	2	45.720	8229.6*	48.813	10983*	0.143	43*	43.703	19666.5*	44.853	40368*
temperature	2	246.910	44443.8*	259.603	58410.74*	380.813	114244*	174.803	78661.5*	44.853	40368*
GXT	4	38.590	6946.2*	47.613	10713*	0.143	43*	43.703	19666.5*	44.853	40368*
Error	18	0.006		0.004		0.003		0.002		0.001	

	Days	3		6		9		12		15	
CO <sub>2</sub> HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	19.393	539.809*	16.523	1652*	60.026	9004*	67.432	10110*	77.595	11640*
gas composition	2	75.111	2091*	51.263	5126*	18.563	2784*	18.310	2747*	8.290	1244*
temperature	2	1.911	53.206*	13.043	1304*	210.863	31630*	240.370	36060*	294.390	44160*
GXT	4	0.278	7.649*	0.893	89.333*	5.338	800.75*	5.525	828.75*	3.850	577.5*
Error	18	0.036		0.010		0.007		0.007		0.007	

	Days	18		21		24		27	
CO <sub>2</sub> HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	99.608	22410*	92.096	27630*	81.343	36600*	45.630	41070*
gas composition	2	44.443	10000*	0.323	97*	46.573	20960*	45.630	41070*
temperature	2	260423.000	58600*	367.413	110200*	185.653	83540*	45.630	41070*
GXT	4	46.783	10530*	0.323	97*	46.573	20960*	45.630	41070*
Error	18	0.004		0.003		0.002		0.001	



**Plate 4.1 Final sample stored in LDPE**



**Plate 4.2 Final sample stored in HDPE**

### Effect of gaseous composition

It is clear from the data presented in Fig. 4.31-4.32 that PLW of fresh bengal gram kernels increased with the advancement of storage duration but rate of increase weight loss was significantly affected by different gaseous compositions during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum PLW was recorded in G<sub>1</sub> (1.32%), while maximum in G<sub>2</sub> (2.62%). On 24<sup>th</sup> day of storage minimum PLW was recorded in G<sub>1</sub> (9.23%) and maximum in G<sub>2</sub> (13.20%). At the end of experiment, 18.56% PLW was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the minimum PLW was observed in G<sub>1</sub> (1.57%), while maximum was recorded in G<sub>3</sub> (3.57%). Similarly on 21<sup>st</sup> day of storage, minimum PLW was recorded in G<sub>1</sub> (11.64%) and maximum in G<sub>2</sub> (18.68%). At the end of experiment, 18.51% PLW was recorded in G<sub>1</sub> on 27<sup>th</sup> day of storage.

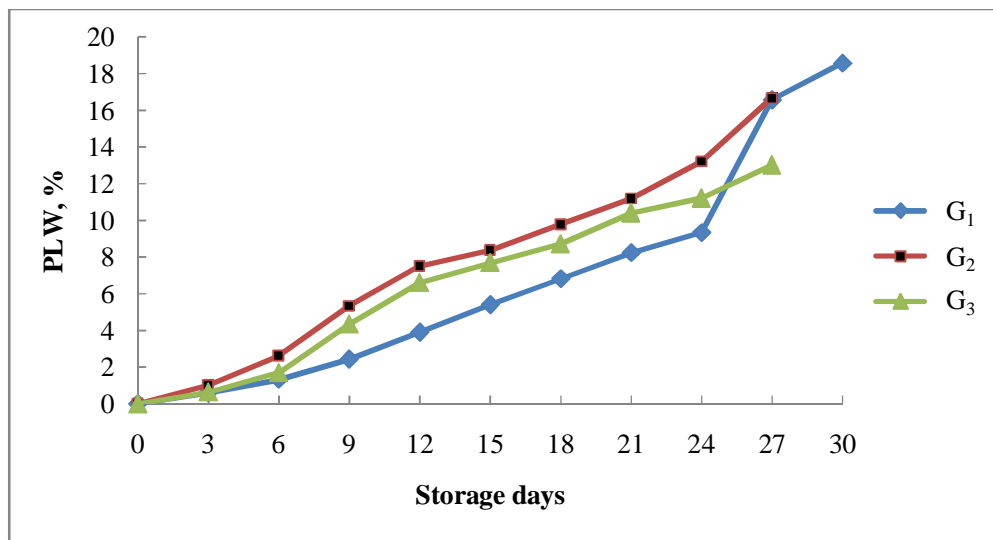
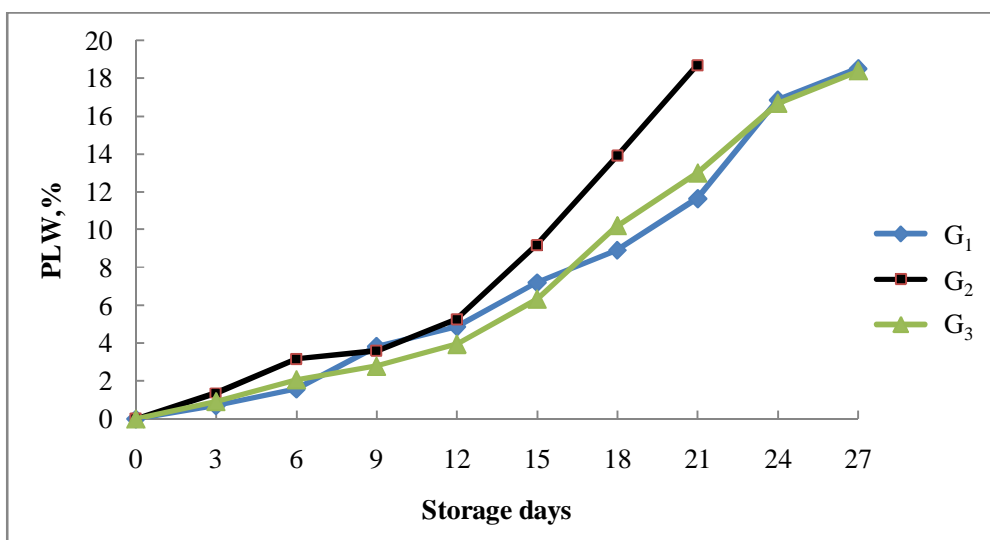


Fig. 4.31 Effect of gas composition on PLW in LDPE



**Fig. 4.32 Effect of gas composition on PLW in HDPE**

From Fig. 4.31-4.32 it was interpreted that the in LDPE, PLW in G<sub>2</sub> gas composition is higher than G<sub>1</sub> and G<sub>3</sub>. Up to 6<sup>th</sup> day of storage the PLW is nearly same in all the three gas composition but it is were influenced at later part of storage. Similar results were found in HDPE film also. PLW in G<sub>2</sub> gas composition was higher whereas in G<sub>1</sub> and G<sub>3</sub> gas composition, PLW was nearly same.

#### **Effect of storage temperature**

Fig. 4.33-4.34 shows that in the sample stored at ambient condition, PLW increased rapidly as compared to other storage conditions. Increase in PLW of bengal gram kernels stored in refrigerated conditions was slow as compared to sample stored at ambient temperature.

On 6<sup>th</sup> day of storage, for LDPE, minimum PLW was recorded at T<sub>3</sub> condition (0.87%) and maximum was recorded in temperature T<sub>1</sub> (5.73%) On 21<sup>st</sup> day of storage, minimum PLW was recorded at T<sub>3</sub> condition (8.24%) and maximum was recorded at T<sub>2</sub> condition (11.39%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 19.57% PLW was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum PLW was recorded at T<sub>3</sub> condition (1.62%) and maximum was recorded at T<sub>1</sub> condition (3.30%). On 18<sup>th</sup> day of storage, minimum PLW was recorded at T<sub>3</sub> condition (10.22%) while maximum was in T<sub>3</sub> condition (11.78%). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 20.82% PLW was recorded T<sub>3</sub> condition.

The rates of increase in PLW at all the storage temperature were significantly different with each other.

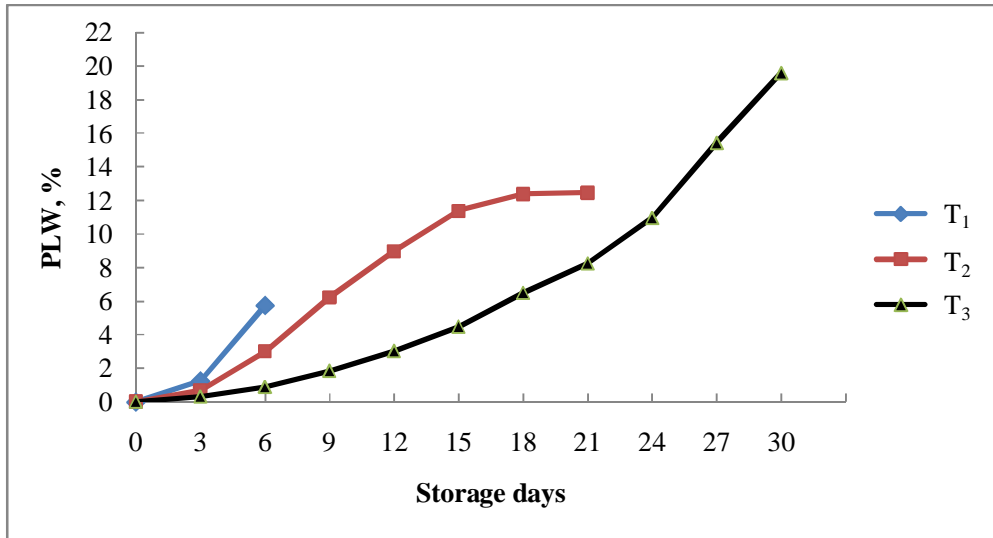


Fig. 4.33 Effect of storage temperature on PLW in LDPE

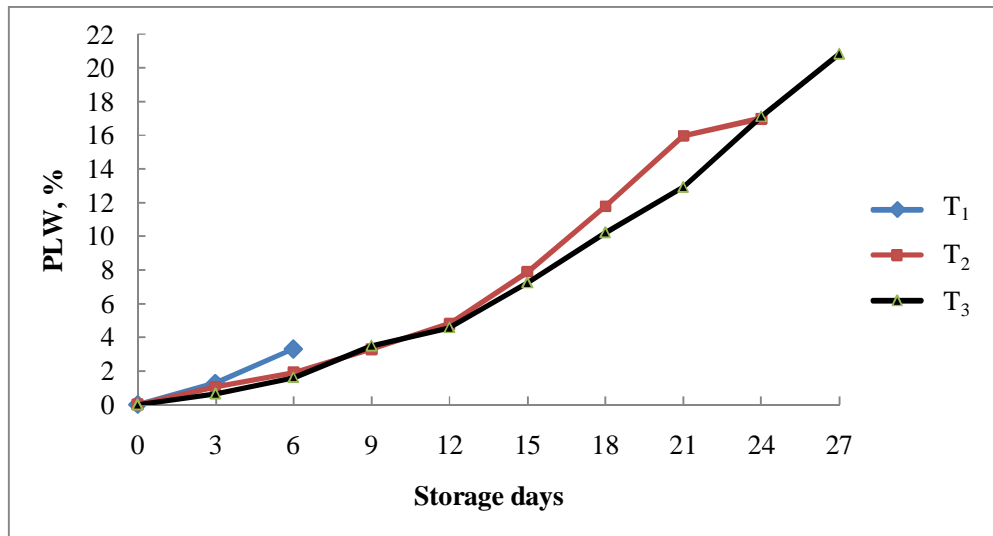


Fig. 4.34 Effect of storage temperature on PLW in HDPE

From Fig. 4.33-4.34 it is clear that in LDPE, PLW in T<sub>3</sub> condition is higher than T<sub>1</sub> and T<sub>2</sub> condition. Similar results were found in HDPE film also. PLW at T<sub>3</sub> condition was higher than at T<sub>1</sub> and T<sub>2</sub> condition.

#### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on bengal gram kernels were shown in Fig. 4.35-4.36.

On 6<sup>th</sup> day of storage minimum PLW was observed in LG<sub>1</sub>T<sub>3</sub> (0.54%) and maximum was in LG<sub>2</sub>T<sub>1</sub> (6.94%) treatment combination. On 15<sup>th</sup> day of storage, minimum PLW was recorded in LG<sub>1</sub>T<sub>3</sub> (3.15%) while maximum was in LG<sub>2</sub>T<sub>2</sub> (16.21%). Similarly on 24<sup>th</sup> day of storage minimum PLW was recorded in LG<sub>1</sub>T<sub>3</sub> (9.23%) and maximum was in LG<sub>2</sub>T<sub>3</sub> (13.20%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 18.56% PLW was recorded in LG<sub>1</sub>T<sub>3</sub> treatment combination.

On 6<sup>th</sup> day of storage minimum PLW was observed in HG<sub>1</sub>T<sub>3</sub> (1.11%) and maximum was in HG<sub>2</sub>T<sub>1</sub> (5.77%) treatment combination. On 15<sup>th</sup> day of storage, minimum PLW was recorded in HG<sub>1</sub>T<sub>3</sub> (5.98%) while maximum was in HG<sub>2</sub>T<sub>2</sub> (10.06%). Similarly on 21<sup>st</sup> day of storage minimum PLW was recorded in HG<sub>1</sub>T<sub>3</sub> (9.26%) and maximum was in HG<sub>2</sub>T<sub>2</sub> (22.21%). At the end of experiment i.e. on 27<sup>th</sup> day of storage, 18.51% PLW was recorded in HG<sub>1</sub>T<sub>3</sub> treatment combination.

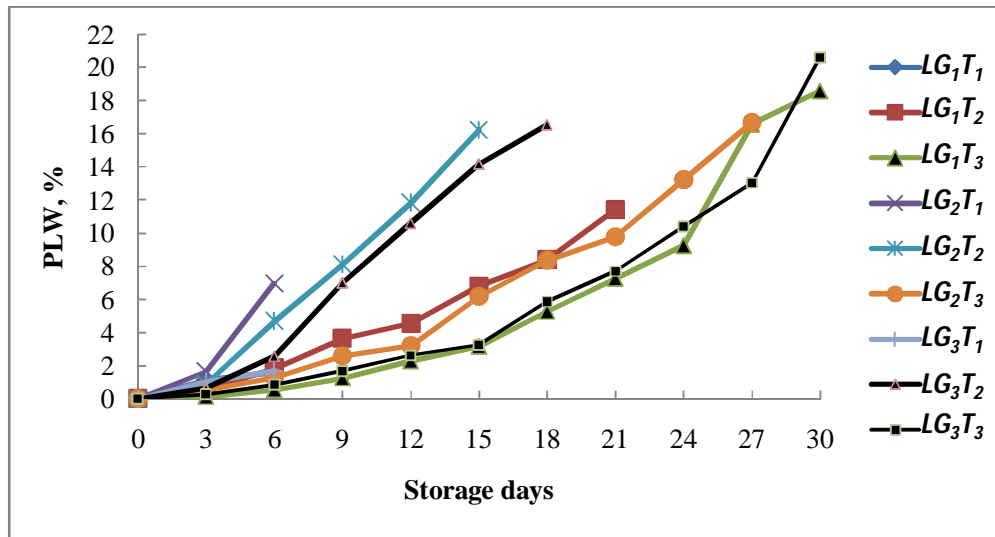


Fig. 4.35 Combined effect of gas composition and temperature on PLW in LDPE

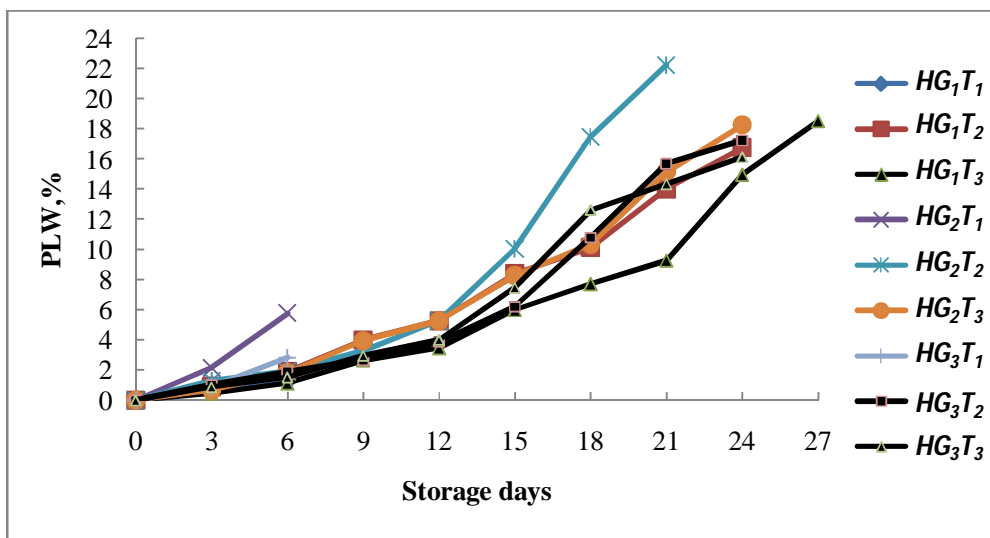


Fig. 4.36 Combined effect of gas composition and temperature on PLW in HDPE

The data depicted that the use of lower storage temperature contributed to the significant reduction of weight loss bengal gram kernels through the storage time.

#### Effect of polythene film on PLW

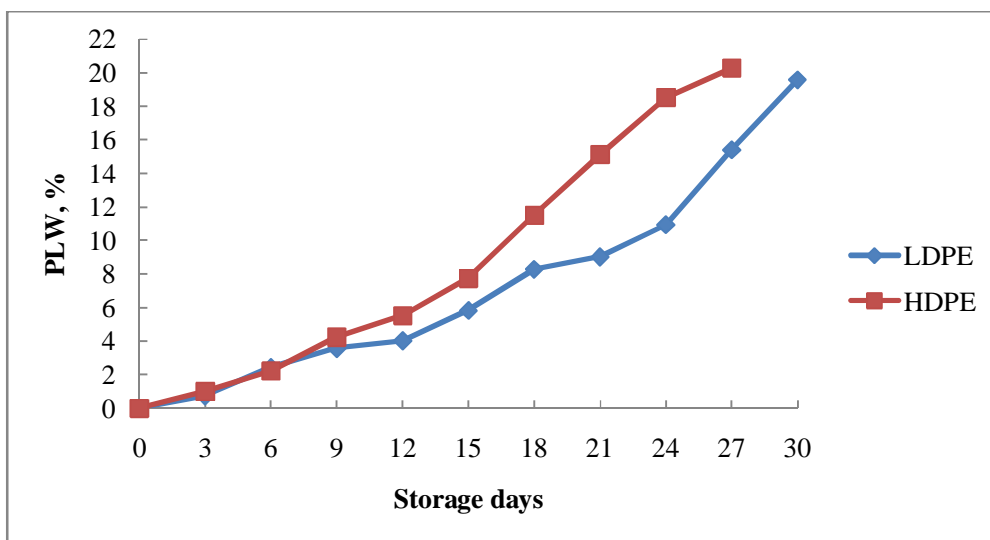


Fig. 4.37 Effect of polythene film on PLW

From Fig. 4.37 it is clear that the physiological loss in weight (PLW) increases continuously during the entire storage days. Up to 9 days of storage the PLW was nearly same in both packaging films but after that PLW increases rapidly in HDPE than in LDPE.

The comparative effect of gas composition and storage temperature on PLW could be observed by F values in the ANOVA (Table 4.8) for both polythene films i.e. LDPE and HDPE. The F values indicated that gas composition was the more influencing factor than

temperature of storage. ANOVA also shows that gas composition and storage temperature have significant effect on PLW at 5% level of significance.

#### **4.4.3 Decay**

After noting the sample weight for PLW, the visible decay was determined by separating the kernels having dark blemishes almost more than 1/3<sup>rd</sup> on its surface as well as having loose texture. The kernels weight was taken after discarding of decayed material. The effect of gas composition, temperature, combined effect of gas composition and storage temperature and polythene film is shown in Fig. 4.38-4.44.

A sample of bengal gram kernels was considered unacceptable when 10% of the kernels were visibly decayed as suggested by Steen *et al.*, 2002 for fruits like strawberry and raspberries.

**Table 4.8 Anova of physiological loss in weight (PLW) for LDPE and HDPE**

PLW LDPE	Days	3		6		9		12		15	
	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	3.580	153.133*	9.832	933.750*	44.699	2980.663*	92.840	2732.676*	156.897	9716.081*
gas composition	2	0.086	3.693*	5.673	538.743*	8.671	578.197*	37.794	1112.430*	69.887	4327.869*
temperature	2	13.664	584.403*	29.405	2792.640*	161.254	10752.889*	309.674	9115.005*	512.182	31717.687*
GXT	4	0.286	12.217*	2.125	201.809*	4.436	295.782*	11.946	351.634*	22.759	1409.384*
Error	18	0.023		0.110		0.015		0.034		0.016	

PLW LDPE	Days	18		21		24		27		30	
	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	201.91	6544.72*	261.07	29407.81*	350.125	139020.253*	356.65	90846.951*	274.8	10602603.5*
Gas composition	2	47.109	1526.95*	25.529	2875.57*	7.589	3013.098*	206.29	52546.305*	274.8	10602603.5*
temperature	2	581.18	18838.07*	889.54	100199.02*	1377.73	547041.719*	807.75	205748.890*	274.8	10602603.5*
G X T	4	89.684	2906.93*	64.615	7278.32*	7.589	3013.098*	206.29	52546.305*	274.8	10602603.5*
Error	18	0.031		0.009		0.003		0.004		0.0	

PLW HDPE	Days	3		6		9		12		15	
	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	14.028	15100*	29.334	13100*	79.734	102000*	164.489	86400*	262.258	117100*
gas composition	2	20.937	22610*	59.429	26650*	22.844	29200*	44.579	23420*	57.924	25770*
temperature	2	10.695	11550*	33.249	14910*	274.369	351100*	587.662	308700*	953.134	424000*
GXT	4	12.239	13220*	12.329	5530*	10.861	13900*	12.858	6750*	20.987	9330*
Error	18	0.001		0.002		0.010		0.002		0.002	

PLW HDPE	Days	18		21		24		27	
	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	350.489	162000*	414.612	110.382*	319.654	3590000*	261.022	10070000*
gas composition	2	92.715	42800*	25.399	6.762*	183.053	2059000*	261.022	10070000*
temperature	2	1020.127	471000*	1582.250	421.241*	729.456	8206000*	261.022	10070000*
GXT	4	144.557	66830*	25.399	6.762*	183.053	2059000*	261.022	10070000*

Error	18	0.002		3.756		0.000		0.000	
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### Effect of gaseous composition

It is clear from data presented in Fig. 4.38-4.39 that decay increased with advancement of storage duration, but it is significantly affected with the gaseous composition during the storage.

On 3<sup>rd</sup> day of storage, for LDPE minimum decay was recorded in G<sub>3</sub> (3.59%), while maximum in G<sub>1</sub> (5.67%). On 24<sup>th</sup> day of storage minimum decay was recorded in G<sub>1</sub> (24.685%) and maximum in G<sub>2</sub> (100%). At the end of experiment, complete 100% decay was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 3<sup>rd</sup> day of storage the minimum decay was observed in G<sub>1</sub> (5.70%), while maximum was recorded in G<sub>3</sub> (8.17%). Similarly on 24<sup>th</sup> day of storage, decay was minimum in G<sub>1</sub> (35.235%) and maximum in G<sub>3</sub> (100%). At the end of experiment, 100% decay was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage.

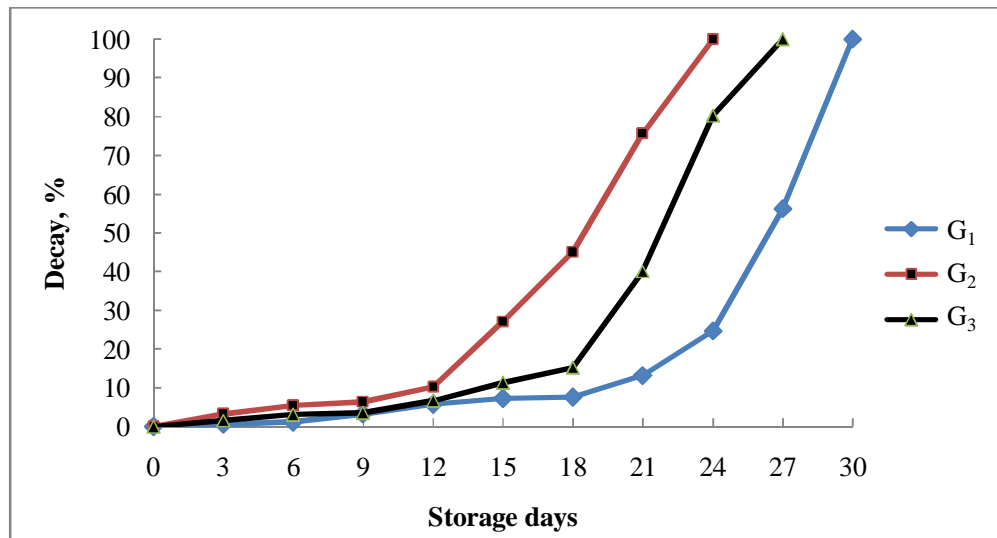
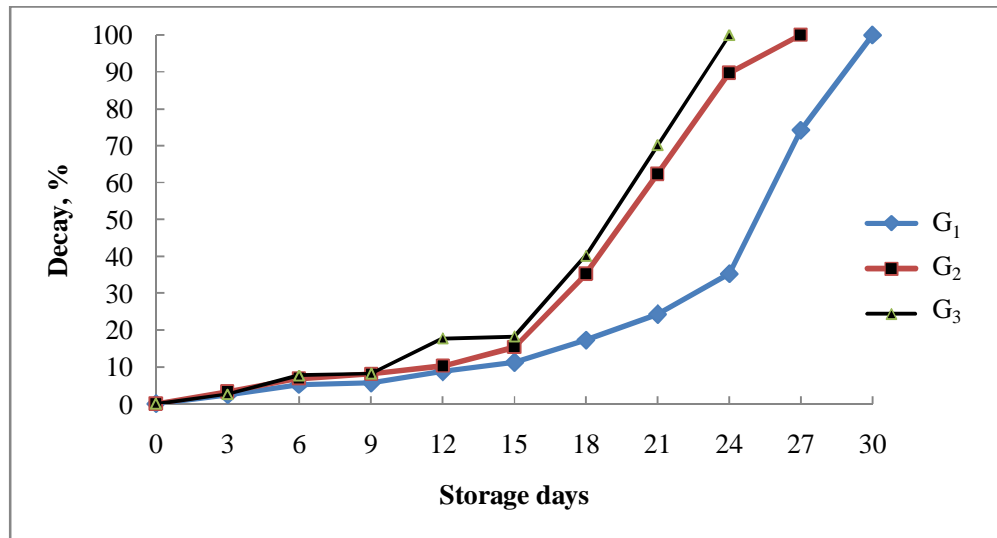


Fig. 4.38 Effect of gas composition on decay in LDPE



**Fig. 4.39 Effect of gas composition on decay in HDPE**

From Fig. 4.38-4.39 it is clear that for LDPE, lower decay % was observed in G<sub>1</sub> gas composition as compared to other two gas composition. Similar results were obtained for the product packaged in HDPE film.

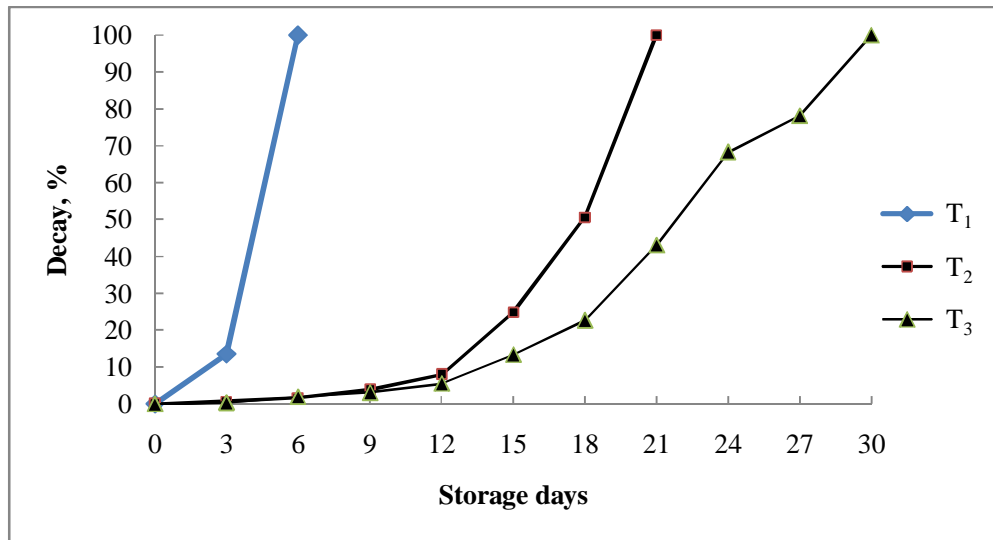
#### **Effect of storage temperature**

Fig. 4.40-4.41 shows that in the product stored at ambient condition, 100% decay was observed on 6<sup>th</sup> day as atmosphere condition was not favorable for both LDPE and HDPE. The spoilage took place with foul smell. This might be due to high respiration rate under high temperatures, and low oxygen in package causing anaerobic condition which might have contributed in deterioration of kernels at a faster rate and caused bad odour (Steen *et al.*, 2000).

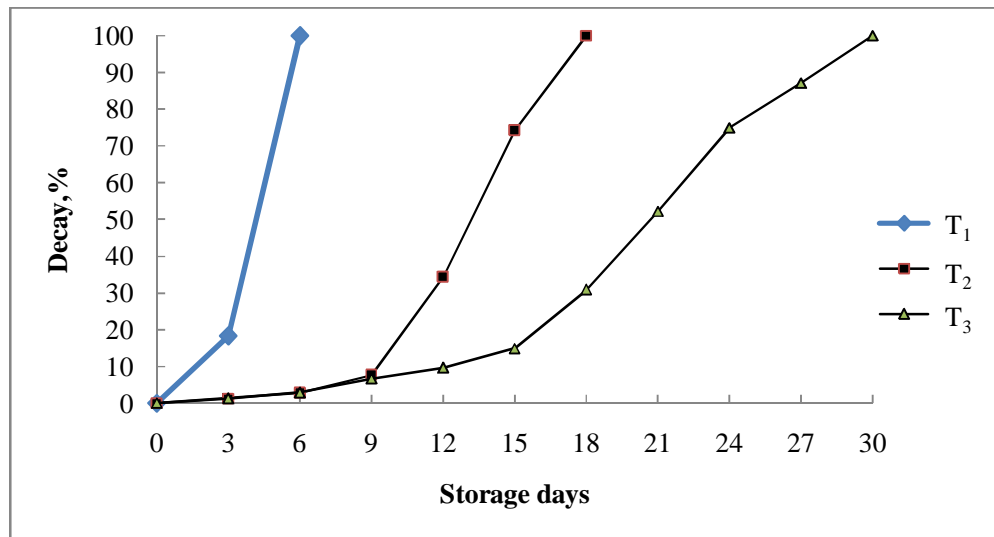
On 6<sup>th</sup> day of storage, for LDPE, minimum decay was recorded in T<sub>2</sub> condition (1.72%) and maximum was recorded in T<sub>1</sub> condition (100%) and the rate of increase in decay in all the treatments were significantly differ with each other. On 21<sup>st</sup> day of storage, minimum decay was recorded at T<sub>3</sub> condition (43.01%) and maximum was recorded in T<sub>2</sub> condition (100%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 100% decay was recorded in T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum decay was recorded at T<sub>2</sub> condition (2.73%) and maximum was recorded in T<sub>1</sub> condition (100%) and the rate of increase in decay in all the treatments were significantly differ with each other. On 18<sup>th</sup> day of storage, minimum decay was recorded at T<sub>3</sub> condition (30.87%) while maximum was at T<sub>2</sub> condition

(100%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 100% decay was recorded at T<sub>3</sub> condition.



**Fig. 4.40 Effect of temperature on decay in LDPE**



**Fig. 4.41 Effect of temperature on decay in HDPE**

From Fig. 4.40-4.41 it is clear that for LDPE, lower decay % was observed in condition T<sub>3</sub> as compared to other two conditions. Similar results were obtained for the product packaged in HDPE film. From the results it is clear that as the storage temperature increased the rate of decay increased.

#### **Combined effect of gaseous composition and storage temperature**

The combined effect of gaseous composition and storage temperature on bengal gram kernels were shown in Fig.4.42-4.43.

On 6<sup>th</sup> day of storage minimum decay was observed in LG<sub>1</sub>T<sub>3</sub> (0.325%) and maximum was in LG<sub>1</sub>T<sub>1</sub>, LG<sub>2</sub>T<sub>1</sub> and LG<sub>3</sub>T<sub>1</sub> (100%) treatment combination. On 15<sup>th</sup> day of storage, minimum decay was recorded in LG<sub>1</sub>T<sub>3</sub> (4.36%) while maximum was in LG<sub>2</sub>T<sub>2</sub> (50%). Similarly on 24<sup>th</sup> day of storage minimum decay was recorded in LG<sub>1</sub>T<sub>3</sub> (24.68%) and maximum was in LG<sub>3</sub>T<sub>3</sub> (100%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 100% decay was recorded in LG<sub>1</sub>T<sub>3</sub> treatment combination.

On 6<sup>th</sup> day of storage minimum decay was observed in HG<sub>3</sub>T<sub>2</sub> (2.35%) and maximum was in HG<sub>1</sub>T<sub>1</sub>, HG<sub>2</sub>T<sub>1</sub> and HG<sub>3</sub>T<sub>1</sub>, (100%) treatment combination. On 15<sup>th</sup> day of storage, minimum decay was recorded in HG<sub>1</sub>T<sub>3</sub> (11.21%) while maximum was in HG<sub>2</sub>T<sub>2</sub> (100%). Similarly on 24<sup>th</sup> day of storage minimum decay was recorded in HG<sub>1</sub>T<sub>3</sub> (35.23%) and maximum was in HG<sub>3</sub>T<sub>3</sub> (100%). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 100% decay was recorded in HG<sub>1</sub>T<sub>3</sub> treatment combination.

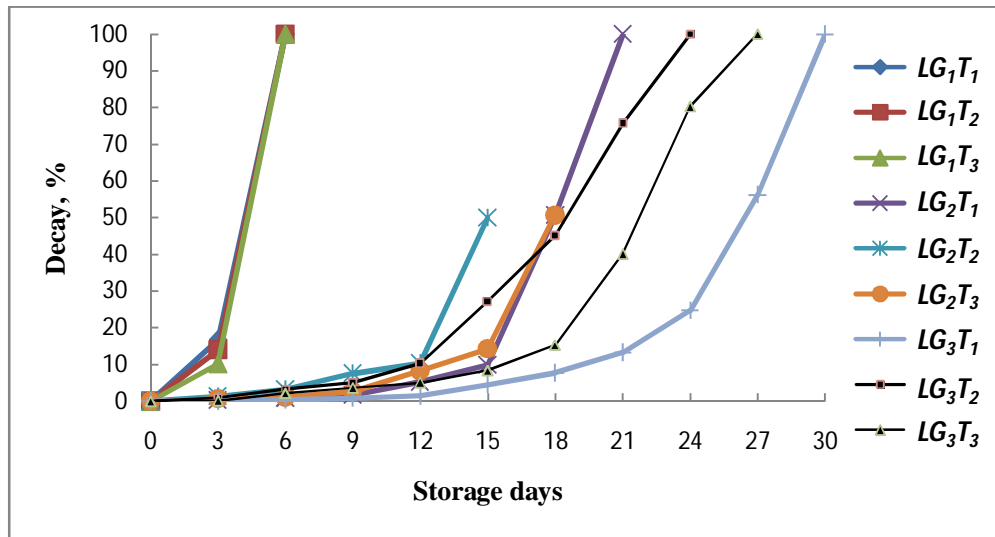
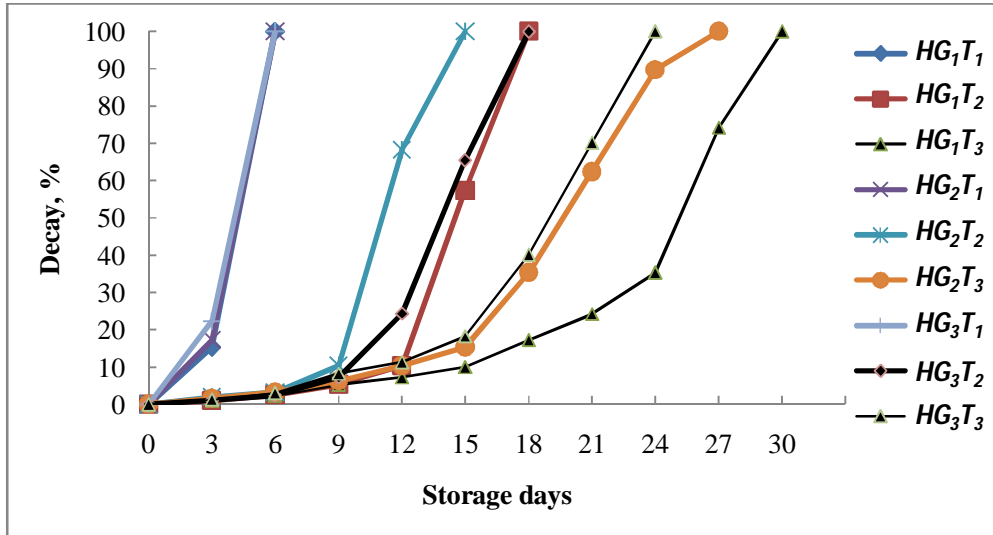
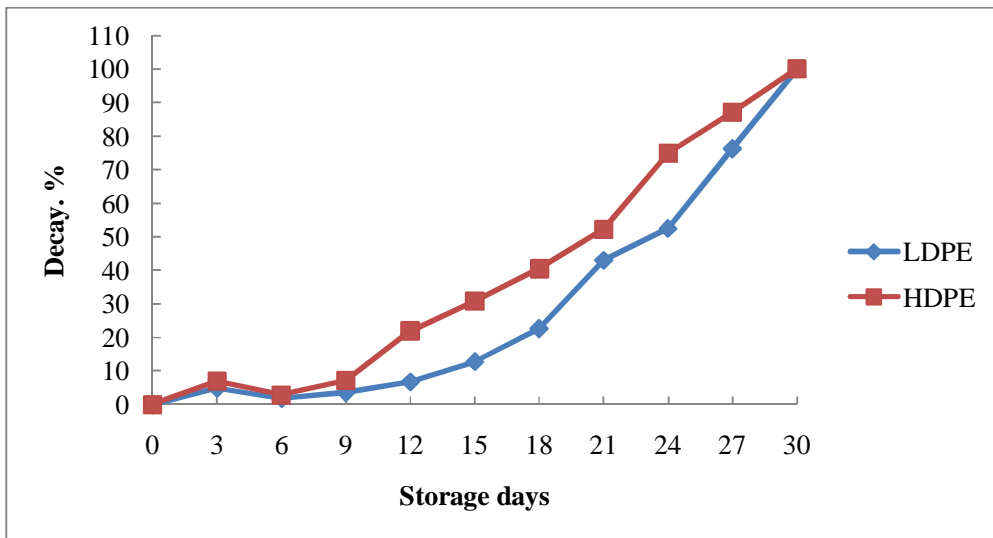


Fig. 4.42 Combined effect of gas composition and temperature on decay in LDPE



**Fig. 4.43 Combined effect of gas composition and temperature on decay in HDPE**

From Fig. 4.42 and 4.43 it is clear that product stored at ambient temperature decayed at faster rate as compared to all other combinations. At the end of experiment only LG<sub>1</sub>T<sub>3</sub> product survived. Similar results were obtained for HDPE film too. Hence the G<sub>1</sub> gas composition with T<sub>3</sub>storage temperature resulted into better quality product with more shelf life..



**Fig.4.44 Effect of Polythene film on decay**

From Fig. 4.44, it is clear that for HDPE film decay % was observed to be slightly more than LDPE film for all three storage conditions. The product in the HDPE films became more spoiled because of favorable condition for micro-organism.

The comparative effect of gas composition and storage temperature on decay could be observed by F values in the ANOVA (Table 4.9) for both polythene films i.e. LDPE and HDPE. The F values indicated that gas composition was more influencing than temperature of storage. ANOVA also shows that gas composition and storage temperature have significant effect on decay at 5% level of significance.

It can be inferred from the data that gas composition G<sub>1</sub> with storage condition T<sub>3</sub> results in decay of less than or equal to 10% value till 15 and 21 days for HDPE and LDPE packaging film, respectively. The decay level of 10% was considered acceptable as suggested by Steen *et al.*,(2002).Therefore the product can be acceptable up to 21 days in LDPE.

#### **4.3.4 Texture**

Under texture analysis, texture was determined by two ways viz. penetration by 5 mm needle and compression by P/75 plate. Firmness parameter, along with the external appearance is the factor that determined the acceptance or rejection by the consumer (Rodríguez, *et al.*, 1999; Siomoset *al.*, 2000; Zurera, Muñ ozet *al.*, 2000).

**Table 4.9 Anova of decay of LDPE and HDPE**

Decay LDPE	df	3		6		9		12		15	
		MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	291.413	0.816	5653.37	2522995.623*	532.856	122861.757*	1414.860	481730.220*	3549.724	6655732.715*
gas composition	2	394.373	1.105	15.837	7067.548*	209.471	48298.198*	413.496	140786.789*	889.152	1667160.673*
temperature	2	277.701	0.778	22531.3	10055289.575*	1711.808	394695.153*	4550.301	1549282.662*	11935.152	22378409.215*
GXT	4	246.790	0.691	33.191	14812.685*	105.073	24226.838*	347.821	118425.716*	687.296	1288680.486*
Error	18	357.049		0.002		0.004		0.003		0.001	

Decay LDPE	df	18		21		24		27		30	
		MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	3960.783	26493.532*	4535.889	53247391.184*	4914.610	189563542.5*	4800.9	144027004*	3267	29403*
gas composition	2	2370.938	15859.117*	2542.326	29844697.217*	345.125	13311956.714*	2800.4	84012004*	3267	29403*
temperature	2	7875.060	52675.985*	7887.911	92597212.217*	18623.067	718318300.0*	10802.4	324072004*	3267	29403*
GXT	4	2798.567	18719.513*	3856.659	45273827.652*	345.125	13311956.714*	2800.4	84012004*	3267	29403*
Error	18	0.150		0.000		0.000		0.0		0.111	

Decay HDPE	df	3		6		9		12		15	
		MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	910.049	154100*	5204.64	86.747*	657.700	149500*	1907.598	374900*	4667.017	20590*
gas composition	2	160.498	27190*	354.975	5.916*	243.198	55270*	536.930	105500*	549.603	2424*
temperature	2	3063.127	518800*	20105.7	335.108*	2225.419	505800*	6493.799	1276000*	17305.514	76340*
GXT	4	208.286	35280.000	178.923	2.982*	81.091	18430*	299.831	58920*	406.475	1793*
Error	18	0.006		59.998		0.004		0.005		0.227	

Decay HDPE	df	18		21		24		27	
		MS	F	MS	F	MS	F	MS	F
Corrected Model	8	4246.985	37360*	4479.610	39510*	4364.321	39060*	3267.000	29400*
gas composition	2	3039.235	26740*	461.401	4069*	2605.338	23320*	3267.000	29400*
temperature	2	6939.967	61060*	16534.238	145800*	9641.268	86280*	3267.000	29400*
GXT	4	3504.370	30830*	461.401	4069*	2605.338	23320*	3267.000	29400*
Error	18	0.114		0.113		0.112		0.111	

#### 4.3.4.1 Firmness

##### Effect of gaseous composition

It is clear from data presented in Fig. 4.45-4.46 that firmness decreases with advancement of storage duration, but it is significantly affected with the gaseous composition during the storage.

On 6<sup>th</sup> day of storage, for LDPE maximum firmness was recorded in G<sub>1</sub> (3.70 N), while minimum in G<sub>2</sub> (2.98 N). On 24<sup>th</sup> day of storage maximum firmness was recorded in G<sub>1</sub> (1.90 N) and minimum in G<sub>2</sub> (0.79 N). At the end of experiment, 0.85N firmness was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the maximum firmness was observed in G<sub>1</sub> (3.44 N), while minimum was recorded in G<sub>2</sub> (3.32 N). Similarly on 21<sup>st</sup> day of storage, maximum firmness was recorded in G<sub>1</sub> (1.13 N) and minimum in G<sub>2</sub> (0.81 N). At the end of experiment, 0.86N firmness was recorded in G<sub>1</sub> on 27<sup>th</sup> day of storage.

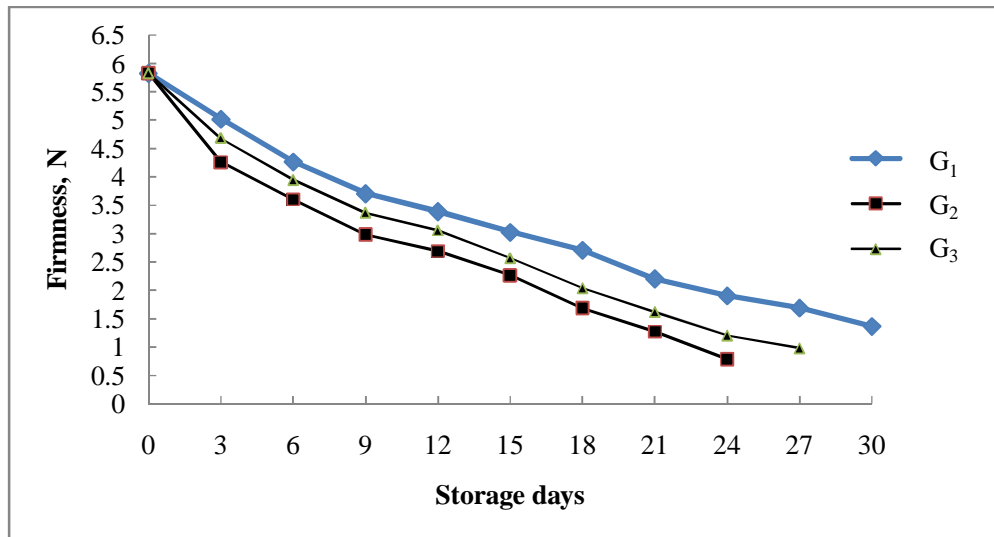
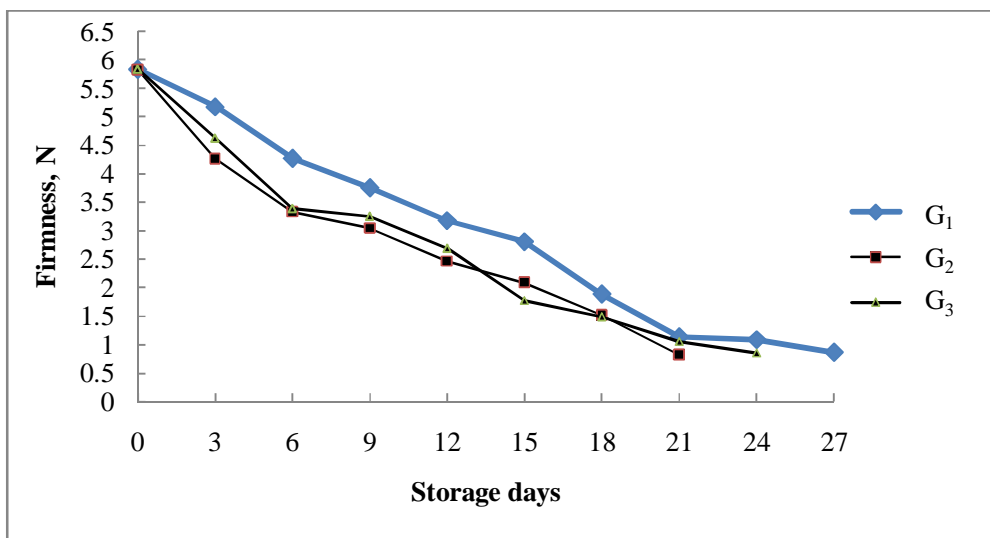


Fig. 4.45 Effect of package gas composition on firmness in LDPE



**Fig. 4.46 Effect of package gas composition on firmness in HDPE**

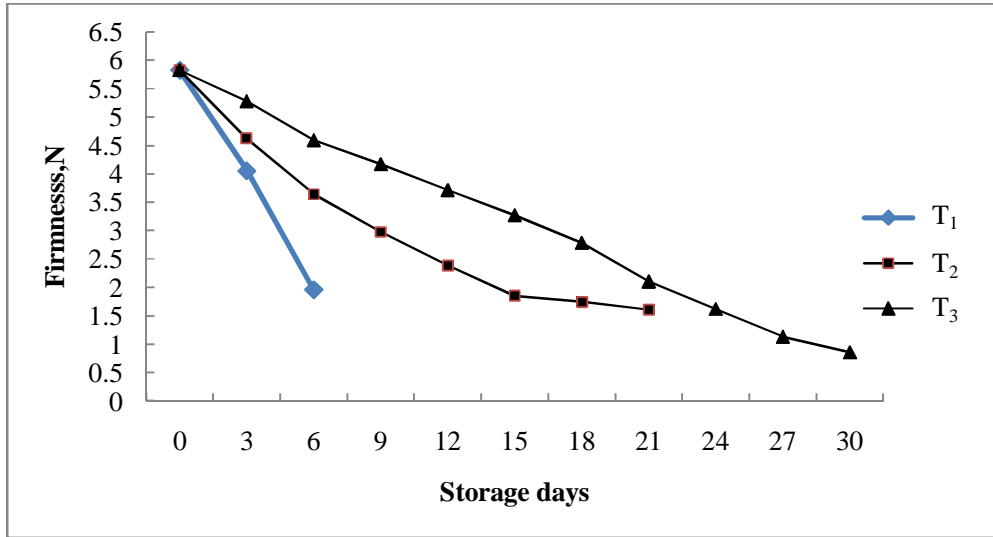
From Fig. 4.45 and 4.46 firmness of the sample in LDPE and HDPE with G<sub>1</sub> gas composition loses texture at slower rate in comparison with G<sub>2</sub> and G<sub>3</sub> gas composition, respectively which in confirmation of result of Chinnan (1989) that firmness decreases with high O<sub>2</sub> concentration and low CO<sub>2</sub> concentrations.

#### **Effect of storage temperature**

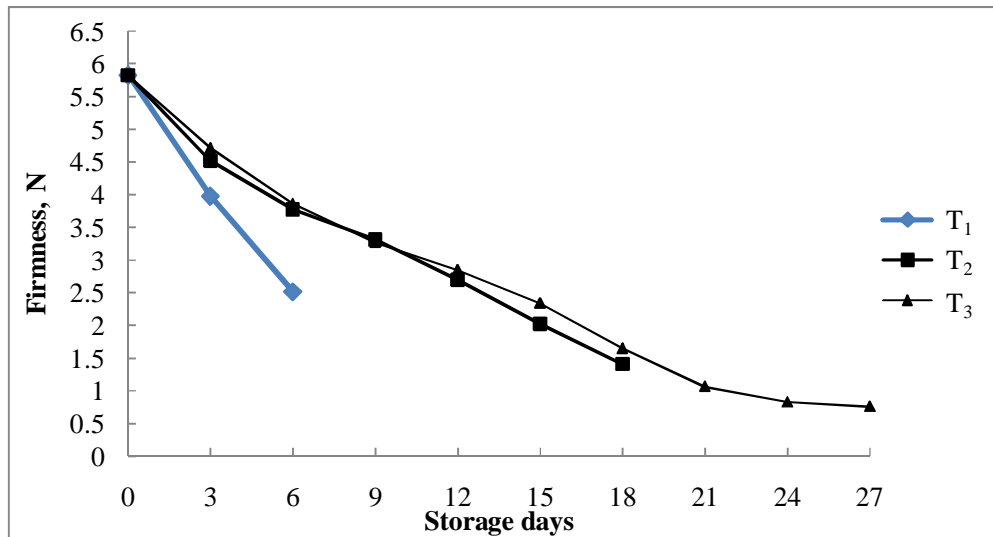
Fig. 4.47-4.48 shows that in the sample stored at ambient condition, firmness decreased rapidly as compared to other storage conditions. Decrease in firmness of bengal gram kernels stored in refrigerated condition was slow as compared to sample stored at ambient temperature.

A critical examination of data in temperature reveals that firmness decreased under all three temperature treatments. On 6<sup>th</sup> day of storage, for LDPE, maximum firmness was recorded at T<sub>3</sub> condition (4.59 N) and minimum was recorded at T<sub>1</sub> condition (1.95 N). On 21<sup>st</sup> day of storage, maximum firmness was recorded at T<sub>3</sub> condition (2.10N) and minimum was recorded at T<sub>2</sub> condition (1.60 N). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.85 N firmness was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, maximum firmness was recorded at T<sub>3</sub> condition (3.86 N) and minimum was recorded at T<sub>1</sub> condition (2.51%). On 18<sup>th</sup> day of storage, maximum firmness was recorded at T<sub>3</sub> condition (1.65 N) while minimum was at T<sub>2</sub> condition (1.41 N). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.76 N firmness was recorded at T<sub>3</sub> condition.



**Fig. 4.47 Effect of storage temperature on firmness in LDPE**



**Fig. 4.48 Effect of gas composition on firmness in HDPE**

From Fig. 4.47 and 4.48 firmness of the sample in LDPE and HDPE with at T<sub>3</sub> condition loses texture at slower rate than T<sub>2</sub> and T<sub>1</sub>, respectively.

Firmness decreases at steady state with the duration of storage at all three conditions. Firmness of sample stored at ambient decreases at a much faster rate compared to the sample stored at lower temperature. This might be due to the high respiration rate because of high temperature at this condition. Chinnan (1989) reported that firmness decreases with increasing O<sub>2</sub> concentration and decreasing CO<sub>2</sub> concentration. Similar trends were obtained for kernels stored at refrigerated conditions. But the firmness was relatively high as compared to the ambient condition. Duration of storage and storage conditions

(ambient and refrigerated) also had a significant effect on firmness which is in confirmation with findings of Yang *et al.*,2010 for blueberry that firmness decreases continuously during storage with a higher rate, of decline at higher temperature.

### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on bengal gram kernels were shown in Fig.4.49-4.50.

On 6<sup>th</sup> day of storage maximum firmness was observed in LG<sub>1</sub>T<sub>3</sub> (4.99 N) and minimum was in LG<sub>2</sub>T<sub>1</sub>(1.27 N) treatment combination. On 15<sup>th</sup> day of storage, maximum firmness was recorded in LG<sub>1</sub>T<sub>3</sub> (3.80 N) while minimum was in LG<sub>2</sub>T<sub>2</sub> (1.23N). Similarly on 24<sup>th</sup> day of storage maximum firmness was recorded in LG<sub>1</sub>T<sub>3</sub> (1.90 N) and minimum was in LG<sub>2</sub>T<sub>3</sub> (0.79 N). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.85 N firmness was recorded in LG<sub>1</sub>T<sub>3</sub>treatment combination.

On 6<sup>th</sup> day of storage maximum firmness was observed in H G<sub>1</sub>T<sub>3</sub> (4.14) and minimum was in H G<sub>1</sub>T<sub>1</sub> (2.27) treatment combination. On 15<sup>th</sup> day of storage, maximum firmness was recorded in H G<sub>1</sub>T<sub>3</sub> (2.90 N) while minimum was in H G<sub>3</sub>T<sub>2</sub> (1.42 N). Similarly on 21<sup>st</sup> day of storage maximum firmness was recorded in H G<sub>1</sub>T<sub>3</sub> (1.13) and minimum was in H G<sub>2</sub>T<sub>3</sub> (0.81 N). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.86 N firmness was recorded in H G<sub>1</sub>T<sub>3</sub>treatment combination.

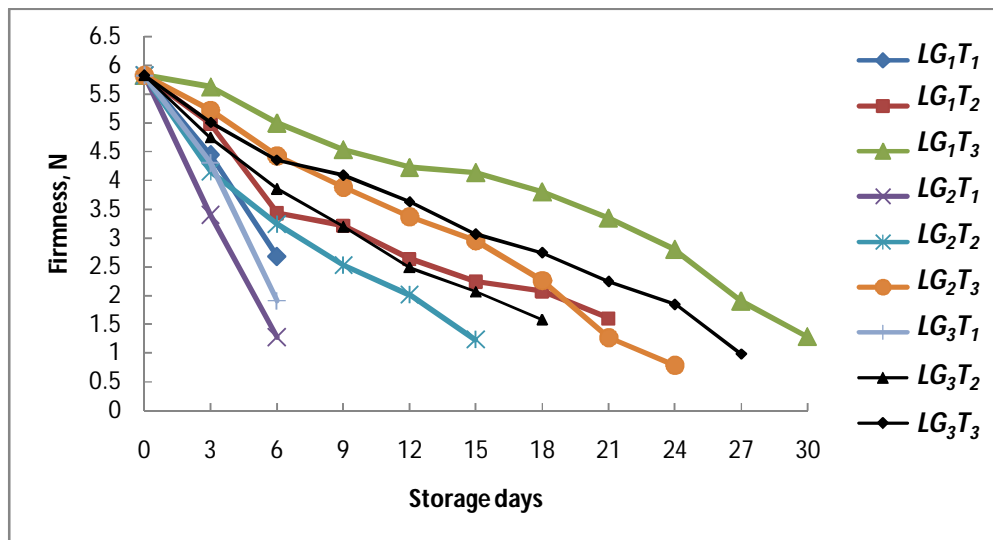
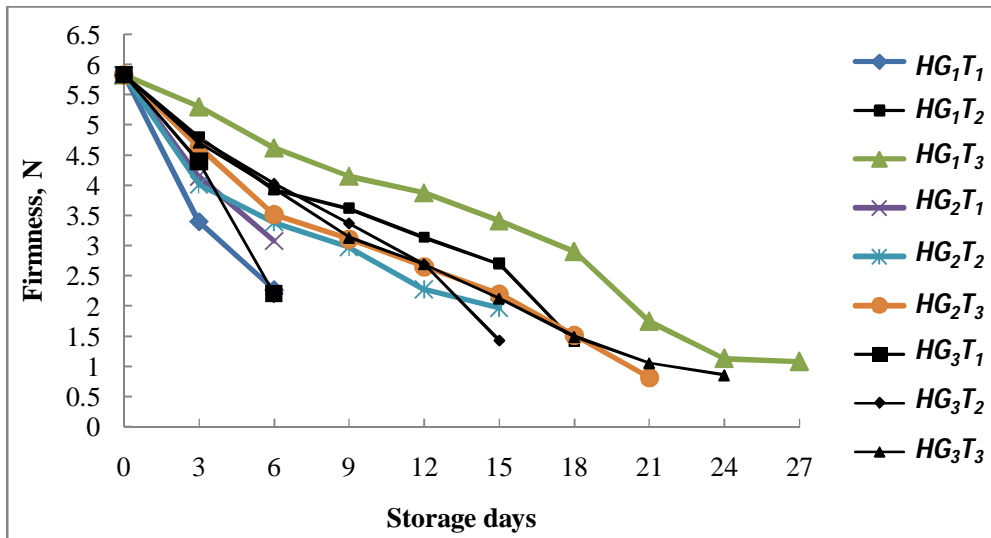


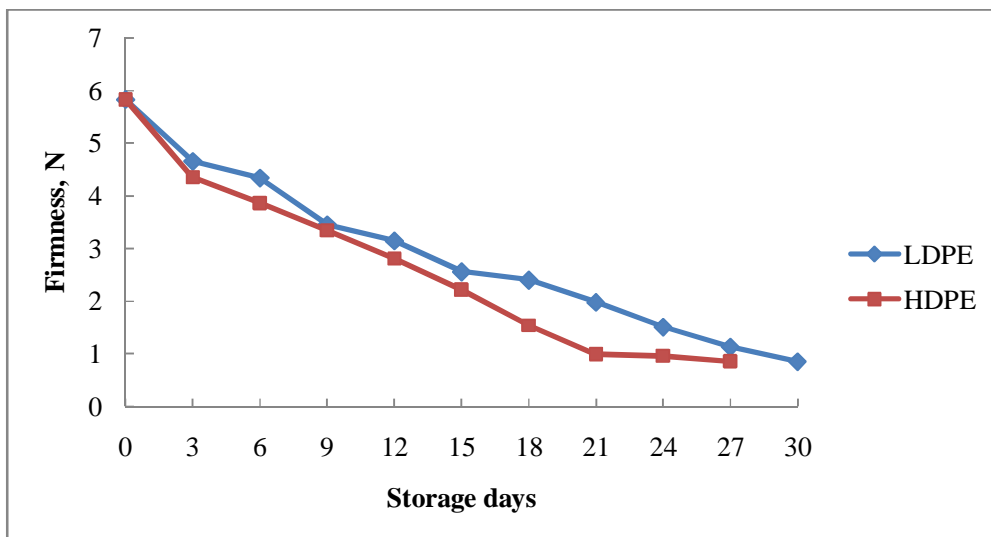
Fig. 4.49 Combined effect of gas composition and temperature on firmness in LDPE



**Fig. 4.50 Combined effect of gas composition and temperature on firmness in HDPE**

From Fig. 4.49 and 4.50 it is clear that sample stored at ambient temperature loose texture at faster rate as compared to all other combinations. At the end of experiment only LG<sub>1</sub>T<sub>3</sub> sample was survived. Similar results were obtained for HDPE film too. Hence, the G<sub>1</sub> gas composition with T<sub>3</sub> condition results into better product than other combination. Fruit firmness decrease continuously during storage, with a higher rate of decline in bayberry stored at higher temperature (Yang *et al.*, 2010).

**Effect of Polythene film on firmness (penetration)**



**Fig. 4.51 Effect of Polythene film on firmness (penetration)**

**Table 4.10 Anova of firmness for LDPE and HDPE**

		3		6		9		12		15	
<b>Firmness LDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.300	1.165	4.324	11.102*	10.582	87.319*	8.154	49.260*	6.444	43.507*
gas composition	2	1.291	1.157	1.028	2.638	0.464	3.829	0.481	2.907	0.868	5.861
temperature	2	3.409	3.055	15.309	39.304*	41.534	342.721*	31.843	192.379*	24.262	163.811*
GXT	4	0.250	0.224	0.480	1.233	0.165	1.364	0.145	0.877	0.323	2.180
Error	18	1.116		0.389		0.121		0.166		0.148	

	Days	18		21		24		27		30	
<b>Firmness LDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	5.727	27.414*	3.795	20.404*	2.013	16.161*	0.655	23.984*	0.245	37.677*
gas composition	2	2.072	9.920	2.582	13.882*	0.393	3.157	0.419	15.325*	0.245	37.677*
temperature	2	18.885	90.393*	10.802	58.086*	6.871	55.171*	1.365	49.959*	0.245	37.677*
GXT	4	0.976	4.672	0.897	4.8253*	0.393	3.158	0.419	15.325*	0.245	37.677*
Error	18	0.209		0.186		0.125		0.027		0.006	

	Days	3		6		9		12		15	
<b>Firmness HDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.612	61.817*	1.625	164.315*	9.126	1346*	6.013	19.665*	4.902	89.769*
gas composition	2	0.493	49.872*	0.032	3.277*	0.522	76.985*	0.109	0.656	1.542	28.245*
temperature	2	0.928	93.76*	5.120	517.51*	35.621	5253*	23.256	76.052*	17.048	312.186*
GXT	4	0.513	51.819*	0.675	68.236*	0.180	26.59*	0.344	1.125	0.509	9.322*
Error	18	0.010		0.010		7.000		0.306		0.055	

	Days	18		21		24		27	
<b>Firmness HDPE</b>	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	2.286	452.561*	0.904	348.721*	0.066	332.424*	0.282	488.308*
gas composition	2	1.042	206.354*	0.027	10.424*	0.390	195.434*	0.282	488.308*
temperature	2	6.756	1337*	3.535	1364*	1.484	743.393*	0.282	488.308*
GXT	4	0.674	133.323*	0.027	10.424*	0.390	195.434*	0.282	488.308*
Error	18	0.005		0.003		0.002		0.001	

From Fig. 4.51, the firmness of the bengal gram kernel decreases over the entire storage days. Sample in HDPE film loses firmness quickly as compared to the sample in LDPE film.

The comparative effect gas composition and storage temperature on firmness could be observed by F values in the ANOVA (Table 4.10) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was the most influencing factor. ANOVA shows that both gas composition and storage temperature has significant effect on decay at 5% level of significance. In case of LDPE polythene film the firmness data is found to be non-significant on 3<sup>rd</sup> day.

It can be inferred from the data that gas composition G<sub>1</sub> with storage condition T<sub>3</sub> results in firmness of more than or equal to 60% value till 15 and 21 days for HDPE and LDPE packaging film respectively. The firmness level of 60% was considered acceptable based on sensory panel judgment. Therefore the product can be acceptable up to 21 days in LDPE.

#### **4.3.4.2 Hardness**

##### **Effect of gaseous composition**

It is clear from data presented in Fig. 4.52-4.53 that hardness decreases with advancement of storage duration, but it is significantly affected with the gaseous composition during the storage.

On 6<sup>th</sup> day of storage, for LDPE maximum hardness was recorded in G<sub>1</sub> (53.43 N), while minimum in G<sub>2</sub> (43.76 N). On 24<sup>th</sup> day of storage maximum hardness was recorded in G<sub>1</sub> (24.26 N) and minimum in G<sub>2</sub> (8.32 N). At the end of experiment, 13.87 N hardness was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the maximum hardness was observed in G<sub>3</sub> (52.45 N), while minimum was recorded in G<sub>1</sub> (49.37 N). Similarly on 21<sup>st</sup> day of storage, maximum hardness was recorded in G<sub>1</sub> (29.01 N) and minimum in G<sub>2</sub> (12.93). At the end of experiment, 9.71 N hardness was recorded in G<sub>1</sub> on 27<sup>th</sup> day of storage. Since sample stored with G<sub>2</sub> and G<sub>3</sub> gas composition were not survived to 27<sup>th</sup> day of storage.

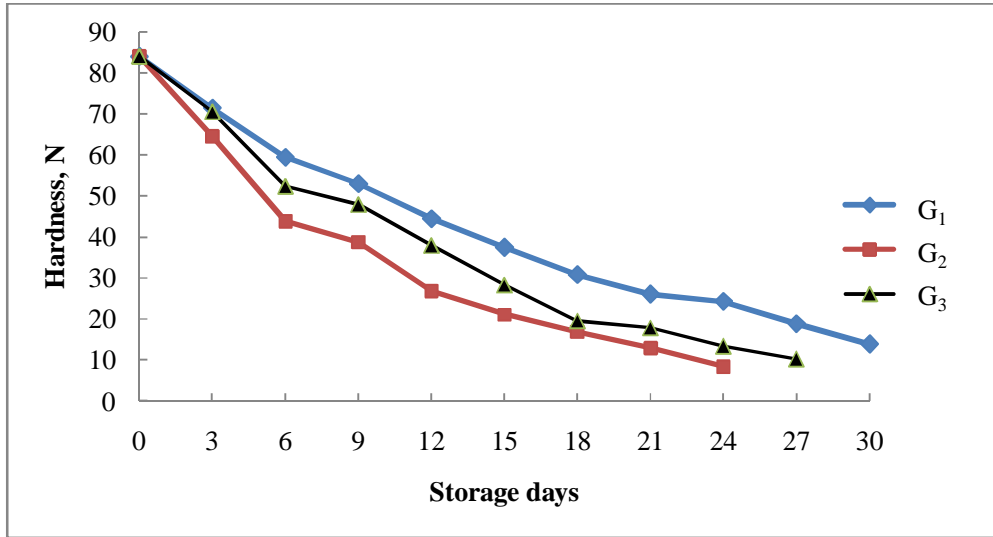


Fig. 4.52 Effect of package gas composition on hardness in LDPE

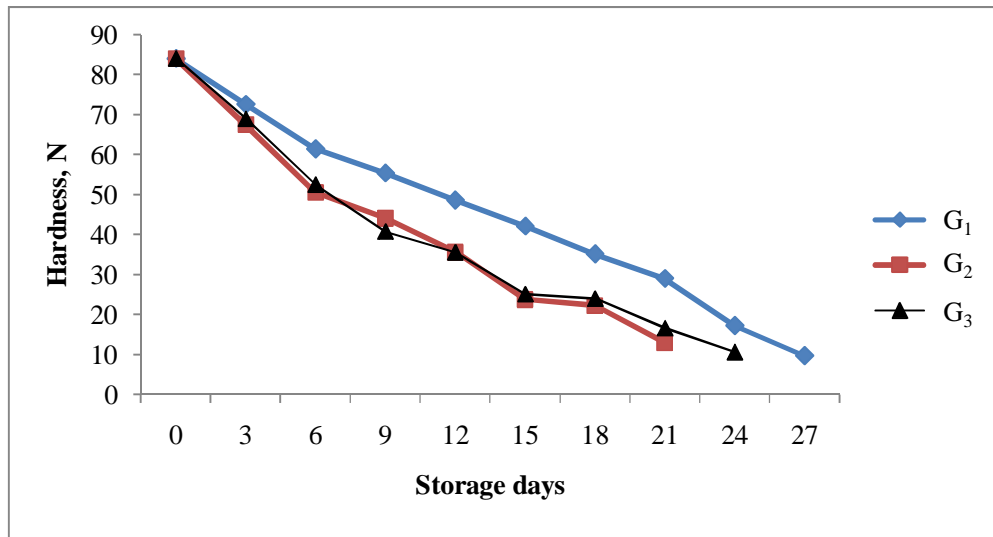


Fig. 4.53 Effect of package gas composition on hardness in HDPE

#### Effect of storage temperature

Fig. 4.54-4.55 shows that in the sample stored at ambient condition, hardness decreased rapidly as compared to other storage conditions. Decrease in hardness of bengal gram kernels stored in refrigerated condition was slow as compared to sample stored at ambient temperature.

A critical examination of data in temperature level that hardness decreased under all three temperature treatments. On 6<sup>th</sup> day of storage, for LDPE, maximum hardness was recorded at T<sub>3</sub> condition (61.20 N) and minimum was recorded at T<sub>1</sub> condition (30.28 N). On 21<sup>st</sup> day of storage, maximum hardness was recorded at T<sub>2</sub> condition (24.92 N) and minimum

was recorded at  $T_3$  condition (19.32 N). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 13.87 N hardness was recorded at  $T_3$  condition.

On 6<sup>th</sup> day of storage, for HDPE, maximum hardness was recorded at  $T_3$  condition (63.03 N) and minimum was recorded at  $T_1$  condition (33.85 N). On 18<sup>th</sup> day of storage, maximum hardness was recorded at  $T_3$  condition (30.13 N) while minimum was at  $T_2$  condition (26.07 N). At the end of experiment i.e. on 27<sup>th</sup> day of storage, 9.71 N hardness recorded at  $T_3$  condition.

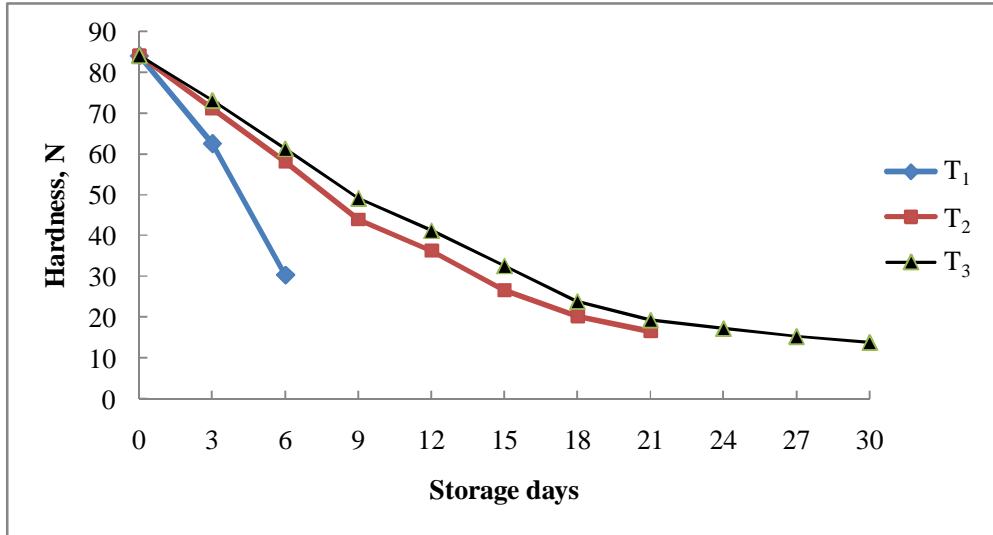


Fig. 4.54 Effect of storage temperature on hardness in LDPE

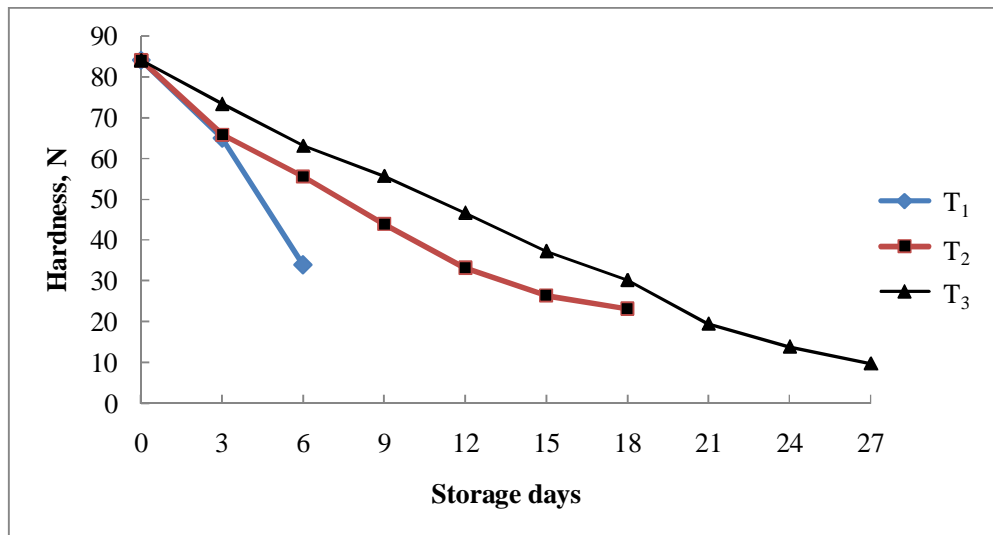


Fig. 4.55 Effect of storage temperature on hardness in HDPE

### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on Bengal gram kernels were shown in 4.56-4.57.

On 6<sup>th</sup> day of storage maximum hardness was observed in LG<sub>1</sub>T<sub>3</sub> (68.92 N) and minimum was in LG<sub>2</sub>T<sub>1</sub> (28.92 N) treatment combination. On 15<sup>th</sup> day of storage, maximum hardness was recorded in LG<sub>1</sub>T<sub>3</sub> (39.42 N) while minimum was in LG<sub>2</sub>T<sub>2</sub> (16.20N). Similarly on 24<sup>th</sup> day of storage maximum hardness was recorded in LG<sub>1</sub>T<sub>3</sub> (24.26 N) and minimum was in LG<sub>2</sub>T<sub>3</sub> (8.32 N). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage decay was recorded in LG<sub>1</sub>T<sub>3</sub>(13.87 N) treatment combination.

On 6<sup>th</sup> day of storage maximum hardness was observed in HG<sub>1</sub>T<sub>3</sub> (71.66 N) and minimum was in HG<sub>1</sub>T<sub>1</sub> (24.18 N) treatment combination. On 15<sup>th</sup> day of storage, maximum hardness was recorded in HG<sub>1</sub>T<sub>3</sub> (52.47 N) while minimum was in HG<sub>2</sub>T<sub>2</sub> (17.47 N). Similarly on 21<sup>st</sup> day of storage maximum hardness was recorded in HG<sub>1</sub>T<sub>3</sub> (29.01 N) and minimum was in HG<sub>2</sub>T<sub>3</sub> (12.93 N). Similarly at the end of experiment i.e. on 27<sup>th</sup>day of storage hardness was recorded in HG<sub>1</sub>T<sub>3</sub>(9.71 N) treatment combination.

The decrease in hardness during storage could be related with the development of fungal growth and the increases in the metabolism, which increase the enzymatic activity. This is also in confirmation with results of Gorny *et al.*, (1998a) that hardness loss in fresh-cut pears is influenced by storage temperature and initial maturity stage of produce.

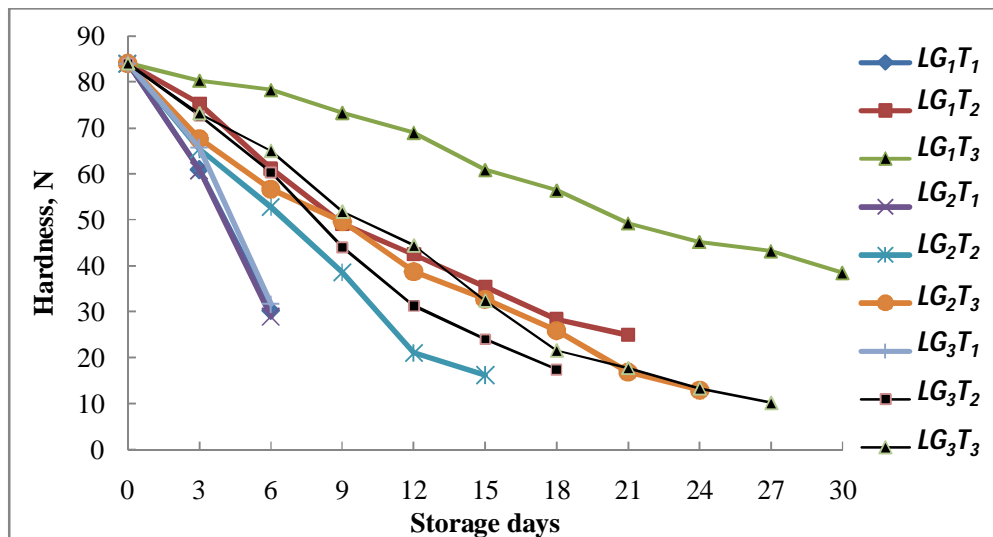


Fig. 4.56 Combined effect of gas composition and temperature on hardness in LDPE

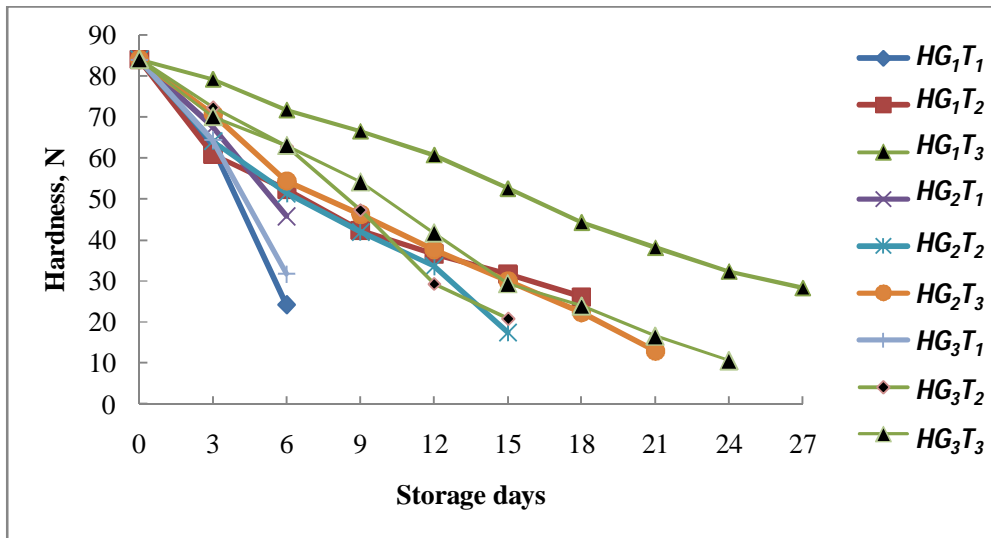


Fig. 4.57 Combined effect of gas composition and temperature on hardness in HDPE

Effect of polythene film on hardness (compression)

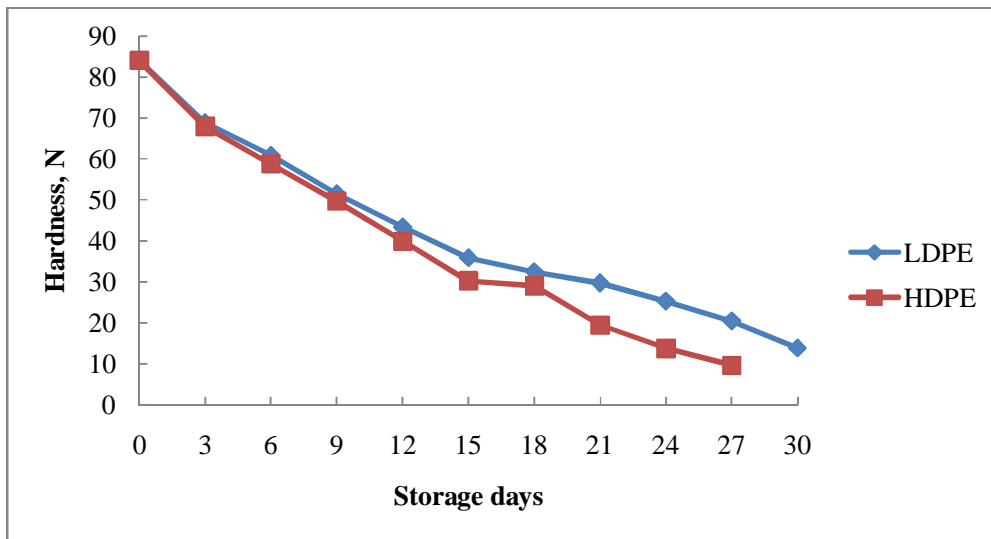


Fig. 4.58 Effect of polythene film on hardness

Fig. 4.58 shows that the sample in HDPE film loses texture faster nearly same as with LDPE.

The comparative effect gas composition and storage temperature on hardness could be observed by F values in the ANOVA (Table 4.11) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was the more influencing factor than gas composition ANOVA also shows that gas composition and storage temperature have significant effect on hardness at 5% level of significance.

**Table 4.11 Anova of hardness for LDPE and HDPE**

		3		6		9		12		15	
<b>Compression LDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	142.360	0.525	746.643	4.693	1634.890	14.107*	1072.968	18.904*	662.070	49.764*
gas composition	2	163.685	0.604	251.782	1.583	153.841	1.327	219.745	3.872	155.055	11.655
temperature	2	315.185	1.163	2605.170	16.375*	6285.976	54.241*	3840.775	67.669*	2402.325	180.570
GXT	4	45.284	0.167	64.809	0.407	49.872	0.430	115.676	2.038	45.450	3.416
Error	18	271.011		159.090		115.888		56.758		13.304	

		18		21		24		27		30	
<b>Compression LDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	493.588	27.117*	406.368	34.679*	225.753	25.468*	161.202	53.673*	64.187	209.973*
gas composition	2	435.919	23.949*	457.106	39.009*	66.336	7.484	108.066	35.989*	64.187	209.973*
temperature	2	1223.574	67.223*	845.841	72.183*	704.005	79.423*	320.609	106.750*	64.187	209.973*
GXT	4	157.431	8.6492*	161.264	13.762*	66.336	7.483	108.066	35.981*	64.187	209.973*
Error	18	18.202		11.718		8.864		3.003		0.306	

	Days	3		6		9		12		15	
<b>Compression HDPE</b>	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	99.985	10780*	692.488	192.481*	2024.688	342100*	1426.939	210400*	974.145	149400*
gas composition	2	6.385	688.241*	28.190	7.836*	108.666	18360*	226.661	33420*	420.024	64400*
temperature	2	196.577	21190*	2017.295	560.72*	7761.137	1311000*	5215.662	769100*	3208.298	491900*
GXT	4	98.488	10620*	262.233	100.685*	114.476	19340*	132.716	19570*	134.129	20560*
Error	18	0.009		3.598		0.006		0.007		0.007	

	Days	18		21		24		27	
<b>Compression HDPE</b>	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	828.158	178700*	340.890	134200*	133.253	57810*	32.035	31920*
gas composition	2	746.288	161100*	71.318	28070*	76.182	36020*	32.035	31920*
temperature	2	2179.336	470400*	1149.607	452500*	260.463	123200*	32.035	31920*
GXT	4	193.504	41760*	71.318	28070*	76.182	36020*	32.035	31920*
Error	18	0.005		0.003		0.002		0.001	

It can be inferred from the data that gas composition  $G_1$  with storage condition  $T_3$  results in hardness of more than or equal to 60% value till 15 and 21 days for HDPE and LDPE packaging film respectively. The firmness level of 60% was considered acceptable based on sensory panel judgment. Therefore the product can be acceptable up to 21 days in LDPE.

#### **4.3.5 Colour**

The green colour of fresh bengal gram kernel is usually a major factor in consumer preference. Thus hue angle was chosen as the detected criterion of the changes of bengal gram kernels quality during storage at different temperatures. Kernel yellowing is particularly important in case of storage of fresh green kernels.

During storage period,  $a^*$  values increased which indicated the decrease of greenness ( $a^*$  value) and thus increase in yellowness ( $b^*$  value). The values of  $a^*$  negative indicates that fresh bengal gram kernels were green in colour. It was found that  $b^*$  values and apparent kernel yellowing increased during storage, where as hue angle decreased.

##### **4.3.5.1 Chroma**

Chroma ( $C^*$ ), considered the quantitative attribute of colourfulness, is used to determine the degree of difference of a hue in comparison to a grey colour with the same lightness. The higher the chroma value, the higher is the colour intensity of samples perceived by humans.

Chroma value indicated the decrease in colour intensity in all samples significantly. The data on chroma of bengal gram kernels during storage were influenced by gas compositions, storage temperatures and their compositions are presented in Fig.4.59-4.65.

#### **Effect of gaseous composition**

It is evident from the data shown in Fig.4.59-4.60 that the chroma of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation but rate of increase in chroma was significantly affected by the different gas composition in package during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum chroma was recorded in  $G_2$  (12.07), while maximum in  $G_3$  (12.77). On 24<sup>th</sup> day of storage minimum chroma was recorded in  $G_3$  (32.30) and maximum in  $G_2$  (36.99). At the end of experiment, 45.38 chroma values were recorded in  $G_1$  on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the minimum chroma was observed in  $G_3$  (9.99), while maximum was recorded in  $G_1$  (12.22). Similarly on 21<sup>st</sup> day of storage, minimum

chroma was recorded in  $G_2$  (24.27) and maximum in  $G_1$  (33.17). At the end of experiment, 38.93 chroma value was recorded in  $G_1$  on 27<sup>th</sup> day of storage.

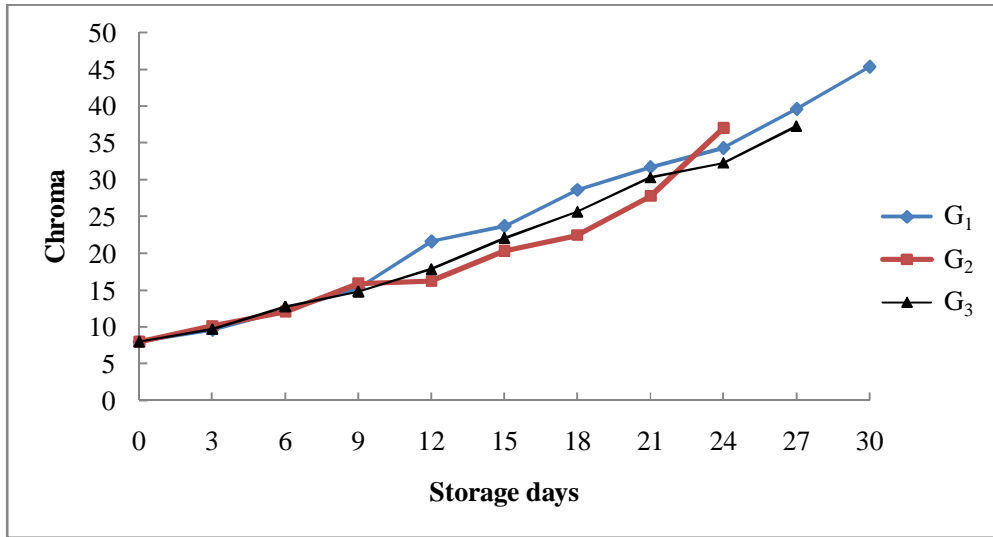


Fig. 4.59 Effect of package gas composition on chroma in LDPE

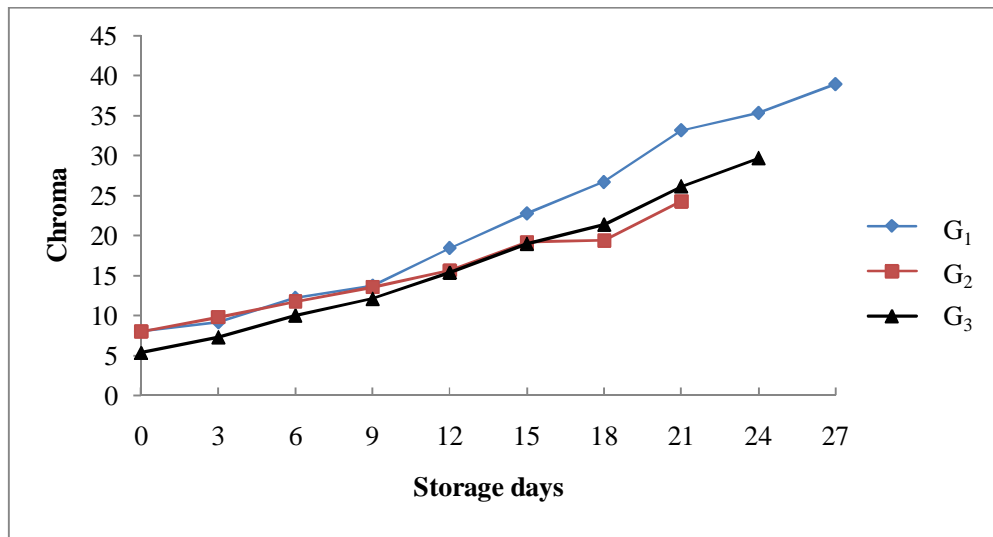


Fig. 4.60 Effect of package gas composition on chroma in HDPE

#### Effect of storage temperature

Fig. 4.61-4.62 shows that, chroma increased in the sample stored at all three condition. Increase in chroma of bengal gram kernels stored in refrigerated was slow as compared to sample stored at ambient temperature.

On 6<sup>th</sup> day of storage, for LDPE, minimum chroma was recorded at  $T_3$  condition (10.06) and maximum was recorded at  $T_1$  condition (13.87). On 21<sup>th</sup> day of storage, minimum chroma was recorded at  $T_2$  condition (30.29) and maximum was recorded at  $T_3$  condition

(30.42). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 45.38 value of chroma was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum chroma was recorded at T<sub>2</sub> condition (11.57) and maximum was recorded at T<sub>1</sub> condition (13.59). On 18<sup>th</sup> day of storage, minimum chroma was recorded at T<sub>3</sub> condition (24.59) while maximum was at T<sub>2</sub> condition (25.72). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 38.93 chroma value was recorded at T<sub>3</sub> condition.

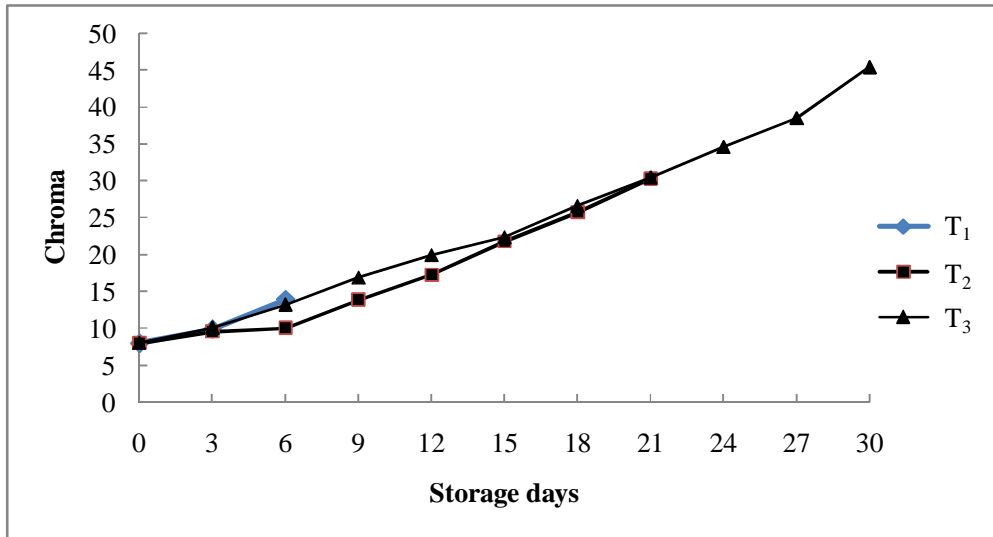


Fig. 4.61 Effect of storage temperature on chroma in LDPE

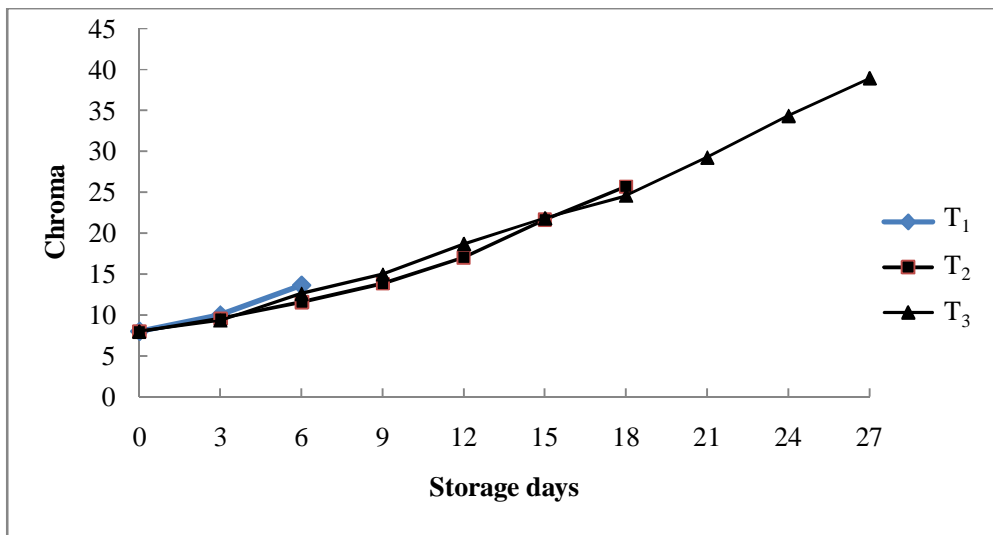


Fig. 4.62 Effect of storage temperature on chroma in HDPE

Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on Bengal gram kernels were shown in Fig. 4.63-4.64.

On 6<sup>th</sup> day of storage minimum chroma was observed in LG<sub>2</sub>T<sub>2</sub> (8.80) and maximum was in LG<sub>3</sub>T<sub>1</sub> (14.68) treatment combination. On 15<sup>th</sup> day of storage, minimum chroma was recorded in LG<sub>2</sub>T<sub>3</sub> (20.29) while maximum was in LG<sub>1</sub>T<sub>2</sub> (23.72). Similarly on 24<sup>th</sup> day of storage minimum chroma was recorded in LG<sub>3</sub>T<sub>3</sub> (32.30) and maximum was in LG<sub>2</sub>T<sub>3</sub> (36.99). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage chroma was recorded in LG<sub>1</sub>T<sub>3</sub> (45.38) treatment combination.

On 6<sup>th</sup> day of storage minimum chroma was observed in HG<sub>2</sub>T<sub>2</sub> (9.85) and maximum was in HG<sub>3</sub>T<sub>1</sub> (16.20) treatment combination. On 15<sup>th</sup> day of storage, minimum chroma was recorded in HG<sub>2</sub>T<sub>3</sub> (19.07) while maximum was in HG<sub>3</sub>T<sub>2</sub> (23.67). Similarly on 21<sup>st</sup> day of storage minimum chroma was recorded in HG<sub>2</sub>T<sub>3</sub> (24.27) and maximum was in HG<sub>3</sub>T<sub>3</sub> (33.17). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage chroma was recorded in HG<sub>1</sub>T<sub>3</sub> (38.93) treatment combination.

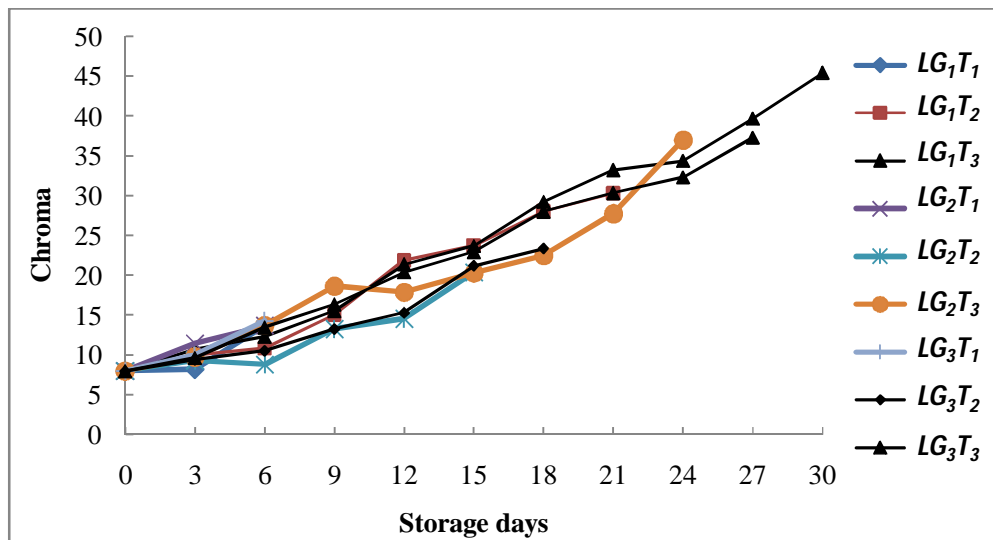


Fig. 4.63 Combined effect of gas composition and temperature on chroma in LDPE

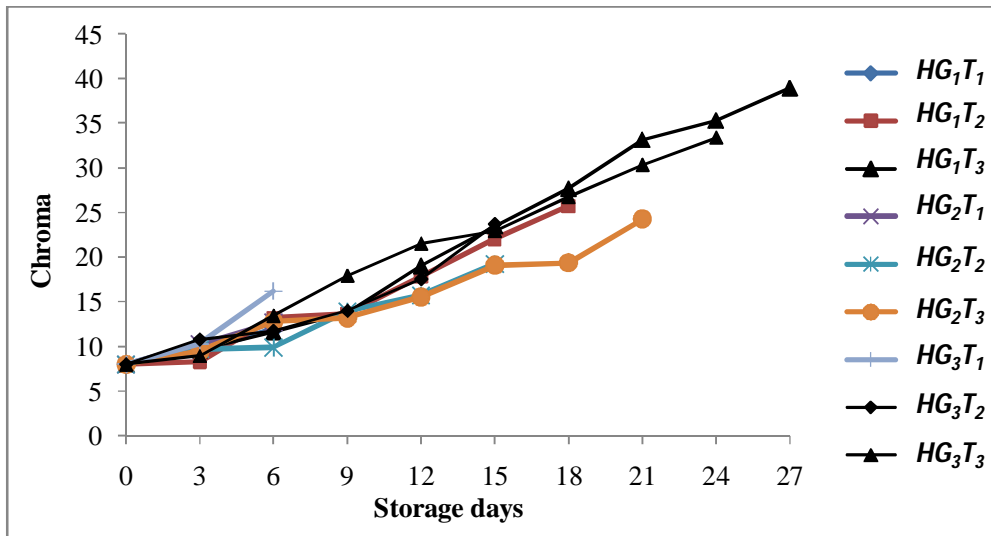


Fig. 4.64 Combine effect of gas composition and temperature on chroma in HDPE

#### Effect of polythene film on chroma

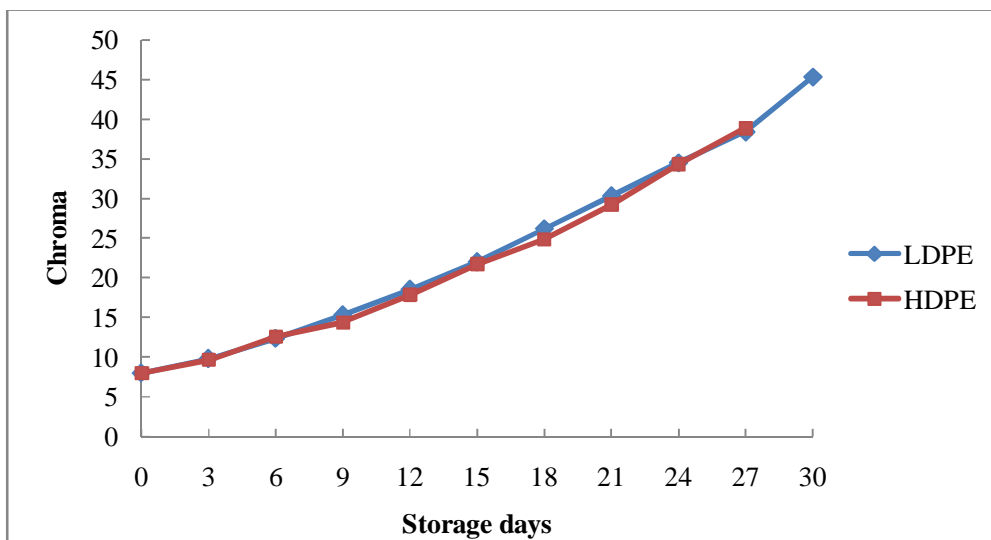


Fig. 4.65 Effect of polythene film on chroma

From Fig. 4.65, chroma is not significantly affected by the polythene film. The chroma value increases at a steady rate in both packaging material.

The comparative effect gas composition and storage temperature on chroma could be observed by F values in the ANOVA (Table 4.12) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was the more influencing factor than gas composition. ANOVA also shows that gas composition and storage temperature have significant effect on chroma at 5% level of significance.

After kernels reaching at climacteric respiration peak changed to more dark colour during storage and colour deteriorate very fast at higher temperature than at lower temperature as evidenced by increase in  $L^*$  and chroma intensities.  $a^*$  and  $b^*$  values also changed over time and showed continuously increase with increase in storage time. The chroma values, associated to the higher  $L^*$  values, resulted in dark brown colour (Nikhane, 2011).

#### 4.3.5.2 Hue angle

Hue angle ( $h^*$ ), considered the qualitative attribute of colour, is the attribute according to which colours have been traditionally defined as reddish, greenish, etc., and it is used to define the difference of a certain colour with reference to grey colour with the same lightness. This attribute is related to the differences in absorbance at different wavelengths. A higher hue angle represents a lesser yellow character in the assays

The data on  $h^0$  (hue angle) of bengal gram kernels during storage influenced by gas composition, temperature and their combinations are presented in Fig. 4.66-4.72.

#### Effect of gaseous composition

It is evident from the data presented in Fig.4.66-4.67 that the hue angle of bengal gram kernels decreased with the advancement of storage time during the entire period of experimentation but rate of decrease in hue angle was significantly affected by the different gas composition in package during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum hue angle was recorded in  $G_1$  (-1.31), while maximum in  $G_3$  (-1.25). On 24<sup>th</sup> day of storage minimum hue angle was recorded in  $G_2$  (-1.54) and maximum in  $G_1$  (-1.50). At the end of experiment, -1.53 degrees of hue angle was recorded in  $G_1$  on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the minimum hue angle was observed in  $G_1$  (-1.33), while maximum was recorded in  $G_2$  (-1.29). Similarly on 21<sup>st</sup> day of storage, minimum hue angle was recorded in  $G_2$  (-1.51) and maximum in  $G_1$  (-1.50). At the end of experiment, -1.52 degrees of hue angle was recorded in  $G_1$  on 27<sup>th</sup> day of storage. Since sample stored with  $G_1$  and  $G_3$  gas composition were not survived to 27<sup>th</sup> day of storage.

**Table 4.12 Anova of chroma values of LDPE and HDPE**

	Days	3		6		9		12		15	
Chroma LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	2.465	10735.951*	10.709	26047.945*	184.681	8310638.166*	277.236	8317094.249*	369.158	24918159.374*
gas composition	2	0.767	3341.822*	1.188	2890.297*	1.284	57783.166*	30.939	928172.333*	11.375	767822.249*
temperature	2	0.556	2421.354*	37.053	90127.891*	727.548	32739672.666*	1050.322	31509662.333*	1457.952	98411742.749*
GXT	4	4.269	18590.314*	2.297	5586.797*	4.946	222548.416*	13.842	415271.166*	3.652	246536.249*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	18		21		24		27		30	
Chroma LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	587.17	15853645.07*	775.2	69767968.4*	899.08	80917243.4*	864.36	19448121*	686.650	185395456*
gas composition	2	346.46	9354528.1*	397.4	35772972.9*	5.532	497888.9*	494.73	11131419*	686.650	185395456*
temperature	2	1632.4	44076997.3*	2160.6	194457276.9*	3579.7	322175306.9*	1973.25	44398227*	686.650	185395456*
GXT	4	184.87	4991527.45*	271.3	24420811.9*	5.532	497888.9*	494.73	11131419*	686.650	185395456*
Error	18	0.00		0.0		0.000		0.00		0.000	

	Days	3		6		9		12		15	
Chroma HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.697	163.16	9.00	992.594*	163.18	30100*	280.86	45890	365.72	57210*
gas composition	2	1.902	182.84	9.95	1097*	7.30	1347*	15.97	2923	20.25	3168*
temperature	2	1.029	98.99	9.36	1032*	632.73	116000*	972.77	177900	1430.45	223800*
GXT	4	1.928	185.41	8.35	920.572*	6.36	1173*	7.34	1344	6.10	954.34*
Error	18	0.010		0.009		0.005		0.005		0.006	

	Days	18		21		24		27	
Chroma HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	535.635	124900*	661.301	239000*	693.246	224700*	507.347	698900*
gas composition	2	322.574	75210*	20.573	7436*	396.656	128600*	507.347	698900*
temperature	2	1414.679	329800*	2583.485	933800*	1583.016	513100*	507.347	698900*
GXT	4	202.644	47250*	20.573	7436*	396.656	128600*	507.347	698900*
Error	18	0.004		0.003		0.003		0.001	

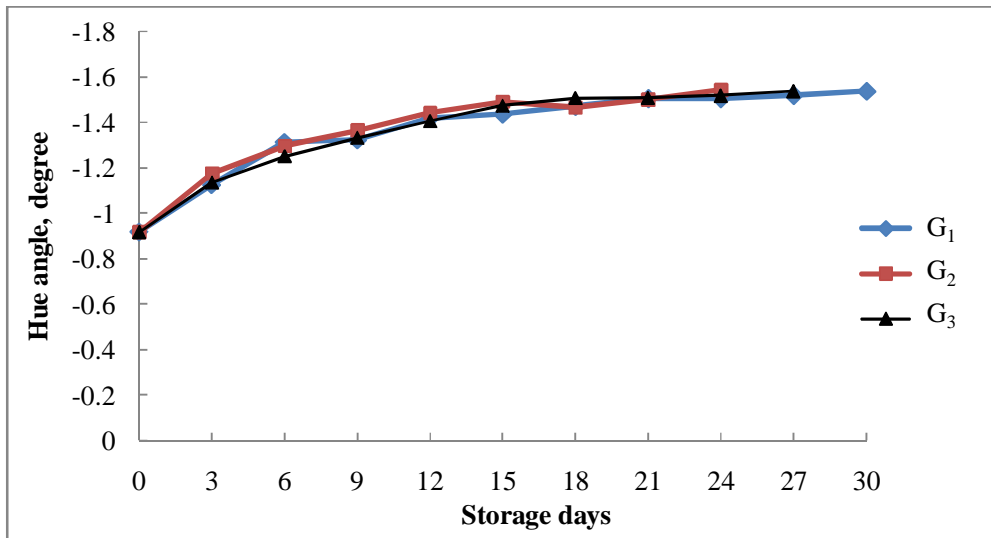


Fig. 4.66 Effect of package gas composition on hue angle in LDPE

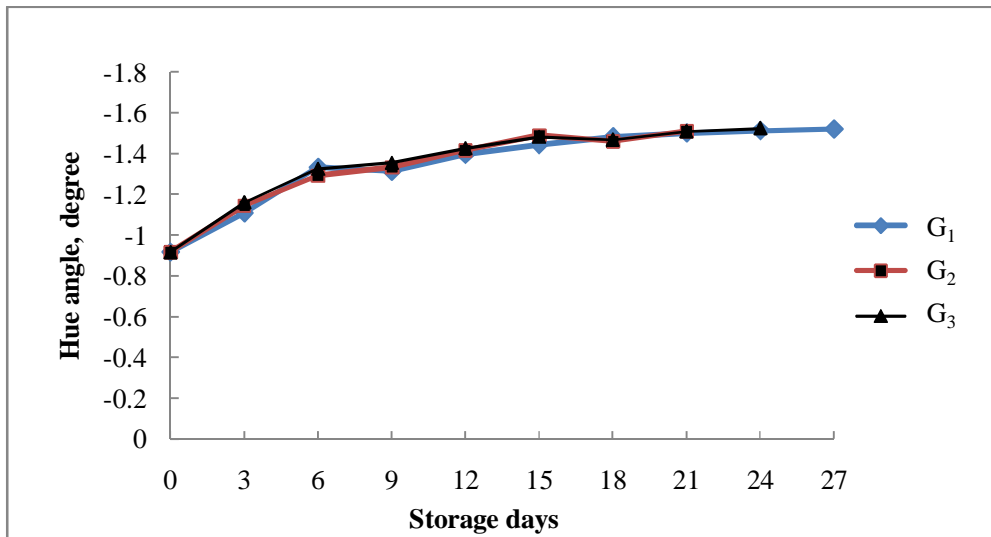


Fig. 4.67 Effect of package gas composition on hue angle in HDPE

#### Effect of storage temperature

Fig. 4.68-4.69 shows that, hue angle decreased in the sample stored at all three condition. Decrease in hue angle of bengal gram kernels stored in refrigerated was slow as compared to sample stored at ambient temperature.

On 6<sup>th</sup> day of storage, for LDPE, minimum hue angle was recorded at T<sub>3</sub> condition (-1.42) and maximum was recorded at T<sub>2</sub> condition (-1.19). On 21<sup>th</sup> day of storage, minimum hue angle was recorded at T<sub>2</sub> condition (-1.52) and maximum was recorded at T<sub>3</sub> condition (-1.49). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, -1.53 degrees of hue angle was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum hue angle was recorded at T<sub>1</sub> condition (-1.45) and maximum was recorded at T<sub>3</sub> condition (-1.23). On 18<sup>th</sup> day of storage, minimum hue angle was recorded at T<sub>2</sub> condition (-1.49) while maximum was at T<sub>3</sub> condition (-1.46). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, -1.52 degrees of hue angle was recorded at T<sub>3</sub> condition.

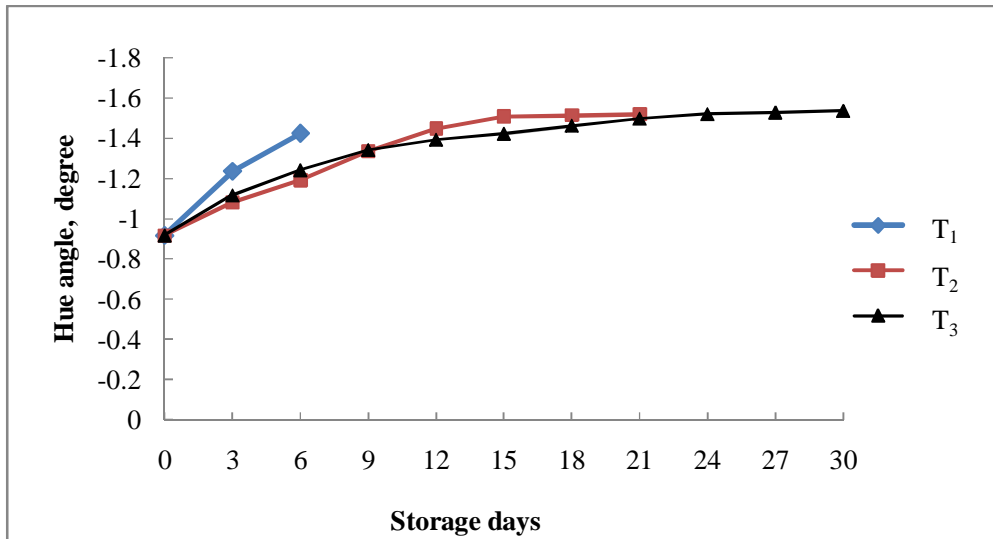


Fig. 4.68 Effect of storage temperature on hue angle in LDPE

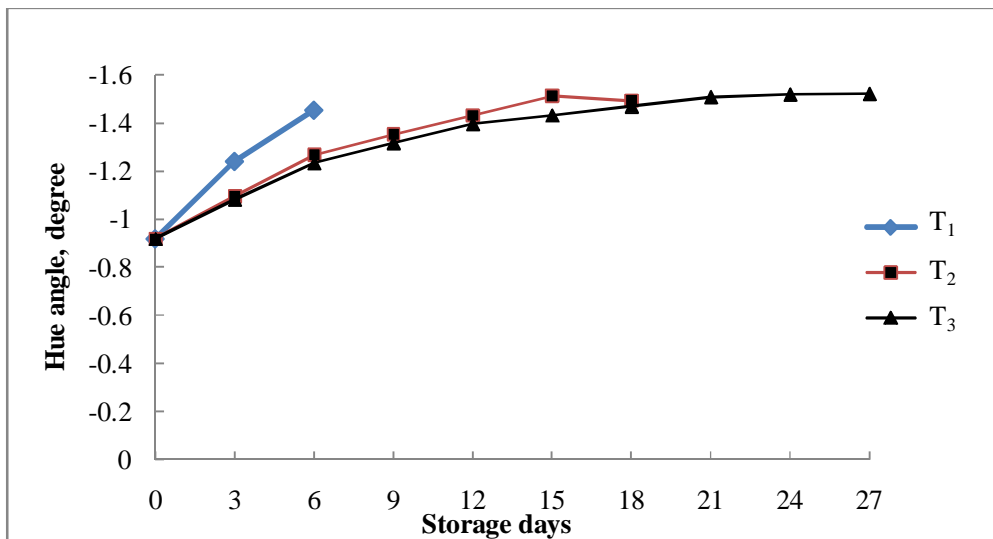


Fig. 4.69 Effect of storage temperature on hue angle in HDPE

### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on Bengal gram kernels were Fig. 4.70-4.71.

On 6<sup>th</sup> day of storage minimum hue angle was observed in LG<sub>2</sub>T<sub>1</sub> (-1.50) and maximum was in LG<sub>2</sub>T<sub>2</sub> (-1.15) treatment combination. On 15<sup>th</sup> day of storage, minimum hue angle was recorded in LG<sub>2</sub>T<sub>2</sub> (-1.55) while maximum was in LG<sub>1</sub>T<sub>3</sub> (-1.42). Similarly on 24<sup>th</sup> day of storage minimum hue angle was recorded in LG<sub>2</sub>T<sub>3</sub> (-1.54) and maximum was in LG<sub>1</sub>T<sub>3</sub> (-1.50). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, -1.53 degrees of hue angle was recorded in LG<sub>1</sub>T<sub>3</sub> treatment combination.

On 6<sup>th</sup> day of storage minimum hue angle was observed in HG<sub>1</sub>T<sub>1</sub> (-1.48) and maximum was in HG<sub>2</sub>T<sub>2</sub> (-1.21) treatment combination. On 15<sup>th</sup> day of storage, minimum hue angle was recorded in HG<sub>2</sub>T<sub>3</sub> (-1.55) while maximum was in HG<sub>2</sub>T<sub>2</sub> (-1.55). Similarly on 21<sup>st</sup> day of storage minimum hue angle was recorded in HG<sub>1</sub>T<sub>3</sub> (-1.50) and maximum was in HG<sub>2</sub>T<sub>3</sub> (-1.51). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, -1.52 degrees of hue angle was recorded in HG<sub>1</sub>T<sub>3</sub> treatment combination.

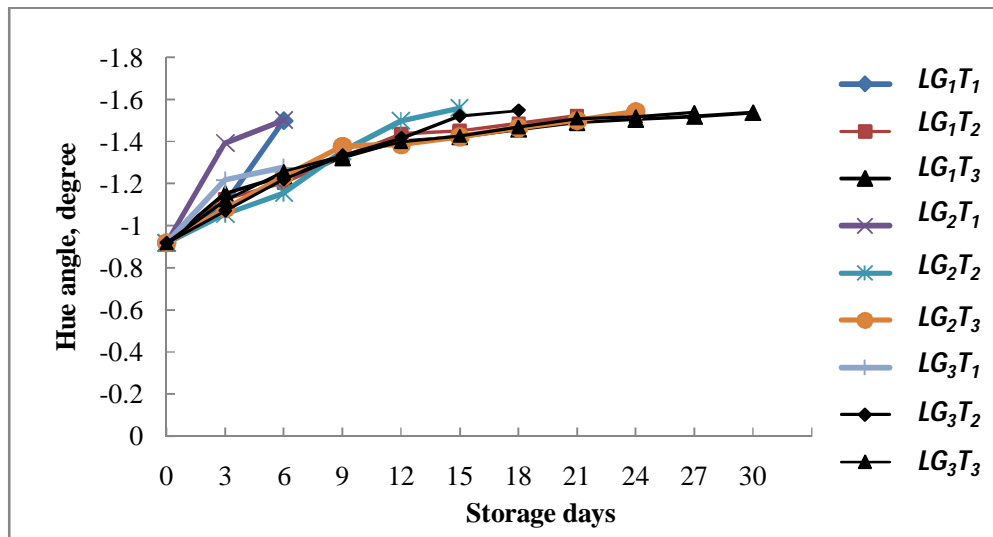


Fig. 4.70 Combined effect of gas composition and temperature on hue angle in LDPE

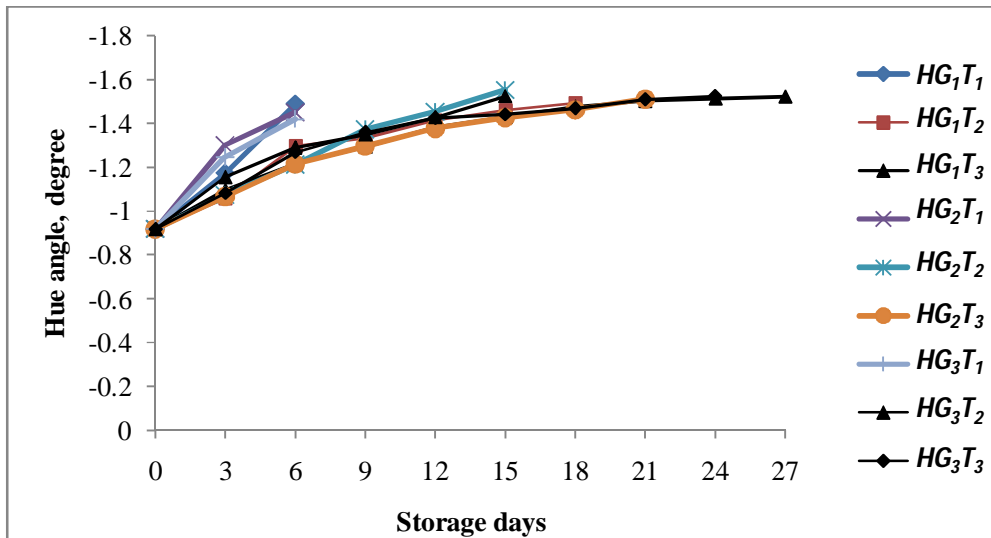


Fig. 4.71 Combined effect of gas composition and temperature on hue angle in HDPE

#### Effect of polythene film on hue angle

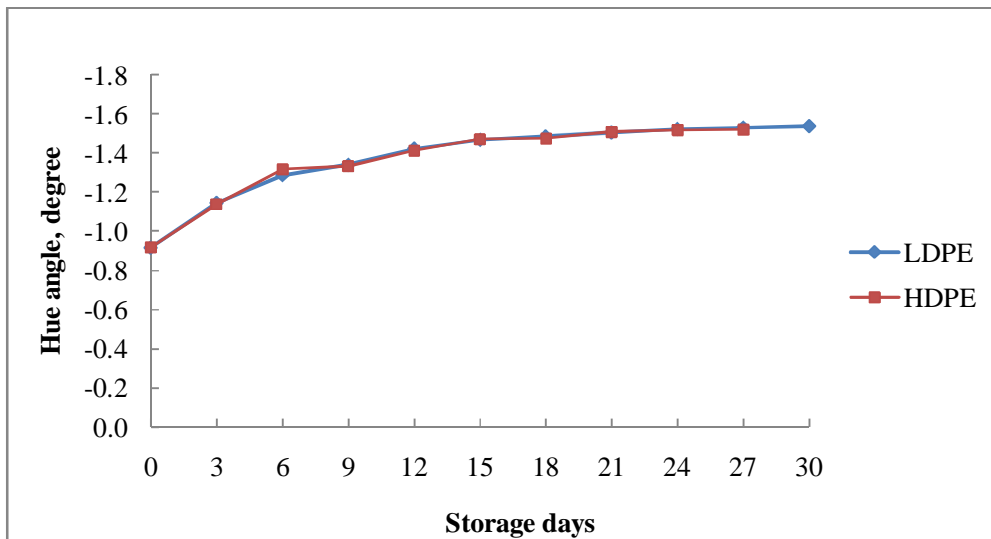


Fig. 4.72 Effect of polythene film on hue angle

From Fig. 4.72, the hue angle is not affected by the polythene films. Hue angle decreased rapidly at start of experiment but afterwards it becomes nearly constant.

The comparative effect gas composition and storage temperature on hue angle could be observed by F values in the ANOVA (Table 4.13) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was more influencing factor than gas composition. ANOVA shows that gas composition and storage temperature have significant effect on hue angle at 5% level of significance.

**Table 4.13 Anova of Hue angle for LDPE and HDPE**

	Days	3		6		9		12		15	
Hue angle LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.034	2274.75*	0.047	6404.625*	1.347	181781.375*	1.525	411717.249*	1.631	24470.375*
gas composition	2	0.007	459.75*	0.009	1189.5*	0.002	278*	0.001	361*	0.002	33.5*
temperature	2	0.060	4055.25*	0.137	18478.5*	5.382	726633.5*	6.094	1645399*	6.516	97734.5*
GXT	4	0.034	2292*	0.022	2975.25*	0.001	107*	0.002	554.5*	0.004	56.749*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	18		21		24		27		30	
Hue angle LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.844	248918.375*	0.735	16539.75*	1.736	468608.5*	1.393	62667*	0.808	31155.571*
gas composition	2	0.768	103694*	5.265	118464.75*	0.000	91*	0.796	35815.5*	0.808	31155.571*
temperature	2	5.067	684036.5*	0.788	17736.75*	6.941	1874161*	3.183	143221.5*	0.808	31155.571*
GXT	4	0.770	103971.5*	0.000		0.000	91*	0.796	35815.5*	0.808	31155.571*
Error	18	0.000				0.000		0.000		0.000	

	Days	3		6		9		12		15	
Hue angle HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.023	226.5*	0.034	343.833*	1.315	19730*	1.479	22180*	1.610	27170*
gas composition	2	0.007	67*	0.005	46.333*	0.002	30.5*	23.632	18.500*	0.002	39.812*
temperature	2	0.068	679*	0.124	1240*	5.256	78840*	0.001	88660*	6.433	108600*
GXT	4	0.008	80*	0.004	44.333*	0.002	26*	5.911	18.500*	0.002	36.156*
Error	18	0.000		0.000		0.000		0.001		0.000	

	Days	18		21		24		27	
Hue angle HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.783	40110*	1.680	50400*	1.321	59460*	0.760	68400*
gas composition	2	0.735	16540*	0.000	1*	0.755	33980*	0.760	68400*
temperature	2	4.940	111100*	6.720	201600*	3.020	135900*	0.760	68400*
GXT	4	0.728	16370*	0.000	1*	0.755	33980*	0.760	68400*
Error	18	0.000		0.000		0.000		0.000	

An angle of 0° or 360° represents red hue, whilst angles of 90°, 180° and 270° represent yellow, green and blue hues, respectively. It has been extensively used in the evaluation of colour parameters in green vegetables, fruits and meats (Barreiro et al. 1997; Lopez et al. 1997; Pathare *et al.*, 2012).

Hue angle did not show any linear pattern with storage time. Lower storage temperature depicted significantly higher hue parameter in comparison to the other treatments. Hue angle decreased from 0 to 15 days and then becomes nearly constant for bengal gram kernels. According to Peiser *et al.*(1998), hue angle decreased as browning occurred. As the decrease of hue angle was minimum in packages with G<sub>1</sub> gas composition and T<sub>3</sub> condition, least browning was observed.

#### **4.3.6 Water Activity (a<sub>w</sub>)**

During storage, the most controllable parameters are the temperature and relative humidity for water activity. The deterioration reaction of the nutrient do not necessarily depend solely on the total moisture content of the food materials, it is the state of water, measured by water activity, that determines the reactions in foods (Deman, 1990). Hence it is more appropriate to relate nutrient loss in food material to water activity rather than to its actual water content. The water activity of fresh bengal gram kernel sample was 0.962.

#### **Effect of gaseous composition**

It is evident from the data presented in Fig.4.73-4.74 that the water activity a of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation but rate of increase in water activity was significantly affected by the different package gas composition in package during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum water activity was recorded in G<sub>2</sub> (0.976), while maximum in G<sub>3</sub> (0.970). On 24<sup>th</sup> day of storage minimum water activity was recorded in G<sub>1</sub> (0.978) and maximum in G<sub>2</sub> (0.985). At the end of experiment, 0.987 water activity was recorded in G<sub>1</sub> on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the minimum water activity was observed in G<sub>3</sub> (0.976), while maximum was recorded in G<sub>2</sub> (0.978). Similarly on 21<sup>st</sup> day of storage, minimum water activity was recorded in G<sub>1</sub> (0.986) and maximum in G<sub>2</sub> (0.992). At the end of experiment, 0.994 water activity was recorded in G<sub>1</sub> on 27<sup>th</sup> day of storage. Since sample stored with G<sub>2</sub> and G<sub>3</sub> gas composition were not survived to 27<sup>th</sup> day of storage.

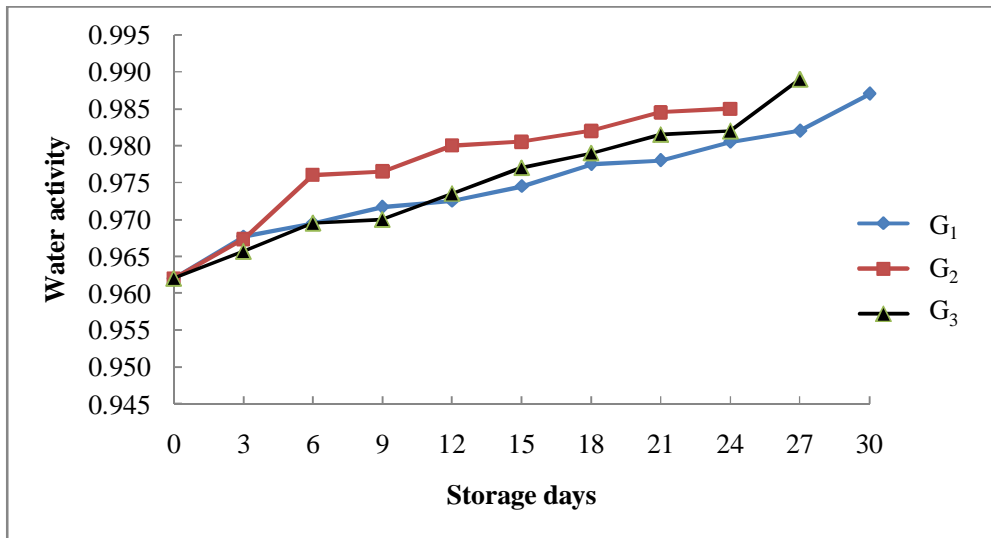


Fig. 4.73 Effect of package gas composition on water activity in LDPE

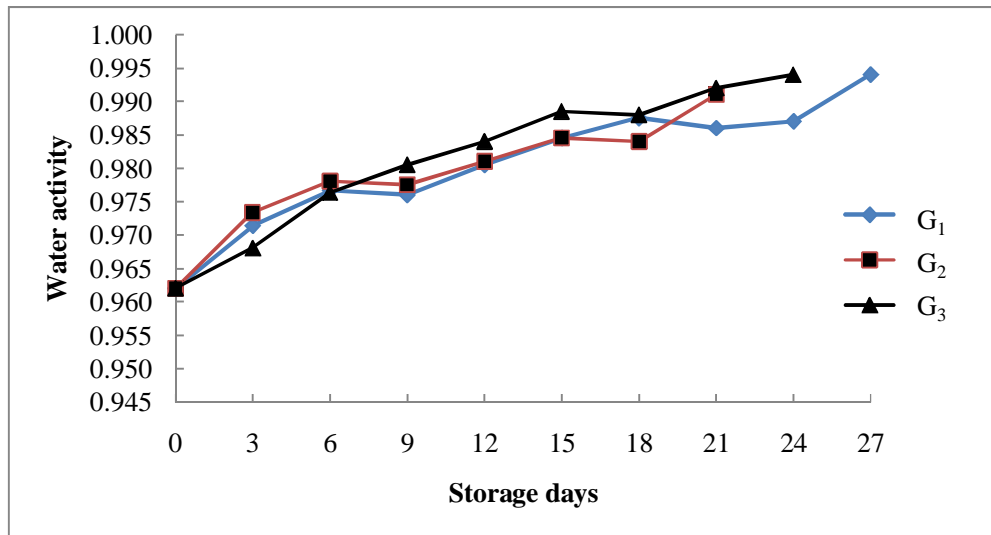


Fig. 4.74 Effect of package gas composition on water activity in HDPE

#### Effect of storage temperature

It is evident from the data presented in Fig.4.75-4.76 that the water activity of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation.

On 6<sup>th</sup> day of storage, for LDPE, minimum water activity was recorded at T<sub>3</sub> condition (0.966) and maximum was recorded at T<sub>1</sub> condition (0.982). On 21<sup>th</sup> day of storage, minimum water activity was recorded at T<sub>3</sub> condition (0.979) and maximum was recorded at T<sub>2</sub> condition (0.985). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.987 water activity was recorded at T<sub>3</sub> condition.

On 6<sup>th</sup> day of storage, for HDPE, minimum water activity was recorded at T<sub>3</sub> condition (0.969) and maximum was recorded at T<sub>1</sub> condition (0.988). On 18<sup>th</sup> day of storage, minimum water activity was recorded at T<sub>3</sub> condition (0.986) while maximum was at T<sub>2</sub> condition (0.990). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.990 water activity was recorded at T<sub>3</sub> condition.

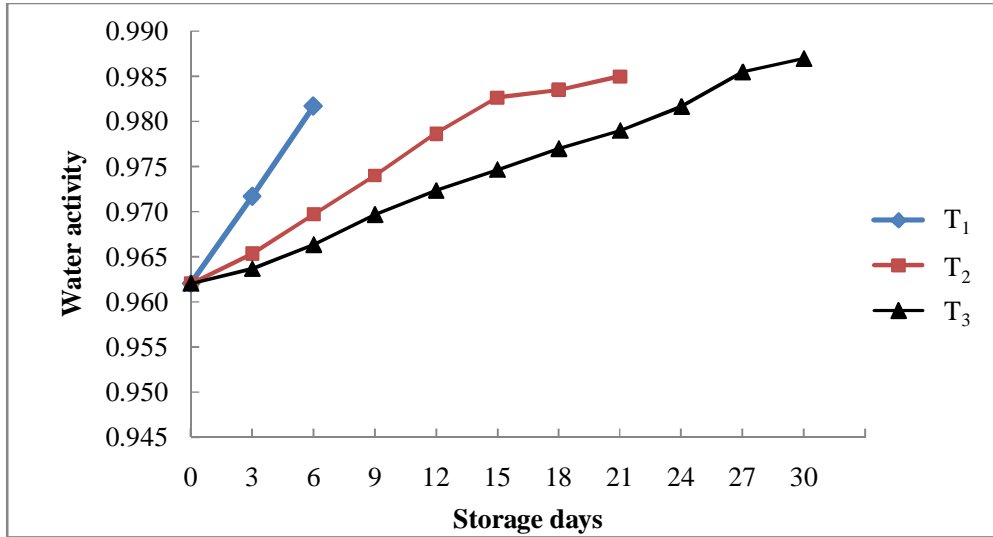


Fig. 4.75 Effect of storage temperature on water activity in LDPE

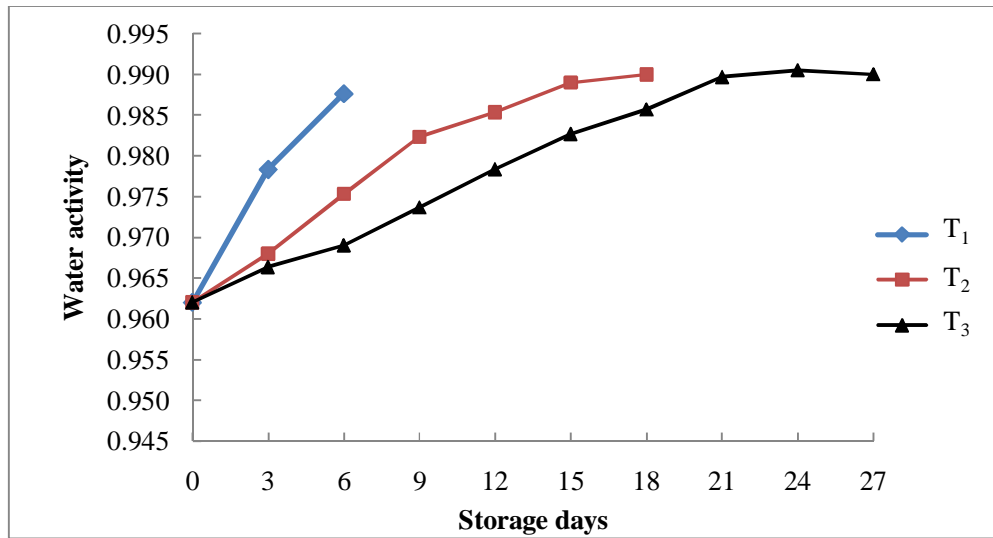


Fig. 4.76 Effect of storage temperature on water activity in HDPE

### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on bengal gram kernels were found to be significant during entire period of storage as presented in Fig 4.77-4.78.

On 6<sup>th</sup> day of storage minimum water activity was observed in LG<sub>3</sub>T<sub>3</sub> (0.965) and maximum was in LG<sub>2</sub>T<sub>1</sub> (0.985) treatment combination. On 15<sup>th</sup> day of storage, minimum water activity was recorded in LG<sub>1</sub>T<sub>3</sub> (0.972) while maximum was in LG<sub>2</sub>T<sub>2</sub> (0.992). Similarly on 24<sup>th</sup> day of storage minimum water activity was recorded in LG<sub>1</sub>T<sub>3</sub> (0.978) and maximum was in LG<sub>2</sub>T<sub>3</sub> (0.985). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage, 0.987 water activity was recorded in LG<sub>1</sub>T<sub>3</sub> treatment combination.

On 6<sup>th</sup> day of storage minimum water activity was observed in HG<sub>1</sub>T<sub>3</sub> (0.968) and maximum was in HG<sub>2</sub>T<sub>1</sub> (0.989) treatment combination. On 15<sup>th</sup> day of storage, minimum water activity was recorded same in both HG<sub>1</sub>T<sub>3</sub> and HG<sub>2</sub>T<sub>3</sub> (0.981) while maximum was in HG<sub>3</sub>T<sub>2</sub> (0.991). Similarly on 21<sup>st</sup> day of storage minimum water activity was recorded in HG<sub>1</sub>T<sub>3</sub> (0.986) and maximum was in HG<sub>1</sub>T<sub>3</sub> (0.992). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage, 0.994 water activity was recorded in HG<sub>1</sub>T<sub>3</sub> treatment combination.

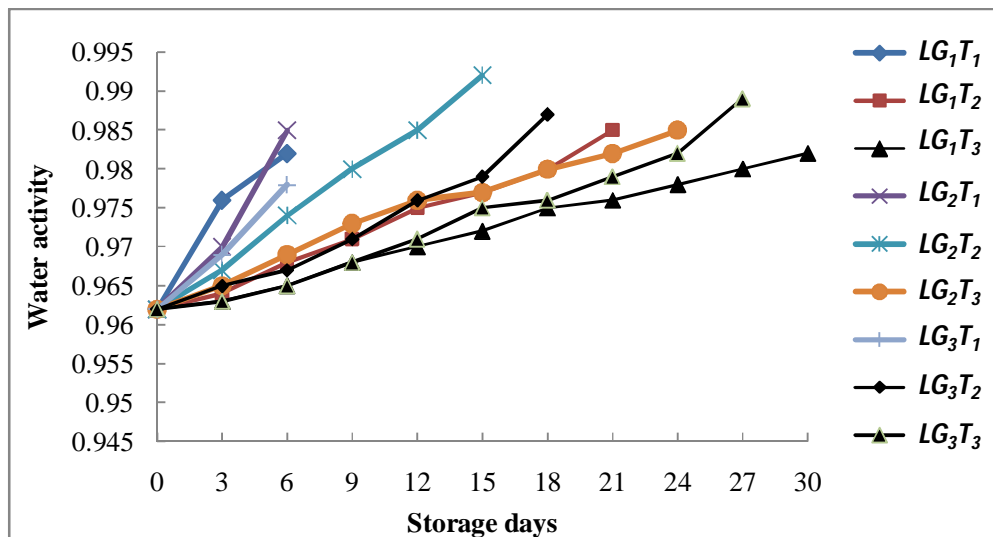
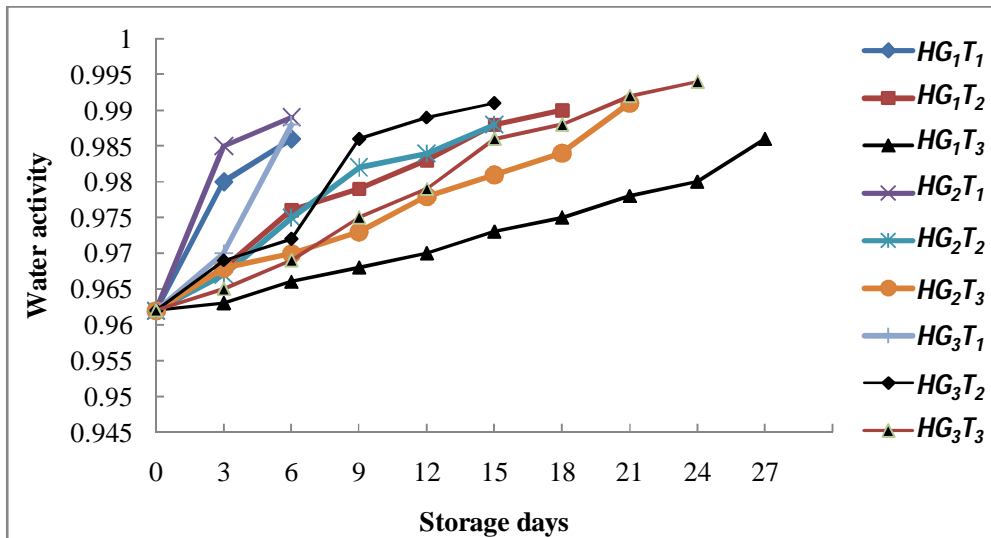
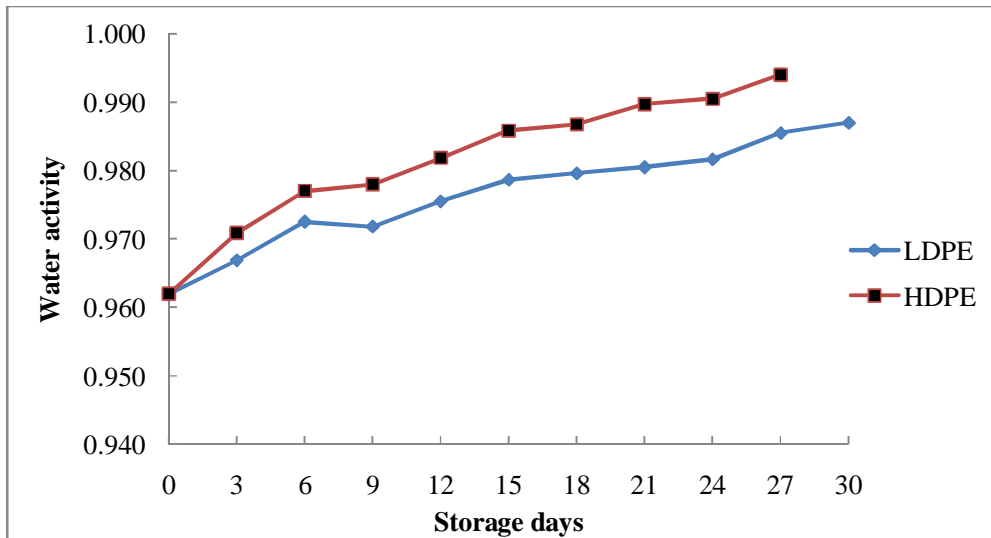


Fig. 4.77 Combined effect of gaseous composition and temperature on water activity in LDPE



**Fig. 4.78 Combined effect of gaseous composition and temperature on water activity in HDPE**

**Effect of polythene film on water activity**



**Fig. 4.79 Effect of polythene film on water activity**

From Fig.4.79, water activity of sample increases in both the polythene films. The water activity of the sample packed in HDPE film has more water activity as compared to the sample packed in LDPE film. Increase in water activity corresponds to increase in microbial load.

The comparative effect gas composition and storage temperature on water activity could be observed by F values in the ANOVA (Table 4.14) for both polythene films i.e. LDPE

and HDPE. ANOVA also shows that gas composition and storage temperature has significant effect on water activity at 5% level of significance.

From the data, it can be inferred that, the water activity of the kernels increases from 0.965 to 0.990. Water activity is related with the microbial load. As water activity increases the microbial load also increases. The gas composition  $G_1$  with storage condition  $T_3$  resulted into the water activity of less than 0.980. Further the water activity suddenly increases. This limit of water activity was shown at 21<sup>st</sup> and 27<sup>th</sup> days for HDPE and LDPE respectively.

#### **4.3.7 Microbial Load**

Microorganisms are ubiquitous in fruits and vegetables; therefore sanitation is essential in keeping the microbial population to a minimum.

Fresh vegetables normally have an elaborate spoilage microflora, due to intense contact with various types of microorganisms during growth and post-harvest handling, and therefore the numbers of microorganisms found on vegetables are highly variable. Initial mesophilic counts of all of the samples fell within the range  $10^1$ – $10^2$  cfu  $g^{-1}$  which agrees with those found by Zagory;1999 and Villanuev *et al.* 2005.

Large differences in microbial counts have been reported between batches of vegetable samples. This has been attributed to numerous factors such as ambient conditions during harvest, the presence of soil accompanying the sample or postharvest handling, etc. (Ponce *et al.*, 2002). The washing process helped to reduce the total microbial load, resulting in maintained quality of the fresh bengal gram kernel. In treatment of chlorine, the concentration was 200 ppm free  $Cl_2$ . However, the results showed that using chlorine for washing treatment reduces initial microbial count on the fresh bengal gram kernel. This confirms the washing fresh bengal gram kernel with chlorinated water (100–200 mg/L free  $Cl_2$ ) delayed the deterioration on microbiological front.

##### **4.3.7.1 Bacterial load**

Bacterial count on the sample at 3 days interval the count was converted into **log CFU/g**.

**Table 4.14 Anova of Water activity for LDPE and HDPE**

	Days	3		6		9		12		15	
AW LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.000	26.166*	0.000	167.342*	0.708	434590.369*	0.714	963785.112*	0.718	1939316.725*
gas composition	2	0.000	5.388*	0.000	87.259*	0.000	42.090*	0.000	105.350*	0.000	303.10*
temperature	2	0.000	76.222*	0.001	573.037*	2.833	1738293.431*	2.856	3854972.45*	2.873	7756671.699*
GXT	4	0.000	11.527*	0.000	4.537*	0.000	12.977*	0.000	31.324*	0.000	146.050*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	18		21		24		27		30	
AW LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.800	4319034.64*	0.801	1802317.27*	0.723	1500779.78*	0.566	1529166.02*	0.325	8761599.99*
gas composition	2	0.319	1724105.59*	0.321	722021.083*	0.000	25.461*	0.324	873829.89*	0.325	8761600*
temperature	2	2.232	12052568.6*	2.234	5026214.58*	2.890	6003042.76*	1.295	3495174.39*	0.325	8761599.99*
GXT	4	0.324	1749732.2*	0.325	730516.708*	0.000	25.461*	0.324	873829.89*	0.325	8761599.99*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	3		6		9		12		15	
AW HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.000	1.500	0.000	2.331	0.705	11900*	0.703	4998*	0.712	7397*
gas composition	2	0.000	1	0.000	0.226	0.000	4.000	0.000	2.447	0.000	0.962
temperature	2	0.000	3	0.001	8.645*	2.820	47580*	2.813	19990*	2.849	29580*
GXT	4	0.000	1	0.000	0.226	0.000	1.188	0.000	0.671	0.000	0.962
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	18		21		24		27	
AW HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	0.795	9333*	0.720	21610*	0.562	21680*	0.320	28810*
gas composition	2	0.331	3888*	0.000	0.000	0.321	12390*	0.320	28810*
temperature	2	2.213	25980*	2.881	86440*	1.285	49560*	0.320	28810*
GXT	4	0.318	37340*	0.000	0.000	0.321	12390*	0.000	28810*
Error	18	0.000		0.000		0.000		0.000	

### Effect of gaseous composition

It is evident from the data presented in Fig.4.80-4.81 that the bacterial count of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation but rate of increase in bacterial count was significantly affected by the different gas composition in package during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum bacterial count was recorded in G<sub>3</sub> (4.22), while maximum in G<sub>1</sub> (4.87). On 24<sup>th</sup> day of storage minimum bacterial count was recorded in G<sub>1</sub> (6.17) and maximum in G<sub>2</sub> (6.33). At the end of experiment, bacteria count was recorded in G<sub>1</sub> (7.50) on 30<sup>th</sup> day of storage for LDPE.

For HDPE, on 6<sup>th</sup> day of storage the minimum bacterial count was observed in G<sub>1</sub> (4.35), while maximum was recorded in G<sub>2</sub> (4.62). Similarly on 21<sup>st</sup> day of storage, minimum Bacterial count was recorded in G<sub>1</sub> (5.94) and maximum in G<sub>2</sub> (6.90). At the end of experiment, bacterial count was recorded in G<sub>1</sub> (7.66) on 27<sup>th</sup> day of storage. Since sample stored with G<sub>2</sub> and G<sub>3</sub> gas composition was not survived to 27<sup>th</sup> day of storage.

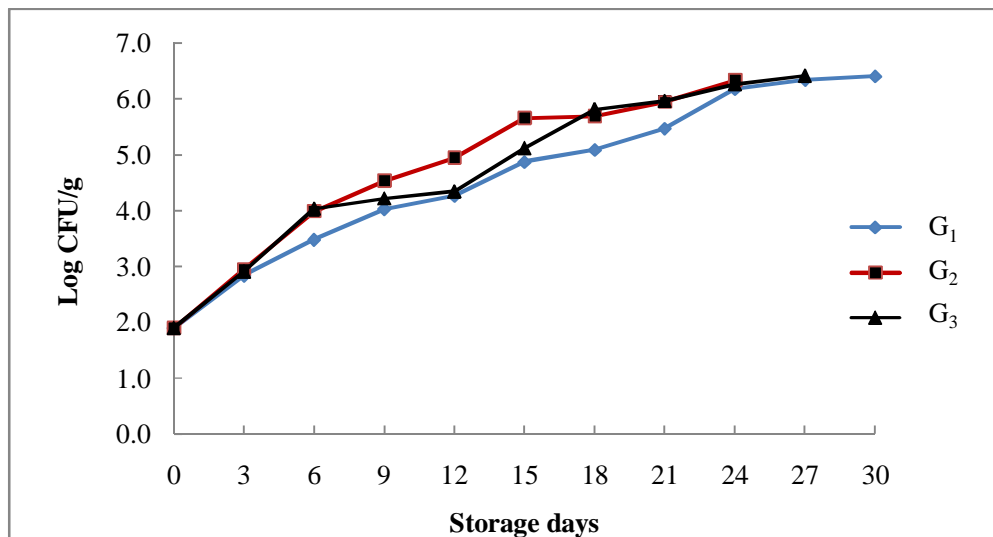
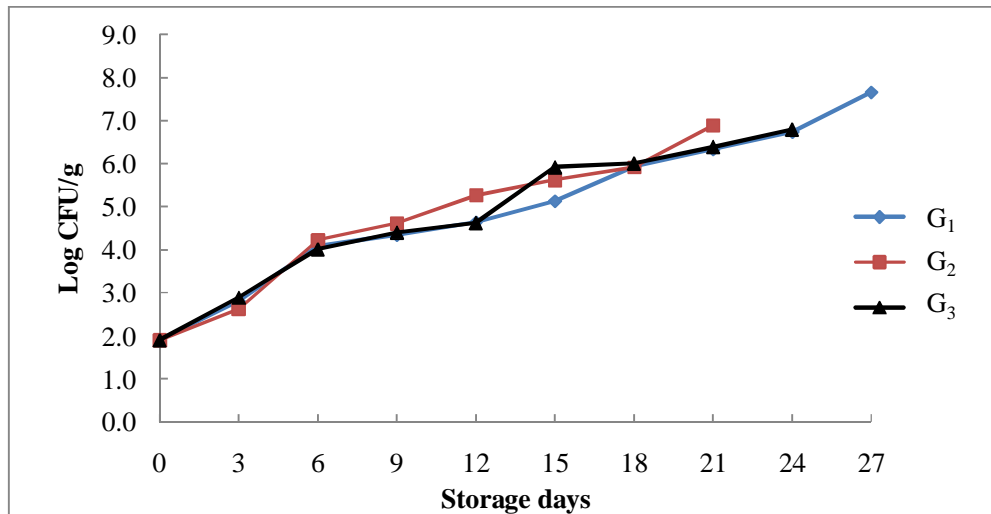


Fig. 4.80 Effect of gas composition on bacterial count in LDPE



**Fig. 4.81 Effect of gas composition on bacterial count in HDPE**

#### **Effect of storage temperature**

It is evident from the data presented in Fig.4.82-4.83 that the bacterial count of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation.

On 6<sup>th</sup> day of storage, for LDPE, minimum bacterial count was recorded at T<sub>2</sub> condition (3.86) and maximum was recorded at T<sub>1</sub> condition (6.27). On 21<sup>st</sup> day of storage, minimum bacterial count was recorded at T<sub>3</sub> condition (5.96) and maximum was recorded at T<sub>2</sub> condition (6.69). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage bacterial count was recorded at T<sub>3</sub> condition (7.50).

On 6<sup>th</sup> day of storage, for HDPE, minimum bacterial count was recorded at T<sub>3</sub> condition (3.65) and maximum was recorded at T<sub>1</sub> condition (6.08). On 18<sup>th</sup> day of storage, minimum bacterial count was recorded at T<sub>3</sub> condition (5.86) while maximum was at T<sub>2</sub> condition (6.94). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage at T<sub>3</sub> condition bacterial count was recorded (7.66).

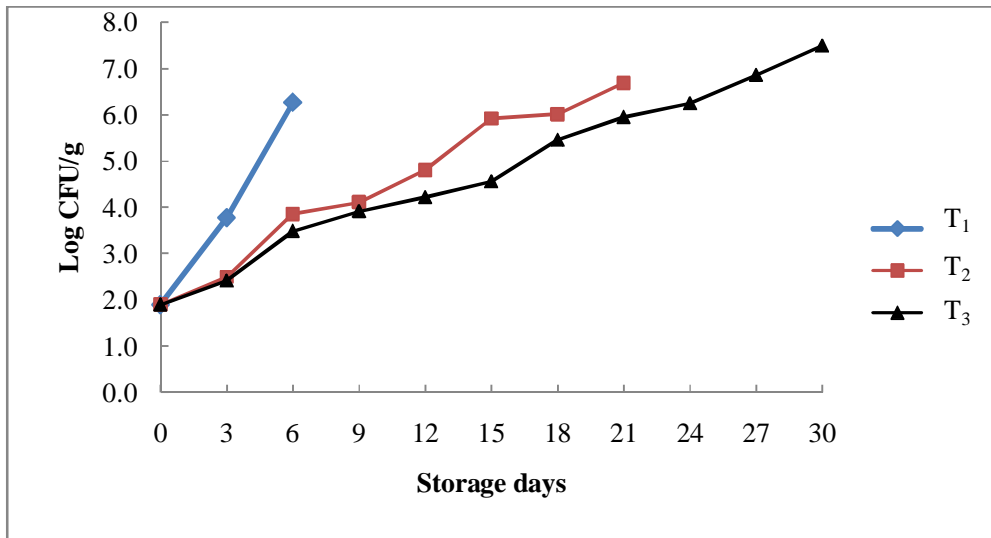


Fig. 4.82 Effect of storage temperature on bacterial count in LDPE

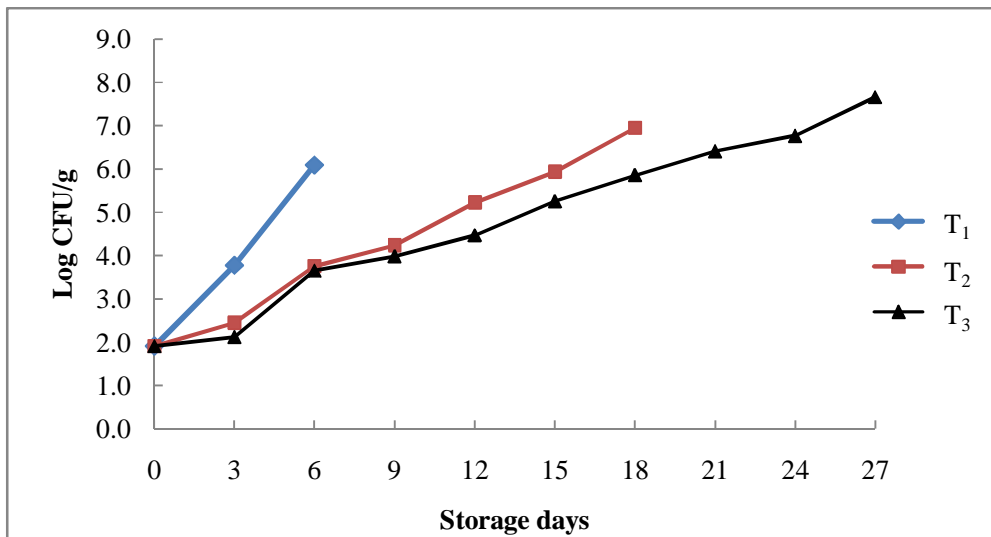


Fig. 4.83 Effect of storage temperature on bacterial count in HDPE

#### Combined effect of gaseous composition and storage temperature

The combined effect of gaseous composition and storage temperature on bengal gram kernels were found to be significant during entire period of storage as presented in Fig 4.84-4.85.

On 6<sup>th</sup> day of storage minimum bacterial count was observed in LG<sub>2</sub>T<sub>3</sub>(0.965) and maximum was in LG<sub>1</sub>T<sub>1</sub> (7.15) treatment combination. On 15<sup>th</sup> day of storage, minimum bacterial count was recorded in LG<sub>1</sub>T<sub>3</sub> (4.46) while maximum was in LG<sub>2</sub>T<sub>2</sub> (6.66). Similarly on 24<sup>th</sup> day of storage minimum bacterial count was recorded in LG<sub>1</sub>T<sub>3</sub> (6.17) and maximum was

in  $LG_2T_3$ (6.33). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage bacterial load was recorded in  $LG_1T_3$ (7.50) treatment combination.

On 6<sup>th</sup> day of storage minimum bacterial count was observed in  $HG_3T_2$  (3.38) and maximum was in  $HG_1T_1$  (5.39) treatment combination. On 15<sup>th</sup> day of storage, minimum bacterial count was recorded in  $HG_1T_3$  (4.91) while maximum was in  $HG_3T_2$  (6.33). Similarly on 21<sup>st</sup> day of storage minimum bacterial count was recorded in  $HG_1T_3$  (5.94) and maximum was in  $HG_2T_3$  (6.90). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage bacterial count was recorded in  $HG_1T_3$ (7.66) treatment combination.

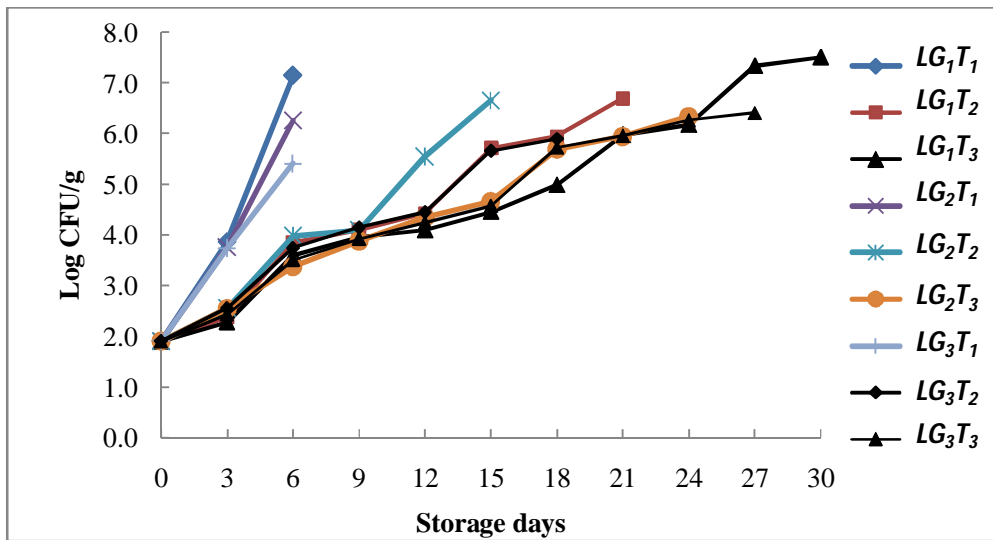


Fig. 4.84 Combined effect of gaseous composition and temperature on bacterial count

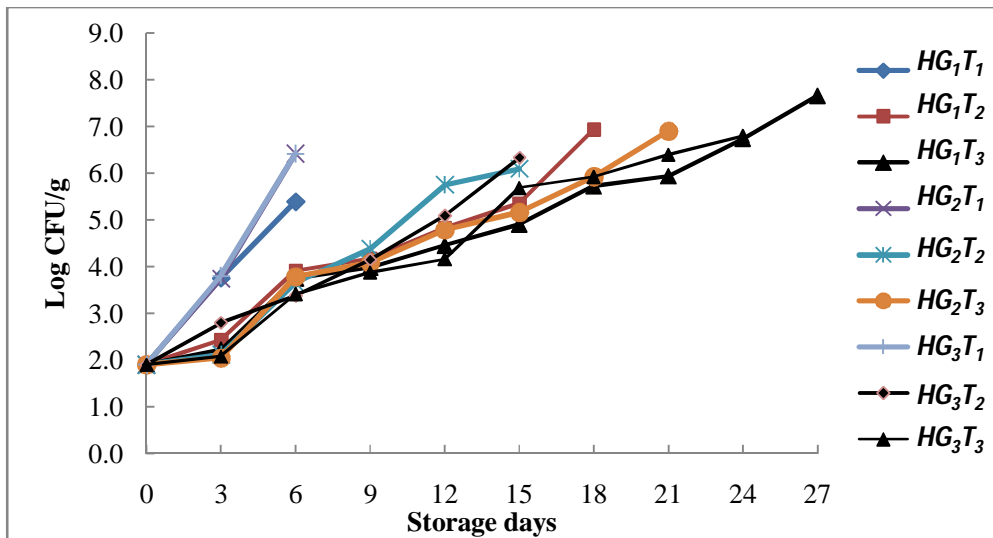


Fig. 4.85 Combined effect of gaseous composition and temperature on bacterial count

### Effect of polythene film on bacterial count

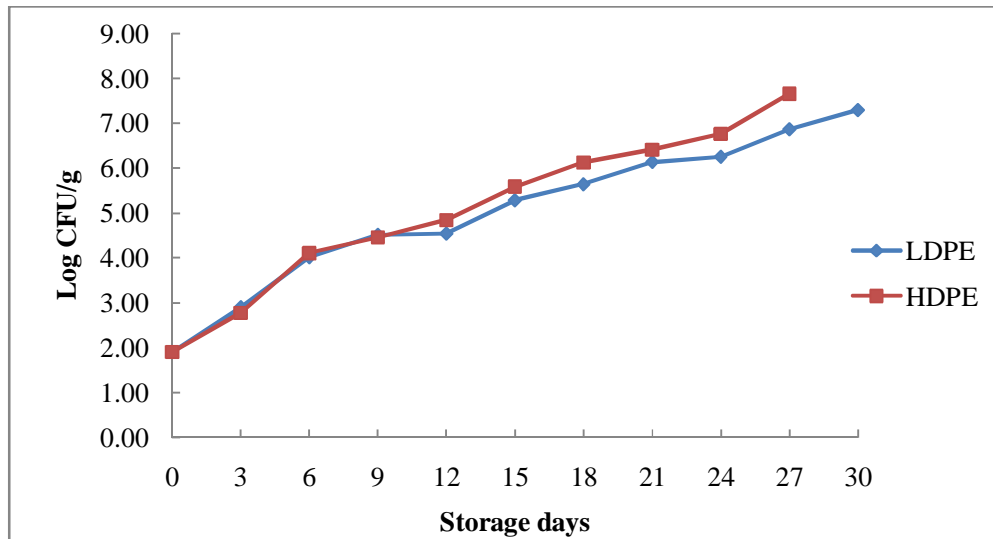


Fig. 4.86 Effect of polythene film on bacterial count

From Fig.4.86, bacterial count of sample increases in both the polythene films. The bacterial count of the sample packed in HDPE film has more bacterial count as compared to the sample packed in LDPE film. Increase in bacterial count corresponds to increase in microbial load.

The comparative effect gas composition and storage temperature on bacterial count could be observed by F values in the ANOVA (Table 4.15) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was the most influencing factor than gas composition. ANOVA also shows that gas composition and storage temperature have significant effect on bacterial count at 5% level of significance.

#### 4.3.7.2 Fungal load

##### Effect of gaseous composition

It is evident from the data presented in Fig.4.87-4.88 that the fungal count of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation but rate of increase in fungal count was significantly affected by the different gas composition in package during storage.

On 6<sup>th</sup> day of storage, for LDPE minimum fungal count was recorded in G<sub>3</sub> (4.15), while maximum in G<sub>1</sub> (4.60). On 24<sup>th</sup> day of storage minimum fungal count was recorded in G<sub>1</sub> (6.66) and maximum in G<sub>2</sub> (7.68). At the end of experiment, fungal count was recorded in G<sub>1</sub> (7.43) on 30<sup>th</sup> day of storage for LDPE.

**Table 4.15 Anova of bacterial count for LDPE and HDPE**

	Days	3		6		9		12		15	
Bacterial count LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.348	121355.833*	5.724	515159.333*	12.435	524.424*	16.030	673.41*	22.364	6038245*
gas composition	2	0.029	2641.333*	0.954	85857.333*	0.011	0.482	0.444	18.670*	0.414	111799*
temperature	2	5.296	476666.333*	20.541	1848650.33*	49.672	2094.884*	62.866	2641*	88.491	23892652*
GXT	4	0.034	3057.833*	0.701	63064.833*	0.028	1.165	0.404	16.982*	0.275	74264.5*
Error	18	0.000		0.000		0.024		0.024		0.000	

	Days	18		21		24		27		30	
Bacterial count LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	26.797	7235218.749*	31.719	713674.312*	29.333	3959974.125*	27.705	7480279*	18.7	5067001*
gas composition	2	10.509	2837452*	15.075	339197.25*	0.007	901.5*	15.953	4307329*	18.7	5067001*
temperature	2	71.648	19345081*	81.984	1844643*	117.313	15837192*	62.960	16999129*	18.7	5067001*
GXT	4	12.515	3379172*	14.908	335428.5*	0.007	901.5*	15.953	4307329*	18.7	5067001*
Error	18	0.000		0.000		0.000		0.000		0.0	

	Days	3		6		9		12		15	
Bacterial count HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	1.976	235.266*	4.723	492.144*	12.748	1797*	18.191	2666*	23.993	3464*
gas composition	2	0.099	11.763*	0.190	19.805*	0.055	7.689*	0.542	79.432*	0.787	113.686*
temperature	2	7.693	915.843*	17.537	1827*	50.903	7177*	71.792	10500*	94.697	13670*
GXT	4	0.057	6.729*	0.582	60.648*	0.014	2.040	0.215	31.507*	0.244	35.222*
Error	18	0.008		0.010		0.007		0.007		0.007	

	Days	18		21		24		27	
Bacterial count HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	31.666	15210*	30.991	11170*	26.749	19160*	19.525	69360*
gas composition	2	15.158	7282*	0.234	84.26*	15.286	10950*	19.525	69360*
temperature	2	78.365	37650*	123.264	44430*	61.141	43790*	19.525	69360*
GXT	4	16.570	7961*	0.234	84.26*	15.286	10950*	19.525	69360*

Error	18	0.002		0.003		0.001		0.000	
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For HDPE, on 6<sup>th</sup> day of storage the minimum fungal count was observed in G<sub>3</sub> (4.12), while maximum was recorded in G<sub>1</sub> (4.66). Similarly on 21<sup>st</sup> day of storage, minimum fungal count was recorded in G<sub>1</sub> (5.72) and maximum in G<sub>2</sub> (7.69). At the end of experiment, fungal count was recorded in G<sub>1</sub> (6.43) on 27<sup>th</sup> day of storage. Since sample stored with G<sub>2</sub> and G<sub>3</sub> gas composition was not survived to 27<sup>th</sup> day of storage.

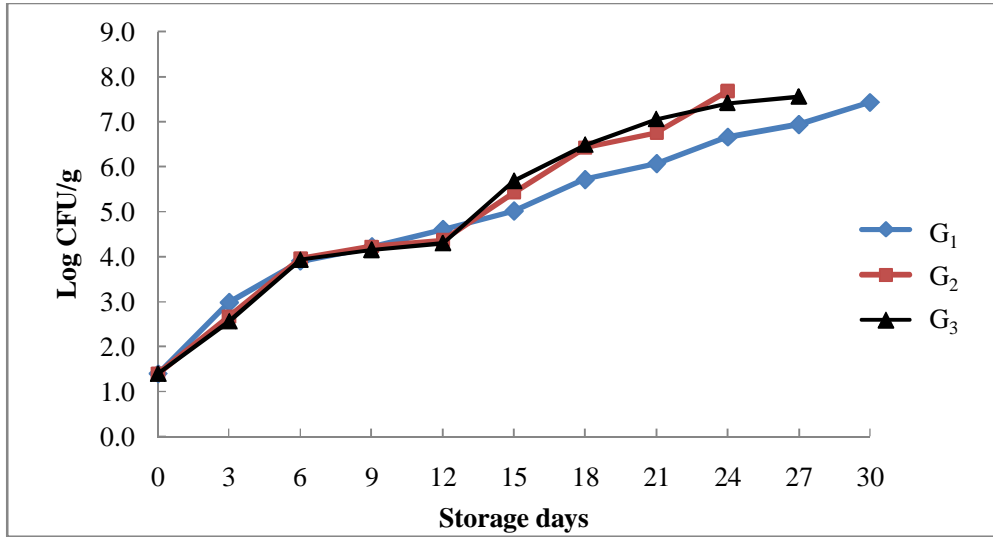


Fig. 4.87 Effect of gas composition on fungal count in LDPE

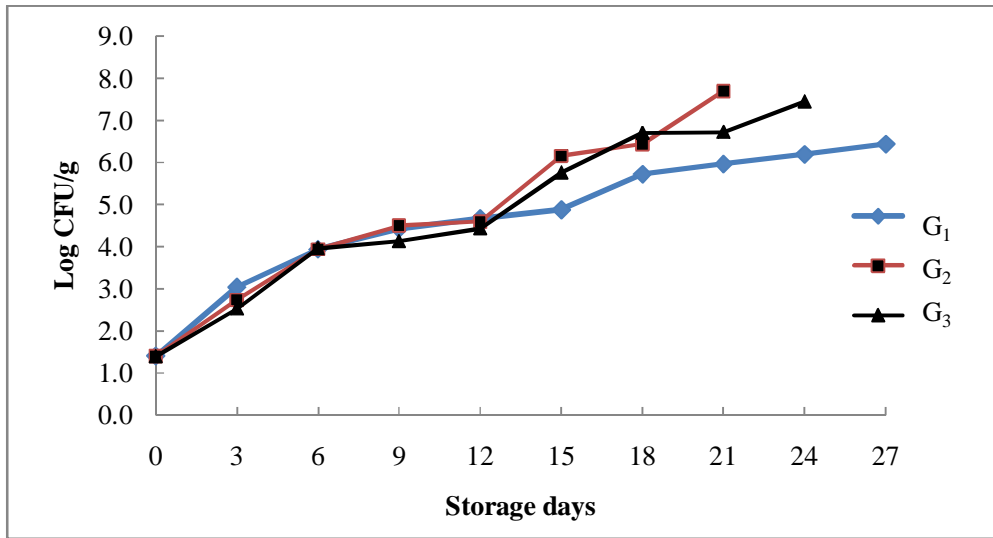


Fig. 4.88 Effect of gas composition on fungal count in HDPE

#### Effect of storage temperature

It is evident from the data presented in Fig.4.89-4.90 that the fungal count of bengal gram kernels increased with the advancement of storage time during the entire period of experimentation.

On 6<sup>th</sup> day of storage, for LDPE, minimum fungal count was recorded at T<sub>3</sub> condition (3.22) and maximum was recorded at T<sub>1</sub> condition (6.26). On 21<sup>th</sup> day of storage, minimum fungal count was recorded at T<sub>3</sub> condition (6.32) and maximum was recorded at T<sub>2</sub> condition (6.42). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage fungal count was recorded at T<sub>3</sub> condition (7.43).

On 6<sup>th</sup> day of storage, for HDPE, minimum fungal count was recorded at T<sub>3</sub> condition (3.32) and maximum was recorded at T<sub>1</sub> condition (6.55). On 18<sup>th</sup> day of storage, minimum fungal count was recorded at T<sub>3</sub> condition (6.11) while maximum was at T<sub>2</sub> condition (6.94). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage at T<sub>3</sub> condition fungal count was recorded (6.43).

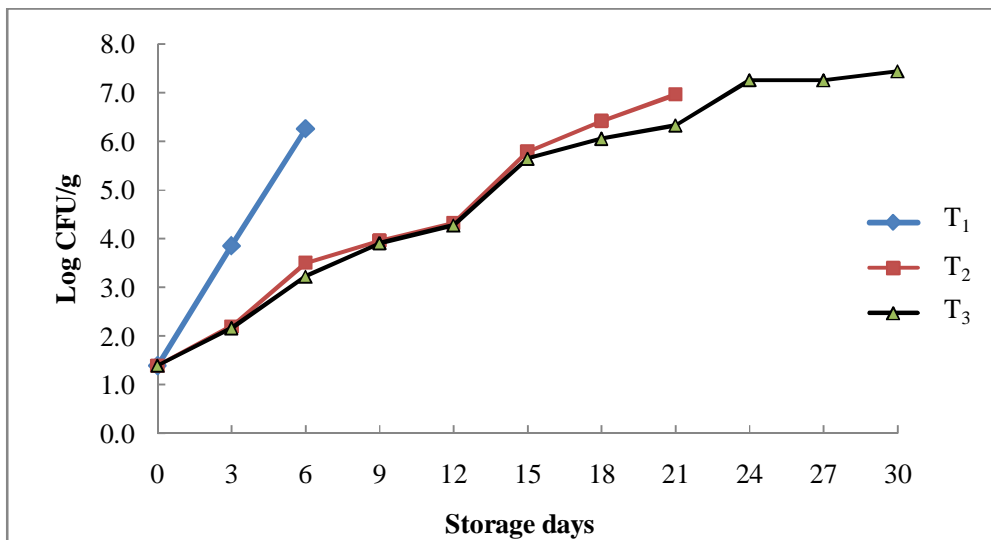
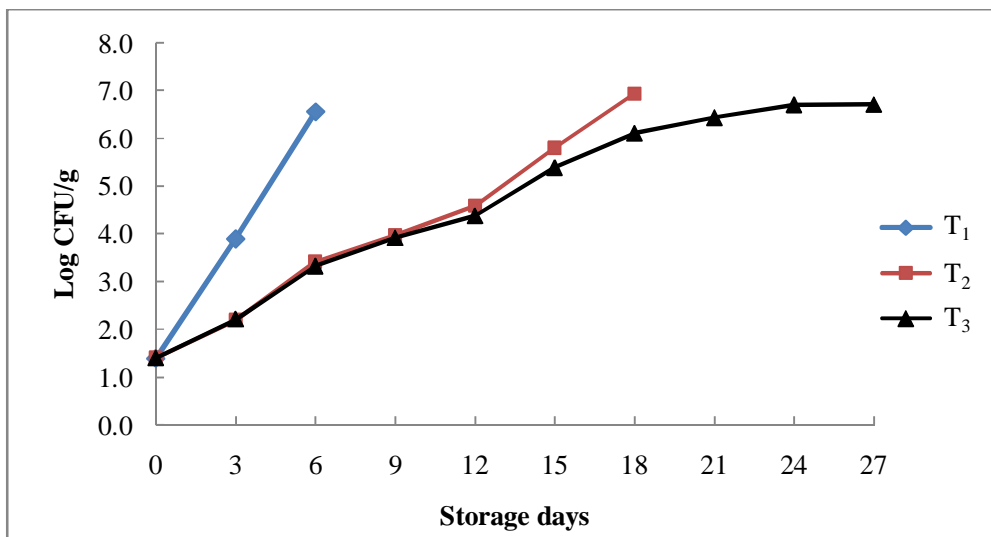


Fig. 4.89 Effect of storage temperature on fungal count in LDPE



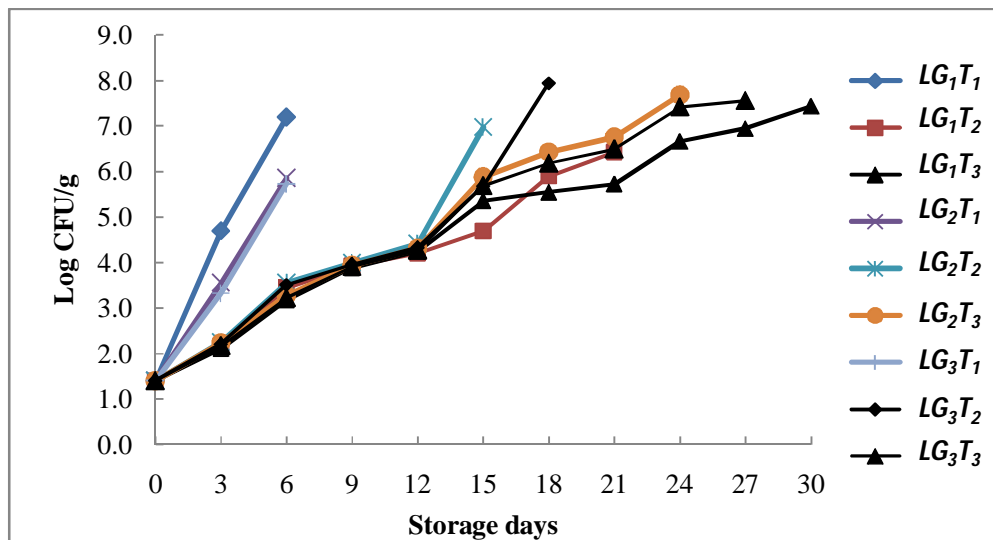
**Fig. 4.90 Effect of storage temperature on fungal count in HDPE**

**Combined effect of gaseous composition and storage temperature**

The combined effect of gaseous composition and storage temperature on bengal gram kernels were found to be significant during entire period of storage as presented in Fig 4.91-4.92.

On 6<sup>th</sup> day of storage minimum fungal count was observed in LG<sub>1</sub>T<sub>3</sub> (3.17) and maximum was in LG<sub>1</sub>T<sub>1</sub> (7.19) treatment combination. On 15<sup>th</sup> day of storage, minimum fungal count was recorded in LG<sub>1</sub>T<sub>2</sub> (4.69) while maximum was in LG<sub>2</sub>T<sub>2</sub> (6.98). Similarly on 24<sup>th</sup> day of storage minimum fungal count was recorded in LG<sub>1</sub>T<sub>3</sub> (6.66) and maximum was in LG<sub>2</sub>T<sub>3</sub>(7.68). Similarly at the end of experiment i.e. on 30<sup>th</sup> day of storage bacterial load was recorded in LG<sub>1</sub>T<sub>3</sub>(7.43) treatment combination.

On 6<sup>th</sup> day of storage minimum fungal count was observed in HG<sub>1</sub>T<sub>3</sub> (3.25) and maximum was in HG<sub>1</sub>T<sub>1</sub> (7.20) treatment combination. On 15<sup>th</sup> day of storage, minimum fungal count was recorded in HG<sub>1</sub>T<sub>3</sub> (4.85) while maximum was in HG<sub>2</sub>T<sub>2</sub> (6.75). Similarly on 21<sup>st</sup> day of storage minimum fungal count was recorded in HG<sub>1</sub>T<sub>3</sub> (5.72) and maximum was in HG<sub>2</sub>T<sub>3</sub> (7.69). Similarly at the end of experiment i.e. on 27<sup>th</sup> day of storage fungal count was recorded in HG<sub>1</sub>T<sub>3</sub>(6.43) treatment combination.



**Fig. 4.91 Combined effect of gaseous composition and temperature on fungal count**

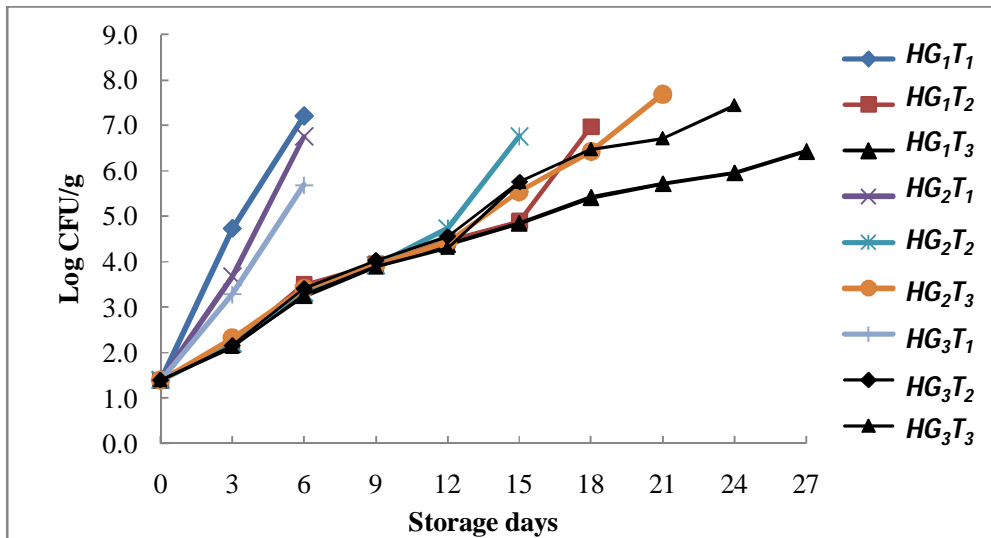


Fig. 4.92 Combined effect of gaseous composition and temperature on fungal count

#### Effect of polythene film on fungal count

From Fig.4.93, fungal count of sample increases in both the polythene films. The fungal count of the sample packed in HDPE film has more fungal count as compared to the sample packed in LDPE film. Increase in fungal count corresponds to increase in microbial load.

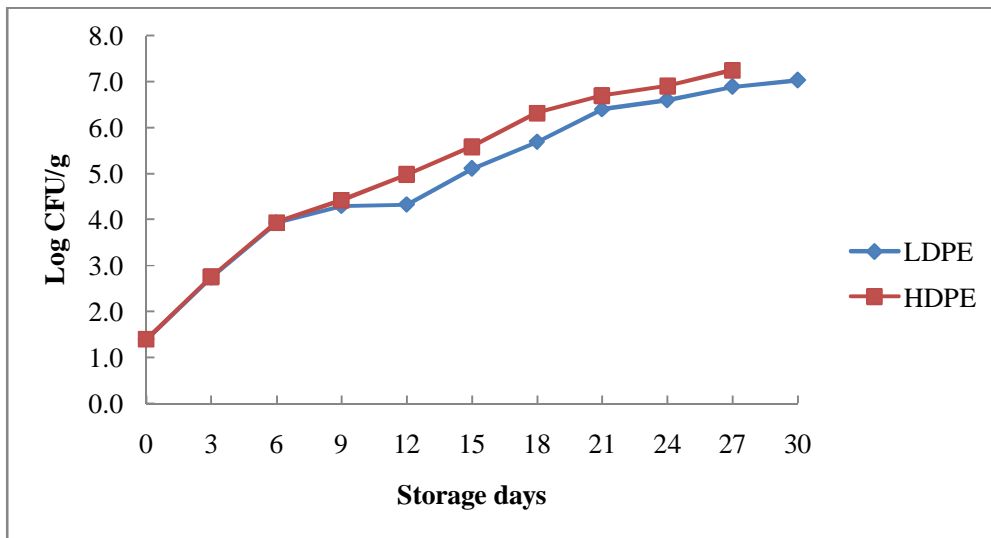


Fig. 4.93 Effect of polythene film on fungal count

The comparative effect gas composition and storage temperature on fungal count could be observed by F values in the ANOVA (Table 4.16) for both polythene films i.e. LDPE and HDPE. The F values indicated that temperature was the more influencing factor than

gas composition. ANOVA also shows that gas composition and storage temperature has significant effect on fungal count at 5% level of significance.

**Table 4.16 Anova of fungal count for LDPE and HDPE**

	Days	3		6		9		12		15	
Fungal count LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	2.503	135146.7*	6.832	614840.25*	11.763	176449.5*	13.850	1246466.580	25.601	384021*
gas composition	2	0.428	23112.6*	0.524	47152*	0.001	19.5*	0.021	1854.333	2.004	30061.5*
temperature	2	8.386	452830.2*	25.348	2281359*	47.046	705685.5*	55.359	4982346.333	98.199	1472989.5*
GXT	4	0.599	32322*	0.727	65425*	0.003	46.5*	0.009	832.833	1.101	16516.5*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	18		21		24		27		30	
Fungal count LDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	35.384	4776865.624*	33.824	456622*	39.701	1191020.5*	30.734	1383009*	18.435	4977361*
gas composition	2	15.234	2056569.5*	10.175	1373568*	0.275	8251*	17.617	792762*	18.435	4977361*
temperature	2	89.928	12140258*	93.118	12570936*	157.978	4739329*	70.083	3153750*	18.435	4977361*
GXT	4	18.188	2455317.5*	16.001	2160192*	0.275	8251*	17.617	792762*	18.435	4977361*
Error	18	0.000		0.000		0.000		0.000		0.000	

	Days	3		6		9		12		15	
Fungal count HDPE	df	MS	F	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	2.597	391.748*	8.006	993.352*	11.675	3181.000	15.124	4415.000	25.024	624.801*
gas composition	2	0.560	84.396*	0.671	83.217*	0.000	0.076	0.043	12.501	0.908	22.681*
temperature	2	8.762	1322*	30.151	3741*	46.694	12720.000	60.415	17630.000	97.382	2431*
GXT	4	0.534	80.492*	0.601	74.519*	0.003	0.769	0.019	5.550	0.904	22.56*
Error	18	0.007		0.008		0.004		0.003		0.040	

	Days	18		21		24		27	
Fungal count HDPE	df	MS	F	MS	F	MS	F	MS	F
Corrected Model	8	33.780	8014*	34.487	12030*	26.642	14770*	13.839	12290*
gas composition	2	11.703	2777*	0.974	339.598*	15.521	8605*	13.839	12290*
temperature	2	85.565	20320*	135.028	47100*	60.002	33270*	13.839	12290*
GXT	4	18.880	4479*	0.974	339.598*	15.521	8604*	13.839	12290*
Error	18	0.004		0.003		0.002		0.001	

Babic, Watada, and Wergin (1996) found no microbial population on the surface of spinach washed with sodium hypochlorite, but a  $10^6$ – $10^7$  CFU/g population of mesophilic and psychrotrophic aerobic microflora was present in spinach tissue. Apparently, the microorganisms entered the tissue through the cracks, but the chlorine solution was not able to penetrate sufficiently these areas.

Chlorine compounds are the most widely used sanitizer in food processing, of which sodium hypochlorite solution (200 ml/l chlorine) is used most widely in the fresh-cut industry (Watada, 1997). Most probably, the washing in chlorinated water has been adequate to guarantee a good hygienic level (McKellar et al., 2004).

The total bacterial and fungal load ( $10^5$  and  $10^6$ CFU/g) for the samples was within the permissible range of  $10^6$  and  $10^7$  CFU/g at 15 and 21 day for HDPE and LDPE, which depicts that these products are safe for the human consumption.

#### **4.3.8 Sensory evaluation**

The sensory evaluation was done on the basis of colour, texture, taste, visual appearance, odor and overall acceptability. There were total 18 samples of bengal gram for different gas and temperature combinations. The quality was judged by a five member's consumer panel. The bengal gram kernels were rated on a nine-point hedonic scale as described in chapter III. The scores for colour, texture, odour, taste, appearance and overall acceptability (OA) of bengal gram kernels were found to decrease with duration of storage (appendix J 67-71). It was observed that temperature and gas composition also significantly affect the scores.

It was observed that for both packaging material and all three gas composition combination with storage at ambient conditions was not accepted by the judges of consumer panel after 3 days of storage. While, samples stored at  $0^\circ\text{C}$  i.e.  $G_1T_3$ ,  $G_2T_3$ ,  $G_3T_3$  were most accepted by the panel of judges. The different headspace environment under different packaging treatments affected the equilibrated in-pack aroma differently.

It is evident from the data that acceptable scores for colour were obtained for bengal gram kernels with  $G_1$  gas composition and  $T_3$  condition in both LDPE and HDPE, respectively up to 21 and 15 days. The panel have disliked the bengal gram kernels packed with all gas composition and stored in  $T_1$  condition after 3<sup>rd</sup> day with respect to colour when subjected under sensory evaluation. The combination of  $G_1$  gas composition and  $T_3$  condition with LDPE

depicted the acceptability till 21 storage days while same combination with HDPE film resulted into 15 days of acceptable storage life.

Texture of the bengal gram kernels decreases with increase in storage days and storage temperature. Bengal gram kernels packed with  $G_1$  gas composition shows acceptable score up to 15 and 21 days for HDPE and LDPE film, respectively while storage at  $T_3$  condition resulted into acceptable score up to 12 and 15 days for HDPE and LDPE, respectively. With respect to the texture, judges have accepted bengal gram kernels from all the treatments up to an acceptable limits. The combination of  $G_1$  gas composition and  $T_3$  condition with LDPE shows the maximum acceptability for 21 storage days while same combination with HDPE film shows maximum acceptability till 15 days of acceptable storage life.

The results indicated that odour of bengal gram kernels packed with  $G_1$  gas composition shows acceptable score up to 15 and 21 days for HDPE and LDPE film respectively while  $T_3$  condition shows acceptable score up to 15 and 18 days for HDPE and LDPE respectively. The combination of  $G_1$  gas composition and  $T_3$  condition with LDPE shows the maximum acceptability till 21 storage days while same combination with HDPE film shows maximum acceptability till 15 days of acceptable storage life.

Visual appearance of the bengal gram kernels decreases with increase in storage days and storage temperature. Bengal gram kernels packed with  $G_1$  gas composition shows acceptable score up to 15 and 21 days for HDPE and LDPE film, respectively while  $T_3$  condition shows acceptable score up to 12 and 18 days for HDPE and LDPE respectively. With respect to the visual appearance (decay), judges have accepted bengal gram kernels from all the treatments up to a acceptable limits. The combination of  $G_1$  gas composition and  $T_3$  condition with LDPE shows the maximum acceptable 21 storage days while same combination with HDPE film shows maximum 15 days of acceptable storage life.

Overall acceptability of the bengal gram kernels decreases as the increase in storage days and storage temperature. Bengal gram kernels packed with  $G_1$  gas composition shows acceptable score up to 15 and 21 days for HDPE and LDPE film respectively while  $T_3$  condition shows acceptable score up to 15 and 21 days for HDPE and LDPE respectively. With respect to the visual appearance (decay), judges have accepted bengal gram kernels from all the treatments up to a acceptable limits. The combination of  $G_1$  gas composition and  $T_3$  condition with LDPE depicts the maximum acceptable 21 storage days while same combination with HDPE film depicts maximum 15 days of acceptable storage life.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

Bengal gram (*Cicer arietinum L.*) is a major pulse crop in India and accounts for 40-45% of the total pulse production. Foods based on chickpeas are prepared by a wide range of recipes and preparation methods. India is the single largest producer of bengal gram, contributing for about 67% of the global production. Normally bengal gram accounts for 4-7 million tons, (40-45%) of India's total pulses crop production of 12-15 million tons. Major producing states are Madhya Pradesh, Rajasthan, Uttar Pradesh, and Maharashtra.

Premature bengal gram green kernels is used for direct consumption as well as for making their preparation for food items. The deposing and shelling is done manually and green fresh kernels are used for making different vegetables, sweet dishes and as a substitute of pea in rice and pulao etc. Green bengal gram kernels have a good demand as a convenience/ ready to use product, if made available as fresh for long time and increased shelf life. Food packaging technologies maintain freshness, quality and help a lot in extending shelf-life. The physical shelf-life of the packaged products taking into account their fitness for human consumption along with their essential nutrients and bioactive compounds etc. can be enhanced by means of suitable packaging technologies such as MAP.

The physical properties of immature green bengal gram kernels such as moisture content, linear dimensions, unit mass and volume, sphericity, density, porosity, angle of repose were determined of the green (immature) bengal gram kernel of crop maturity from 50 to 100 days. The MAP along with low temperature storage extends the shelf life of fresh produce packaged in polymeric film package through interaction of the natural process of respiration of produce with the restricted gaseous exchange across the polymeric film package to control in-pack O<sub>2</sub> and CO<sub>2</sub>. The oxygen consumption and carbon dioxide evolution of the fruits and vegetables are the basic pre-requisites of any MAP study. However data on these parameters are not readily available in the literature for green bengal gram kernel in India. Therefore an experiment was taken up to investigate the respiration characteristics of fresh bengal gram, which serve as a base for future MAP studies.

Hence, with a view to enhance shelf-life and retain the quality of fresh bengal gram kernels, this study was proposed with the following specific objectives:

- To determine the physical properties of fresh bengal gram kernels.
- To study the effect of MAP on the shelf life of fresh bengal gram kernels.
- To study the effect of packaging material and storage temperature on quality of bengal gram kernels.

Effects of different levels of head space gas composition and storage temperature was explored for increasing the shelf life of fresh bengal gram kernels. Hence the storage study of bengal gram kernels was carried with three gas compositions, two polythene film package and at three storage temperature to select the best combination that maintain the product quality parameters. The observations included rate of respiration, package headspace and physiological loss in weight, decay, firmness, colour, water activity and microbial load affecting the final quality of the product besides sensory evaluation through a panel of judges. The experiments were carried out as per standard procedures. Based of the statistical analysis of data, the following interference have been drawn from the study:

- The range of average length, width, thickness was 9.536 to 12.499 mm, 2.949 to 8.604 mm, 5.99 to 8.29 mm, over the maturity of crop 50-100 days with moisture reduction from 90 to 60% (wb).
- With crop maturity the geometric mean diameter increased from 0.72 to 0.9 mm and sphericity increased from 0.63 to 0.82.
- The bulk density and true density increased from 593.90 to 714.86 kgm<sup>-3</sup> and from 1350 to 1467 kgm<sup>-3</sup> respectively, while the bulk porosity decreased from 56.007 to 51.270% with crop maturity 50-100 days. The average thousand grain mass was increased from 262.12 to 415.39 g with maturity 50-100 days.
- The angle of repose decreased from 33.42 to 23.96<sup>0</sup> over maturity days 50-100.
- At steady state, the rate of oxygen consumption at ambient, 5 and 0±1<sup>0</sup>C for fresh bengal gram kernels was 180.85, 146.14 and 79.05 ml kg<sup>-1</sup>h<sup>-1</sup> and rate of of carbon dioxide evolution was 125.77, 92.21, 59.11 ml kg<sup>-1</sup>h<sup>-1</sup> respectively.
- The inhibition constants obtained by non-linear analysis of the respiration data showed that respiration of fresh bengal gram kerenels was subjected to competitive type of inhibition at all three storage conditions i.e. ambient, 5±1 and 0±1<sup>0</sup>C.
- The fresh bengal gram kernels packed in LDPE film package with G<sub>1</sub> gas composition i.e. (2% O<sub>2</sub> and 8% CO<sub>2</sub>) and stored in T<sub>3</sub> temperature condition helped to retain most of desirable qualiity parameters such as sensory score, colour & texture with least bacterial and fugal load .
- The physiological loss in weight was found within the acceptable limit for maximum days for sample stored at T<sub>3</sub> condition. For sample LG<sub>1</sub>T<sub>3</sub> and HG<sub>1</sub>T<sub>3</sub>, the PLW was 9.23 and 9.26% at 21<sup>st</sup> and 24<sup>th</sup> days respectively.

- Decay was found to be within permissible limit of 10% for maximum days for sample stored at T<sub>3</sub> condition. For sample LG<sub>1</sub>T<sub>3</sub> and HG<sub>1</sub>T<sub>3</sub>, the decay was 10.00 and 9.028% for 15<sup>th</sup> and 21<sup>st</sup> day, respectively.
- The data that gas composition G<sub>1</sub> with storage condition T<sub>3</sub> resulted in firmness and hardness of more than or equal to 60% of initial value till 15 and 21 days for HDPE and LDPE packaging film, respectively. The firmness and hardness level till 60% was considered acceptable based on sensory panel judgment. Therefore the product can be acceptable up to 21<sup>st</sup> day in LDPE.
- The microbial load on the sample was found in the range of 10<sup>3</sup>-10<sup>5</sup>. The microbial load was within permissible limit for the sample stored at T<sub>3</sub> condition and with G<sub>1</sub> composition.
- Overall acceptability of the bengal gram kernels decreases with increase in storage days and storage temperature. Bengal gram kernels packed with G<sub>1</sub> gas composition depicted acceptable score up to 15 and 21 days for HDPE and LDPE film, respectively while T<sub>3</sub> composition shows acceptable score up to 15 and 21 days for HDPE and LDPE, respectively. With respect to the visual appearance (decay), judges have accepted bengal gram kernels from all the treatments up to a certain limit. The combination of G<sub>1</sub> gas composition and T<sub>3</sub> condition with LDPE depicted the maximum acceptability till 21<sup>st</sup> storage days while same combination with HDPE film resulted into maximum acceptability till 15<sup>th</sup> days.
- It was further inferred that the product obtained with G<sub>1</sub> gas composition (2% O<sub>2</sub> and 8% CO<sub>2</sub>) was better than the product obtained at other two gas composition i.e. G<sub>2</sub> and G<sub>3</sub>. The storage at lower temperature resulted into maximum shelf life and minimum quality loss. The bengal gram kernels stored in LDPE packaging film retain higher quality attributes than HDPE packaging film.

## **SUGGESTIONS FOR FUTURE STUDY**

1. The biochemical analysis may be conducted to further establish MAP.
2. The study may be further carried out with other gas compositions with low oxygen and high carbon dioxide.
3. The storage of packages may be done at temperatures below 0°C.
4. Other types of polythene films may be explored for packaging of the fresh bengal gram kernels

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