INVESTIGATIONS ON THE MINIMAL PROCESSING OF RED ONION

by

Ms. Holikatti Nikita Shivakumar
(Reg. No. K-16/310)

DIVISION OF HORTICULTURE

RCSM COLLEGE OF AGRICULTURE, KOLHAPUR

MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI-413722, DIST-AHMEDNAGAR
MAHARASHTRA, INDIA
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A Thesis submitted to the
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RCSM COLLEGE OF AGRICULTURE, KOLHAPUR

**MAHATMA PHULE KRISHI VIDYAPEETH
RAHURI-413722, DIST-AHMEDNAGAR
MAHARASHTRA, INDIA**
2018

CANDIDATE'S DECLARATION

I hereby declare that this thesis or part
there of has not been submitted
by me or other person to any
other University or Institute
for a Degree or
Diploma

Place : Kolhapur (N. S. Holikatti)

Date : / 12 /2018

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This is to certify that the thesis entitled, **"INVESTIGATIONS ON THE MINIMAL PROCESSING OF RED ONION"** submitted to the Faculty of Agriculture, Mahatma Phule Krishi Vidyapeeth, Rahuri, Dist. Ahmednagar (Maharashtra) in partial fulfilment of the requirement for the award of the degree of **MASTER OF SCIENCE (AGRICULTURE)** in **HORTICULTURE (VEGETABLE SCIENCE)**, embodies the result of a piece of bonafide research work carried out by **Ms. HOLIKATTI NIKITA SHIVAKUMAR** under the guidance and supervision of **Dr. S. S. DHUMAL,** Associate Professor of Horticulture, College of Agriculture, Karad, Dist. Satara, Maharashtra, India and that no part of the thesis has been submitted for any other degree or diploma.

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Place : Kolhapur (G. G. Khot)
Date : / /2018

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Date :

LIST OF ABBREVIATIONS

Abbreviations	**:**	**Description**
%	:	Percent
/	:	Per
₹	:	Rupees
<	:	Smaller than sign
>	:	Greater than sign
µg	:	Micrograms
µl	:	Microliter
^0C	:	Degree Celsius
Abst.	:	Abstract
ABTS	:	2,2’-azino-bis (3-ethylbenzothiazoline-6-sulphonic acid)
ACSOs	:	S-ak(en)yl-1-cysteinesulphoxides
Anon.	:	Anonymous
ANOVA	:	Analysis of variance
AOAC	:	Association of Official Analytical Chemist
Atm	:	Atmosphere
Av.	:	Average
BGWL	:	Borosil Glass Works Ltd.
BIUD	:	Best if used by date
C_2H_4	:	Ethylene
CA	:	Controlled Atmosphere
Ca	:	Calcium
$CaCl_2$	:	Calcium Chloride
CD	:	Critical Difference
CFP	:	Commercial fermentation product
cfu/g	:	Colony forming unit per gram
ClO_2	:	Chlorine dioxide
cm	:	Centimeter
CO_2	:	Carbon dioxide
cv	:	Cultivar
DPPH	:	2,2 diphenyl-1-picrylhydrazyl
EFF	:	Enhanced Freshness Formulation
Equi	:	Equivalent
et al.	:	Et alli (and others)
etc.	:	Et centra

f. w.	:	Fresh weight
FCRD	:	Factorial Completely Randomized Design
Fig.	:	Figure
g	:	Gram
GAE	:	Gallic acid equivalent
GRAS	*:*	Generally Recognized as Safe
H_2O_2	:	Hydrogen peroxide
ha	:	Hectare
HCl	:	Hydrochloric acid
HDPE	:	High Density Polyethylene
HOA	:	High Oxygen Atmospheres
hr	:	Hour
i.e.	:	id est (That is)
IBM SPSS	:	IBM Statistical Package for the Social Sciences
Kg	:	Kilogram
kGy	:	kiloGrays
kPa	:	Kilopascals
L	:	Litre
L^*	:	Luminocity
LDPE	:	Low Density Polyethylene
log cfu g^{-1}	:	Logarithm colony forming units per gram
Ltd.	:	Limited
M	:	Molarity
MA	:	Modified Atmosphere
MAP	:	Modified Atmosphere Packaging
Max	:	Maximum
mg	:	Milligram (s)
mg/100g	:	Milligram per hundred gram
mg/g	:	Milligram per gram
Min	:	Minimum
min	:	Minute (s)
ml	:	Milliliter (s)
mm	:	Millimeter
mM	:	Millimolar
MP	:	Minimally Processed
MT	:	Metric Tonnes

mt	:	Meter
MVP	:	Merrimack Valley Plastic
N	:	Normality
N_2	:	Nitrogen
NABL	:	National Accreditation Board for Testing and Calibration Laboratories
NADCC	:	Sodium dichloroisocyanurate
NaOCl	:	Sodium hypochlorite
NaOH	:	Sodium hydroxide
nm	:	Nanometer
No.	:	Number
NPOP	:	National Programme for Organic Production
O_2	:	Oxygen
OD	:	Optical Density
OPP	:	Oriented polypropylene film/bag
PA	:	Pyruvic acid
PBS	:	Phosphate Buffer Saline
PE	:	Polyethylene
PLD	:	Phospholipase D
PLW	:	Physiological Loss in Weight
pp	:	Page
PP	:	Polypropylene
ppm	:	Parts per million
PrenCSO	:	trans-S-1-propenyl-L-cysteine sulfoxide
Pub.	:	Publication
Pvt.	:	Private
RH	:	Relative humidity
rpm	:	Revolutions per minute
RTU	:	Ready-to-use
SE	:	Standard error
Sr. No.	:	Serial number
TNAU	:	Tamil Nadu Agriculture University
TSA-YE	:	Trypticase Soy Agar - Yeast Extract
TSS	:	Total Soluble Solids
UV-C	:	Ultraviolet, electromagnetic radiation subtype C
v/v	:	Volume by volume basis

viz.	:	Namely
vol	:	Volume
w.b.	:	Weight basis
w/v	:	Weight by volume basis
wt	:	Weight
μg	:	Micro gram
μm	:	Micro meter
μmol	:	Micromole

ABSTRACT

INVESTIGATIONS ON THE MINIMAL PROCESSING OF RED ONION

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A candidate for the degree of

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Research guide	:	Dr. S. S. Dhumal
Department	:	Horticulture (Vegetable Science)

The present study entitled, “Investigations on the minimal processing of red onion”, was carried out in three different parts in laboratory of Post-harvest Technology, Horticulture Section, RCSM College of Agriculture, Kolhapur during 2016-2017. In the first part, effectiveness of nine different post-harvest treatments was studied on the shelf life stability of four different types of cut red onion stored at 0-5^{0}C. In the second part, fresh cut onions i.e. whole peeled as well as diced onions treated with the best post-harvest treatment from the first part, were packed in four different packaging materials and stored in two different storage temperatures for further studies while in the third part pretreated fresh cut onions (whole peeled and diced onions) packed in polypropylene bags were evaluated for the effectiveness of eight different modified atmosphere packagings treatments in two different storage temperatures for the extension of shelf life. The entire experiment was statistically analysed by using Factorial Completely Randomized Design.

The red onion bulbs of cultivar Baswant-780 having average weight 67.70 g with 88.24 per cent moisture, 5.28 pH, 0.38 per cent acidity, 11.5^{0}Brix TSS, 37.20 mg/100g anthocyanins and 5.242 µmol pyruvic acid per g fresh weight are selected for study. The four different types of cut i.e. sliced, diced, shredded and whole peeled onions were evaluated for post-harvest behavior during storage at 0-5^{0}C. The fresh cut onions were treated with nine different post-harvest treatments of organic and inorganic chemicals and irradiations and packed in 200 gauge polypropylene bags. The different types of fresh cut red onion can be stored up to 15-18 days by applying different postharvest treatments. Decrease in percent moisture, pH, TSS, anthocyanin and pyruvic acid was observed in all treatments irrespective of types of cut and

post-harvest treatments. Among the types of cut, the whole peeled onion can be stored up to 18 days without deterioration in quality as compared to sliced, shredded and diced onions. The pretreatment with 1% hexanal (EFF- nano emulsion) was found to be the best among all the postharvest treatments tried. The maximum per cent decay was observed in diced onion treated with distilled water (control). The whole peeled onion treated with 1% hexanal packed in 200 gauge polypropylene bags stored at 0-5^{0}C recorded the minimum changes in physico-chemical parameters, headspace gas concentrations with minimum PLW, decay, restricted microbial growth and maintained sensorial qualities. The pretreatment with nisin (50µg-mL^{-1}) + Citric acid (1% w/v) as well as hexanal was found to be effective in restricting microbial load on minimally processed red onions.

The shelf life of pretreated whole peeled as well as diced onions was extended up to 18 and 15 days, respectively when packaged in 200 gauge polypropylene bags with freshpaper and stored at 0±1^{0}C without much change in physico-chemical characters, headspace gas concentrations and had minimum microbial population. The pretreated fresh cut onion packed in perforated terephthalate plastic punnets recorded the maximum decay and microbial count and had shelf life up to 12 days only. The storage of fresh cut onions at 7±1^{0}C registered maximum changes in physico-chemical parameters, headspace gas concentration, decay with increase in microbial count and deterioration in sensory qualities as compared to 0±1^{0}C storage.

Modified atmosphere packaging with 0.5% oxygen plus 10% carbon dioxide flushing and 2% oxygen plus 10% carbon dioxide flushing extended shelf life of pretreated fresh cut onions i.e. whole peeled as well as diced onion up to 18-21 days when stored at 0±1^{0}C. Pretreated fresh cut onion i.e. whole peeled and diced onions packed in polypropylene bags with super atmospheric oxygen i.e. M_7 (100% oxygen) and M_8 (80% oxygen plus 20% carbon dioxide) recorded shelf life up to 6 and 9 days only. The modified atmosphere packaging with air/passive MAP had shelf life up to 12 days only. Decrease in percent moisture, pH, TSS, anthocyanin, pyruvic acid and sensory parameters while increase in PLW, decay, acidity, headspace ethylene concentration and microbial count was recorded in all MAP conditions. The MAP treatment, M_3 (0.5% oxygen plus 10% carbon dioxide) recorded minimum changes in physico-chemical parameters, headspace gas concentrations, restricted microbial growth and decay, maintained quality and enhanced acceptability of pretreated fresh cut onions (whole peeled and diced) up to 21 days when stored at 0±1^{0}C.

Holikatti N. S. (1 to 160)

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1. INTRODUCTION

Onions are one of the most widely utilized vegetables worldwide, with demand for fresh cut onions steadily increasing. With an annual per capita consumption of nearly 6 Kg onions, are one of the highest volume vegetable sold worldwide (Page *et al.,* 2016). Onion (*Allium cepa* L.), belonging to an Alliaceae family is an important commercial vegetable crop grown in India. India is the second largest producer of onion after China, with the production of 218.38 Lakh MT on an area of 13.15 Lakh ha (Anon., 2018) sharing 21.5 percent in the world's production. The onion productivity of India is 16.97 MT/ha. Maharashtra ranks first in area (4.716 Lakh ha) as well as production (67.73 Lakh MT) sharing 31.41 percent in India with a productivity of 14.36 MT/ha (Anon., 2017). India is major exporter of onion to other countries and exported 24.16 Lakh MT of fresh onion amounting Rs. 310650.09 Lakh in 2016-17 (Anon., 2017). Onion importance is greatly increasing and now it has become second most medicinal and horticultural crop after tomatoes. It is most important horticultural crop that is extensively used as a food and in medicinal applications (Lanzotti, 2006). Onions are one of the basic ingredients in most of the Indian cuisine and their health benefits are well known. Although onions contribute significantly to the human diet and therapeutic properties, they are primarily consumed for their ability to enhance the flavour of the other food. All types of onions are reported to be rich in flavonols, mainly quercetin and are recognized as a major dietary source of quercetin. In addition, onions are a source of polysaccharides and vitamins and minerals (Galdon *et al.,* 2008). Sweetness is also an important factor in onion flavor. Sweetness in many vegetables is regarded as an advantage as they improve the selling point (Crowther *et al*., 2005). The three major sugars that have been reported in onions are the fructose, glucose and sucrose. The presence of sugars is difficult to perceive in raw onions due to the pungency of the sulfur-based flavour volatiles. The pungency of onions is primarily due to the rapid production of the lachrymatory factor thiopropanal S-oxide whenever tissue is damaged from the rapid breakdown of 1-propenyl cysteine sulphoxide (PrenCSO) cleaved by the enzyme alliinase (Crowther *et al.*, 2005).

Onions are versatile vegetables and typically used as an ingredient in many dishes besides a variety of uses in the fresh form, such as salads and in sandwiches. However, when preparing the onions for consumption, volatile compounds that cause irritations on contact with human nostrils and eyes are released. The action of lachrymatory-factor synthase, which gives rise to the tear producing effect. The pungency in onion and lacrimation effect during bulb peeling and cutting or crushing makes the process undesirable to perform and increases the inconvenience to consumers. Another drawback is the onion’s odour that can saturate the handler's hand for a period of time. Minimal processing of onion results in convenience and freshness in a single product. Also, it will engage the rural farming women in the business.

As the faster life rhythm of modern people, the fresh cut fruits and vegetables are more and more welcome. Due to change in consumers lifestyle over the decade, demand for ready-to-use (RTU) onions has notably increased with onions among the fine most commonly sold vegetables in western countries (Anon., 2008). The consumption of fresh fruits and vegetables increased due to the life and quality of education of consumers who are health conscious and therefore call for fresh, healthy and, preferably, practical and convenient, not requiring prior preparation before consumption. Given this consumer need, the minimal processing of vegetables, especially onion, offers products with quality and freshness. The forms of consumption vary widely depending on vegetables to be processed and they are designed for the consumer market. Minimally processed vegetables are rapidly expanding a segment of the fresh food industry due to convenience and increased demand by the consumers. Availability of onion in ready-to-use form can contribute to its increased consumption and expansion of this market segment (Du *et al.*, 2012). Under Indian conditions, this will also help to stabilize the price of onions in the market, convenient to both producer and consumer. However, the main limitation of minimally processed vegetables is short shelf-life and deterioration of quality due to tissue damage during processing. It is therefore required that these products have optimum hygienic, sensorial and nutritional properties.

The minimal processing of vegetables includes many operations such as selection, washing, sorting, cutting/slicing, sanitizing, rinsing, draining, packing and cooling in such a way as to obtain a fresh product, without subsequent preparation. Although the product makes it practical and convenient, all operations involved in minimal processing are responsible for the immediate and subsequent physical responses (loss of water and juice cellular change in the diffusion of gases, exposure to microorganisms), physiological (ethylene production and increased respiratory rate) and biochemical (induction in enzyme activity and oxidative reactions) in the regions of injured cells, as in the adjacent contributing to the reduction of product life (Costa *et al.*, 2013).

No single treatment is known to limit overall quality deterioration, several strategies are being implemented in order to reduce the rate of deterioration for MP products. Besides starting with high-quality raw produce, these include implementing sanitation practices, controlling temperature, lowering respiration rate, lowering ethylene production and preventing mechanical abuse. Packaging technology is the common denominator allowing these strategies to be employed and it is key to quality preservation (Al-Ati and Hotchkiss, 2002). The most used systems for disinfectant are chemical and irradiation-based treatments. Generally, the chlorine-containing compounds group is considered first by those searching for an antimicrobial activity, for being in expensive and easy to use, and for having a broad spectrum of activity (Artes *et al.*, 2009). Hypochlorites are the most frequently used forms of chlorine, with sodium hypochlorite receiving broadest application. Hydrogen peroxide or organic chlorinated product (sodium dichloroisocyanurate, potassium dichloroisocyanurate, dichloroisocyanuric acid and trichloroisocyanuric acid) are alternative sanitizing agents that gained interest in recent years (Beerli *et al.*, 2004). Hexanal is one such natural compound which is considered as GRAS (Generally Recognized as Safe) for enhancing the shelf life of fruits and vegetables. It is a precursor to the formation of alcohols and esters that produce aroma. It is used for pre or post-harvest application by combining with EFF (Enhanced Fresh Formulation) to enhance the shelf life of fruits and fresh cut vegetable (cauliflower, carrot, cucumber etc.) (Ashwini *et al.*, 2018). Among the chemical methods for controlling postharvest diseases, UV-C irradiation appears to be one of the most attractive. Numerous studies have demonstrated the effectiveness of UV-C (254 nm) radiation from germicidal lamps in reducing deterioration of fruits and vegetables (Erkan *et al.*, 2001). UV radiation in the range 250-260 nm is lethal to most of the microorganisms, including bacteria, viruses, protozoa, mycelial fungi, yeasts and algae (Perez-Gregorio *et al.*, 2011).

Packaging is one of the important factors influencing the microbial quality of fresh cut products. Fresh cut products are mostly packaged under modified atmospheric conditions and stored under refrigeration. The Modified Atmosphere Packaging (MAP) is an atmosphere created around a produce that is different from that of air, which brings beneficial effect like extension of shelf-life of fresh produce. Modified atmospheres (MA) depends upon the commodity, cultivar, physiological age, initial quality, concentrations of O_2 and CO_2, temperature and duration of exposure to such conditions (Kader *et al.*, 1989). MAP vegetables need special attention due to rapid respiratory, enzymatic factors and microbiological profile during storage that has impact on the quality and safety. The physiological and biochemical changes are much faster in MP vegetables as compared to intact raw vegetables (Kim *et al*., 1993). For most of the produce, maintaining cool temperatures (to slow deterioration) and high humidity (to prevent moisture loss) are the most effective means of preserving quality. Low O_2 modified atmospheres packaging has been used to extend the shelf-life of fresh cut fruits and vegetables, helping to reduce respiration and ethylene production, inhibiting or delaying enzymatic reactions and preserving the product from quality losses (Han *et al*., 2010). Atmosphere modification can also substantially delay the growth of most aerobic spoilage microorganisms. An alternative for low O_2 modified atmosphere packaging, used for prolonging the shelf-life of respiring ready-to-use vegetables, could be packaged under high oxygen atmospheres (Day, 1996). Atmosphere modification can also substantially delay the growth of most aerobic spoilage microorganisms.

Also due to heightened safety concerns and consumer demand, the implications of sanitizing and packaging of fresh cut onion safety and quality need to be better understood. Hence, the present research work was undertaken to investigate the influence of the type of cut, produce sanitizers, storage temperatures and packagings including MAP on shelf life and postharvest behavior of processed fresh cut red onion with the following objectives,

i. To evaluate the effect of different types of cut, post-harvest treatments and packagings on the quality of minimally processed red onion.
ii. To study the influence of Modified Atmosphere Packaging on the shelf life of fresh cut red onion.
iii. To study the post-harvest behavior of fresh cut onion at different storage temperatures.

2. REVIEW OF LITERATURE

Onion is one of the potential foreign exchange earners. India is the second largest onion growing country in the world. Onion, being highly perishable crop of India, has poor keeping quality. It is liked in the world because of its nutrition, pungency as well as delicious taste (Han *et al.*, 2010). Onions are consumed fresh, in culinary prepartions as well as in salads. The onion is considered one of the most important vegetable and spice, which ensures its importance from an economic perspective and its consumption worldwide. However this vegetable is not very convenient to cut, prepare or process due to its pungency, unwanted distict odour and tearing effect increases the inconvenience to consumers. In this sense, besides the speed and ease of preparation, the provision of cut onions in market could lead to find favourable field (Costa *et al.*, 2013). The great change in eating behavior of consumers, who are health conscious had a call for fresh, healthy and preferably practical and convenient fruits and vegetable with no prior preparation before consumption. Therefore, the faster life rhythm of people has attracted and raised the interest of fresh cut fruits and vegetables. Although a variety of vegetables are available in the fresh cut form, individually or as mixed vegetable trays, fresh cut market for onion has not been exploited to-date. Availabiliy of onion in ready-to-eat or use form can contribute to its increased consumption and expansion of this market segment (Du *et al.,* 2012). The shelf life of onion and its use can be increased by developing suitable preservation technique capable of keeping the product safe and preserving the original organoleptic characteristics. The minimal processing of onion is practical and convenient to consumers. The minimal processing techniques have emerged to meet the challenges of replacing traditional methods of preservation by retaining nutritional and sensory quality (Ohlsson, 2002). Demand for minimally processed fruits and vegetables has increased rapidly in Europe and USA, and in developing countries like India demand is expected to represent 25% of the total food market (Valverde *et al.,* 2010). With this background, the literature available on the minimal processing and modified atmosphere packaging of onion and other vegetables are reviewed as under different headings.

2.1 Type of Cut

Bahram-Parvar and Lim (2018) reported that the processing of onion can accelerate senescence, physiological deterioration, biochemical changes and microbial degradation. The decompartmentalization of enzymes and substrates can result in alterations of colour, texture and flavor. Further they stated that in minimal processing, onion is sliced, diced or shredded. Dicing cuts the onion in 3 directions to obtain cubes while slicing uses a single direction cutting.

Berno *et al.* (2014) evaluated the effect of storage temperature and type of cut of fresh cut purple onions on its biochemical and physiological characteristics. They processed onions using two types of cut (10 mm cubes and 3-5 mm thick slices) and stored at 0, 5, 10 and 15^0C with 85-90% relative humidity for 15 days. Fresh onions stored at 0^0C showed less pungency, lower respiratory rate levels and less variation of total phenolic, anthocyanin and quercetin contents. Further, they opined that slicing enabled a higher stability of the physico-chemical and biochemical aspects in comparison to dicing. Storage of slices at 0^0C extended preservation up to 15 days.

Costa *et al.* (2013) studied the changes in chlorophyll, anthocyanins and phenolic compounds concentration in minimally processed whole peeled onion (white and purple) by removing external catophilos, sanitizing and rinsing them for 10 minutes with 200 and 5 mgL^{-1} free chlorine and stored at 4 ± 0.5^0C under 65 ± 5% RH for eight days. They observed reduction in chlorophyll content more in purple than white onion and 30 per cent decrease in anthocyanin. However, levels of phenolics increased until day 2 of storage and then reduced until last day of storage.

Siddiq *et al.* (2013) reported that when 3 mm round slices of yellow onion were treated with mild heat by dipping in 50, 60 or 70^0C water for one min, packaged in polystyrene rigid containers and stored at 4 ± 1^0C, lowest weight loss was exhibited by 50^0C treated samples during 21 days storage. The 60^0C heat treatment resulted in significant increase in total phenols from 44.92 to 52.32 mg GAE/100g. However, during storage total phenols in fresh cut sliced onion decreased in control and 60^0C treated samples. The mild heat treatments did not affect the ABTS and DPPH antioxidant activities and colour of fresh cut onions.

Kasim (2009) studied the effect of harvesting onions at five different diameters trimming leaf tips and roots on storage quality attributes, colour in fresh cut green onion during storage at 2^0C temperature and 90-95 per cent humidity for 28 days. They observed that harvesting of onions at >17.5 mm diameter significantly effected changes in colour of white stem and weight loss. However electrolyte leakage was low in this treatment. TSS content was highest in onion harvested at the diameter less than 10 mm.

Lee *et al.* (2008) concluded that shelf life of whole peeled onions packed in LDPE bags could be effectively increased upto 12 days with minimum total bacterial count by use of 50 ppm hypochlorous acid with improvement in safety and quality.

Hernandez *et al.* (2007) studied the effect of four cut type (wedges, slices, ½ and ¼ slices) of ‘Lisbon’ lemons (*Citrus lemons* L.) and storage at four temperatures (0, 2, 5 and 10^0C) on post-cutting life and observed the retention of vitamin C and antioxidant properties and 2-5 times higher respiration rates in sliced and wedged lemons over the whole lemons at 0, 2 and 5^0C storage temperature that increased upto 12 fold at 10^0C.

Liu and Li (2006) reported that fresh cut onions into 0.7 cm thick slices when stored at -2, 4 and 10^0C under modified atmospheres showed yellowing, loss in firmness and an increase in microbial population growth with increase in temperature.

Matrinez *et al.* (2005) stated that cutting did not change the quercetin concentration of chopped onions compared to whole bulb cv. Grano de Oro during the initial 11 days of the storage period. However, the concentration increased thereafter from 11 to 30 days 4^0C. The chopped onions packed in MAP after washing in either water (462 mg/kg fresh weight) or hypochlorite (471 mg/kg fresh weight) has increased in quercetin concentration of 19.5 and 22 per cent, respectively when compared to whole onions stored in MAP after washing in water (386mg/kg fresh weight) or hypochlorite (387 mg/kg fresh weight). Thus, they concluded that minimal processing did not significantly affected the quercetin concentration in onion products and helped in preserving health promoting characteristics of raw onion.

Beerli *et al.* (2003) studied the effect of different concentrations of hydrogen peroxide (2, 4, 6 per cent) and sodium dichloroisocianurate (50 and 100 ppm) on the microbial, physicochemical characteristics and shelf life of fresh cut onions. They concluded that H_2O_2 (4 and 6%) was more effective that sodium dichloroisocianurate as a sanitizer for sliced onion as it had lower counting of mesophile aerobic, decreased psychrotroph aerobic and total coliforms without affecting TSS and mass loss. The same treatment had lower titratable acidity and higher firmness with 7 days shelf life.

Erkan *et al.* (2001) reported that tissue slices of zucchini squash (*Cucurbita pepo* L. cv. Tigress) fruit when exposed to ultraviolet-C (UV-C) radiation from germicidal lamps for 1, 10 or 20 min; microbial quality and deterioration was significantly reduced by only 10 and 20 min UV-C exposure during storage at 5 or 10^0C. Further they observed that UV-C treated slices had higher respiration rates than controls; however, the ethylene production of slices was not affected by UV-C treatments.

2.2 Post-harvest Treatments

The minimal processing induces surface damage increasing the tissue respiration which leads to biochemical deterioration of the fresh cut fruits and vegetables (Martin-Belloso *et al.*, 2006). Many chemical treatments which include antioxidant like ascorbic acid, citric acid and surfactants like sodium hypochlorite ($NaOCl_2$) and chlorinated water showing broad biocidal effectiveness due to high antimicrobial action have been tested in ready-to-eat food products in recent years.

Ashwini *et al.* (2018) exposed the banana fruits to hexanal vapour of 600, 900 and 1200 ppm for 2 and 4 hours and stored at 27 ± 2^0C and 65-75% relative humidity and reported that hexanal 1200 ppm treatment for 2 hours improved the shelf life of banana fruits upto 18 days and delayed the ripening of fruits leading to retention of firmness, physiological weight retention, slower breakdown of starch into sugars, slower yellow pigmentation of peel over all other treatments.

Jincy *et al.* (2017) reported that ethylene evolution rate, oxidants content and PLD enzyme activity in the mango fruits cv Neelum was reduced when dipped in 0.02 per cent hexanal solution as compared to control. Further, they observed that post-harvest dip of mango fruits in 0.02 per cent hexanal solution extended the shelf life of mango fruits under ambient storage conditions without loss of quality.

Anusuya *et al.* (2016) opined that preharvest sprays of 1.6 mM EFF (nano emulsion hexanal formulation) on 30 and 15 days before mango cv. Alphonso and Bainganpalli harvest, significantly reduced post-harvest diseases, minimized post-harvest losses with increase in the shelf life of mangoes by 24-25 days under ambient conditions and 36-46 days at cold storage. They also observed lower physiological loss in weight, maximum firmness, higher total sugars, acidity in treated mango fruits than their respective controls.

Chen *et al.* (2016) studied the effect of nisin (50µg/ml) in combination with 1% (w/v) citric acid as a sanitizer in fresh cut onions. They opined that nisn and citric acid treatment decreased the total polyphenols and quercetin contents as compared to control at day 0 of storage, but did not affect phenolic acids and antioxidant capacity. During storage, antioxidant capacity, total phenols and flavonoid increased. The treatment combination reduced the microbial counts and total viable counts of fresh cut onions below the detection limit until 5 days of storage. After 15 days storage, total viable count in nisin plus citric acid treated samples remained significantly lower than controls. In addition, they observed better colour retention duration and hence recommended nisin plus citric acid as a safe preservative for fresh cut onions.

Page *et al.* (2016) studied the interactions between sanitizers and packaging gas compositions and their effects in the safety and quality of fresh cut onions. Diced onions were inoculated or not with *S. typhimurium*, sanitized in sodium hypochlorite (80 mg/L free chlorine acidified with citric acid), peroxyacetic acid (80 mg/L), or liquid chlorine dioxide (2mg/L) and then packaged in either polylactic acid bags (11x12.5 cm, total surface area of 275 cm^2) containing super atmospheric O_2 (92 kPa O_2 + 8 kPa N_2), elevated CO_2 (14 kPa CO_2 + 4 KPa O_2 + 82kPa N_2) or air (21 kPa O_2 + 79 kPa N_2), or in polyethylene terephthalate snap-fit containers (9.5 x 9.5 x 2.5 cm with a total volume of 210 ml). They observed significant effect of both, sanitizers and in package atmosphere on microbiological safety and quality of diced onion. The sanitizers affected fewer parameters like *S. typhimurium,* mesophiles, yeast and moulds, headspace CO_2, weight loss and pH, in package atmosphere had a significant effect on all parameters evaluated. They further opined that 80 ppm chlorine plus elevated CO_2 was the best sanitizer and in package combination for enhancing safety, quality and acceptability of packaged diced onions up to 14 days. It also recorded reduced *S. typhimurium* growth.

de Oliveira *et al.* (2015) stated that sophorolipids are the most promising glycolipids biosurfactants producted in large quality by several non pathogenic yeast species (*Candida bombicola* ATCC 22214) and are composed of disachharide sophorose linked to a long fatty acid chain. They further opined that sophorolipids acts as a antimicrobial/germicidal agent with a concentration of 1 per cent only killing 100 per cent *E coli, S. typhi* and *Shigella dysenteriae* in 30 seconds after application. It is also effective against majority of gram negative bacteria affecting majority of fruits and vegetables decreasing microbial spoilage and increasing shelf life of fruits and vegetables.

Costa *et al.* (2013) reported reduction in chlorophyll content, anthocyanin content (35%) with initial increase in polyphenols and then gradual decrease in polyphenols in minimally processed white and purple onions treated with 200 mg L^{-1} free chlorine for 10 minutes, packed in polystyrene (PS 6, 100 ml) with lid and stored at 4 ± 0.5^0C.

Piercey *et al.* (2012) determined the antimicrobial effect of allyl isothiocyanate entrapped in alpha and beta cyclodextrin inclusion complexes in packaged fresh cut onions at 5^0C for 20 days. They found that application of beta cyclodextrin inclusion complex (100 and 200 µl/L) to packaged fresh cut onion effectively decreased numbers of *L. monocytogenes* as compared to untreated cut onions. The total aerobic counts were calculated 4 log cfu/g lower on fresh cut onions treated with beta cyclodextrin inclusion complex (100 and 200 µl/L) compared to untreated controls.

Yuan *et al.* (2012) found that sophorolipids extracted from *Wickerhamiella domercqiae* Y2A had antimicrobial activity against pathogenic fungi associated with fruits, inhibiting proliferation, spore germination and spread of mycelium by changing or damaging cell wall or membrane structure and hence could be used in fruit and vegetable processing increased the shelf life and quality of fruits.

Yang *et al.* (2011) reported that application of a commercial fermentation product (CFP) on fresh cut onion stored 4 and 7^0C at had a antimicrobial effect significantly lowering microbial loads. The aerobic plate counts, yeast and mold counts and coliform counts were lower by 2, 5, 3.2 and 1.4 log, respectively as compared with the controls. They, further, concluded that application of 0.5 or 1 per cent commercial fermentation product maintained the shelf life of fresh cut onions for up to 14 and 18 days, respectively as compared with 10 days for the control.

Silveira *et al.* (2011) reported that calcium ascorbate, calcium chloride and calcium lactate (0.15 g Ca g^{-1}) combined with water at 60^0C and H_2O_2 (50 mgL^{-1}) could be successfully used for overall quality retention of fresh cut 'Galia' melon up to 10 days at 5^0C under a passive modified atmosphere reaching 4.5 kPa O_2 and 14.7 kPa CO_2. They further stated that after 10 days of shelf life these three Ca salts provided Galia melon pieces had maintained good firmness and lower microbial growth.

Silveira *et al.* (2010) evaluated the effect of 150 mg/L chlorine (control) for 1 min, 80 mg/L peracetic acid (PAA) for 1 min, ozonated water (0.4 mg/L) for 3 and 5 min dipping on 'Galia' melon pieces packaged in polypropylene trays under passive modified atmosphere (7.4 kPa O_2 + 7.4 kPa CO_2) stored at 5^0C for 10 days. They observed that the use of PAA recorded the lowest microbial load, however decreased the total vitamin C and antioxidant activity. Further they stated that the combination of PAA with 0.4 mg/L of ozonated water (3 min) could be used as a good substitute for chlorine as it was effective in reducing the microbial load, maintained antioxidant compounds and respiration rate and maintained sensorial quality of the product for 10 days at 5^0C.

Lee and Kim (2009) studied the effect of various hypochlorous acid concentrations and steeping time on the shelf life, microbiology and sensory quality of whole peeled onion packed in LDPE bags. They detected total bacterial counts at H-III after 4 days while the total bacterial count of the whole peeled onion increased with increase in steeping time. The decrease in L-value and increase in a and b value were also observed in all the treatments, but these effect were mitigated with increase in hypochlorous acid concentrations.

Aguayo *et al.* (2007) compared the effects of calcium salts (carbonate, chloride, propionate and lactate) at 0.5 per cent for 1 min at 60^0C on the fresh cut 'Amarillo' melon. They opined calcium chloride as the best alternative as texture enhancer among other calcium compounds. Further reported that calcium chloride, propionate and lactate decreased the rate of softening in fresh cut melon; however calcium lactate and propionate provided a slight off-flavor and a whitish color to the fruits' flesh.

Lamikanra and Watson (2007) studied the effect of mild heat (60^0C) with and without dissolved calcium lactate (1%) treatment on fresh cut cantaloupe. They reported reduced respiration in heat treated fruits with reduced lipase activity during storage at 10^0C while the fruit that was cut 24 hr after treatment had reduced peroxidase activity. They also opined that the presence of calcium in the treatment solution did not affect respiration and textural changes caused by heat treatment.

Kim *et al.* (2005) reported that irradiation of fresh cut green onions at 0.5, 1.0 and 1.5 kGy doses and storage at 4^0C reduced total aerobic count and the development of decay and off-odour, improved visual quality and preserved green colour of onions. Further they stated that warm water (50^0C) treatment even though reduced total aerobic count by 0.9 log initially, couldn't managed to keep the low population during storage and didn't provided added benefit for quality improvements.

Sy *et al.* (2005) applied gaseous chlorine dioxide (ClO_2) to whole Vidalia onions to determine the possible reductions in Salmonella and yeast/mold growth for the produce. *Salmonella enterica* surface inoculated onions were treated with ClO_2 in concentrations of 0 (control), 1.4, 2.7 and 4.1 mg/L, resulting in reductions of 0 (control), 0.83, 1.89 and 1.94 log cfu/piece, respectively. Yeast and mold growth was also reduced on the onion surface after ClO_2 treatment, with reductions of 0.36 and 0.22 log cfu/piece for 1.4 and 2.7 mg/L treatments, and an increase of 0.22 log cfu/piece for those treated with 4.1 mg/L ClO_2. This study illustrates that chlorine dioxide is a viable alternative sanitizing option for onions, but that the proper concentration must be utilized to ensure that the onions are not damaged, allowing for increased yeast and mold growth.

Beerli *et al.* (2004) studied the effect of hydrogen peroxide (H_2O_2) and sodium dichloroisocianurate (NaDCC) sanitizers on the microbial and physico-chemical quality of sliced onions stored at 4^0C for one week and concluded that H_2O_2 (4 and 6%) was more effective sanitizer for fresh cut onion slices than NaDCC (50 and 100 ppm) and control as it recorded higher firmness, TSS with lower mass loss and also had lower aerobic mesophiles and yeast and mold populations with proper edible conditions up to 7 days.

Francis and O'Beirne (2002) and Watada and Qui (1999) reported that chlorine-based chemicals, especially liquid chlorine and hypochlorite, are most widely used at the level of 50-200 ppm free chlorine and contact time less than 5 minutes as a sanitizers for decontaminating fresh produce.

Luna-Guzman and Barrett (2000) reported that calcium chlorite at 15^0C and calcium lactate at 25 and 60^0C maintained melon firmness throughout the storage period. However, $CaCl_2$ imparted undesirable bitterness to fruit pieces. Both calcium salts increased shelf life of fresh cut cantaloupes up to 12 days at 5^0C and 95% relative humidity.

Luna-Guzman *et al.* (1999) studied the effects of $CaCl_2$ (1-5% for 1 to 5 minutes) dips and heat treatments on the firmness and metabolic activity of fresh cut cantaloupe. They reported that CO_2 production was higher in untreated samples than in calcium treated and intact fruits. They further stated that application of calcium dips at any temperature resulted in unchanged ethylene production, improved firmness throughout storage at 5^0C and inhibited respiration. The dipping fresh cut melons for 1 min in 2.5 per cent calcium chloride solution at higher dip temperature 60^0C found to be best in maintaining firmness.

Park and Lee (1995) evaluated the effect of chlorine treatment of different concentrations at 25^0C for one minute on fresh cut water cress and onion to reduce microbial populations and improving the keeping quality. Cut water cress and white cut onion had high initial microbial contamination of $10^{7.5}$ cfu/g and $10^{1.7}$ cfu/g. They found that treatment with ≤100 ppm chlorine effectively reduced the microbial load of the produce without significant quality losses. However, higher concentrations of chlorine resulted in greater microbial proliferation after 7 days, ascorbic acid destruction and significant colour change in stored cut vegetables. Thus they opined that the effectiveness of chlorine treatment was limited to short term storage.

As an alternative to immersion sanitizing techniques, Hadjok *et al.* (2008) applied ultraviolet (UV) light combined with hydrogen peroxide (H_2O_2) to sliced Spanish onions to reduce both surface and internal pathogenic microorganisms. The onion slices were submerged in 500 mL of inoculum containing 7 log cfu/g of *Salmonella* Montevideo for 20 minutes before being vacuumed cyclically to induce internalization of the bacteria. Each side of the onion slice was treated with 5^0C 1.5% v/v H_2O_2 mist while exposed to a UV lamp (254 nm) for 1 minute while control samples were treated with a 200 ppm calcium hypochlorite solution for 3 minutes. *Salmonella* populations present on the surface of the slices were reduced 3.66 log cfu/g while the calcium hypochlorite control was only reduced 0.34 log cfu/g. Internalized *Salmonella* were reduced 0.97 log cfu/g when treated with UV/H_2O_2, and 0.05 log cfu/g for the control, indicating that this experimental sanitizing technique is significantly more effective at reducing surface populations of *Salmonella* Montevideo than calcium hypochlorite on sliced onions. While the observed surface *Salmonella* reduction is notable, studying the additional effect of storage time on microbial populations is necessary to deem UV/H_2O_2 as a viable alternative sanitizing technique for sliced onions.

Perez-Gregorio *et al.* (2011) investigated the effect of different chemical and UV-C irradiation based sanitizing technologies on the quality appearance and antioxidant levels in onion slices of cultivar *Vermelha da Povoa* and observed significant decrease in onion flavonoids (6-23%) by use of chemically disinfectant procedures which included use of high levels of sodium hypochlorite (300 ppm) treated with sulphuric acid at temperatures of 50^0C, hydrogen peroxide, amukine and sodium dichloroisocyanate. Further they recommended the use of dry contamination treatments like UV-C irradiation as it increased the natural levels of flavonoids i.e. 35% for flavonols and 29% for anthocyanins.

Kasim and Kasim (2010) investigated the effect of four different UV-C treatments viz; UV-C radiation for 3 min, for 5 min, for 10 min and 15 min on the storage quality of fresh cut green onions stored at 5^0C and 85-90 per cent humidity. They found that an electrolyte leakage of fresh cut green onions was getting high with higher doses of UV-C so, recommended lower doses for control of pathogens because of both lower electrolyte leakage and lower decay percentage at the 10^{th} day of storage. The L* value of tissues also remained best in UC-C treatment for 5 mintues. However, enhanced antioxidant activity was observed in higher doses of UV-C treatments, especially UV-C treatment for 15 minutes.

2.3 Packaging and Modified Atmosphere Packaging

Modified Atmosphere Packaging (MAP), a novel technology has been extensively used to achieve safety and/or to prolong the shelf-life of fruit and vegetables products. Modified Atmosphere Packaging (MAP) refers to any container used to control the concentration of specific gases in order to achieve levels desirable to content. The goals for MAP of fresh cut produce are to maintain a lower oxygen and higher carbon dioxide level than that of the surroundings. Reducing respiration rate and extending shelf life are the returns for the added cost of using MAP films. The design of a MAP appears to be rather simple on the surface, but many considerations must be accounted for Active MAP involves quick process of gas flushing or gas replacement or the use of gas-scavenging agents to establish a desired gas mixture within the package to avoid the buildup of unsuitable gases (Kader and Watkins, 2000; Charles *et al.*, 2003; Farber *et al.,* 2003). The design of MAP appears to be rather simple on the surface, but many considerations must be accounted for. The temperature the produce is going to be held at, is important since metabolic activity is very dependent on temperature. Most packages will go from the packing house, to a truck, to the point of sale, all with different temperatures. The change in respiration rate due to an increase in temperature is usually greater than the change in permeability of the package (Exama *et al.,* 1993). The package may not be able to get back to equilibrium even once the lower temperature is achieved again, since the product may have used more oxygen than planned and gone into anaerobic respiration. Determination of the optimal surrounding atmosphere for fresh cut produce is difficult due to the numerous possible combinations of oxygen and carbon dioxide concentrations.

Martinez *et al.* (2005) recorded increase in quercetin concentration of 19.5% and 22% in chopped onion cv. Grano de Oro packed in MAP after washing in either water (462 mg/kg f.w.) or sodium hypochlorite (471 mg/kg f.w.) respectively when compared to whole onions stored in MAP after washing with water (386 mg/kg f.w.) or hypochlorite (387 mg/kg f.w.) at the end of 30 days at 4^0C storage temperature. No statistical differences in total quercetin concentration were recorded in minimally processed onions packed under vacuum or MAP.

Baskaran *et al.* (2015) studied the effect of minimal processing (MP) and Modified Atmosphere Packaging (MAP) on the shelf- life and quality characteristics of fresh cut onions and stated that pretreated and minimally processed onions packed in Polypropylene (PP) bags of 37 microns thickness with passive MAP had a shelf life of 14 days at 4 ± 2^0C with retention of all quality attributes, minimum microbial load within the threshold level (log 6) and had sensory acceptance. The only control fresh cut onion deteriorated in all sensory quality attributes.

Oliveira *et al.* (2015) overviewed the effect of Modified Atmosphere Packaging (MAP) on the survival and growth of food borne pathogens on fresh cut fruits and vegetables. They opined that MAP in combination with refrigeration temperatures could be used as a mild preservation technique for safety of minimally processed fruits and vegetables. However, the effect of MAP on microorganisms could vary, depending mainly on the storage conditions and the type of packaged product.

Han *et al.* (2010) evaluated the effect of five different modified atmospheres viz. 100% O_2, 95%O_2/5%CO_2, 80%O_2/20%CO_2, 75%O_2/25%CO_2 and air, on sliced fresh cut onion packaged in a polypropylene (PP) trays of 18×24 cm^2 high-barrier film of 70µm thickness and stored at room temperature. The study showed that the weight loss and respiration rate of high oxygen modified atmosphere packagings were remarkable smaller than the air packaging during storage. Further they opined that high oxygen modified atmosphere packaging with 80% O_2/20% CO_2 could obtain longer shelf life 7 days at room temperature with acceptable primary quality indices including slowest increase in microbial load.

Radziejewska-Kubzdela *et al.* (2007) reported that modified atmosphere with the content of 5% or 10% CO_2, 2% O_2 and balanced N_2 in the packaging of celeriac flakes during storage at 4 and 15^{0}C for 12 days, inhibited growth of mesophilic, psychrophilic and coliform bacteria.

Rico *et al.* (2007) stated that modified atmosphere packaging and active packaging could be utilized to increase the shelf life of fresh fruits and vegetables by slowing down the rate of respiration and decreasing product metabolism and maturation.

Liu and Li (2006) studied the growth of total psychrotrophs and yeasts in sliced onions packaged in LDPE bags containing 40% CO_2 + 1% O_2 or air during storage at -2, 4 and 10^{0}C for 2 weeks. The authors found that onions packaged in high CO_2 at 4^{0}C maintained initial psychrotroph counts (~3 log cfu/g) through day 5, and yeast growth was also maintained, with both high CO_2 and air stored onions at -2 and 4^{0}C containing ~4 log cfu/g of growth at day 7. Thus, calling attention to the fact that storage temperature is a more influential parameter than inpackage atmosphere for preventing yeast growth in sliced onions.

Robertson (2006) recommended oriented polypropylene (40µm thick) or polyamide low-density polypropylene (70-100 µm thick) as a suitable material for packaging shredded onion as it maintains all the marketable and sensory qualities.

Ahn *et al.* (2005) concluded that Modified Atmosphere Packaging (MAP) enhanced the reduction of total aerobic and coliform bacteria in cut Chinese cabbage, irradiated at dose up to 2 kGy with air CO_2 or CO_2 /N_2 packaging during refrigerated storage for 3 weeks.

Gomez and Artes (2005) opined that MAP treatments of 6 kPa O_2+7 kPa CO_2 in oriented polypropylene (OPP) and polyethylene-perforated bags improved the sensory quality, avoided the loss of green colour, decreased the development of pithiness and retarded the growth of microorganisms in celery sticks stored at 4^{0}C for 15 days than compared to the control (air).

Hong and Kim (2004) investigated the effect of five different packaging treatments including two passive MAP (polythene and polypropylene) using LDPE and PP films in normal air, two active MAP viz; ethylene scavenger using LDPE film and sing LDPE film with a gas mixture of 18.2 kPa O_2 and 9.5 kPa CO_2 balanced with nitrogen and one moderate Modified Vacuum Packaging (MVP) with a vacuum degree of 30.3 kPa on the storage quality of minimally processed bunched onion stored at 10^0C. No significant differences in weight loss, colour and proliferation of microorganisms when bunched onions were stored under modified atmosphere conditions such as 1.5-3.0 kPa O_2 and 4.1-6.6 kPa CO_2 and maintained marketable sensory and microbial qualities for 14 days. They further stated that MVP with a gas permeable plastic film retained better quality of minimally processed bunch onion with reduced microbial decay and visual sensory aspects as compared with other packages and extended shelf lif of bunched onions up to 21 days at refrigerated temperatues.

Allende *et al.* (2004) studied that the effect of super atmospheric O_2 and Modified Atmosphere Packaging (MAP) on plant metabolism, organoleptic quality and microbial growth of minimally processed baby spinach and reported that packages prepared with the barrier film with an initial O_2 level at 21% accumulated CO_2 during storage exhibited a significant reduction in aerobic mesophilic bacterial growth, better sensory quality and eliminated the possibility of post processing contamination over perforated film packages (control).

Hong *et al.* (2003) studied the effect of packaging methods on the storage quality of minimally processed (prepeeled) onions to determine the optimal packaging design. They used two passive MAP using LDPE and PP films, two active MAP using gas mixtures of 20% O_2/10 and an ethylelne scavenging sachet and moderate vacuum packaging. They opined that the packaging methods did not significantly influenced surface colour, weight loss and microbiological populations of mesophiles, psychrotrophs and lactic acid bacteria. However, it affected sensory characteristics as well as decay occurrence. Further they recommended that seal packaging with a gas permeable plastic film under a mild vacuum condition which retained better quality of fresh cut onion in terms of microbial decay and visual sensory aspects.

Allende *et al*. *(*2002) reported no growth of micro-organisms in the fresh cut salad mixes containing lettuce, packaged in a low or a high barrier film with an initial oxygen level of 95 kPa and stored at 4^0C. They also studied the effect of MAP technique on mixed vegetable salad during storage and reported that overall visual appearance (mainly color) of the mixed vegetable salads was better maintained and the shelf-life prolonged when packaged under O_2 concentrations greater than 60 kPa under both low barrier and high barrier films used as packaging material.

Cantwell and Suslow (2002) reported that micro-organism differ in their sensitivity to modified atmospheres. Low oxygen (1%) atmospheres generally have little effect on the growth of fungi and bacteria. High CO_2 concentrations may indirectly affect microbial growth by retarding deterioration (softening, compositional changes) of the product. High CO_2

atmospheres may have a direct effect by lowering cellular pH and affecting the metabolism of the micro-organisms.

Hong *et al.* (2000) concluded that controlled atmospheres of 0.1-0.2% O_2 + 7.5-9% CO_2 at 5^0C were adequate storage conditions to maintain high visual quality and reduced telescoping of intact and minimally processed green onions. However, the onions treated with heat treatment (55^0C water dip for 2 mins) led to maintainance of TSS over untreated onions.

Qi *et al.* (1999) evaluated the quality, physiology and microbial population of honeydew cubes held in air or CA of 2% O_2 + 10% CO_2 at 5^0C and 4% O_2 + 10% CO_2 at 10^0C. They concluded that quality of melons deteriorated rapidly with increase in respiration rate up to 6 days at 10^0C or 10 days at 5^0C shelf life.

Portela and Cantwell (1998) evaluated the quality changes of minimally processed honeydew melons (Green Flesh, Morning Ice, Rico, RML 2704) stored in air and or controlled atmosphere (CA = air + 15% CO_2) at 5^0C. They observed significant variation in soluble solids concentration (9.9 to 12.2%), firmness (14.0 to 19.9 N) and colour of varieties. They opined that controlled atmosphere storage reduced losses, development of microscopic decay, translucency and off odours significantly and had higher visual quality scores than those stored in air.

Farber *et al.* (1998) investigated the effect of passive MAP in combination with chlorine sanitizer on the growth of *Listeria monocytogenes* on inoculated sliced onions. Whole peeled onions were dipped in a 200 ppm sodium hypochlorite solution for 10 seconds before being sliced. Onion slices were then inoculated with *L. monocytogenes* and stored in sealed OPE bags at 4 and 10^0C for 9 days. In-package CO_2 accumulation was 23% in bags stored at 4^0C and 52% in bags at 10^0C on day 9. There was no increase in *L. monocytogenes* growth in onion slices stored at 4^0C, likely because *Listeria* does not grow well at low temperatures. There was a slight (~1 log cfu/g) increase in *L. monocytogenes* populations from day 0 to day 9 in onions at 10^0C. The unexpectedly low increase of *L. monocytogenes* during the 9 day storage period can be attributed to the large buildup of CO_2 inside the bags, preventing *Listeria* proliferation.

Peiser *et al.* (1997) observed that food service garden salad packages (containing commercially processed iceberg lettuce, carrot and red cabbage) obtained from 5 California processors had 0.2-1.0% O_2 and 5-20% CO_2 after over 15 days of storage at 5°C. Acetaldehyde and ethanol developed in the tissues at concentrations of 2-22 μl/kg and 50-1500 μl/kg, respectively, by the 'Best if used by Date' (BIUD). Packages from all processors were above the limit of stability for overall visual quality by the BIUD, although off-odours were detected.

Bennik *et al.* (1996) studied the microbiology of cut chicory endive in MAP’s with 0, 1.5 or 21% O_2 in combination with 0, 5 or 20% CO_2 and filled with N_2 to make up final gas volume 100% and reported that the MAP conditions were favourable for product quality, retarded growth of spoilage microoraganisms at lower temperatures.

Blanchard *et al.* (1996) carried out a CA study using diced yellow onions that had been dipped in a 100 ppm chlorine solution for 30 seconds before storage in either: 2% O_2 + 0% CO_2, 2% O_2 + 5% CO_2, 2% O_2 + 10% CO_2, 2% O_2 + 15% CO_2, 20% O_2 + 0% CO_2, or air at 4^0C for 2 weeks. Throughout storage, 2% O_2 + 10% CO_2 had the lowest psychrotrophic growth (~2.5 log cfu/g increase) while onions stored in 2% O_2 + 0% CO_2 or air had the most, with an increase of more than 4 log cfu/g from day 0 to day 14. Further they reported that high CO_2 and low O_2 with treatment of 2/10 delayed the rise in respiration rate and reduction in sucrose content, browning after cooking upto 14 days of storage. The treatment also suppressed the microbial proliferation over rest of the treatments.

Ferreres *et al.* (1996) studied the storage of shredded onion under perforated and non-perforated polypropylene films for 7 days at 8^0C and observed that non-perforated films led to off-flavors accumulation, which made the product unacceptable. When the commodity was stored on open trays, the water loss produced shriveling. The best results were obtained when and shredded onions were stored under perforated polypropylene films at 8^0C which led to reduction in anthocyanins but the appearance of the commodity was acceptable after 7 days storage period.

The quality and bacterial populations of diced yellow onions with passive MAP and an ethylene absorber were studied by Howard *et al.* (1994). Onions were first diced by hand with a knife and then submerged in a 100 ppm chlorine solution before being packaged in PE bags and stored at 2^0C for 10 days. Packages with and without an ethylene absorber reached a CO_2 concentration of 7% after 10 days. Differences were observed, however, for mesophilic bacterial 11 populations, starting on day 3 of storage. Onions packed with an ethylene absorber reached a growth level of 7 log cfu/g, while those without the absorber were less than 6 log cfu/g on day 10. These results indicate that the naturally accumulating ethylene inside the diced onion package is beneficial to reduce the growth of bacterial microorganisms during storage, even at low temperature (2^0C).

Selman (1993) reported that diced onions packaged in OPE/PE bags that were either perforated or contained modified atmosphere showed varying shelf lives depending on atmosphere and storage temperature. Diced onions experienced no discoloration when packaged in air for 14 days at 5^0C and 11 days at 10^0C. Packages containing 10% O_2 + 5% CO_2 helped to maintain onion quality for 1 week at 5^0C and 5 days at 10^0C, while perforated (control) bags only allowed for 5 days at 5^0C and 2 days at 10^0C. In polyvinylchloride bags sealed with air, diced onions experienced no discoloration for 7 days at 5^0C and 3 days at 10^0C indicating that not only is temperature and in-package atmosphere important, but also packaging material for maintaining typical onion color during storage.

A similar passive atmosphere packaging and chlorine sanitizing technique was studied by Park and Lee (1995) with hand-diced onions in polystyrene trays wrapped with linear low density polyethylene film for storage at 5^0C for 3 weeks. Diced onions were dipped into a 25^0C 10 sanitizing solution containing either 0 (control), 30, 50, or 100 ppm chlorine for 1 minute. Mesophilic populations were reduced to approximately 0.5 log cfu/g at the initial sampling for all samples treated with chlorine, while the control contained populations of nearly 2 log cfu/g. There were no differences between sanitizer concentration and all treatments exceeded 8 log cfu/g at the end of storage. The authors also observed that the surface color of the diced onions did not vary between treatments throughout storage. Because there were no differences between microbial populations or onion color over time, the minimum 10 ppm chlorine sanitizer was determined to be sufficient for reducing initial microflora. This study helps to point out the need for more innovative methods to reduce microbial populations in diced onions throughout their storage to improve overall marketability.

Kader *et al.* (1989) reported that when O_2 consumption equals O_2 diffusion into the package and CO_2 production equals CO_2 diffusion out of package, a steady-state conditions during MAP of produced. They observed accumulation of CO_2 and C_2H_4 and the depletion of O_2 occurred faster at 10^0C then at 5^0C in chilli when papers were placed in sealed containers to stimulate a gas-tight film package.

2.4 Storage

Berno *et al.* (2014) studied the effect of storage temperatures (0, 5, 10, 15^0C) type of cut and storage duration on purple onion and reported that the reduction in storage temperature led to a decrease of respiratory rate that prolonged the product shelf life and reduction in rate of deterioration and anthocyanin loss.

Costa *et al.* (2013) studied changes in chlorophyll, anthocyanins and phenolic compounds concentration in fresh cut onion during stoarge. They compared the levels of phenolic compounds of purple, red and white onion and concluded that phenolic compounds of purple onion obtained increased until second day of analysis and then reduced until the final period of conservation, while in white onion increase in phenolic compounds was recorded on day 2 further reducing till the fourth day and increased again until the last day of conservation.

Forney *et al.* (2012) studied the influence of biodegradable polymer polylactide (PLA) (sealed and vented) and polythene packaging on loss of aroma and quality of diced red onions stored at 4.5^0C and assessed for volatile content after 0, 7, 12, 14, 18, and 21 days respectively. They observed that after 7 days, the total headspace volatile content of diced red onions stored in sealed PLA containers decreased by only 15% compared to 98 and 85% in the vented PLA and sealed polyethylene packages, respectively. During the 21 days storage onion gas exchange rates increased 5 to 6 fold and electrolyte leakage doubled. Aerobic and anaerobic microbial plate counts exceeded 10^6 cfu/g after 12 days. Marketable quality of diced red onions were maintained for 12 days in sealed PLA and PE packages stored at 4.5^0C.

Miguel and Durigan (2007) assessed the quality of minimally processed onions cv. Superex stored under refrigeration and opined that minimally processed onions maintained appropriate quality until 13^{th} day when stored at 11^0C in case of product prepared from onion bulbs stored in cold room at 10^0C and 60% RH for 61 days while minimally processed product produced with bulbs stored for 91 days had only 9 days shelf life. During the storage period, fresh cut products turned yellow, with decrease in soluble solid contents, increase in titratable acidity and reduction in aliinase activity. However increased aliinase activity was recorded in whole bulbs during storage.

Crowther *et al.* (2005) studied the flavour of fresh uncooked onions by taste panels and analysed flavour precursors, pyruvate and sugar and observed that a significant linear relationship exists between a sensory measure of strength and pyruvate over the range 1.2-9.3 μmol.

Gennaro *et al.* (2002) researched on flavonoid and carbohydrate contents in tropea red onions and effects of home like peeling and storage and recorded that the edible portion of onion contains 79% of the total content of quercetin 4'-glucoside but only 27% of the anthocyanins. When onion stored at different condition for 6 weeks the total anthocyanin content reduced to 64-73% and total anti-oxidant activity to 29-35%.

Adam and Ongley (1972) reviewed the beneficial influence of low temperature storage on various pigmented fruit and vegetable products. They observed that, bottling of fruits/vegetables at low pH (between 1-2), without adding sugar, led to small but significant increase in the pigment stability. The pigment degradation was faster when stored at ambient temperature (35^0C).

Schwimmer *et al.* (1961) reported that pyruvic acid appears enzymatically in onion tissue disintegrated by comminution. Over 95% of the maximum amount of pyruvic acid is produced within 6 minutes after the start of comminution. In addition weak onion produced 2 to 4 μmoles, those of intermediate strength 8 to 10 μmoles, and strong onions 15 to 20 μmoles of pyruvic acid per gram of onion.

3. MATERIAL AND METHODS

The present investigations on the minimal processing of fresh cut onion (*Allium cepa* L.) and it's storage at different conditions were conducted in three different parts at Post-harvest Technology Laboratory of Horticulture section, Rajashri Chhatrapati Shahu Maharaj College of Agriculture, Kolhapur from September- December, 2017. The details of materials used, methods adopted and the statistical procedure followed during the course of investigation are described below.

3.1 Materials

3.1.1 Onion

The freshly harvested well mature, healthy and sound onion bulbs of cultivar Baswant-780 were collected from local market of Kolhapur and used for research.

3.1.2 Chemicals

Food grade and analytical grade chemicals obtained from Omkar Traders, Pune were used for the studies.

3.1.3 Glass Wares

All the glass wares used were obtained from manufacturer M/s. Borosil Glass Works Ltd. (BGWL), Ahmedabad, Gujarat.

3.1.4 Packaging Materials

The different packaging materials were used for packaging of various fresh cut onions. Polypropylene bags (200 gauge) and Polyethylene terephthalate plastic punnets were obtained from Swaroop Plastics, Kolhapur. Active package lacquered with Nanosilver (medium bags -225 mm width x 325 mm height) received from Nichem Solutions, Thane (west) and Fresh paper (Fenugreen- magic paper) procured from Cloudtail India Pvt. Ltd., Kacherakanahalli, Bangalore were used for research.

3.1.5 Cleaning and Sterilization of Processing Unit

The working area of the processing unit, sealing machine and other instruments and equipment needed was pre-sterilized with 100 ppm chlorine solution and air dried. The entire area was sprayed with 1 percent hydrogen peroxide solution to minimize the load of aerobic microflora and to remove off flavour.

3.2 Experimental Details

The research work was conducted in three parts as listed below,

Part 1: Effect of postharvest treatments and cut types on fresh cut onion

Part 2: Effect of packaging materials and storage temperatures on pre-treated fresh cut onion

Part 3: Effect of modified atmosphere packaging on pre-treated fresh cut onion

3.2.1 Effect of Postharvest Treatments and Cut Types on Fresh cut Onion

The freshly harvested well mature, healthy and sound onion bulbs of cultivar Baswant-780 were minimally processed into various cut types and pre-treated with different postharvest treatments. The pre-treated fresh cut onion samples were packed in polypropylene bags and stored in different environments i.e. in cold storage at 0-5^{0}C and at ambient temperature. Pilot trials conducted revealed that the shelf life of fresh cut onion stored at ambient condition was up to one day only, irrespective of the pretreatments. Therefore, for the further experimentation the storage in a cold environment at 0-5^{0}C was considered.

3.2.1.1 Sample preparation

The freshly harvested well mature, healthy and sound onion bulbs were selected. All tools and equipment were sanitized with sodium hypochlorite solution (150 ppm) prior to processing. The onions are processed by removing the entire peel and by cutting distal ends with sharp knife giving horizontal cuts and used for a further experiment.

Statistical Design : Factorial Completely Randomized Design

Packaging material : Polypropylene bags (200 gauge)

Storage Temperature : 0-5^{0}C

Sample Size : 200g per packaging

Table 1: Treatment combinations of types of cut and postharvest treatments

Treat. Symbol	**Treatment combinations**
A_1	Sliced onion
A_2	Diced onion
A_3	Shredded onion
A_4	Whole peeled onion (Control)
Symbol	**Treatment combinations**
T_1	Control (Distilled water)
T_2	Sodium hypochlorite (80 ppm) acidified at 6.5 pH with citric acid for 5 minutes
T_3	1% EFF solution (Hexanal)
T_4	2% EFF solution (Hexanal)
T_5	6% Food grade Hydrogen Peroxide (H_2O_2)
T_6	1% Sophorolipid extract
T_7	Calcium lactate (1%)
T_8	Nisin (50µg-mL^{-1}) + Citric acid (1% w/v)
T_9	UV-C radiation

3.2.1.2 Type of cut

3.2.1.2.1 Whole peeled onion

For the whole peeled treatment, the onions were processed by removing the entire peel as well by cutting distal ends by giving horizontal cuts with a sharp knife.

3.2.1.2.2 Sliced onion

The whole peeled onions were horizontally cut into 4 mm size with a sharp knife. The slices were kept without disturbing and used for further dipping treatment.

3.2.1.2.3 Shredded onion

The peeled and cleaned onions were cut in two equal halves. The longitudinal cuts were given to yield 3 mm size onion shreds.

3.2.1.2.4 Diced onion

The whole peeled onions were cut with a sharp and clean knife to produce diced onion cubes of 3 mm size approximately and used for a further experiment.

3.2.1.3 Postharvest dip treatments

3.2.1.3.1 Control (distilled water)

The fresh cut onions were dipped in cold distilled water (13^0C) for five minutes and then air dried.

3.2.1.3.2 Acidified sodium hypochlorite solution

Loba-Chemie makes food grade Sodium hypochlorite solution containing 4 percent active chlorine was procured from Omkar Traders, Pune. From this stock solution, desired concentration of 80 ppm Sodium hypochlorite solution was prepared by diluting it with distilled water and acidified at 6.5 pH by adding citric acid. The fresh cut onions were dipped in the 80 ppm Sodium hypochlorite solution for 5 minutes and air dried for 20 minutes.

3.2.1.3.3 Nano emulsion hexanal formulation (Enhanced Freshness Formulation)

Nano emulsion of hexanal (EFF) was obtained from the Department of Nano Science and Technology, Directorate of Natural Resource Management, TNAU, Coimbatore. The stock solution of EFF was prepared by diluting 20 ml of EFF per litre of water to give 2 percent nano-emulsion of hexanal. Similarly, the 1 percent hexanal solution is prepared by diluting 10 ml of EFF per litre of water. The nano emulsion hexanal of 1 and 2 percent concentrations were used for dip treatment. The fresh cut onion was dipped in the desired concentration of EFF for 5 minutes and air dried.

3.2.1.3.4 Hydrogen peroxide

Food grade hydrogen peroxide was obtained from Omkar Traders, Pune. The fresh cut onions were immersed in 400 ml of an aqueous solution of 6% food grade hydrogen peroxide for 5 minutes at 4^0C.

3.2.1.3.5 Sophorolipid extract

NPOP (National Programme for Organic Production) and NABL approved and GreenCert certified, commercially available organic vegetable and fruit wash containing Sophorolipid extract with trade name 'Evergreen' was procured from Green Pyramid Biotech Pvt. Ltd. Pune, Maharashtra. As per the recommendations, 1% sophorolipid solution was prepared by diluting 1 ml of the product in 99 ml distilled water and the desired quantity of stock solution was used for dipping fresh cut onion for 5 minutes. The fresh cut onions were then air dried.

3.2.1.3.6 Calcium lactate

Analytical grade Calcium lactate was procured from Omkar Traders, Pune. 10 g of Calcium lactate was dissolved in little quantity of distilled water and volume was made up to 100 ml by adding distilled water. Then this solution was heated at 50^0C temperature. From this stock solution, the desired concentration of 1% Calcium lactate was prepared. The fresh cut whole peeled, sliced, shredded and diced onions were dipped in 1% calcium lactate for 10 minutes. Fresh cut onions were gently spread on pre-sterilized large stainless-steel tables, covered with a clean muslin cloth to drain out the excess water. The fresh cut onions were air dried by using cool air generated by blower for 30 minutes.

3.2.1.3.7 Nisin (0.005%) plus 1 per cent citric acid

The nisin is procured from Sigma Aldrich and food grade citric acid is obtained from the Omkar Traders, Pune. The combination of nisin and citric acid was used for the pre-treatment. The nisin solution of 50 $\mu g\text{-}mL^{-1}$ concentration is prepared by dissolving 50 mg nisin per litre of water. 10 g of citric acid was dissolved in the little quantity of distilled water and volume was made up to 100 ml by adding distilled water. From this stock solution, the desired concentration of 1% citric acid was prepared. The fresh cut onions were first washed with nisin solution for 5 minutes and then same drained fresh cut onions were dipped in 1% citric acid solution for 5 minutes and then air dried.

3.2.1.3.8 UV-C radiation

Fresh cut onions dipped in distilled water were air dried to drain out the excess water and used for further treatment. Air dried fresh cut onion were exposed to UV-C radiation (250 nm to 255 nm) in a laminar air flow system for 30 minutes and then packed in polypropylene bags of 200 gauge in aseptic conditions.

3.2.1.4 Packaging

Consumer polypropylene food grade plastic bags of 200 gauge thickness and 10 x 14 inch size offering low moisture permeability were procured from Swaroop Plastics, Kolhapur. The polypropylene bags were sanitized with 3% (v/v) food grade hydrogen peroxide (H_2O_2). The treated fresh cut onion samples weighing 200 g were filled in each pre-sterilized polypropylene bag.

3.2.1.5 Storage condition

The pretreated fresh cut onion samples sealed in polypropylene bags were kept in Celfrost make multideck and countertop retail display shelf refrigerated chiller at 0 - 5^0C.

3.2.2 Effect of Packaging Materials and Storage Temperatures on Pre-treated Fresh Cut Onion

The best pre-treatment for the diced and whole peeled onion obtained in the first part of the study was taken for further packaging and storage studies. As regards the cut types, even though whole peeled onion was found best, the diced onion cut type was also considered from the commercial point of view. The fresh cut onions i.e. whole peeled and diced, pre-treated with 1% hexanal formulation (EFF) were air dried and packed in different packages and stored at two different commercial refrigerated temperatures viz; 0 ± 1^0C and 7 ± 1^0C.

Statistical Design : Factorial Completely Randomized Design

Sample Size : 200g per packaging

Table 2: Treatment combinations of packaging materials and storage temperatures

Treat. Symbol	**Packaging combinations**
P_1	Polypropylene bags (200 gauge)
P_2	Active package lacquered with nano silver
P_3	Polyethylene terephthalate plastic punnets
P_4	Polypropylene bags with fresh paper
Symbol	**Storage combinations**
S_1	0±1^0C
S_2	7±1^0C

Separate experiment was laid out for whole peeled and diced onion

3.2.2.1 Packaging treatments

3.2.2.1.1 Polypropylene bags (200 gauge)

Consumer polypropylene food grade plastic bags of 200-gauge thickness and 10 x 14 inch size offering low moisture permeability were procured from Swaroop Plastics, Kolhapur. The polypropylene bags were sanitized with 3% (v/v) food grade hydrogen peroxide (H_2O_2). The treated fresh cut onion samples weighing 200g were filled in each pre-sterilized polypropylene bag.

3.2.2.1.2 Active package lacquered with nanosilver

Active package lacquered with Nanosilver (medium bags- 225 mm width x 325 mm height) received from Nichem Solutions, Thane (west) were used for the experimentation. The treated fresh cut onion weighing 200g was filled in active package lacquered with nanosilver and sealed.

3.2.2.1.3 Polyethylene terephthalate plastic punnets

Polyethylene terephthalate plastic punnets were procured from Swaroop Plastics, Kolhapur. The plastic punnets were sanitized with 3% (v/v) food grade hydrogen peroxide (H_2O_2). The treated fresh cut onion weighing 200g were filled in each presterilized Polyethylene terephthalate plastic punnets and sealed with an interlocking system.

3.2.2.1.4 Polypropylene bags with fresh paper

Fresh paper (Fenugreen- magic paper) procured from Cloudtail India Pvt. Ltd., Kacherakanahalli, Bangalore were used for research. Natural produce saver sheet in fused with organic, active botanicals (fenugreek extract) and having 5 x 5 inch size was inserted in polypropylene bags (200 gauge). The treated fresh cut onion weighing 200g was filled in each pre-sterilized polypropylene bags having a sheet.

3.2.2.2 Storage conditions

The pre-treated fresh cut onion samples sealed in different packagings were kept in Celfrost make multideck and countertop retail display shelf refrigerated chiller with curtain at two different temperatures viz; 7 ± 1^0C and 0 ± 1^0C.

3.2.3 Effect of Modified Atmosphere Packaging on Pre-treated Fresh Cut Onion

The fresh cut onions i.e. whole peeled and diced onions pre-treated with the best postharvest treatment obtained in first part of study were taken for further MAP studies. The pre-treated fresh cut onion samples sealed-in with different modified atmosphere conditions were stored in Celfrost make multideck and countertop retail display shelf refrigerated chiller with drop curtain at two different temperatures viz; 7 ± 1^0C and 0 ± 1^0C. The packagings were carried out in a closed glass chamber with desirable modified atmosphere concentrations.

Statistical Design : Factorial Completely Randomized Design

Sample Size : 200g per packaging

Table 3: Modified atmosphere packaging of pre-treated fresh cut onion

Symbol	Treatment combinations
A_1	Whole peeled onion
A_2	Diced onion
Symbol	**Packaging combinations**
M_1	Air/Passive MAP with no vacuum
M_2	Active MAP- combination of 2% O_2+10% CO_2
M_3	Active MAP- combination of 0.5% O_2+10% CO_2
M_4	Active MAP- combination of 3% O_2+10% CO_2

M_5	Active MAP- combination of 0.5% O_2+5% CO_2
M_6	100% N_2 flushing
M_7	Super atmospheric oxygen (100%)
M_8	Super atmospheric oxygen (80%) plus CO_2 (20%)
Symbol	**Storage combinations**
S_1	0±1^{0}C
S_2	7±1^{0}C

The pre-treated fresh cut onions i.e. whole peeled and diced onions were kept in two different sets for the conduction of experiment

3.2.3.1 Polypropylene bags (200 gauge)

The best packaging found in the second part of study i.e. consumer polypropylene food grade plastic bags of 200 gauge thickness and 10 x 14 inch size offering low moisture permeability, were used for the MAP studies. The treated fresh cut onion samples weighing 200g were filled in each presterilized polypropylene bag.

3.2.3.2 MAP treatments

3.2.3.2.1 Air/ Passive MAP with no vacuum

The pre-treated fresh cut onions i.e. whole peeled and diced, were packaged in polypropylene plastic bags of 200 gauge thickness without flushing of any external gas. The condition so created is considered as passive MAP.

3.2.3.2.2 Gas composition

The flow of desired gas compositions to be flushed in packaged fresh cut onion was calculated and the respective gas cylinders were fixed to inlets. The internal gas flow was regulated and weighed fresh cut onions packed in polypropylene plastic bags were flushed desired gas compositions viz.;

i. 2% O_2+10% CO_2
ii. 0.5% O_2+10% CO_2
iii. 3% O_2+10% CO_2
iv. 0.5% O_2+5% CO_2

3.2.3.2.3 Nitrogen flushing (100%)

The flushing of 100% nitrogen gas was done in packaged fresh cut onions by regulating internal gas flow in a closed glass chamber devoid of CO_2 and O_2 with the syringe.

3.2.3.2.4 Super atmospheric oxygen (100%)

The flushing of 100% oxygen gas was done in packaged fresh cut onions by regulating internal gas flow in a closed glass chamber devoid of CO_2 and N_2 with the syringe.

3.2.3.3 Storage conditions

The pretreated fresh cut onion samples sealed in with different modified atmosphere conditions were stored in Celfrost make multideck and countertop retail display shelf refrigerated chiller with drop curtain, at two different temperatures viz; 7±1^0C and 0±1^0C.

3.3 Analysis of Fresh Cut Onion

The pretreated fresh cut onions during experimentation were analyzed for per cent moisture, physiological loss in weight, per cent decay, pH, TSS, anthocyanin, acidity, pyruvic acid, microbial limit tests, headspace gas concentration including volatiles, colour, flavour, appearance and overall acceptability. Three sets of 200g fresh cut onion per package were maintained. One set was used for recording physiological loss in weight, another for organoleptic studies and microbial count and third for physico-chemical analysis at three days interval till the termination of treatments. Fresh cut onions were analyzed for physical parameters, bio-chemical parameters and microbial limit tests prior to processing as well as during the experimentation.

3.3.1 Physical Parameters

3.3.1.1 Moisture (%)

The percent moisture was determined by drying known weight of sample into hot air oven (Metalab) at 60^0C for 24 hours for a constant weight. (A.O.A.C., 2010). The percent moisture was calculated by using the following formula:

$$\%\ \text{Moisture (w.b.)} = \frac{(W_2 - W_0)}{(W_1 - W_0)} \times 100$$

Weight of empty bag = W_0

Weight of bag + sample = W_1

Weight of bag + oven dried sample = W_2

3.3.1.2 Physiological loss in weight (%)

Weight loss was estimated based on the fresh produce weight and the significant change in physiological weight loss of fresh cut onion during storage was determined on the percentage basis. In all samplings, the fresh weight was measured by an electronic scale of ±0.01 g accuracy and reduction in weight over initial weight in percentage was calculated according to Ranganna (1986).

$$\text{Physiological loss in weight (\%)} = \frac{\text{Initial weight} - \text{Final weight}}{\text{Initial weight}} \times 100$$

Weighing was carried at three days interval on individually packaged samples at controlled air conditions to avoid moisture condensation on the packages. Minimum 7% PLW was taken into account as an acceptable parameter for the economic shelf life of fresh cut onion as suggested by Kays (1991) and Kang *et al*. (2002).

3.3.1.3 Decay (%)

The percent decay of fresh cut onions during storage was calculated based on a visual inspection of each fresh cut onion for infection. Per cent decay was calculated according to Gihan (2010) on the weight basis.

$$\text{Per cent Decay} = \frac{\text{Weight of decayed fresh cut onions}}{\text{Weight of sample taken}} \times 100$$

3.3.2 Chemical Parameters

3.3.2.1 pH

The pH of fresh cut onion was measured by using Perkin-Elmer pH meter. The pH meter calibrated every day of testing with buffer solutions at pH 4 and 7. Approximately 10g of onions were used to extract juice by adding 10 ml of distilled water. The pH of the resulting solution was measured twice and the average value was used to represent pH of the package. Between each sample, the pH probe was rinsed with distilled water and patted dry.

3.3.2.2 TSS (^{0}Brix)

The content of TSS in fresh cut onion was estimated by using Atago, Tokyo hand refractometer and the values were corrected to 20^{0}C with the help of temperature correction chart (A.O.A.C., 2005) and expressed in percentage.

3.3.2.3 Anthocyanins (mg per 100g)

Total anthocyanin content was estimated as per the procedure described by Ranganna (1986). Total anthocyanin content was calculated by using molecular extinction coefficient values.

Reagents:	Ethanol	95 %
	HCl	1.5 N

Blended ethanol and HCl in 85:15 proportion to obtain ethanolic HCl.

Procedure:

Exactly 10g of onions were taken and macerated in mortar and pestle using 75 milliliters of ethanolic HCl and transferred to 250 milliliter volumetric flask using few milliliters of ethanolic HCl for washing. The volumetric flasks were kept overnight in a refrigerator. The solution was filtered under vacuum through a Whatman No. 1 paper using Buchner funnel. Paper and funnel were washed repeatedly with ethanolic-HCl and the volume was made to 250 milliliters. To determine the optical density measurements within the optimum range of the instrument, 10 milliliter aliquots of the filtrate was diluted with ethanolic-HCl making 100 milliliter volume stored in dark for 2 hours and the colour was read at 535 nm on Spectronic-20 and O.D. values were recorded for quantitative measurement of the total anthocyanins expressed as mg/100g fresh weight.

Formula

$$\text{Total OD per 100g of sample} = \frac{\text{Absorbance at 535 nm X Volume made up of the extracts used for colour measurements X Total volume X 100}}{\text{ml of extract used X Weight of sample taken}}$$

$$\text{Total anthocyanin content (mg/ 100g of sample)} = \frac{\text{Total OD per 100 g of sample}}{\text{Extinction coefficient (98.2)}}$$

Where the extinction coefficient value is the average of anthocyanins in alcoholic media at 535 nm for one percent solution (10 mg per milliliter) is equal to 982. Therefore, the absorbance of a solution containing one mg per milliliter is equal to 98.2.

3.3.2.4 Acidity (%)

The titratable acidity of fresh cut onions was determined in terms of an anhydrous citric acid by titrating 10 milliliter juice against 0.1N NaOH using phenolphthalein as an indicator as per method advocated by A.O.A.C. (2005).

$$\text{Acidity (\%)} = \frac{\text{Titre} \times \text{N. of alkali} \times \text{Vol. made up} \times \text{Equi. wt. of acid}}{\text{Vol. of sample taken for estimation x Weight or Vol. of sample x 1000}} \times 100$$

3.3.2.5 Pyruvic acid (µmol/g fresh weight)

The onion pungency in terms of pyruvic acid content in fresh cut onions was determined by the modified method using dinitrophenylhydrazine as suggested by Anthon and Barrett (2003) over Schwimmer and Weston (1961).

Onion sample preparation

Onions were sliced in half and weighed. Onion sample was then homogenized without any additional water in a domestic electric blender for 2 min. After 30 min. at room temperature, the homogenized sample was filtered through a paper filter by the aid of vacuum. The total volume of the sample thus obtained was used for determination of pyruvic acid content.

Spectrophotometric determination of pyruvic acid

25 ml of the clarified onion filtrate was added to 1.0 ml of water in 13 mm x 100 mm test tube with a pipetter. To this was added 1.0 ml of 0.25 gl^{-1} DNPH in 1M HCl and the samples were placed in a 37^0C water bath. After 10 min the samples were removed from the water bath and 1.0 ml of 1.5M NaOH was added. The absorbance at 515 nm was then determined within 10 minutes. A blank and standards were prepared by adding 25µl of sodium pyruvate solutions ranging in concentration from 0 to 8 mM, instead of the onion sample. The standard calibration curve was prepared. The samples were kept for 8 min. at 37^0C for full colour

development. The sample reading was taken promptly after the addition of NaOH to avoid faint turbidity. The data were expressed as µmol of PA/g fresh weight.

3.3.3 In Package Atmosphere (Package Headspace Gas Concentration)

The in-package atmosphere (O_2, CO_2 and N_2) concentration was measured in terms of per cent with a Map-Pak Combi portable gas analyzer (Make: AGC Instruments, Ireland) having range 0-100 per cent.

The ethylene released by fresh cut onions in packages was recorded in parts per million by portable ethylene gas analyzer (Make Bioconservacion-ETHAN', FST Spain) having range 0-100 ppm.

3.3.4 Sensorial Analysis

Subjective overall acceptability measurements were done on the basis of colour, flavour (in and out package), appearance and microbial limit test parameters of samples by a panel of testers based on rating with nine point Hedonic scale suggested by Amerine *et al.* (1965) was considered (Appendix I). A score of 6 was considered the limit of acceptability.

3.3.5 Microbial Limit Tests

Microbial limit tests for fresh cut onions were carried out at the initial and final day of storage. The sample bag was cut and open in sterile conditions and 25 g of sample was taken and blended with 125 ml of sterile phosphate buffer solution (PBS) in stomacher bag by using stomacher for 1 minute at 200 rpm. Serial dilutions were prepared in 9 ml PBS.

From each dilution, 1 ml aliquots were aseptically pipetted for assessing total aerobic and plated onto TSA-YE. The plates with 20-200 colonies were considered for log cfu/ g value and were statistically analyzed.

The treatments exceeding the maximum range of testing and limits of detection of specific microbial species were terminated and discarded. The maximum permissible limit for aerobic microbial count is not greater than 1000 cfu/g sample.

3.3.6 Statistical Analysis

The data was reported as an average value of replicates with standard deviation. Analysis of variance (ANOVA) was performed using IBM SPSS Statistics-22 (Windows 8.1, Statistical Analysis). The level of significance for all the tests was $\alpha=0.05$. Followed by Duncan's Multiple Range Test ($P \leq 0.05$) was carried out to evaluate the significant statistical difference of data. For the data expressed as proportions arcsine transformation was applied before analysis.

3.3.7 Economics of Processed Products

The economics of the processed fresh cut onions was calculated from the cost of raw material required, labour cost, processing cost and miscellaneous charges.

4. RESULTS AND DISCUSSION

The present investigations on minimal processing of fresh cut onion cv. B-780 were undertaken to study effectiveness of types of cut, post-harvest treatments, packaging materials and modified atmosphere packaging on fresh cut onion. Experiment wise data pertaining to physico-chemical parameters, headspace gas concentration, pathological observation as well as sensorial analysis are presented hereunder with suitable headings.

4.1 Initial Physico-chemical Analysis of Onion cv. Baswant-780

The physico-chemical parameters of onion bulbs of cultivar B-780 (Table 4) revealed that the bulbs were round shaped slightly flattened both ends and dark red in colour. The average weight of the bulb was 67.70 g. The freshly harvested onion bulbs of cv. B-780 had 88.24 percent moisture, 5.28 pH, 0.38 percent acidity and 11.5^{0}Brix TSS. The anthocyanin content in the fresh onion bulbs was 37.20 mg/100g and pyruvic acid content was 5.242 µmol per g fresh weight. The total aerobic count in bulb recorded was 8.72 log cfu per g.

Table 4: Physico-chemical parameters of onion cv. Baswant-780

Sr. No.	Parameters	Content
1.	Shape of the onion bulbs	Round with slightly flattened ends
2	Colour of bulbs	Dark red
3	Average bulb weight (g)	67.70
4	Moisture (%)	88.24
5	pH	5.28
6	Acidity (%)	0.38
7	TSS (^{0}Brix)	11.5
8	Anthocyanin (mg per 100g)	37.20
9	Pyruvic acid (µmol per g fresh weight)	5.242
10	Total aerobic count (log cfu per g)	8.72

The physico-chemical parameters of the onion bulbs differ with variety, stage of maturity, type of soil, soil moisture and other growing conditions (Kalra *et al.*, 1995, Havey *et al.*, 2002). The physico-chemical parameters analyzed in the present investigation are in conformity with Dhumal *et al.* (2007).

4.2 Effectiveness of Post-harvest Treatments and Types of Cut on the Stability of Fresh Cut Onion

4.2.1 Physical Parameters

4.2.1.1 Percent moisture

The data presented in Table 5 and graphically depicted in Fig. 1 and 2 revealed that, at the beginning of the storage, the moisture content in fresh cut onion was 88.20%. It was significantly influenced by various types of cut and pretreatments. The interactions were found to be non-significant on 3rd, 6th, 9th, 12th and 15th day of storage. Interaction effect was significant only on 18th day of storage. With the advancement of storage period, decreasing trend in percent moisture content of fresh cut onion was recorded irrespective of treatments under study.

As regards types of cut, the whole peeled onion recorded minimum decrease in percent moisture than other types of cut. During the entire storage period whole peeled onion (A_4) recorded maximum percent moisture content (86.57%) while diced (A_2) and shredded onion (A_3) registered minimum moisture content (85.81%) at the end of 18th day of storage.

As the storage period advanced, the percent moisture content of pretreated onion decreased gradually but decrease was minimum than that of untreated fresh cut onion. Among all the treatments, fresh cut onion treated with 1% hexanal (T_3) registered slow decrease in moisture (86.14%) at the end of storage period i.e. 18th day. All other treatments were terminated on 15th day.

At all the stages (days) of storage, the whole peeled onion treated with effective freshness formulation (nano emulsion) containing 1% hexanal (A_4T_3) had the maximum retention of percent moisture than any other treatment combination. At the end of the 15th day of storage, the treatment combinations A_4T_3, A_4T_4 and A_1T_4 recorded maximum moisture content (86.97%) while the minimum moisture content (86.81%) was registered by untreated diced onion (A_3T_1).

Water loss in vegetables is determined by many factors, the most important of which is resistance exerted by the outer periderm or cuticle movement of water due to respiration. However, produce cuttings, results in resistance reduction of these barriers to transpiration. In present study, the moisture content of fresh cut onion was found to be decreased throughout the storage period irrespective of pretreatments and type of cutting, but the rate of decrease was slower throughout the storage period. This might be due to the low temperature and the polypropylene packaging arresting the water molecules released due to transpiration. Among the cut types, the diced onion exhibited maximum moisture loss. This was due to largest loss of surface water as resulted by a larger exposed surface area and more damaged cells as reported by Berno *et al.* (2014) in purple onion. Interestingly pretreatment with 1% hexanal had maximum retention in percent moisture. The results of the present findings are in agreement with Yaptenco *et al.* (2001) in highland vegetables and Anusuya *et al.* (2016) in Mango. The percent moisture of fresh cut onion in all pretreatments and cut types did not differ much at the beginning of storage period. The exogenous application of hexanal slowed down the lipogenases in the skin of fruits and vegetables which would have assisted in arresting moisture as reported by Anusuya (2014) in banana.

Table 5: Effect of types of cut and pretreatments on percent moisture of fresh cut onion during storage

Treatment combinations	Moisture (%)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1		87.96	87.80	87.56	87.25	86.85	-
A_1T_2		88.05	87.87	87.65	87.33	86.94	-
A_1T_3		88.09	87.91	87.67	87.37	86.97	86.36
A_1T_4		88.07	87.91	87.67	87.36	86.97	-
A_1T_5		88.06	87.89	87.65	87.34	86.95	-
A_1T_6		88.00	87.85	87.60	87.30	86.91	-
A_1T_7		88.03	87.85	87.62	87.30	86.92	-
A_1T_8		88.03	87.86	87.64	87.32	86.93	-
A_1T_9		87.99	87.83	87.58	87.28	86.89	-
A_2T_1		87.91	87.75	87.52	87.23	86.79	-
A_2T_2		88.00	87.82	87.61	87.30	86.88	-
A_2T_3		88.05	87.87	87.64	87.34	86.95	85.81
A_2T_4		88.03	87.86	87.63	87.33	86.91	-
A_2T_5		88.02	87.84	87.61	87.30	86.89	-
A_2T_6		87.97	87.80	87.55	87.27	86.84	-
A_2T_7		87.98	87.81	87.57	87.27	86.86	-
A_2T_8		88.00	87.82	87.58	87.29	86.87	-
A_2T_9		87.93	87.78	87.53	87.25	86.84	-
A_3T_1		87.93	87.78	87.53	87.23	86.81	-
A_3T_2		88.03	87.85	87.62	87.31	86.90	-
A_3T_3		88.07	87.89	87.66	87.35	86.95	85.81
A_3T_4	88.20	88.05	87.89	87.65	87.34	86.93	-
A_3T_5		88.05	87.87	87.63	87.32	86.92	-
A_3T_6		87.98	87.82	87.58	87.28	86.88	-
A_3T_7		88.00	87.83	87.58	87.29	86.89	-
A_3T_8		88.02	87.84	87.60	87.29	86.90	-
A_3T_9		87.96	87.80	87.55	87.26	86.84	-
A_4T_1		87.99	87.82	87.59	87.28	86.87	-
A_4T_2		88.07	87.89	87.66	87.35	86.94	-
A_4T_3		88.10	87.92	87.69	87.38	86.97	85.81
A_4T_4		88.09	87.92	87.69	87.38	86.97	-
A_4T_5		88.08	87.90	87.68	87.37	86.95	-
A_4T_6		88.03	87.86	87.63	87.32	86.91	-
A_4T_7		88.05	87.87	87.64	87.33	86.92	-
A_4T_8		88.05	87.88	87.65	87.34	86.93	-
A_4T_9		88.01	87.84	87.61	87.30	86.89	-
SE ±		0.0307	0.0343	0.0325	0.0284	0.0248	0.0282
CD at 1%		NS	NS	NS	0.1093	NS	0.1086
A_1		88.03	87.86	87.62	87.31	86.92	86.36
A_2	88.20	87.99	87.81	87.58	87.28	86.87	85.81
A_3		88.01	87.84	87.60	87.29	86.89	85.81
A_4		88.05	87.88	87.65	87.34	86.93	86.57
SE ±		0.0217	0.0114	0.0108	0.0095	0.0083	0.0094
CD at 1%		0.0834	0.0439	0.0417	0.0364	0.0317	0.0362
T_1		87.94	87.79	87.55	87.25	86.83	-
T_2		88.04	87.85	87.63	87.32	86.91	-
T_3		88.08	87.89	87.66	87.36	86.96	86.14
T_4		88.06	87.89	87.66	87.35	86.94	-
T_5	88.20	88.05	87.87	87.64	87.33	86.92	-
T_6		87.99	87.83	87.59	87.29	86.88	-
T_7		88.01	87.84	87.60	87.29	86.90	-
T_8		88.02	87.85	87.62	87.31	86.90	-
T_9		87.97	87.81	87.57	87.27	86.86	-
SE ±		0.0153	0.0171	0.0163	0.0142	0.0124	0.0141
CD at 1%		0.0589	0.0659	0.0626	0.0546	0.0476	0.0543

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% hexanal (EFF- nano emulsion)
T_4= 2% hexanal (EFF- nano emulsion)
T_5= 3% hexanal (EFF- nano emulsion)
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50μg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 6: Effect of types of cut and pretreatments on percent physiological loss in weight of fresh cut onion during storage

Treatment combinations	Physiological loss in weight (%)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	0.00	0.58	0.65	0.73	0.81	0.96	-
A_1T_2		0.35	0.52	0.58	0.67	0.75	-
A_1T_3		0.26	0.46	0.51	0.56	0.68	0.79
A_1T_4		0.29	0.49	0.55	0.59	0.70	-
A_1T_5		0.31	0.52	0.56	0.64	0.72	-
A_1T_6		0.43	0.58	0.65	0.75	0.85	-
A_1T_7		0.38	0.55	0.61	0.72	0.84	-
A_1T_8		0.38	0.54	0.61	0.69	0.81	-
A_1T_9		0.48	0.62	0.69	0.79	0.93	-
A_2T_1		0.59	0.66	0.75	0.83	1.02	-
A_2T_2		0.37	0.53	0.60	0.71	0.79	-
A_2T_3		0.31	0.48	0.51	0.59	0.69	0.79
A_2T_4		0.33	0.50	0.53	0.63	0.71	-
A_2T_5		0.36	0.52	0.58	0.69	0.74	-
A_2T_6		0.45	0.58	0.66	0.78	0.87	-
A_2T_7		0.41	0.56	0.65	0.76	0.85	-
A_2T_8		0.39	0.56	0.63	0.73	0.83	-
A_2T_9		0.48	0.63	0.69	0.8	1.00	-
A_3T_1		0.58	0.65	0.73	0.81	0.96	-
A_3T_2		0.35	0.52	0.58	0.67	0.75	-
A_3T_3		0.26	0.46	0.51	0.56	0.68	0.79
A_3T_4		0.29	0.49	0.55	0.59	0.70	-
A_3T_5		0.31	0.52	0.56	0.64	0.72	-
A_3T_6		0.43	0.58	0.65	0.75	0.85	-
A_3T_7		0.38	0.55	0.61	0.72	0.84	-
A_3T_8		0.38	0.54	0.61	0.69	0.81	-
A_3T_9		0.48	0.62	0.69	0.79	0.93	-
A_4T_1		0.43	0.55	0.58	0.67	0.79	-
A_4T_2		0.23	0.35	0.43	0.47	0.59	-
A_4T_3		0.17	0.28	0.35	0.42	0.49	0.55
A_4T_4		0.17	0.31	0.37	0.42	0.53	-
A_4T_5		0.20	0.34	0.40	0.46	0.59	-
A_4T_6		0.33	0.40	0.49	0.58	0.65	-
A_4T_7		0.31	0.38	0.49	0.56	0.63	-
A_4T_8		0.28	0.35	0.45	0.51	0.60	-
A_4T_9		0.37	0.41	0.51	0.61	0.69	-
SE ±		0.0258	0.0227	0.0255	0.0275	0.0239	0.0072
CD at 1%		NS	NS	NS	NS	0.0921	0.0278
A_1	0.00	0.38	0.54	0.61	0.69	0.80	0.79
A_2		0.41	0.56	0.62	0.72	0.83	0.79
A_3		0.38	0.55	0.60	0.68	0.80	0.79
A_4		0.28	0.37	0.45	0.52	0.61	0.55
SE ±		0.0086	0.0076	0.0085	0.0092	0.0080	0.0024
CD at 1%		0.0330	0.0291	0.0327	0.0353	0.0307	0.0093
T_1	0.00	0.55	0.62	0.70	0.78	0.93	-
T_2		0.32	0.48	0.54	0.63	0.72	-
T_3		0.25	0.42	0.47	0.53	0.63	0.73
T_4		0.27	0.44	0.50	0.55	0.66	-
T_5		0.29	0.47	0.52	0.60	0.69	-
T_6		0.42	0.53	0.61	0.71	0.80	-
T_7		0.37	0.51	0.59	0.69	0.79	-
T_8		0.33	0.50	0.57	0.63	0.76	-
T_9		0.45	0.57	0.64	0.75	0.88	-
SE ±		0.0129	0.0113	0.0128	0.0138	0.0120	0.0036
CD at 1%		0.0495	0.0437	0.0491	0.0529	0.0460	0.0139

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2

T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

4.2.1.2 Physiological loss in weight (%)

The observations recorded on percent physiological loss in weight of fresh cut onion are presented in Table 6 and graphically represented in Fig. 3 and 4. The data revealed that physiological loss in weight of fresh cut onions was significantly influenced by various types of cut and pretreatments. The interactions between types of cut and pretreatments were found to be non-significant on 3rd, 6th, 9th and 12th day of storage. The interaction effect was significant on 15th and 18th day of storage. The physiological loss in weight of fresh cut onions recorded increasing trend throughout the storage period irrespective of types of cut and pretreatments. However, the physiological loss in weight recorded in all the treatments was less than 1 percent only.

As regards the type of cut, the whole peeled onion recorded minimum increase in per cent physiological loss in weight than other types of cut and recorded 0.55 per cent PLW at the end of storage period i.e. 18 days after storage. While diced onion (A_2), shredded (A_3) and sliced onion (A_1) registered maximum physiological loss in weight (0.79%) after 18 days of the storage.

As the storage period advanced, the per cent physiological loss in weight of pretreated onions increased gradually but it was minimum than that of the untreated fresh cut onions. Among all the post-harvest pretreatments, fresh cut onions treated with 1% nano emulsion of hexanal (T_3) registered significantly minimum physiological loss in weight (0.63%) while highest physiological loss in weight was recorded by untreated fresh cut onions (0.93%) followed by UV-C radiation treated fresh cut onions (0.88%) on the 15th day of storage. At the end of storage period i.e. on the 18th day, significantly minimum PLW (0.73%) was recorded by fresh cut onions pretreated with nano emulsion of 1% hexanal.

As regards interaction effect of types of cut and pretreatments under study, minimum physiological loss in weight was recorded by the whole peeled onion treated with effective freshness formulation (nano emulsion) containing 1% hexanal (A_4T_3) than any other treatment combination under study throughout the storage period. At the end of the 15th day of storage, the treatment combination, A_2T_1 recorded maximum physiological loss in weight (1.02%) while a minimum physiological loss in weight (0.49%) was recorded in whole peeled onion treated with EFF (nano emulsion) containing 1% hexanal (A_4T_3). At the end of storage i.e. on the 18th day of storage, 1% hexanal treated whole peeled onion registered lowest PLW (0.55 %).

Fresh cut products are highly susceptible to physiological loss in weight because internal tissues are exposed to atmospheric conditions. The physiological loss in weight, during present investigation, registered increasing trend throughout the storage period irrespective of the types of cut and pretreatments under study. This might be due to the high energy required by the fresh cut onion to run the senescence process for which starch is converted into sugars and used as energy as reported by Ashwini *et al.* (2018) in banana. However, the decrease in physiological loss in weight was minimum in all the treatments and types of cut which might be attributed to the low storage temperature and proper curing of scaly onion bulbs after harvesting. The low storage temperature might be responsible for the reduced metabolism in cut onion and thus led to a decrease of the respiratory rate of fresh cut onions as reported by Berno *et al.* (2014) in fresh cut purple onions. As regards the type of cut, the diced onion registered a maximum physiological loss in weight as compared to the other types of cut. This might be attributed to the cell disruption and greater stress caused by the peeling, higher intensity of cutting and exposing more surface area than other types of cut as reported by Berno *et al.* (2014) in fresh cut purple onion, Blanchard *et al.* (1996) in freshly prepared diced yellow onion and Liu and Li (2006) in sliced onion.

In the present study, the pretreatment of hexanal had the lowest physiological weight loss as compared with the other pretreatments. Loss of fresh cut fruits and vegetables starts with the loss of integrity of the cell wall membrane, initiated by phospholipase D enzyme, playing important role in senescence of fresh commodities (Paliyath and Subramanium, 2008). The present study showed that the postharvest applications of hexanal inhibited PLD activity as reported by Jincy *et al.* (2017), Anusuya *et al.* (2016) in mango, Ashwini *et al.* (2018) in banana, Paliyath *et al.* (2003) and Paliyath and Murr (2008) in common fruits, vegetables and flowers. As regards interaction effect of types of cut and pretreatments applied, the whole peeled onion treated with hexanal had minimum PLW which may be attributed to lower intensity of cutting, cell disruption and smaller surface area along with PLD inhibitory action of hexanal increasing freshness of the product as reported by Berno *et al.* (2014) in fresh cut purple onion and Jincy *et al.* (2017) in mango.

4.2.1.3 Percent decay

The perusal of data presented in Table 7 and Fig. 5 and 6 indicated that no decay was observed up to the 5th day of storage in all the types of cut, pretreatments and their interactions also but it increased throughout the storage period thereafter in all the treatments under study, irrespective of storage period. Per cent of decay in fresh cut onion packages was significantly influenced by various pretreatments, types of cut and their interactions during storage.

As regards the types of cut tried, the whole peeled onion registered significantly lowest decay (4.31%) as compared to diced (5.02%), shredded onion (4.99%) and sliced (4.40%) forms at the end of storage period i.e. on the 18th day.

With the advancement of the storage period, per cent decay in packaged fresh cut onion increased gradually. At all the stages (days) of storage, pretreated fresh cut onions had minimum decay than the untreated control (T_1). No decay was observed in all the pretreated fresh cut onion samples till 9th day of storage. However, untreated control (T_1) recorded 4.13 per cent decay in fresh cut onion day 6th of storage. Fresh cut onions treated with 80 ppm sodium hypochlorite (T_2), 1 per cent calcium lactate (T_7) and UV-C radiation (T_9) recorded 1.64 %, 1.98 % and 1.98 % decay on day 9th of storage. No decay was recorded in fresh cut onions treated with hexanal, H_2O_2, sophorolipid extract and Nisin plus citric acid till the 12th day of storage. The minimum decay (3.11%) was recorded in fresh cut onions treated with 1% hexanal (T_3) followed 2% hexanal (3.19%).

Regarding treatment combinations, the minimum per cent decay (4.31%) was recorded by A_4T_3 treated fresh cut onions at the end of storage period i.e. after the 18th day of storage.

Gradual deterioration in packed fresh cut onion was observed during the present study as reported by Berno *et al.* (2014) in fresh cut purple onion. Product decay was intensified with an increase of wounded tissue surface that causes condensation in the packaging material which created aqueous environment accelerating the development of microorganisms. The low temperature might have contributed to longer preservation for up to 15 days in all treatments. The results of present findings are in close conformity with Kaur (2016) and Patil (2016) in minimally processed lettuce. The loss of membrane integrity, as well as damaging stress caused due to cutting, might have initiated decay in diced onions as reported by Jincy *et al.* (2017) in mango and Berno *et al.* (2014) in fresh cut purple onion, Piercey *et al.* (2012) in fresh cut onions, Liu and Li (2006) in sliced onion and Howard *et al.* (1994) in diced onions. Cantwell and Suslow (2002) in minimally processed products, O'Connor-Shaw *et al.* (1994) in minimally processed muskmelon cv. Honey Dew. As regards pretreatments, antimicrobial properties of sodium hypochlorite reported by Page *et al.* (2016) in diced onion, hydrogen peroxide reported by Beerli *et al.* (2004), sophorolipid studied by de Oliveira (2015) in fresh cut products, Nisin reported by Chen *et al.* (2016) in fresh cut onion, UV-C radiation reported by Hadjoak *et al.* (2008) in fresh cut onion and hexanal reported by Anusuya *et al.*(2016), Jincy *et al.* (2017) in mango had resulted in preventing decay in packed fresh cut onions. However, at the end of storage period i.e. after 18 days whole peeled onions pretreated with hexanal recorded minimum per cent decay. This might be attributed to hexanal vapour producing volatile compounds like (E)-2-hexanal which had antifungal properties and deterrence against postharvest pathogens in wide array of fruits and vegetables as reported by Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears. Also, the hexanal treatment might have caused the reduction in ethylene evolution rate in fresh cut onion preventing decay. Similar results were observed by Jincy *et al.* (2017) in mango.

Table 7: Effect of types of cut and pretreatments on decay of fresh cut onion during storage

Treatment combinations	Decay (%)				
	Storage period (days)				
	6	9	12	15	18
A_1T_1	3.64	6.98	9.55	12.99	-
A_1T_2	0.00	1.63	2.59	3.14	-
A_1T_3	0.00	0.00	1.22	3.05	4.70
A_1T_4	0.00	0.00	1.28	3.13	-
A_1T_5	0.00	0.00	1.38	3.52	-
A_1T_6	0.00	0.00	1.76	3.77	-
A_1T_7	0.00	1.97	2.98	3.65	-
A_1T_8	0.00	0.00	1.25	3.28	-
A_1T_9	0.00	1.98	2.89	3.99	-
A_2T_1	5.36	7.49	10.25	13.13	-
A_2T_2	0.00	1.68	2.80	3.36	-
A_2T_3	0.00	0.00	1.46	3.25	5.02
A_2T_4	0.00	0.00	1.49	3.37	-
A_2T_5	0.00	0.00	1.62	3.75	-
A_2T_6	0.00	0.00	1.98	3.99	-
A_2T_7	0.00	2.00	3.75	3.88	-
A_2T_8	0.00	0.00	1.48	3.37	-
A_2T_9	0.00	2.00	3.06	4.16	-
A_3T_1	4.26	7.26	10.85	13.07	-
A_3T_2	0.00	1.65	2.69	3.33	-
A_3T_3	0.00	0.00	1.36	3.15	4.99
A_3T_4	0.00	0.00	1.37	3.21	-
A_3T_5	0.00	0.00	1.58	3.66	-
A_3T_6	0.00	0.00	1.96	3.86	-
A_3T_7	0.00	1.99	3.51	3.75	-
A_3T_8	0.00	0.00	1.36	3.26	-
A_3T_9	0.00	1.99	2.99	4.09	-
A_4T_1	3.26	6.36	8.22	9.90	-
A_4T_2	0.00	1.61	2.12	3.07	-
A_4T_3	0.00	0.00	1.02	2.99	4.31
A_4T_4	0.00	0.00	1.02	3.06	-
A_4T_5	0.00	0.00	1.26	3.42	-
A_4T_6	0.00	0.00	1.54	3.65	-
A_4T_7	0.00	1.94	2.85	3.55	-
A_4T_8	0.00	0.00	1.03	3.16	-
A_4T_9	0.00	1.95	2.46	3.57	-
SE ±	0.0256	0.0718	0.1077	0.0084	0.0078
CD at 1%	0.0984	0.2761	0.4141	0.0323	0.0301
A_1	0.40	1.40	2.87	4.50	4.40
A_2	0.60	1.46	3.21	4.69	5.02
A_3	0.47	1.43	3.18	4.60	4.99
A_4	0.36	1.32	2.50	4.04	4.31
SE ±	0.0085	0.0239	0.0359	0.0028	0.0026
CD at 1%	0.0328	0.0920	0.1380	0.0108	0.010
T_1	4.13	7.02	9.82	12.27	-
T_2	0.00	1.64	2.66	3.22	-
T_3	0.00	0.00	1.37	3.11	4.76
T_4	0.00	0.00	1.40	3.19	-
T_5	0.00	0.00	1.57	3.59	-
T_6	0.00	0.00	1.92	3.82	-
T_7	0.00	1.98	3.38	3.71	-
T_8	0.00	0.00	1.39	3.26	-
T_9	0.00	1.98	2.96	3.95	-
SE ±	0.0128	0.0359	0.0538	0.0042	0.0039
CD at 1%	0.0492	0.1381	0.2070	0.0162	0.0150

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin ($50\mu g\text{-}mL^{-1}$) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

4.2.2 Chemical Parameters

4.2.2.1 pH

Initial pH value of the fresh cut onion recorded was 5.25 (Table 8). The data revealed that pH content of fresh cut onion was significantly influenced by various pretreatments on the 15^{th} and 18^{th} day of storage and types of cut on 3^{rd}, 6^{th}, 12^{th}, 15^{th} and 18^{th} day of storage. The interactions between pretreatments and types of the cut were found to be significant only at the end of storage i.e. on the 18^{th} day. The pH content of fresh cut onion decreased throughout the storage period irrespective of types of cut and pretreatments.

As regards the types of cut, pH content gradually decreased through the storage period. The maximum pH (4.94) was recorded in whole peeled onion (A_4) while the diced onion (A_2) and shredded onion (A_3) recorded 4.87 and 4.88 pH on the 18^{th} day of storage.

Among the pretreatments, 1% hexanal recorded 4.90 pH on the 18^{th} day of storage. On the 15^{th} day of storage, pH recorded by untreated onion (T_1) was 4.84 while of fresh cut onion with 1 per cent hexanal recorded a slow decrease in pH (4.94). Pretreatment with 2 per cent hexanal (4.93) and 6 per cent H_2O_2 (4.92) was at par with T_3.

The interaction effects between types of cut and pretreatments for pH of fresh cut onion were non-significant through the storage period. However, significant differences were observed on day 18^{th} of storage. Treatment combination A_4T_3 recorded maximum pH (4.94) followed by A_1T_3 (4.92) while the maximum change in pH was observed in A_2T_3 (4.87) at the end of the storage period.

The acidity and pH were related to the organic acid contents, greater stress caused due to higher intensity of cut might have resulted in larger production of acids, and consequently, an increase in acidity and slow reduction in pH content of fresh cut onion as reported by Berno *et al.* (2014) in fresh cut purple onion. This slow decrease in pH with the relatively slow increase in acidity might be due to the increased microbial growth in minimally processed onions, producing organic acids during storage irrespective of pretreatments under study. The results of the present investigation under study are in conformity with that the results reported by of Forney *et al.* (2012) in onion. The pretreatment with hexanal reported the maximum pH throughout the storage period. These results implied that hexanal vapours were effective to delay the breakdown of starch content and delaying senescence. Similar results were reported by Ashwini *et al.* (2018) in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

4.2.2.2 Total soluble solids (^{0}Brix)

The perusal of data (Table 9) revealed that at the beginning of the storage, TSS of fresh cut onion recorded was 11.54^{0}Brix and found to be decreased throughout the storage period. The significant differences in TSS were recorded due to types of cut, pretreatments and

Table 8: Effect of types of cut and pretreatments on pH of fresh cut onion during storage

Treatment combinations	pH						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	5.25	5.18	5.13	5.12	5.08	4.85	-
A_1T_2		5.20	5.17	5.15	5.12	4.94	-
A_1T_3		5.22	5.18	5.17	5.13	4.96	4.92
A_1T_4		5.21	5.18	5.16	5.13	4.95	-
A_1T_5		5.21	5.17	5.16	5.13	4.94	-
A_1T_6		5.19	5.15	5.14	5.10	4.88	-
A_1T_7		5.20	5.15	5.14	5.11	4.90	-
A_1T_8		5.20	5.16	5.15	5.11	4.91	-
A_1T_9		5.18	5.14	5.13	5.08	4.87	-
A_2T_1		5.15	5.09	5.07	5.01	4.81	-
A_2T_2		5.18	5.12	5.11	5.07	4.87	-
A_2T_3		5.20	5.15	5.13	5.10	4.92	4.87
A_2T_4		5.20	5.14	5.13	5.09	4.91	-
A_2T_5		5.18	5.13	5.12	5.08	4.88	-
A_2T_6		5.16	5.10	5.09	5.05	4.84	-
A_2T_7		5.17	5.11	5.10	5.05	4.84	-
A_2T_8		5.17	5.11	5.11	5.06	4.85	-
A_2T_9		5.15	5.10	5.08	5.03	4.83	-
A_3T_1		5.16	5.11	5.10	5.04	4.83	-
A_3T_2		5.19	5.14	5.13	5.09	4.89	-
A_3T_3		5.20	5.16	5.15	5.12	4.94	4.88
A_3T_4		5.20	5.15	5.14	5.11	4.92	-
A_3T_5		5.19	5.14	5.14	5.10	4.90	-
A_3T_6		5.17	5.12	5.11	5.07	4.86	-
A_3T_7		5.18	5.13	5.12	5.08	4.86	-
A_3T_8		5.18	5.13	5.12	5.08	4.87	-
A_3T_9		5.17	5.11	5.11	5.06	4.86	-
A_4T_1		5.19	5.16	5.15	5.11	4.87	-
A_4T_2		5.20	5.18	5.17	5.13	4.95	-
A_4T_3		5.23	5.19	5.19	5.16	4.97	4.94
A_4T_4		5.22	5.19	5.18	5.15	4.96	-
A_4T_5		5.22	5.19	5.17	5.14	4.95	-
A_4T_6		5.20	5.17	5.15	5.13	4.91	-
A_4T_7		5.20	5.17	5.16	5.13	4.92	-
A_4T_8		5.20	5.18	5.16	5.13	4.93	-
A_4T_9		5.19	5.16	5.15	5.11	4.91	-
SE ±		0.0281	0.0278	0.0250	0.0260	0.0232	0.0051
CD at 1%		NS	NS	NS	NS	NS	0.0198
A_1	5.25	5.20	5.16	5.14	5.11	4.91	4.92
A_2		5.17	5.11	5.10	5.06	4.86	4.87
A_3		5.18	5.13	5.12	5.08	4.88	4.88
A_4		5.20	5.17	5.16	5.13	4.93	4.94
SE ±		0.0094	0.0093	0.0083	0.0087	0.0077	0.0017
CD at 1%		NS	0.0356	0.0320	0.0334	0.0297	0.0066
T_1	5.25	5.17	5.12	5.11	5.06	4.84	-
T_2		5.19	5.15	5.14	5.10	4.91	-
T_3		5.21	5.17	5.16	5.13	4.94	4.90
T_4		5.21	5.16	5.15	5.12	4.93	-
T_5		5.20	5.16	5.15	5.11	4.92	-
T_6		5.18	5.13	5.12	5.09	4.87	-
T_7		5.19	5.14	5.13	5.09	4.88	-
T_8		5.19	5.14	5.13	5.09	4.89	-
T_9		5.17	5.12	5.12	5.07	4.86	-
SE ±		0.0140	0.0139	0.0125	0.0130	0.0116	0.0026
CD at 1%		NS	NS	NS	NS	0.0446	0.0099

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

their interactions under study throughout the storage period. The total soluble solids content was decreased slowly throughout the storage period irrespective of the pretreatments and types of cut.

After 18 days, whole peeled onion (A_4) recorded a minimum decrease in TSS value (10.52^0Brix) than that of other types of cut. The maximum decrease was recorded in diced onion (A_2) followed by shredded onion (10.36^0Brix).

Among the various pretreatments, 1 per cent hexanal dipping (T_3) recorded maximum TSS throughout the storage period than that of other pretreatments. On 15th day of storage, maximum decrease in TSS value of fresh cut onion (10.22^0Brix) was recorded in control (T_1) while pretreatment with 1 and 2% hexanal (T_3 and T_4) and nisin ($50\mu g\text{-}ml^{-1}$ plus citric acid (1% w/v) (T_9) registered maximum TSS (10.56^0Brix). At the end of storage period i.e. after the 18th day, 1% hexanal treated fresh cut onion recorded minimum decrease in TSS content (10.37^0Brix).

As regards, interaction of different types of cut and pretreatments, whole peeled onion pretreated with 1% hexanal (A_4T_3) recorded a minimum decrease in TSS throughout the storage period. On the 15th day of storage, significantly minimum decrease in TSS (10.61^0Brix) was recorded in A_4T_3 while it was maximum (10.22^0Brix) in A_1T_1 treatment combination. At the end of storage period i.e. after 18th day of storage, A_4T_3 treatment combination recorded 10.41^0Brix TSS in fresh cut onion.

A decrease in TSS content of fresh cut onion over a period of time might be attributed to the damage caused in the cell structure by the cutting process, thus causing part of its content to be eliminated as reported by Berno *et al.* (2014) in fresh cut purple onions and decompartmentalization of enzymes and substrates altering TSS and flavor as reported by Blanchard *et al.* (1996) in diced yellow onions, Rico *et al.* (2007) and Hodges and Toivonen (2008) in fresh cut fruits and vegetables. Also, utilisation of soluble solids as a source of energy reserves over time could be another reason for the reduction in TSS of fresh cut onions (Brecht *et al.*, 2007). The maximum decrease in TSS was recorded in diced onion as compared to other cut types. This might be due to the increased intensity of cut as reported by Toivonen and DeEll (2002) in fresh cut fruits and vegetables and Baskaran *et al.* (2015) in Fresh cut onions. The pretreatment with hexanal registered maximum TSS in the fresh cut onion throughout the storage period. This might be attributed to the effectiveness of the hexanal in delaying the breakdown of starch content as reported by Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) in Tomato and Ashwini *et al.* (2018) in banana. The hexanal treated fresh cut onions had lower TSS content because of decreased reducing, non-reducing and total sugars contents. The sugars tended to accumulate in tissues and increase the structural integrity of tissues. The results of present findings are in conformity with Sharma *et al.* (2010) in sweet cherry, Jincy *et al.* (2017) and Anusuya *et al.* (2016) in mango.

Table 9: Effect of types of cut and pretreatments on TSS (^{0}Brix) content of fresh cut onion during storage

Treatment combinations	TSS (^{0}Brix)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	11.54	11.46	11.44	10.94	10.39	10.22	-
A_1T_2		11.51	11.48	11.20	10.95	10.54	-
A_1T_3		11.52	11.49	11.21	10.97	10.61	10.37
A_1T_4		11.52	11.49	11.20	10.96	10.60	-
A_1T_5		11.51	11.47	11.17	10.85	10.49	-
A_1T_6		11.50	11.46	11.16	10.82	10.46	-
A_1T_7		11.49	11.47	11.15	10.80	10.44	-
A_1T_8		11.52	11.48	11.20	10.97	10.60	-
A_1T_9		11.50	11.45	11.15	10.81	10.44	-
A_2T_1		11.43	11.40	10.91	10.35	10.20	-
A_2T_2		11.49	11.46	11.14	10.91	10.49	-
A_2T_3		11.50	11.47	11.16	10.92	10.51	10.35
A_2T_4		11.49	11.47	11.15	10.92	10.50	-
A_2T_5		11.48	11.43	11.12	10.82	10.42	-
A_2T_6		11.47	11.42	11.11	10.80	10.41	-
A_2T_7		11.46	11.41	11.10	10.77	10.39	-
A_2T_8		11.49	11.46	11.15	10.91	10.50	-
A_2T_9		11.46	11.41	11.12	10.78	10.39	-
A_3T_1		11.44	11.41	10.92	10.36	10.22	-
A_3T_2		11.50	11.46	11.15	10.92	10.51	-
A_3T_3		11.51	11.47	11.18	10.93	10.52	10.36
A_3T_4		11.51	11.47	11.18	10.93	10.52	-
A_3T_5		11.49	11.44	11.13	10.82	10.43	-
A_3T_6		11.48	11.44	11.14	10.81	10.41	-
A_3T_7		11.47	11.42	11.11	10.78	10.40	-
A_3T_8		11.51	11.47	11.17	10.93	10.52	-
A_3T_9		11.47	11.43	11.13	10.80	10.40	-
A_4T_1		11.47	11.44	10.99	10.41	10.24	-
A_4T_2		11.52	11.49	11.21	10.98	10.56	-
A_4T_3		11.53	11.50	11.22	10.99	10.62	10.41
A_4T_4		11.53	11.50	11.21	10.98	10.61	-
A_4T_5		11.52	11.49	11.18	10.87	10.53	-
A_4T_6		11.52	11.48	11.17	10.85	10.51	-
A_4T_7		11.50	11.48	11.16	10.81	10.50	-
A_4T_8		11.52	11.51	11.21	10.98	10.63	-
A_4T_9		11.50	11.48	11.20	10.85	10.50	-
SE ±		0.0009	0.0009	0.0009	0.0010	0.0010	0.0005
CD at 1%		0.0035	0.0035	0.0034	0.0037	0.0040	0.0019
A_1	11.54	11.50	11.47	11.15	10.84	10.49	10.37
A_2		11.47	11.44	11.10	10.80	10.42	10.35
A_3		11.48	11.44	11.12	10.81	10.44	10.36
A_4		11.51	11.48	11.17	10.86	10.52	10.41
SE ±		0.0003	0.0003	0.0003	0.0003	0.0003	0.0002
CD at 1%		0.0012	0.0012	0.0011	0.0012	0.0013	0.0006
T_1	11.54	11.45	11.42	10.94	10.38	10.22	-
T_2		11.51	11.47	11.17	10.94	10.53	-
T_3		11.52	11.48	11.19	10.95	10.56	10.37
T_4		11.51	11.48	11.18	10.95	10.56	-
T_5		11.50	11.46	11.15	10.84	10.46	-
T_6		11.49	11.45	11.14	10.82	10.45	-
T_7		11.48	11.44	11.13	10.79	10.43	-
T_8		11.51	11.48	11.18	10.95	10.56	-
T_9		11.48	11.44	11.15	10.81	10.43	-
SE ±		0.0005	0.0004	0.0004	0.0005	0.0005	0.0002
CD at 1%		0.0017	0.0017	0.0017	0.0018	0.0020	0.0009

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% hexanal (EFF- nano emulsion)
T_4= 2% hexanal (EFF- nano emulsion)
T_5= 3% hexanal (EFF- nano emulsion)
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 10: Effect of types of cut and pretreatments on acidity content of fresh cut onion during storage

Treatment combinations	Acidity (%)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	0.35	0.53	0.59	0.61	0.65	0.70	-
A_1T_2		0.44	0.47	0.53	0.57	0.61	-
A_1T_3		0.38	0.43	0.45	0.52	0.55	0.63
A_1T_4		0.38	0.44	0.48	0.54	0.58	-
A_1T_5		0.42	0.44	0.49	0.56	0.58	-
A_1T_6		0.49	0.55	0.58	0.63	0.66	-
A_1T_7		0.47	0.53	0.57	0.62	0.64	-
A_1T_8		0.46	0.50	0.55	0.60	0.62	-
A_1T_9		0.51	0.57	0.60	0.65	0.68	-
A_2T_1		0.56	0.65	0.68	0.71	0.72	-
A_2T_2		0.48	0.53	0.57	0.60	0.63	-
A_2T_3		0.42	0.44	0.49	0.56	0.60	0.65
A_2T_4		0.40	0.46	0.47	0.53	0.61	-
A_2T_5		0.44	0.46	0.53	0.59	0.63	-
A_2T_6		0.53	0.61	0.63	0.67	0.68	-
A_2T_7		0.52	0.59	0.60	0.65	0.66	-
A_2T_8		0.49	0.55	0.58	0.64	0.65	-
A_2T_9		0.55	0.64	0.65	0.70	0.70	-
A_3T_1		0.55	0.63	0.66	0.68	0.71	-
A_3T_2		0.46	0.49	0.55	0.60	0.61	-
A_3T_3		0.39	0.44	0.46	0.55	0.58	0.65
A_3T_4		0.39	0.45	0.51	0.56	0.58	-
A_3T_5		0.44	0.46	0.51	0.58	0.60	-
A_3T_6		0.51	0.56	0.59	0.66	0.66	-
A_3T_7		0.48	0.55	0.59	0.65	0.63	-
A_3T_8		0.48	0.51	0.57	0.63	0.63	-
A_3T_9		0.53	0.59	0.62	0.68	0.68	-
A_4T_1		0.50	0.54	0.59	0.63	0.68	-
A_4T_2		0.42	0.45	0.49	0.53	0.57	-
A_4T_3		0.37	0.39	0.41	0.46	0.53	0.61
A_4T_4		0.37	0.40	0.44	0.46	0.55	-
A_4T_5		0.39	0.42	0.47	0.49	0.55	-
A_4T_6		0.47	0.52	0.55	0.61	0.64	-
A_4T_7		0.45	0.51	0.53	0.59	0.60	-
A_4T_8		0.45	0.49	0.51	0.56	0.58	-
A_4T_9		0.48	0.54	0.57	0.63	0.67	-
SE ±		0.0198	0.0170	0.0185	0.0216	0.0048	0.0071
CD at 1%		NS	NS	NS	0.0831	0.0186	0.0274
A_1	0.35	0.45	0.50	0.54	0.59	0.63	0.63
A_2		0.49	0.55	0.58	0.63	0.66	0.65
A_3		0.47	0.52	0.56	0.62	0.63	0.65
A_4		0.43	0.47	0.50	0.55	0.60	0.61
SE ±		0.0066	0.0057	0.0062	0.0072	0.0016	0.0024
CD at 1%		0.0253	0.0218	0.0238	0.0277	0.0062	0.0091
T_1	0.35	0.53	0.60	0.63	0.66	0.71	-
T_2		0.45	0.48	0.53	0.57	0.60	-
T_3		0.39	0.42	0.45	0.52	0.57	0.64
T_4		0.38	0.44	0.47	0.52	0.58	-
T_5		0.42	0.45	0.50	0.55	0.59	-
T_6		0.50	0.56	0.59	0.64	0.66	-
T_7		0.48	0.54	0.57	0.62	0.64	-
T_8		0.47	0.51	0.55	0.60	0.62	-
T_9		0.52	0.58	0.61	0.66	0.68	-
SE ±		0.0099	0.0085	0.0093	0.0108	0.0024	0.0036
CD at 1%		0.0380	0.0327	0.0357	0.0416	0.0093	0.0137

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50μg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

4.2.2.3 Acidity (%)

The observations recorded on per cent acidity of fresh cut onion are presented in Table 10. The data revealed that initial acidity recorded at the beginning of storage was 0.35 per cent. The acidity of the packaged fresh cut onion was significantly influenced by various types of cut, pretreatments and interactions. The interaction effects were found to be non-significant on 3rd, 6th and 9th day of storage. The acidity content of the packed fresh cut onions was increased gradually throughout the storage period irrespective of the types of cut and pretreatments.

As the storage period advanced, acidity content of fresh onions increased gradually, but increase was minimum in whole peeled onion than that of diced, shredded and sliced onions. At the end of 15th day of storage, the whole peeled onion (A_4) recorded 0.60% acidity while 0.66 per cent acidity was recorded by diced onion (A_2).

Among all the pretreatments, minimum increase in acidity was recorded in all the pretreatments than that of untreated fresh cut onion. Among all the pretreatments, 1% hexanal registered minimum change in acidity and recorded 0.64% acidity at the end of the storage period i.e. after 18th day.

Regarding the treatment combinations, A_4T_3 registered minimum changes in the acidity of fresh cut onion. On 18th day of storage, the same treatment recorded 0.61% acidity.

In the present study, significant increase in acidity was noted. The acidity and pH were related to the organic acid contents, greater stress caused due to higher intensity of cut might have resulted in larger production of acids, and consequently, an increase in acidity and slow reduction in pH content of fresh cut onion as reported by Berno *et al.* (2014) in fresh cut purple onion. This increase in acidity may be attributed to the increased microbial growth in minimally processed onions, producing organic acids during storage irrespective of pretreatments under study. The results of a present investigation are in conformity with the results reported by Forney *et al.* (2012) in onion. The pretreatment with hexanal reported the minimum change in acidity throughout the storage period. These results implied that hexanal vapors were effective to delay the breakdown of starch content into sugars, delayed senescence and thus had minimum changes in acidity over the period of time. Similar results were reported by Ashwini *et al.* (2018) in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

4.2.2.4 Anthocyanins (mg per 100g)

The data given in Table 11 and graphically represented in Fig. 7 and 8 revealed that at the beginning of the storage, initial anthocyanin content in fresh cut onion was 37.17 mg per 100g and was significantly influenced by pretreatments, types of cut and interactions. The interaction effect was found to be non-significant on the 9th and 12th day of storage. Initially, after pretreatments, the anthocyanin content in fresh cut onion was found to be decreased and then increased gradually till 9th day and again showed decreased trend thereafter.

Among the types of cut under study, whole peeled onion (A_4) had minimum change in anthocyanin content (37.06 mg per 100g) while maximum change was recorded in diced onions (A_2) (36.83 mg per 100g) on the 3rd day of storage. At the end of storage i.e. after 18th day of storage, the maximum anthocyanin content was observed in A_4 (37.75 mg per 100g) while minimum anthocyanin content was recorded in A_2 and A_3 (37.71 mg per 100g).

Among all the pretreatments, initially on the 3rd day of storage, highest (37.09 mg per 100g) and lowest (36.84 mg per 100g) anthocyanin content was recorded in T_6 and T_8 treatments respectively. At the end of 15th day of storage, minimum anthocyanin content (37.21 mg per 100g) was recorded in treatment with 1% sophorolipid extract (T_6) while maximum (37.80 mg per 100 g) was recorded in pretreatment with 1% hexanal (T_3). At the of the storage period i.e. after 18th day of storage, T_3 treatment recorded 37.73 mg per 100g anthocyanins in fresh cut onion.

Regarding treatment combinations, A_4T_3 recorded minimum changes in total anthocyanins. At the end of the storage period, the treatment combination A_4T_3 recorded 37.75 mg per 100g total anthocyanins in fresh cut onion.

Colour is an important parameter in determining the sensorial quality of pigmentate fruits and vegetables. The anthocyanins are important in these aspects. In the present investigation, the anthocyanins in fresh cut onion decreased after pretreatments. This decrease was due to the water solubility of the anthocyanins and slight loss of pigment due to immersion in water as observed by Perez-Gregorio *et al.* (2011) in sliced red onion and Dhumal (2012) in Pomegranate. The considerable increase in anthocyanin of fresh cut onion recorded in diced, shredded and sliced onion as compared to whole peeled onion irrespective of pretreatments applied. This increase in anthocyanin in later stages of storage was associated with the slow biosynthesis of coloured pigments and/or *de novo* synthesis of anthocyanins at low temperatures as a response against the stress caused by cutting process and low temperature. The anthocyanins increase the tolerance of the vegetables and fruits to refrigeration temperature as reported by Ferreres *et al.* (1996) in in shredded red onion, Perez-Greogorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions, Gould and Lister (2006) in fruits and vegetables and Perez-Vicente *et al.* (2004) in pomegranate cv. Mollar. The anthocyanin during storage and at the end of product shelf-life, presented in the last cell layer of the epidermal tissue migrated to other cells that did not contain the pigment, thus turning the onions pinkish. The migration occurred more intensely in the diced onions, indicating that the intensity of cut affected the process as reported by Berno *et al.* (2014) in fresh cut purple onion. As regards pretreatments, the initial decrease in anthocyanin might be attributed to the increased activity of polyphenoloxidase (PPO) activity as reported by Dhumal (2012) in pomegranate cv. Bhagawa. However, the minimum changes were observed in hexanal pretreated fresh cut onion. This might be due to enzyme inhibitory effect of hexanal and thereby increasing cell integrity and membrane preservation as reported by Sharma *et al.* (2010) in sweet cherry.

4.2.2.5 Pyruvic acid (µmol/g fresh weight)

The data shown in Table 12 and graphically represented in Fig. 9 and 10 revealed that at the beginning of the storage, pyruvic acid content in fresh cut onion was 5.285 µmol/g fresh weight and was significantly influenced by types of cut, pretreatments and interactions. The interaction effect was found to be significant throughout the storage. The pyruvic acid content in the fresh cut showed decreasing trend irrespective of the types of cut and pretreatments.

In respect of types of cut, the maximum decrease in pyruvic acid content was recorded in diced and shredded onion as compared to a sliced and whole peeled onion. Among the types of cut, diced onions (A_2) recorded maximum loss in pyruvic acid content (4.836 µmol/g fresh weight) while maximum retention recorded in whole peeled onion (A_4) (5.266 µmol/g fresh weight) on the 3rd day of storage. At the end of storage i.e. after 18th day of storage, the maximum pyruvic acid was observed in A_4 (5.000 µmol/g fresh weight) while minimum pyruvic acid was recorded in A_2 (3.458 µmol/g fresh weight).

Among all the pretreatments under study, on the 3rd day of storage, maximum (5.112 µmol/g fresh weight) and minimum pyruvic acid (4.998 µmol/g fresh weight) were recorded in T_3 and T_1 treatments respectively. At the end of 15th day of storage, maximum pyruvic acid (4.482 µmol/g fresh weight) was recorded in T_3 while minimum (4.419 µmol/g fresh weight) was recorded in T_1. At the of the storage period i.e. after 18th day of storage, T_3 treatment recorded maximum pyruvic acid (4.260 µmol/g fresh weight) in fresh cut onion.

Regarding treatment combinations, A_4T_3 recorded minimum changes in pyruvic acid. At the end of the storage period, the treatment combination A_4T_3 recorded 5.000 µmol/g fresh weight pyruvic acid followed by A_1T_3 (4.425 µmol/g fresh weight) whereas A_2T_3 recorded minimum pyruvic acid (3.458 µmol/g fresh weight).

Pyruvic acid is a reliable indicator of pungency, which is a stable product from the hydrolysis of S-ak(en)yl-1-cysteinesulphoxides (ACSOs). When the onion cells are disrupted by cutting and chopping, the enzyme alliinase is released in the cytoplasm, which hydrolyses the ACSOs to many volatile sulphur compounds, pyruvate and ammonia (Lancaster and Boland, 1990; Lancaster and Kelley, 1983). The characteristic aroma and flavor of onions are mainly originated from thiosulfinate volatile compounds and is mainly recognized as a measure of pungency and a flavor index in onions (Lanzotti, 2006). In the present investigations, a gradual loss in pyruvic acid occurred during storage of fresh cut onion irrespective of pretreatments and types of cut. A lower pyruvic acid content in all the treatments might be attributed to the higher

Table 11: Effect of types of cut and pretreatments on anthocyanin content (mg per 100g) of fresh cut onion during storage

Treatment combinations	Anthocyanins (mg per 100g)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	37.17	36.95	37.23	37.70	37.65	37.61	-
A_1T_2		37.01	37.25	37.81	37.81	37.72	-
A_1T_3		37.03	37.31	37.81	38.00	37.78	37.73
A_1T_4		37.01	37.28	37.75	37.58	37.42	-
A_1T_5		37.10	37.25	37.75	37.46	37.39	-
A_1T_6		37.10	37.10	37.40	37.29	37.19	-
A_1T_7		36.94	37.15	37.52	37.43	37.31	-
A_1T_8		37.13	37.30	37.43	37.70	37.70	-
A_1T_9		36.94	37.15	37.43	37.31	37.27	-
A_2T_1		36.88	37.17	37.69	37.60	37.57	-
A_2T_2		36.98	37.20	37.77	37.78	37.68	-
A_2T_3		36.92	37.23	37.77	37.96	37.77	37.71
A_2T_4		36.92	37.21	37.70	37.51	37.36	-
A_2T_5		37.00	37.19	37.68	37.41	37.35	-
A_2T_6		37.03	37.10	37.35	37.24	37.19	-
A_2T_7		36.87	37.12	37.47	37.40	37.26	-
A_2T_8		37.01	37.27	37.39	37.69	37.63	-
A_2T_9		36.87	37.12	37.35	37.24	37.20	-
A_3T_1		36.91	37.19	37.69	37.63	37.58	-
A_3T_2		37.00	37.20	37.78	37.81	37.71	-
A_3T_3		36.96	37.27	37.79	37.98	37.77	37.71
A_3T_4		36.94	37.23	37.73	37.54	37.38	-
A_3T_5		37.05	37.22	37.71	37.42	37.36	-
A_3T_6		37.08	37.10	37.38	37.27	37.20	-
A_3T_7		36.91	37.12	37.51	37.41	37.28	-
A_3T_8		37.06	37.29	37.42	37.69	37.65	-
A_3T_9		36.91	37.12	37.39	37.26	37.22	-
A_4T_1		36.98	37.26	37.72	37.67	37.67	-
A_4T_2		37.03	37.27	37.84	37.86	37.78	-
A_4T_3		37.09	37.36	37.82	38.02	37.80	37.75
A_4T_4		37.09	37.36	37.77	37.60	37.44	-
A_4T_5		37.14	37.30	37.76	37.49	37.42	-
A_4T_6		37.15	37.11	37.46	37.33	37.26	-
A_4T_7		36.95	37.18	37.55	37.48	37.35	-
A_4T_8		37.15	37.37	37.48	37.74	37.74	-
A_4T_9		36.94	37.19	37.45	37.34	37.34	-
SE ±		0.0115	0.0124	0.0112	0.0102	0.0094	0.0025
CD at 1%		0.0442	0.0478	NS	NS	0.0361	0.0096
A_1	37.17	37.02	37.22	37.62	37.58	37.49	37.74
A_2		36.83	37.18	37.57	37.54	37.46	37.71
A_3		36.98	37.19	37.60	37.56	37.46	37.71
A_4		37.06	37.27	37.65	37.61	37.53	37.75
SE ±		0.0038	0.0041	0.0037	0.0034	0.0031	0.0008
CD at 1%		0.0147	0.0159	0.0143	0.0131	0.0120	0.0032
T_1	37.17	36.93	37.21	37.70	37.64	37.61	-
T_2		37.00	37.23	37.80	37.81	37.72	-
T_3		37.00	37.29	37.80	37.99	37.80	37.73
T_4		36.99	37.27	37.74	37.56	37.40	-
T_5		37.07	37.24	37.72	37.45	37.38	-
T_6		37.09	37.10	37.40	37.28	37.21	-
T_7		36.92	37.14	37.51	37.43	37.30	-
T_8		36.84	37.31	37.43	37.71	37.68	-
T_9		36.92	37.14	37.41	37.29	37.26	-
SE ±		0.0057	0.0062	0.0056	0.0051	0.0047	0.0012
CD at 1%		0.0221	0.0239	0.0215	0.0196	0.0181	0.0048

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 12: Effect of types of cut and pretreatments on pyruvic acid (µmol/g of fresh weight) of fresh cut onion during storage

Treatment combinations	Pyruvic acid (µmol/g of fresh weight)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	5.285	5.136	5.114	4.789	4.672	4.609	-
A_1T_2		5.164	5.162	4.825	4.706	4.626	-
A_1T_3		5.213	5.201	4.888	4.769	4.699	4.425
A_1T_4		5.195	5.182	4.856	4.745	4.653	-
A_1T_5		5.178	5.165	4.826	4.712	4.632	-
A_1T_6		5.153	5.152	4.812	4.698	4.623	-
A_1T_7		5.205	5.196	4.872	4.758	4.678	-
A_1T_8		5.186	5.174	4.832	4.716	4.635	-
A_1T_9		5.147	5.122	4.803	4.698	4.612	-
A_2T_1		4.754	4.236	4.152	3.746	3.652	-
A_2T_2		4.813	4.268	4.175	3.785	3.669	-
A_2T_3		4.963	4.360	4.209	3.896	3.706	3.458
A_2T_4		4.874	4.305	4.196	3.893	3.684	-
A_2T_5		4.851	4.286	4.182	3.841	3.674	-
A_2T_6		4.803	4.258	4.175	3.772	3.665	-
A_2T_7		4.840	4.325	4.205	3.896	3.689	-
A_2T_8		4.865	4.301	4.185	3.845	3.675	-
A_2T_9		4.762	4.241	4.169	3.759	3.653	-
A_3T_1		4.862	4.402	4.502	4.496	4.406	-
A_3T_2		4.945	4.457	4.523	4.552	4.436	-
A_3T_3		4.990	4.521	4.593	4.589	4.495	4.165
A_3T_4		4.968	4.485	4.562	4.575	4.475	-
A_3T_5		4.956	4.464	4.523	4.558	4.456	-
A_3T_6		4.926	4.435	4.512	4.513	4.431	-
A_3T_7		4.971	4.512	4.582	4.578	4.478	-
A_3T_8		4.967	4.468	4.536	4.563	4.462	-
A_3T_9		4.896	4.435	4.510	4.498	4.412	-
A_4T_1		5.239	5.203	5.155	5.108	5.008	-
A_4T_2		5.263	5.223	5.176	5.124	5.013	-
A_4T_3		5.284	5.298	5.197	5.148	5.029	5.000
A_4T_4		5.281	5.245	5.189	5.135	5.019	-
A_4T_5		5.264	5.226	5.178	5.129	5.016	-
A_4T_6		5.256	5.214	5.163	5.110	5.012	-
A_4T_7		5.283	5.271	5.195	5.136	5.020	-
A_4T_8		5.276	5.227	5.185	5.132	5.017	-
A_4T_9		5.248	5.213	5.157	5.109	5.011	-
SE ±		0.0082	0.0063	0.0036	0.0041	0.0035	0.0022
CD at 1%		0.0316	0.0241	0.0139	0.0159	0.0136	0.0087
A_1		5.175	5.163	4.834	4.719	4.641	4.425
A_2		4.836	4.287	4.183	3.826	3.674	3.458
A_3		4.942	4.464	4.538	4.547	4.450	4.165
A_4		5.266	5.235	5.177	5.125	5.016	5.000
SE ±		0.0027	0.0021	0.0012	0.0014	0.0012	0.0007
CD at 1%		0.0105	0.0080	0.0046	0.0053	0.0045	0.0029
T_1		4.998	4.738	4.649	4.505	4.419	-
T_2		5.046	4.777	4.675	4.541	4.436	-
T_3		5.112	4.845	4.722	4.600	4.482	4.260
T_4		5.079	4.804	4.701	4.587	4.457	-
T_5		5.062	4.785	4.677	4.560	4.444	-
T_6		5.034	4.765	4.665	4.523	4.433	-
T_7		5.075	4.826	4.714	4.592	4.466	-
T_8		5.074	4.792	4.684	4.564	4.447	-
T_9		5.013	4.753	4.660	4.516	4.422	-
SE ±		0.0041	0.0031	0.0018	0.0021	0.0018	0.0011
CD at 1%		0.0158	0.0120	0.0069	0.0080	0.0068	0.0043

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

consumption of pyruvic acid as a metabolic substrate of respiration as reported by Berno *et al.* (2014) in fresh cut purple onion. In general, the dicing led to lower pyruvic acid content as compared to other types of cut. This reduction in the pungency i.e. low pyruvic acid content resulting from minimal processing might be due to the cell disruption caused by peeling, cutting and pretreatments through volatilization, leakage and leaching of the substances responsible for the pungency. The higher intensity of cut caused more acid leaching and thus less pungency. The results are in conformity with those findings observed by Berno *et al.* (2014) in fresh cut purple onion; Schwimmer and Weston (1961); Anthon and Barrett (2003); Lanzotti (2006); Bretch *et al.* (2007); Bhat *et al.* (2010); Miguel and Durigan (2007) in onions. The pretreatment with hexanal reported the minimum change in pyruvic acid content throughout the storage period. These results implied that hexanal vapors were effective to maintain aroma by acting as a precursor for the production of alcohols and esters. Also, inhibition of phospholipase D activity by hexanal might have reduced the degradation of membranes thus reducing the leaching of pyruvates from cut and damaged tissues of onions. Similar results were reported by Ashwini *et al.* (2018) in banana; Jincy *et al.* (2017) in mango; Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

4.2.3 In Package Atmosphere (Headspace Gas Concentrations)

Immediately after pretreatments, fresh cut onions were packed in polypropylene bags using normal air (no vacuum) in order to create a passive MAP. The results presented here under represents the behavior of the inpackage gaseous atmosphere and their effect on the quality of pretreated fresh cut onions.

4.2.3.1 Oxygen (%)

The initial headspace oxygen concentration in the packages of fresh cut onion recorded was 20.15 per cent (Table 13 and Fig. 11 and 12). At all the stages (days) of the storage at 0-5^{0}C, oxygen concentration in the package headspace was significantly influenced by all the pretreatments, types of cut and their interactions. However, after 3rd day of storage, the interaction effect was found to be non-significant. At the end of 3rd day of storage, the oxygen concentration in all the packages was drastically reduced from 20.15 per cent to 10-11 per cent irrespective of types of cut and pretreatments. Thereafter, the concentration of oxygen in headspace was reduced at constant pace.

As regards types of cut, the maximum decrease in the headspace concentration of oxygen was recorded in the A_2 (diced onion) and A_3 (shredded onion) throughout the storage period. The oxygen concentration in headspace of packages recorded decreasing trend in all the types of cut, irrespective of pretreatments. At the end of storage period i.e. after 18 day, A_4 (whole peeled onion) registered maximum headspace concentration of oxygen (2.56%) while diced onion (A_2) recorded minimum concentration of oxygen (1.49%) in its headspace.

Among all the pretreatments tried, initially on the 3rd day of storage, the maximum (11.55%) and minimum oxygen concentration (10.26) were recorded in T_3 and T_1 treatments, respectively. At the end of 15th day of storage, maximum oxygen concentration (2.52%) was recorded in T_3 while minimum (2.08%) was recorded in T_1. At the end of the storage period i.e. after 18th day of storage, T_3 treatment had maximum oxygen concentration (2.12%) in headspace of packaged fresh cut onion.

The treatment combination of whole peeled onion pretreated with 1 per cent hexanal recorded maximum oxygen in the headspace of package throughout the storage period. At the end of 15th day of storage, as regards the treatment combinations, A_2T_3 recorded maximum concentration of headspace oxygen (3.15%) followed by A_4T_4 (3.09%). At the end of storage period i.e. after 18th day of storage, A_4T_3 treatment combination registered 2.56 per cent oxygen in headspace of packed fresh cut onion.

In the present study, the significant decrease in headspace oxygen concentration of the package was noted. The reduction in the headspace oxygen concentration is related to the increase in the rate of respiration. The greater stress caused due to higher intensity of cut or wounding might have resulted in the increase in the rate of respiration and thus noted decrease in the headspace gas concentration. The respiration rate of the fresh cut onions was higher than the whole peeled onion. The respiratory substance was consumed with respiratory metabolism, so the respiration rate declined when the respiration substance was not enough. The results are in conformity with that of Bahram-Parvar *et al.* (2018) in onion and Berno *et al.* (2014) in fresh cut onion. The respiratory rate of diced onion resulted higher than sliced onion due to higher intensity of cut and more damage to the cell structures in dicing. The rate of respiration was lower in hexanal treated produce throughout the storage period. These results implied that hexanal vapors were effective to delay the senescence due to PLD inhibitory action leading to maintaining freshness of the product and reduction in ethylene production. Thus, hexanal treated fresh cut onion might have slow and constant consumption of oxygen for respiratory metabolism. Similar results were reported by Ashwini *et al.* (2018) Golding *et al.*, 1998,1999; Pathak *et al.*, 2003; Pelayo *et al.*,2003; Lohini *et al.*, 2004 in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

4.2.3.2 Carbon dioxide (%)

The data given in Table 14 and graphically represented in Fig. 13 and 14 revealed that at the beginning of the storage, the headspace carbon dioxide concentration in the fresh cut onion packages was 0.05 per cent, which was significantly influenced by types of cut and pretreatments throughout the storage period. However, up to the 12th day of storage, the nonsignificant differences were recorded in the interactions under study. Significant differences among the interactions were recorded only on the 15th and 18th day of storage.

Table 13: Effect of types of cut and pretreatments on headspace oxygen (%) concentration of packed fresh cut onion during storage

Treatment combinations	Oxygen (%)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	20.15	10.28	8.61	7.02	4.56	2.23	-
A_1T_2		10.91	9.23	7.57	5.06	2.57	-
A_1T_3		11.53	9.35	8.10	5.27	2.67	2.31
A_1T_4		11.35	9.31	7.81	5.21	2.64	-
A_1T_5		11.12	9.28	7.61	5.15	2.60	-
A_1T_6		10.56	9.72	7.15	4.85	2.48	-
A_1T_7		10.79	8.84	7.24	4.92	2.51	-
A_1T_8		10.83	9.17	7.46	4.94	2.55	-
A_1T_9		10.59	8.63	7.08	4.63	2.46	-
A_2T_1		10.30	8.64	7.11	4.63	1.59	-
A_2T_2		10.97	9.29	7.65	5.15	1.79	-
A_2T_3		11.61	9.46	8.15	5.34	1.89	1.49
A_2T_4		11.45	9.38	7.86	5.37	1.85	-
A_2T_5		11.21	9.31	7.70	5.24	1.80	-
A_2T_6		10.62	8.80	7.23	4.91	1.68	-
A_2T_7		10.81	8.91	7.29	4.99	1.71	-
A_2T_8		10.90	9.24	7.54	5.02	1.76	-
A_2T_9		10.68	8.69	7.16	4.67	1.63	-
A_3T_1		10.28	8.64	7.08	4.60	2.08	-
A_3T_2		10.95	9.27	7.64	5.13	2.28	-
A_3T_3		11.59	9.42	8.15	5.31	2.40	2.14
A_3T_4		11.40	9.36	7.85	5.34	2.35	-
A_3T_5		11.18	9.31	7.68	5.21	2.34	-
A_3T_6		10.59	8.76	7.19	4.90	2.12	-
A_3T_7		10.81	8.89	7.27	4.97	2.15	-
A_3T_8		10.86	9.21	7.52	4.99	2.19	-
A_3T_9		10.64	8.67	7.13	4.65	2.10	-
A_4T_1		10.18	8.53	6.94	4.48	2.45	-
A_4T_2		10.87	9.11	7.44	4.97	2.92	-
A_4T_3		11.48	9.25	7.98	5.18	3.15	2.56
A_4T_4		11.26	9.25	7.76	5.13	3.09	-
A_4T_5		11.05	9.13	7.56	5.05	2.96	-
A_4T_6		10.52	8.65	7.05	4.76	2.82	-
A_4T_7		10.73	8.79	7.15	4.80	2.85	-
A_4T_8		10.79	9.02	7.32	4.85	2.86	-
A_4T_9		10.58	8.59	6.98	4.58	2.61	-
SE ±		0.0203	0.0286	0.0109	0.0125	0.0339	0.0118
CD at 1%		NS	0.1100	0.0420	0.0482	0.1303	0.0456
A_1	20.15	10.88	9.12	7.45	4.95	2.52	2.31
A_2		10.95	9.08	7.52	5.03	1.74	1.49
A_3		10.92	9.06	7.50	5.01	2.22	2.14
A_4		10.83	8.92	7.35	4.87	2.85	2.56
SE ±		0.0068	0.0095	0.0036	0.0042	0.0113	0.0039
CD at 1%		0.0261	0.0367	0.0140	0.0161	0.0434	0.0152
T_1	20.15	10.26	8.60	7.04	4.57	2.08	-
T_2		10.92	9.22	7.58	5.07	2.39	-
T_3		11.55	9.37	8.09	5.28	2.52	2.12
T_4		11.36	9.32	7.82	5.26	2.48	-
T_5		11.14	9.26	7.64	5.16	2.42	-
T_6		10.57	8.98	7.15	4.85	2.27	-
T_7		10.78	8.86	7.24	4.92	2.30	-
T_8		10.84	9.16	7.46	4.95	2.34	-
T_9		10.62	8.64	7.09	4.63	2.20	-
SE ±		0.0102	0.0143	0.0055	0.0063	0.0169	0.0059
CD at 1%		0.0391	0.0550	0.0210	0.0241	0.0652	0.0228

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50μg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 14: Effect of types of cut and pretreatments on headspace carbon dioxide (%) concentration of packed fresh cut onion during storage

Treatment combinations	Carbon dioxide (%) Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	0.05	1.75	4.96	7.15	8.52	9.81	-
A_1T_2		1.64	3.81	6.23	7.57	8.42	-
A_1T_3		1.48	2.89	5.68	6.57	7.60	7.90
A_1T_4		1.54	3.15	5.82	6.69	7.85	-
A_1T_5		1.61	3.62	6.02	6.98	8.26	-
A_1T_6		1.68	4.28	6.91	7.98	9.34	-
A_1T_7		1.67	4.08	6.87	7.81	9.06	-
A_1T_8		1.64	4.00	6.53	7.63	8.75	-
A_1T_9		1.71	4.49	7.05	8.25	9.69	-
A_2T_1		1.81	5.06	7.22	8.58	9.85	-
A_2T_2		1.69	3.88	6.30	7.64	8.52	-
A_2T_3		1.54	2.95	5.75	6.68	7.69	8.39
A_2T_4		1.61	3.21	5.89	6.76	7.93	-
A_2T_5		1.65	3.67	6.12	7.06	8.34	-
A_2T_6		1.73	4.34	6.96	8.03	9.41	-
A_2T_7		1.71	4.15	6.92	7.86	9.12	-
A_2T_8		1.69	4.08	6.58	7.71	8.83	-
A_2T_9		1.76	4.54	7.11	8.29	9.76	-
A_3T_1		1.78	5.01	7.20	8.55	9.83	-
A_3T_2		1.66	3.85	6.27	7.62	8.48	-
A_3T_3		1.51	2.93	5.73	6.63	7.67	8.23
A_3T_4		1.57	3.20	5.86	6.72	7.91	-
A_3T_5		1.64	3.66	6.08	7.01	8.30	-
A_3T_6		1.70	4.31	6.94	8.02	9.38	-
A_3T_7		1.70	4.12	6.90	7.84	9.10	-
A_3T_8		1.67	4.06	6.56	7.68	8.81	-
A_3T_9		1.75	4.53	7.08	8.28	9.73	-
A_4T_1		1.68	4.92	7.03	8.46	9.77	-
A_4T_2		1.59	3.73	6.12	7.48	8.56	-
A_4T_3		1.30	2.72	5.54	6.41	7.48	7.77
A_4T_4		1.47	3.04	5.60	6.58	7.76	-
A_4T_5		1.57	3.50	5.82	6.87	8.14	-
A_4T_6		1.61	4.23	6.85	7.82	9.24	-
A_4T_7		1.61	3.97	6.70	7.74	8.92	-
A_4T_8		1.58	3.86	6.44	7.54	8.64	-
A_4T_9		1.67	4.45	6.89	8.12	9.56	-
SE ±		0.0279	0.0409	0.0362	0.0251	0.0275	0.0112
CD at 1%		NS	NS	NS	NS	0.1057	0.0430
A_1	0.05	1.63	3.92	6.47	7.55	8.75	7.90
A_2		1.69	3.98	6.54	7.62	8.83	8.39
A_3		1.66	3.96	6.51	7.59	8.80	8.23
A_4		1.56	3.82	6.33	7.44	8.67	7.77
SE ±		0.0093	0.0136	0.0121	0.0084	0.0092	0.0037
CD at 1%		0.0358	0.0524	0.0464	0.0322	0.0352	0.0143
T_1	0.05	1.75	4.99	7.15	8.52	9.81	-
T_2		1.64	3.82	6.23	7.57	8.49	-
T_3		1.46	2.87	5.68	6.57	7.61	8.07
T_4		1.55	3.15	5.79	6.69	7.86	-
T_5		1.62	3.61	6.01	6.98	8.26	-
T_6		1.68	4.29	6.91	7.96	9.34	-
T_7		1.67	4.08	6.84	7.81	9.05	-
T_8		1.64	4.00	6.53	7.64	8.75	-
T_9		1.72	4.50	7.03	8.23	9.68	-
SE ±		0.0140	0.0204	0.0181	0.0126	0.0137	0.0056
CD at 1%		0.0537	0.0786	0.0695	0.0483	0.0528	0.0215

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2

T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

At the end of the storage period i.e. after 18th day of storage, the minimum accumulation of the carbon dioxide concentration in the headspace of package was recorded in the whole peeled onion (7.77%) followed by sliced onion (7.90%). The maximum CO_2 (8.39%) was registered in the diced onion (A_2).

Among the pretreatments under study, on the 15th day of storage the minimum headspace concentration of carbon dioxide was recorded in T_3 (7.61%) and it was maximum in T_1 (9.81%) followed by T_9 (9.68%) treated fresh cut onion.

As regards the treatment combinations, A_4T_3 recorded minimum concentration of 7.48 per cent carbon dioxide in headspace of package while A_2T_3 (diced onion treated with 1% hexanal) had maximum headspace concentration of carbon dioxide 7.69 per cent on the day 15 of storage. After 18th day of storage, whole peeled onion treated with 1 per cent hexanal recorded the minimum headspace carbon dioxide concentration (7.77%) in the package.

The CO_2 concentration in the headspace of the packages was found to be increased irrespective of the types of cut, pretreatments and their interactions also. This could be due to the increase in the rate of respiration with maximum consumption of available oxygen in package. The greater stress caused due to higher intensity of cut or wounding might have resulted in the increase in the rate of respiration and thus noted increase in the headspace CO_2 concentration. The respiration rate of the fresh cut onions was higher than the whole peeled onion. The results of present findings are in conformity with that of Blanchard *et al.* (1996) in fresh cut fruits and vegetables, Bahram-Parvar *et al.* (2018) in onion and Berno *et al.* (2014) in fresh cut onion. The accumulation of the carbon dioxide was maximum in the diced onion than the other cut types due to higher intensity of cut and more damage to the cell structures in dicing. The slow accumulation of CO_2 in the headspace of packed onions treated with hexanal might be attributed to the PLD inhibitory action of hexanal vapours leading reduction in ethylene production and delaying senescence. Similar results were reported by Ashwini *et al.* (2018) Golding *et al.,* 1998, 1999; Pathak *et al.,* 2003; Pelayo *et al.,*2003; Lohini *et al.,* 2004 in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

4.2.3.3 Ethylene (ppm)

The data given in Table 15 and graphically represented in Fig. 15 and 16 revealed that, at the beginning of the storage, ethylene concentration in the headspace of fresh cut onion was 7.15 ppm which was significantly influenced by various types of cut, pretreatments and their interactions. As the storage period advanced, ethylene concentration in headspace of fresh cut onion packages increased gradually irrespective of cut forms, post-harvest treatments and their interactions.

With the advancement of the storage period, the ethylene concentration in the headspace of fresh cut onion increased gradually but it was minimum in the A_4 (whole peeled onion). At the end of the storage period i.e. after 18th day of storage, among the types of cut, A_4 recorded minimum concentration of ethylene (13.78 ppm) while maximum concentration was recorded in diced onion (83.75 ppm) irrespective of postharvest treatments applied.

As regards the pretreatments given to the fresh cut onion, pretreatment with 1 per cent hexanal (T_3) registered minimum accumulation of the ethylene gas in the headspace of the packages. At the end of 15th day of storage, the untreated fresh cut onion (T_1) recorded maximum ethylene (77.18 ppm) in the package headspace while it was significantly minimum in the 1% hexanal treated fresh cut onion package (56.75 ppm). On the final day of storage i.e. after 18th day, T_3 treated fresh cut onion had 65.73 ppm of ethylene in the headspace.

As regards the interaction effect, on the 3rd day of storage, the headspace ethylene gas concentration of 7.85 ppm was recorded in A_4T_3 and A_4T_4 treatment combination. It was significantly increased thereafter and on the 15th day of storage, treatment combinations, A_4T_3 and A_4T_4 registered 12.67 and 13.30 ppm ethylene in the headspace of the packages. The maximum accumulation of the ethylene gas in the headspace of the packaged fresh cut onion was recorded in the untreated diced onion (A_1T_1). At the end of the storage period, i.e. after 18th day of storage, whole peeled onion treated with 1 percent hexanal (A_4T_3) recorded minimum headspace ethylene concentration (13.78ppm) in the package.

The ethylene concentration was increased in the present investigation irrespective of the types of cut, pretreatments and their interaction. This increase could be attributed to the cuts, impacts and compression which increased surface area, increased rate of respiration, accelerated deterioration and senescence in vegetative tissues and acceleration of the ripening process as reported by Hong and Kim (2004) in onion and Berno *et al.* (2014) in fresh cut onion. In present study, the ethylene production was highest in diced onion, shredded onion, sliced onion and least in whole peeled onion. It was due to the severe cut given to the onion and large surface exposure to the environment. The results are in conformity with that of Berno *et al.* (2014) in fresh cut onion. The rate of ethylene accumulation in the headspace of package was slower in the whole peeled onion treated with hexanal solution. These results implied that hexanal vapors were effective to delay the senescence due to PLD inhibitory action leading to maintaining freshness of the product and reduction in ethylene production. The exogenous application of hexanal slows down the lipogeneses in the skin which could have assisted in delayed softening process and slowing down ethylene evolution. The data closely coincided with those reported by Sharma *et al.* 2010 in sweet cherry, Ashwini *et al.* (2018) Golding *et al.,* 1998,1999; Pathak *et al.,* 2003; Pelayo *et al.,*2003; Lohini *et al.,* 2004 in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato.

Table 15: Effect of types of cut and pretreatments on headspace ethylene (ppm) concentration of packed fresh cut onion during storage

Treatment combinations	Ethylene (ppm)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	7.15	33.15	56.85	77.15	84.14	97.15	-
A_1T_2		24.59	43.87	65.56	72.48	82.47	-
A_1T_3		21.42	38.15	58.79	65.48	71.24	82.16
A_1T_4		21.45	40.25	62.73	68.71	73.89	-
A_1T_5		24.56	42.47	65.52	70.79	76.52	-
A_1T_6		26.98	50.42	71.16	80.42	94.35	-
A_1T_7		26.87	48.95	70.65	76.49	92.41	-
A_1T_8		24.59	44.70	66.88	74.56	88.68	-
A_1T_9		30.45	54.47	72.45	80.46	96.47	-
A_2T_1		33.21	57.85	77.26	85.58	97.43	-
A_2T_2		25.26	39.88	65.92	72.74	83.77	-
A_2T_3		21.53	34.15	59.26	66.15	71.86	83.75
A_2T_4		23.53	36.70	63.23	68.78	74.26	-
A_2T_5		25.63	38.59	65.92	70.89	77.58	-
A_2T_6		27.17	51.26	71.29	80.97	94.63	-
A_2T_7		27.11	48.69	71.18	77.56	92.85	-
A_2T_8		25.57	43.15	67.10	74.55	88.81	-
A_2T_9		30.45	53.12	72.63	81.34	96.82	-
A_3T_1		33.19	57.80	77.23	85.50	97.34	-
A_3T_2		24.92	39.50	65.59	72.53	83.14	-
A_3T_3		21.47	33.20	58.81	65.57	71.25	83.24
A_3T_4		23.48	36.55	62.77	68.71	73.97	-
A_3T_5		24.59	38.55	65.56	70.81	76.59	-
A_3T_6		27.12	51.10	71.21	80.56	94.55	-
A_3T_7		27.00	48.35	70.65	77.15	92.82	-
A_3T_8		25.11	42.80	66.92	74.21	88.76	-
A_3T_9		30.45	52.65	72.45	80.97	96.47	-
A_4T_1		11.20	13.35	15.70	16.25	16.80	-
A_4T_2		8.35	10.20	11.45	12.80	13.85	-
A_4T_3		7.85	9.20	9.45	12.04	12.67	13.78
A_4T_4		7.85	9.35	10.60	12.50	13.30	-
A_4T_5		8.30	9.61	10.65	12.50	13.50	-
A_4T_6		9.60	10.75	12.20	14.15	14.65	-
A_4T_7		8.80	10.40	11.80	13.50	14.35	-
A_4T_8		8.70	10.25	11.70	13.30	14.30	-
A_4T_9		10.40	11.80	12.85	14.65	15.75	-
SE ±		0.0165	0.0163	0.0165	0.0208	0.0135	0.0037
CD at 1%		0.0634	0.0627	0.0633	0.0801	0.0521	0.0143
A_1	7.15	26.00	46.68	67.87	74.84	85.91	82.16
A_2		26.60	44.82	68.20	75.39	86.44	83.75
A_3		26.37	44.50	67.91	75.11	86.10	83.24
A_4		9.00	10.54	11.82	13.52	14.35	13.78
SE ±		0.0055	0.0054	0.0055	0.0069	0.0045	0.0012
CD at 1%		0.0211	0.0209	0.0211	0.0267	0.0174	0.0048
T_1	7.15	27.68	46.46	61.83	67.87	77.18	-
T_2		20.78	33.36	52.13	57.64	65.81	-
T_3		18.06	28.68	46.58	52.31	56.75	65.73
T_4		19.07	30.71	49.83	54.67	58.85	-
T_5		20.77	32.30	51.91	56.25	61.04	-
T_6		22.72	40.88	56.46	64.02	74.54	-
T_7		22.44	39.09	56.07	61.17	73.10	-
T_8		20.99	35.22	53.15	59.15	70.14	-
T_9		25.43	43.01	57.59	64.35	76.38	-
SE ±		0.0082	0.0082	0.0082	0.0104	0.0068	0.0019
CD at 1%		0.0317	0.0314	0.0316	0.0400	0.0260	0.0072

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

4.2.4 Microbial Limit Tests

4.2.4.1 Total aerobic count (log cfu g^{-1})

Data presented in Table 16 indicated that at the beginning of the storage before treatment applications, total aerobic count of fresh cut onion recorded was 7.76 log cfu per gram. After pretreatments, total aerobic count reduced significantly. Total aerobic count of fresh cut onions decreased slightly (7.04 log cfu g^{-1}) in untreated control (T_1) while pretreatment of fresh cut onions with UV-C radiation recorded 3.95 log cfu g^{-1} count. The pretreatment with 80 ppm sodium hypochlorite (T_2), 6% food grade H_2O_2 and 1 % sophorolipid recorded 4.94, 4.38 and 3.74 log cfu g^{-1} total aerobic count respectively. The total aerobic count was reduced to 3.60 and 3.72 log cfu g^{-1} in 1 and 2 per cent hexanal treated fresh cut onions. However, the lowest total aerobic count (3.54 log cfu g^{-1}) was registered in fresh cut onions pretreated with nisin (50µg-mL^{-1}) + citric acid (1% w/v). Total aerobic count was significantly influenced by types of cut, post-harvest pretreatments and by their interactions.

It is evident from the data that, with the advancement of the storage period, the total microbial load in fresh cut onion increased gradually. At the end of the storage period i.e. on the last day storage for respective treatments, maximum total aerobic count (10.44 log cfu g^{-1}) was registered in the diced onion (A_2) while minimum (8.12 log cfu g^{-1}) was recorded in whole peeled onion (A_4).

Among all the pretreatments, maximum total aerobic count (12.53 log cfu g^{-1}) was recorded in untreated control (T_1) at the end of storage period i.e. after 12 days. After 18th day of storage, pretreatment with 1 percent hexanal (T_3) recorded a minimum total aerobic count (8.26 log cfu g^{-1}). Regarding treatment combinations, A_4T_3 registered minimum total aerobic count (6.84 log cfu g^{-1}) after 18 days storage period while the maximum total aerobic count was recorded in treatment combination of A_2T_1 (13.78 log cfu g^{-1}) followed by A3T1 (13.76 log cfu g^{-1}) after 12 days of storage. Indicator organisms were absent in all samples and product was safe for consumption at the respective days of termination.

Microbial safety is one of the most important factors to be considered for the preservation of minimally processed food. In the present investigations, it is noted that the total aerobic count increased irrespective of types of cut and pretreatments. This might be due to an increase in cut-damaged surfaces in minimal processing, availability of the cell nutrients favoring microbial growth and through transfer of skin microflora to produce flesh in cut vegetables, where micro-organisms could grow rapidly upon exposure to nutrient laden juices as reported by Berno *et al.* (2014), Piercey *et al.* (2012) in fresh cut onions, Liu and Li (2006) in sliced onion, Howard *et al.* (1994) in diced onions. Cantwell and Suslow (2002) in minimally processed products, O'Connor-Shaw *et al.* (1994) in minimally processed muskmelon cv Honey Dew. The initial total aerobic count before pretreatment was reduced after pretreatments. This was due to sanitation and washing out of microbes in all treatments. The minimum microbial load was reported in Nisin (50µg-mL^{-1}) + citric acid (1% w/v) treated fresh cut onions. This might be due to the antimicrobial property of nisin as reported by Chen *et al.* (2016) in fresh cut onions. However, at the end of storage period i.e. after 18 days whole peeled onions pretreated with hexanal recorded minimum microbial load. This might be attributed to hexanal vapour producing volatile compounds like (E)-2-hexanal which had antifungal properties and deterrence against postharvest pathogens in wide array of fruits and vegetables as reported by Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears.

4.2.5 Sensorial Analysis (Visible Quality Markers)

4.2.5.1 Colour, flavour and appearance (In package and out package)

With the advancement of the storage period, decreasing trend in score for colour (Table 17), flavour (Table 18) and appearance (Table 19) of pretreated fresh cut onion was recorded irrespective of the treatments.

Among the various treatment combinations, pretreated fresh cut onion had maximum score for colour, appearance and flavour than control. Immediately after the pretreatments, the initial score of 9.00 was recorded for colour, appearance and flavor of fresh cut onion. The whole peeled onion treated with 1 per cent hexanal (A_4T_3) recorded the highest score for colour (6.13), flavor (6.25) and appearance (6.32). However, untreated diced onion (A_2T_1) registered the lowest score for the colour (6.00), flavor (6.20) and appearance (6.00) at the end of the storage period i.e after 15th of storage. The pretreatment with 1 per cent hexanal had registered an acceptable score for colour, flavor and acceptability of onions even after 18 days of storage, irrespective of different types of cut under study. The diced onion treated with 1 per cent hexanal (A_2T_3) registered score of 6.35, 6.28 and 6.28 for colour, flavor and appearance, respectively after 15th day of storage.

Colour, flavor, texture (appearance) and the nutritional value of fresh cut fruits and vegetable products are factors critical to consumer acceptance of these products. This denote the quality of the product and determines the product rejection or acceptance as reported by Barrett *et al* (2010) in fresh cut fruits and vegetables and Bahram-Parvar and Lim (2017) in fresh cut onion. The anthocyanins in red onion are responsible for the colour and appearance. The decrease in score of colour and appearance of the fresh cut onion irrespective of pretreatments might be attributed to the loss of anthocyanins as well as texture due to chemical and biochemical reactions responsible for onion discolouration as reported by Ferreres *et al.* (1996) in in shredded red onion, Perez-Greogorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions, Gould and Lister (2006) in fruits and vegetables and Perez-Vicente *et al.* (2004) in pomegranate cv. Mollar. The diced onion exhibited the largest loss of surface water due to the larger exposed surface area and more damaged cells leading to the soft textured appearance of

Table 16: Effect of types of cut and pretreatments on total aerobic count (log cfu per g) of packed fresh cut onion during storage

Treatment combinations	Total aerobic count (log cfu g^{-1})		
	Storage periods (days)		
	Initial before treatment	Initial after treatment	Final
A_1T_1	7.76	6.81	11.76
A_1T_2		4.71	9.10
A_1T_3		3.39	8.62
A_1T_4		3.59	8.65
A_1T_5		3.70	8.93
A_1T_6		4.37	10.03
A_1T_7		5.93	11.08
A_1T_8		3.49	9.73
A_1T_9		3.91	9.97
A_2T_1		7.67	13.78
A_2T_2		5.33	10.06
A_2T_3		3.93	8.87
A_2T_4		4.08	8.95
A_2T_5		4.15	10.03
A_2T_6		4.49	10.16
A_2T_7		6.39	11.17
A_2T_8		3.90	9.92
A_2T_9		4.27	11.03
A_3T_1		6.94	13.76
A_3T_2		5.10	9.85
A_3T_3		3.87	8.72
A_3T_4		3.80	8.83
A_3T_5		3.51	9.90
A_3T_6		4.39	10.14
A_3T_7		6.18	11.14
A_3T_8		3.67	9.94
A_3T_9		3.91	10.95
A_4T_1		6.75	10.81
A_4T_2		4.62	7.88
A_4T_3		3.21	6.84
A_4T_4		3.40	6.91
A_4T_5		3.59	7.88
A_4T_6		4.26	8.07
A_4T_7		6.31	8.33
A_4T_8		3.11	7.91
A_4T_9		3.70	8.45
SE ±		0.0784	0.0276
CD at 1%		0.3016	0.1062
A_1	7.76	4.43	9.76
A_2		4.91	10.44
A_3		4.59	10.36
A_4		4.33	8.12
SE ±		0.0261	0.0092
CD at 1%		0.1005	0.0354
T_1	7.76	7.04	12.53
T_2		4.94	9.22
T_3		3.60	8.26
T_4		3.72	8.34
T_5		3.74	9.18
T_6		4.38	9.60
T_7		6.20	10.43
T_8		3.54	9.37
T_9		3.95	10.10
SE ±		0.0392	0.0138
CD at 1%		0.1508	0.0531

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 17: Effect of types of cut and pretreatments on colour (score) of packed fresh cut onion during storage

Treatment combinations	Colour (Score)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	9.00	8.42	7.73	6.82	6.52	6.08	-
A_1T_2	9.00	8.83	8.18	7.64	6.93	6.18	-
A_1T_3	9.00	8.95	8.85	8.40	7.42	6.50	6.05
A_1T_4	9.00	8.88	8.75	8.36	7.00	6.23	-
A_1T_5	9.00	8.82	8.66	8.29	6.95	6.13	-
A_1T_6	9.00	8.67	8.12	7.23	6.86	6.11	-
A_1T_7	9.00	8.73	8.08	7.56	6.89	6.15	-
A_1T_8	9.00	8.68	8.05	7.68	6.90	6.18	-
A_1T_9	9.00	8.63	7.92	6.97	6.68	6.05	-
A_2T_1	9.00	8.25	7.43	6.75	6.46	6.00	-
A_2T_2	9.00	8.57	7.75	7.34	6.72	6.10	-
A_2T_3	9.00	8.72	8.52	7.95	7.23	6.35	6.00
A_2T_4	9.00	8.68	8.23	7.65	6.78	6.18	-
A_2T_5	9.00	8.66	8.11	7.60	6.65	6.11	-
A_2T_6	9.00	8.42	7.74	7.64	6.54	6.09	-
A_2T_7	9.00	8.54	7.77	7.69	6.72	6.10	-
A_2T_8	9.00	8.57	7.65	7.28	6.58	6.08	-
A_2T_9	9.00	8.29	7.54	6.81	6.52	6.03	-
A_3T_1	9.00	8.35	7.57	6.72	6.45	6.00	-
A_3T_2	9.00	8.60	7.94	7.33	6.80	6.13	-
A_3T_3	9.00	8.78	8.59	7.92	7.25	6.46	6.02
A_3T_4	9.00	8.75	8.56	7.74	6.85	6.21	-
A_3T_5	9.00	8.70	8.32	7.71	6.81	6.14	-
A_3T_6	9.00	8.58	8.03	7.15	6.50	6.11	-
A_3T_7	9.00	8.63	8.05	7.17	6.71	6.12	-
A_3T_8	9.00	8.64	8.09	7.48	6.76	6.15	-
A_3T_9	9.00	8.38	7.60	6.92	6.51	6.04	-
A_4T_1	9.00	8.65	7.90	7.20	6.70	6.18	-
A_4T_2	9.00	8.85	8.20	7.80	7.10	6.24	-
A_4T_3	9.00	8.92	8.80	8.50	7.50	6.69	6.13
A_4T_4	9.00	8.88	8.80	8.20	7.20	6.32	-
A_4T_5	9.00	8.81	8.60	8.10	7.10	6.26	-
A_4T_6	9.00	8.78	8.10	7.30	6.90	6.16	-
A_4T_7	9.00	8.82	8.10	7.50	6.90	6.20	-
A_4T_8	9.00	8.88	8.20	7.60	7.10	6.22	-
A_4T_9	9.00	8.74	8.00	7.30	6.70	6.15	-

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

the product as reported by Liu and Li (2006) in fresh cut onion. The storage temperature, time and types of cut were known to affect onion pungency (Blanchard *et al.*, 1996). The loss of flavor of fresh cut onion packages in present investigation as indicated by decrease in flavor score in all treatments could be attributed to loss of pyruvic acid and the inactivation of alliinase, consumption of acids as a metabolic substrate for respiration, a lower content of sulphur volatiles inside the package, or degradation of volatiles as reported by Howard *et al.*, 1994 in fresh cut onions. The off-odour intensity increased in all samples over time. During storage, the onion emitted an unsavory odour in response to wounding during processing and microbial growth during storage.

This might be due to lack of O_2 shifting from aerobic to anaerobic atmosphere inducing fermentative metabolism as reported by Bahram-Parvar and Lim, 2017. As regards pretreatments, the maximum score for colour, appearance and flavor were observed in hexanal pretreated fresh cut onion. This might be due to hexanal vapour producing volatile compounds like (E)-2-hexanal which retained the in package flavor as well as enzyme inhibitory effect of hexanal and thereby increasing cell integrity and membrane preservation retaining colour and appearance as reported by Sharma *et al.* (2010) in sweet cherry, Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears.

Table 18: Effect of types of cut and pretreatments on flavor (score) of packed fresh cut onion (In package and out package) during storage

Treatment combinations	Flavor (Score)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	9.00	8.50	8.15	7.36	6.87	6.10	-
A_1T_2	9.00	8.83	8.71	7.66	7.46	6.29	-
A_1T_3	9.00	8.92	8.75	8.19	7.67	6.48	6.20
A_1T_4	9.00	8.91	8.73	8.16	7.55	6.29	-
A_1T_5	9.00	8.84	8.71	8.09	7.43	6.21	-
A_1T_6	9.00	8.76	8.45	7.38	7.27	6.14	-
A_1T_7	9.00	8.75	8.56	7.54	7.32	6.17	-
A_1T_8	9.00	8.76	8.65	7.73	7.36	6.21	-
A_1T_9	9.00	8.65	8.36	7.35	7.02	6.12	-
A_2T_1	9.00	8.22	7.67	6.85	6.55	6.00	-
A_2T_2	9.00	8.65	8.19	7.32	6.92	6.11	-
A_2T_3	9.00	8.78	8.53	7.98	7.33	6.28	6.06
A_2T_4	9.00	8.76	8.50	7.86	7.31	6.21	-
A_2T_5	9.00	8.75	8.39	7.83	7.24	6.17	-
A_2T_6	9.00	8.44	7.86	7.32	6.75	6.07	-
A_2T_7	9.00	8.56	7.95	7.20	6.82	6.09	-
A_2T_8	9.00	8.55	7.56	7.13	7.14	6.10	-
A_2T_9	9.00	8.49	7.75	6.93	6.62	6.02	-
A_3T_1	9.00	8.29	7.92	7.09	6.71	6.05	-
A_3T_2	9.00	8.68	8.59	7.45	7.16	6.18	-
A_3T_3	9.00	8.84	8.28	8.02	7.49	6.30	6.18
A_3T_4	9.00	8.79	8.62	7.91	7.44	6.25	-
A_3T_5	9.00	8.77	8.55	7.93	7.35	6.20	-
A_3T_6	9.00	8.58	8.46	7.15	6.92	6.12	-
A_3T_7	9.00	8.58	7.90	7.36	6.90	6.15	-
A_3T_8	9.00	8.63	7.95	7.46	7.22	6.16	-
A_3T_9	9.00	8.53	7.59	7.25	6.86	6.09	-
A_4T_1	9.00	8.73	8.33	7.55	7.09	6.18	-
A_4T_2	9.00	8.85	8.78	7.75	7.45	6.35	-
A_4T_3	9.00	8.97	8.88	8.35	7.76	6.56	6.25
A_4T_4	9.00	8.95	8.81	8.37	7.68	6.31	-
A_4T_5	9.00	8.92	8.75	8.32	7.61	6.28	-
A_4T_6	9.00	8.78	8.68	7.52	7.34	6.25	-
A_4T_7	9.00	8.79	8.73	7.66	7.30	6.21	-
A_4T_8	9.00	8.86	8.78	7.68	7.42	6.28	-
A_4T_9	9.00	8.75	8.38	7.68	7.12	6.20	-

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2

T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

Table 19: Effect of types of cut and pretreatments on appearance (score) of packed fresh cut onion during storage

Treatment combinations	Appearance (Score)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	9.00	8.42	7.82	7.00	6.87	6.09	-
A_1T_2	9.00	8.83	8.18	7.64	7.46	6.29	-
A_1T_3	9.00	8.90	8.85	8.40	7.67	6.48	6.28
A_1T_4	9.00	8.88	8.75	8.36	7.55	6.29	-
A_1T_5	9.00	8.82	8.66	8.29	7.43	6.21	-
A_1T_6	9.00	8.67	8.12	7.23	7.27	6.14	-
A_1T_7	9.00	8.73	8.08	7.56	7.32	6.17	-
A_1T_8	9.00	8.68	8.05	7.68	7.36	6.21	-
A_1T_9	9.00	8.63	7.92	6.97	7.02	6.12	-
A_2T_1	9.00	8.20	7.43	6.75	6.55	6.00	-
A_2T_2	9.00	8.57	7.75	7.34	6.92	6.11	-
A_2T_3	9.00	8.72	8.52	7.95	7.33	6.28	6.18
A_2T_4	9.00	8.68	8.23	7.65	7.31	6.21	-
A_2T_5	9.00	8.66	8.11	7.60	7.24	6.17	-
A_2T_6	9.00	8.42	7.74	7.64	6.75	6.07	-
A_2T_7	9.00	8.54	7.77	7.69	6.82	6.09	-
A_2T_8	9.00	8.57	7.65	7.28	7.14	6.10	-
A_2T_9	9.00	8.29	7.54	6.81	6.62	6.02	-
A_3T_1	9.00	8.35	7.57	6.72	6.71	6.05	-
A_3T_2	9.00	8.60	7.94	7.33	7.16	6.18	-
A_3T_3	9.00	8.78	8.59	7.92	7.49	6.30	6.21
A_3T_4	9.00	8.75	8.56	7.74	7.44	6.25	-
A_3T_5	9.00	8.70	8.32	7.71	7.35	6.20	-
A_3T_6	9.00	8.58	8.03	7.15	6.92	6.12	-
A_3T_7	9.00	8.63	8.05	7.17	6.90	6.15	-
A_3T_8	9.00	8.64	8.09	7.48	7.22	6.16	-
A_3T_9	9.00	8.38	7.60	6.92	6.86	6.09	-
A_4T_1	9.00	8.65	7.90	7.20	7.09	6.18	-
A_4T_2	9.00	8.85	8.20	7.80	7.45	6.35	-
A_4T_3	9.00	8.94	8.80	8.50	7.76	6.56	6.32
A_4T_4	9.00	8.88	8.80	8.20	7.68	6.31	-
A_4T_5	9.00	8.81	8.60	8.10	7.61	6.28	-
A_4T_6	9.00	8.78	8.10	7.30	7.34	6.25	-
A_4T_7	9.00	8.82	8.10	7.50	7.30	6.21	-
A_4T_8	9.00	8.88	8.20	7.60	7.42	6.28	-
A_4T_9	9.00	8.74	8.00	7.30	7.12	6.20	-

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2

T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

4.2.5.1 Overall acceptability

The overall acceptability of pretreated fresh cut onion recorded a slight and continuous decreasing trend throughout the storage period (Table 20 and Fig. 17 and 18). The overall acceptability was significantly influenced by all the types of cut and pretreatments under study. The treatments with a minimum score of 6.0 for overall acceptability is the theoretically used as the limit of marketability (Hong and Kim, 2004) and then the shelf-life of fresh cut pretreated onions were terminated.

As regards the types of cut, the whole peeled onion recorded the maximum score than other types of cut. At the end of the storage period, i.e. after 18 days entire storage period whole peeled onion (A_4) recorded maximum score (6.23) while diced (A_2) recorded minimum

Table 20: Effect of types of cut and pretreatments on overall acceptability (score) of packed fresh cut onion during storage

Treatment combinations	Overall acceptability (Score)						
	Storage period (days)						
	0	3	6	9	12	15	18
A_1T_1	9.00	8.45	8.01	6.80	6.75	6.09	-
A_1T_2		8.83	8.53	7.65	6.28	6.25	-
A_1T_3		8.94	8.78	8.33	7.59	6.49	6.18
A_1T_4		8.89	8.74	8.29	7.37	6.27	-
A_1T_5		8.83	8.69	8.22	7.27	6.18	-
A_1T_6		8.70	8.34	7.28	7.13	6.13	-
A_1T_7		8.74	8.40	7.55	7.18	6.16	-
A_1T_8		8.71	8.45	7.70	7.21	6.20	-
A_1T_9		8.64	8.21	7.10	6.91	6.10	-
A_2T_1		8.24	7.59	6.78	6.52	6.00	-
A_2T_2		8.60	8.04	7.33	6.85	6.11	-
A_2T_3		8.74	8.53	7.96	7.30	6.30	6.08
A_2T_4		8.71	8.41	7.72	7.13	6.20	-
A_2T_5		8.69	8.30	7.68	7.04	6.15	-
A_2T_6		8.43	7.82	7.53	6.68	6.08	-
A_2T_7		8.55	7.89	7.53	6.79	6.09	-
A_2T_8		8.56	7.59	7.23	6.95	6.09	-
A_2T_9		8.36	7.68	6.85	6.59	6.02	-
A_3T_1		8.33	7.80	6.84	6.62	6.03	-
A_3T_2		8.63	8.37	7.37	7.04	6.16	-
A_3T_3		8.80	8.38	7.95	7.41	6.35	6.14
A_3T_4		8.76	8.60	7.80	7.24	6.24	-
A_3T_5		8.72	8.47	7.78	7.17	6.18	-
A_3T_6		8.58	8.32	7.15	6.78	6.12	-
A_3T_7		8.61	7.95	7.23	6.84	6.14	-
A_3T_8		8.64	8.00	7.47	7.07	6.16	-
A_3T_9		8.43	7.59	7.03	6.74	6.07	-
A_4T_1		8.68	8.19	7.32	6.96	6.18	-
A_4T_2		8.85	8.59	7.78	7.33	6.31	-
A_4T_3		8.94	8.85	8.45	7.67	6.60	6.23
A_4T_4		8.90	8.81	8.26	7.52	6.31	-
A_4T_5		8.85	8.70	8.17	7.44	6.27	-
A_4T_6		8.78	8.49	7.37	7.19	6.22	-
A_4T_7		8.81	8.52	7.55	7.17	6.21	-
A_4T_8		8.87	8.59	7.63	7.31	6.26	-
A_4T_9		8.74	8.25	7.43	6.98	6.18	-
SE ±		0.0269	0.0277	0.0243	0.0211	0.0183	0.0067
CD at 1%		0.1034	0.1065	0.0935	0.0810	0.0702	0.0256
A_1	9.00	8.75	8.46	7.65	7.07	6.21	6.18
A_2		8.54	7.98	7.40	6.87	6.12	6.08
A_3		8.61	8.16	7.40	6.99	6.16	6.14
A_4		8.82	8.55	7.77	7.28	6.28	6.23
SE ±		0.0090	0.0092	0.0081	0.0070	0.0061	0.0022
CD at 1%		0.0345	0.0355	0.0312	0.0270	0.0234	0.0085
T_1	9.00	8.42	7.90	6.93	6.71	6.07	-
T_2		8.72	8.38	7.53	6.87	6.21	-
T_3		8.85	8.63	8.17	7.49	6.43	6.16
T_4		8.81	8.64	8.01	7.31	6.26	-
T_5		8.77	8.54	7.96	7.23	6.20	-
T_6		8.62	8.24	7.33	6.94	6.14	-
T_7		8.68	8.19	7.46	6.99	6.15	-
T_8		8.69	8.16	7.50	7.13	6.18	-
T_9		8.54	7.93	7.10	6.80	6.09	-
SE ±		0.0134	0.0139	0.0122	0.0105	0.0091	0.0033
CD at 1%		0.0517	0.0533	0.0467	0.0405	0.0351	0.0128

'-' indicates termination of treatments

A_1= Sliced onion
A_2= Diced onion
A_3= Shredded onion
A_4= Whole peeled onion

T_1= Control
T_2= Sodium hypochlorite (80 ppm)
T_3= 1% Hexanal (EFF- nano emulsion)
T_4= 2% Hexanal (EFF- nano emulsion)
T_5= 6% Food grade H_2O_2
T_6= 1% Sophorolipid extract
T_7= 1% Calcium lactate
T_8= Nisin (50µg-mL^{-1}) + citric acid (1% w/v)
T_9= UV-C radiation (250-255 nm)

score (6.08) for overall acceptability.

As the storage period advanced, the overall acceptability of pretreated onion decreased gradually but recorded maximum score for overall acceptability than that of untreated fresh cut onion. Among all the pretreatments, fresh cut onion treated with 1% hexanal (T_3) registered maximum score (6.16) at the end of storage period i.e. 18th day. All other treatments were terminated on 15th day of storage.

At all the stages (days) of storage, the whole peeled onion treated with effective freshness formulation (nano emulsion) containing 1% Hexanal (A_4T_3) had the maximum score than any other treatment combination. At the end of the 15th day of storage, the treatment combinations A_4T_3 recorded maximum score (6.60) while the minimum score (6.00) was registered by untreated diced onion (A_2T_1).

Among all the types of cut treatments, T_3 (whole peeled onion treated with 1% hexanal) registered maximum score for attributes viz; colour, appearance, flavour (in and out package) and overall acceptability in comparison with other treatments. These ratings may be attributed to decreased O_2 content and increase in CO_2 content in the packet as reported by Blanchard *et al.* (1996) in onions. Also, the development of microbial content, changes in physico-chemical composition, change in headspace gas concentration, decrease in anthocyanin content, as well as pyruvic acid content in the fresh cut onions over the period of storage time, might have contributed to the decrease in overall acceptability of fresh cut onions. The results are in conformity with those reported by Berno *et al.* (2014), Piercy *et al.* (2012) in fresh cut onions, Liu and Li (2006) in sliced onion, Howard *et al.* (1994) in diced onions. Cantwell and Suslow (2002) in minimally processed products, O'Connor-Shaw *et al.* (1994) in minimally processed muskmelon cv. Honey Dew and Dhumal (2012) in pomegranate.

4.3 Effectiveness of Packaging Materials and Storage Environments on Pre-Treated Fresh Cut Red Onion (Whole Peeled and Diced Onion)

The best postharvest treatment observed in the first part of the study was taken for further packaging and storage studies. As regards, types of cut, the whole peeled onion was found to be the best among all other cuts under study. However, from the commercial point of view, the diced onion was also included as a separate part to study the effect of packagings and storage temperatures. The results for the whole peeled and diced onion pertaining to physico-chemical parameters, headspace concentration, pathological observations as well as sensorial analysis are discussed hereunder suitable heading.

4.3.1 Physical Parameters

4.3.1.1 Percent moisture

The data given in Table 21 and 22 and graphically represented in Fig. 19 and 20 revealed that at the beginning of the storage, the per cent moisture content in the onion was

88.16. At all the stages (days) of storage, the per cent moisture was significantly influenced by packaging materials and storage temperatures in both the types of cut under study i.e. whole peeled and diced onion. However, the interaction effects were non-significant on 9^{th} and 12^{th} days of storage in whole peeled onion.

Decreasing trend in per cent moisture content was observed irrespective of packaging materials and storage environments under study for both the types of cut. As regards packaging material, at the end of the storage period (18 days storage), whole peeled onion packed in polypropylene bags with freshpaper (P_4) recorded highest per cent moisture (86.03%) while P_3 recorded maximum reduction in moisture (85.20%). The diced onion packaged in the polypropylene bags with freshpaper (P_4) registered minimum loss in per cent moisture (86.05%).

During the entire storage period, the whole peeled onion, as well as diced onion stored at S_2 (7±1^0C), recorded greater decrease in per cent moisture than that of those stored at S_1 (0±1^0C). At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0±1^0C (S_1) temperature recorded maximum moisture percentage of 85.64 and 85.59, respectively.

As regards treatment combination of packagings and storage environments, with the advancement of storage period, slow but constant decrease in per cent moisture was recorded in both the types of cut i.e. whole peel and diced onion. The whole peeled onion and diced onion packaged in polypropylene bag (200 gauge) with freshpaper had retained maximum moisture content (86.12 and 86.02 %), respectively. However, at the end of storage i.e. after 18 days, maximum reduction in the moisture (85.16 and 85.13 %) was recorded in perforated polyethylene terephthalate plastic punnet packed whole peeled and diced onion.

The post-harvest life and quality of fresh and fresh cut fruits and vegetables are primarily dependent on storage temperature. The temperature not only regulates all the physiological activities such as respiration, transpiration, ripening and senescence of fresh and fresh cut produce but also affects the physico-chemical changes of the processed food during storage. The harvested fruits and vegetables continue to lose moisture and rapidly become wilted, tough or mushy and consequently non-edible. Hence, high humidity (over 90%) is essential to avoid shriveling, drying, weight loss and loss of other quality components. Thus, high humidity and low temperature have major effects on storage life of many fresh fruits and vegetables (Roy and Khurdiya, 1986). In present study, slow but decreasing trend in per cent moisture was found in both pretreated cut types i.e. whole peeled and diced onion stored in different storage environments viz., 0±1°C (S_1) and 7±1°C (S_2). However, slightly higher decrease in moisture content was observed in pretreated fresh cut onion stored at 7±1°C. This might be due to increased activity of water and rate of reaction as a metabolic substrate as reported by Sharma and Lee (2016) in yellow onion; Bahram-Parvar and Lim (2018) in fresh cut

Table 21: Effect of packaging treatments and storage temperatures on percent moisture of pretreated whole peeled onion

Treatment combinations	Percent moisture						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	88.16	88.10	87.86	87.64	87.39	86.93	85.96
P_1S_2		88.08	87.83	87.62	87.35	86.90	85.88
P_2S_1		88.05	87.89	87.63	87.33	86.55	85.26
P_2S_2		88.02	87.83	87.60	87.28	86.50	85.20
P_3S_1		88.03	87.85	87.58	87.26	86.52	85.23
P_3S_2		88.00	87.80	87.55	87.22	86.47	85.16
P_4S_1		88.10	87.92	87.72	87.45	86.96	86.12
P_4S_2		88.10	87.90	87.69	87.40	86.92	85.94
SE ±		0.0030	0.0015	0.0127	0.0155	0.0025	0.0105
CD at 1%		0.0127	0.0064	NS	NS	0.0106	0.0443
P_1	88.16	88.09	87.86	87.63	87.37	86.91	85.92
P_2		88.03	87.84	87.62	87.30	86.53	85.23
P_3		88.01	87.82	87.57	87.24	86.49	85.20
P_4		88.10	87.91	87.70	87.43	86.94	86.03
SE ±		0.0021	0.0011	0.0089	0.0110	0.0018	0.0074
CD at 1%		0.0090	0.0046	0.0377	0.0461	0.0075	0.0313
S_1	88.16	88.07	87.88	87.64	87.36	86.74	85.64
S_2		88.05	87.84	87.61	87.31	86.70	85.55
SE ±		0.0015	0.0008	0.0063	0.0077	0.0013	0.0053
CD at 1%		0.0063	0.0032	0.0266	0.0326	0.0053	0.0221

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

Table 22: Effect of packaging treatments and storage temperatures on percent moisture of pretreated diced onion

Treatment combinations	Percent moisture						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	88.16	88.05	87.85	87.63	87.35	86.88	85.90
P_1S_2		88.04	87.82	87.60	87.31	86.78	85.83
P_2S_1		88.00	87.80	87.60	87.30	86.50	85.20
P_2S_2		87.96	87.75	87.55	87.22	86.43	85.15
P_3S_1		87.98	87.76	87.57	87.24	86.48	85.18
P_3S_2		87.93	87.70	87.51	87.18	86.39	85.13
P_4S_1		88.07	87.88	87.67	87.40	86.90	86.08
P_4S_2		88.04	87.85	87.62	87.35	86.82	86.02
SE ±		0.0024	0.0041	0.0038	0.0025	0.0031	0.0020
CD at 1%		0.0099	0.0172	0.0158	0.0104	0.0131	0.0086
P_1	88.16	88.05	87.84	87.62	87.33	86.83	85.86
P_2		87.98	87.77	87.57	87.26	86.46	85.17
P_3		87.95	87.73	87.54	87.21	86.44	85.15
P_4		88.05	87.86	87.64	87.37	86.86	86.05
SE ±		0.0017	0.0029	0.0027	0.0018	0.0022	0.0014
CD at 1%		0.0070	0.0122	0.0112	0.0074	0.0093	0.0061
S_1	88.16	88.02	87.82	87.62	87.32	86.69	85.59
S_2		87.99	87.78	87.57	87.26	86.61	85.53
SE ±		0.0012	0.0020	0.0019	0.0012	0.0016	0.0010
CD at 1%		0.0050	0.0086	0.0079	0.0052	0.0066	0.0043

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

onion. This minimum loss in moisture may be attributed to low temperature, pretreatment with 1 per cent hexanal and the polypropylene packaging arresting water molecules released due to transpiration as reported by Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al*. (1996) in perishable foods and Bahram-Parvar and Lim (2018) in fresh cut onion. The results of the present findings are in agreement with Yaptenco *et al*. (2001) in highland vegetables, Anusuya *et al*. (2016) in Mango and Anusuya (2014) in banana. The fresh cut fruits and vegetables are very high in moisture (85-90 percent). Under ambient conditions, such commodities lose moisture rapidly causing shriveling, drying and losing freshness. The loss of water and gaseous exchange, if prevented would extend its shelf-life. Polymeric film packaging in combination with cool storage has been successful in delaying senescence, maintenance of physico-chemical constituents and extending shelf life. Polypropylene and polyethylene packaging materials modify the gaseous atmosphere around the commodity and also controls its secondary infection. It also helps in arresting the moisture loss and maintains turgidity. The beneficial effects of polyethylene and polypropylene packaging in extending the shelf-life of fresh and fresh cut fruits have been reported by Sahoo *et al.* (2014) in bell pepper, Yommi and Aguiero (2011) in fresh bunched spinach and Piagentini and Guemes (2002) in fresh cut spinach. Among the various packaging treatments tried, the polypropylene bags with freshpaper registered minimum moisture loss. This might be attributed to the freshpaper which had small squares impregnated and/or infused with fenugreek and other spice and herbs extract in addition to the barrier property of the polypropylene bag keeping the freshness of fresh produce as reported by Shukla (2002) in fresh fruits and vegetables and Prasad *et al* (2000) in perishable substances like fresh fruits and vegetables, meat and dairy products.

4.3.1.2 Physiological Loss in Weight (%)

The observations recorded on percent physiological loss in weight of minimally processed onion i.e. whole peeled and diced onion are presented in Table 23 and 24, respectively. The data is also depicted graphically in Fig. 21 and 22. The data revealed that physiological loss in weight of fresh onion i.e. whole peeled and diced onion was significantly influenced by packaging treatments and storage environments. The interaction effects between packagings and storage environments in respect of whole peeled onion were found to be non-significant on 3^{rd}, 6^{th} and 9^{th} day of storage. The physiological loss in weight of pretreated fresh cut onions recorded increasing trend throughout the storage period irrespective of the packagings and storage environments under study.

As regards the packagings tried, the whole peeled onion and diced onion packaged in the polypropylene bags (200 gauge) with freshpaper (P_4) recorded minimum increase in the percent physiological loss in weight than other packaging materials. At the end of

Table 23: Effect of packaging treatments and storage temperatures on percent physiological loss in weight of pretreated whole peeled onion

Treatment combinations	Percent physiological loss in weight					
	Storage period (days)					
	3	6	9	12	15	18
P_1S_1	0.23	0.30	0.46	0.54	0.64	0.79
P_1S_2	0.28	0.34	0.47	0.62	0.69	0.83
P_2S_1	0.25	0.33	0.46	0.61	0.74	0.90
P_2S_2	0.32	0.36	0.50	0.65	0.78	0.95
P_3S_1	0.28	0.35	0.48	0.62	0.76	0.93
P_3S_2	0.34	0.40	0.52	0.68	0.83	0.97
P_4S_1	0.20	0.28	0.43	0.52	0.62	0.74
P_4S_2	0.25	0.34	0.45	0.56	0.66	0.82
SE ±	0.0072	0.0094	0.0099	0.0057	0.0039	0.0038
CD at 1%	NS	NS	NS	0.0238	0.0163	0.0160
P_1	0.26	0.32	0.47	0.58	0.66	0.81
P_2	0.29	0.34	0.48	0.63	0.76	0.93
P_3	0.31	0.38	0.50	0.65	0.79	0.95
P_4	0.23	0.31	0.44	0.54	0.64	0.78
SE ±	0.0051	0.0066	0.0070	0.0040	0.0027	0.0027
CD at 1%	0.0215	0.0278	0.0296	0.0168	0.0116	0.0113
S_1	0.24	0.32	0.46	0.57	0.69	0.84
S_2	0.30	0.36	0.48	0.63	0.74	0.89
SE ±	0.0036	0.0047	0.0050	0.0028	0.0019	0.0019
CD at 1%	0.0152	0.0197	0.0209	0.0119	0.0082	0.0080

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C S_2= 7 ± 1^{0}C

Table 24: Effect of packaging treatments and storage temperatures on percent physiological loss in weight of pretreated diced onion

Treatment combinations	Percent physiological loss in weight					
	Storage period (days)					
	3	6	9	12	15	18
P_1S_1	0.25	0.36	0.53	0.63	0.75	0.87
P_1S_2	0.27	0.41	0.57	0.68	0.82	0.95
P_2S_1	0.26	0.39	0.56	0.68	0.79	0.95
P_2S_2	0.30	0.41	0.62	0.75	0.86	1.03
P_3S_1	0.29	0.39	0.59	0.72	0.82	0.98
P_3S_2	0.35	0.43	0.65	0.78	0.91	1.06
P_4S_1	0.28	0.36	0.51	0.60	0.74	0.83
P_4S_2	0.22	0.38	0.54	0.65	0.79	0.90
SE ±	0.0070	0.0043	0.0042	0.0031	0.0031	0.0017
CD at 1%	0.0295	0.0181	0.0175	0.0130	0.0131	0.0073
P_1	0.26	0.39	0.55	0.66	0.78	0.91
P_2	0.28	0.40	0.59	0.71	0.82	0.99
P_3	0.32	0.41	0.62	0.75	0.86	1.02
P_4	0.25	0.37	0.53	0.62	0.76	0.86
SE ±	0.0050	0.0030	0.0029	0.0022	0.0022	0.0012
CD at 1%	0.0208	0.0128	0.0124	0.0092	0.0093	0.0051
S_1	0.27	0.37	0.55	0.66	0.66	0.91
S_2	0.28	0.41	0.59	0.71	0.71	0.98
SE ±	0.0035	0.0021	0.0021	0.0015	0.0016	0.0009
CD at 1%	0.0147	0.0090	0.0087	0.0065	0.0066	0.0036

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C S_2= 7 ± 1^{0}C

storage period i.e. after 18 days of storage, whole peeled onion packed in polypropylene bags with freshpaper (P_4) recorded minimum PLW (0.78%) while perforated polyethylene terephthalate plastic punnet (P_3) recorded maximum increase in PLW (0.95%). In another experiment, the diced onion packed in the polypropylene bags with freshpaper (P_4) registered minimum PLW (0.86%).

As the storage period advanced, the per cent physiological loss in weight of pretreated fresh cut onions i.e. whole peeled and diced onions increased gradually in both storage environments. However, increase was minimum in the pretreated fresh cut onions stored at S_1 (0 ± 1^0C). At the end of storage period, whole peeled onion stored at S_1 (0 ± 1^0C) registered minimum PLW (0.84%) while S_2 (7 ± 1^0C) environment registered 0.89 percent PLW. As regards the diced onion, storage of diced onion at 0 ± 1^0C (S_1) temperature recorded minimum physiological loss in weight (0.91%) while S_2 recorded 0.98 per cent PLW.

As regards interaction effect of packagings and storage environments under study, minimum physiological loss in weight was recorded by the pretreated fresh cut onion (viz. whole peeled and diced) packaged in polypropylene bags with freshpaper (P_4S_1) than any other treatment combination throughout the storage period. At the end of the storage period i.e. after 18 days, whole peeled onion and diced onion packaged in polypropylene bag (200 gauge) with freshpaper recorded 0.74 and 0.84 per cent PLW, respectively.

The physiological weight loss of fresh and fresh cut fruits and vegetables during storage mainly results from respiration and transpiration. The respiration releases water and carbon dioxide via oxidation of carbohydrates and thus reduces dry matter content (Zhan *et al.*, 2012). Fresh cut products due to exposure of internal tissues to atmospheric conditions are prone to register maximum PLW. In the present investigation, slow increase in physiological loss in weight was recorded irrespective of packaging materials and storage environments in both the types of cut i.e. whole peel and diced onion. However, the rate of increase was very slow in both the storage temperatures and thus maintained quality of fresh cut onions. This might be due to the refrigeration storage ($<7^0$C) environments which slowed the respiration rate, enzymatic process and microbial activity as reported by Nicolla *et al*. (2009) and Waghmare *et al*. (2013) in fresh cut Papaya, Zhan *et al*. (2012) in fresh cut broccoli and Sahoo *et al*. (2014) in fresh bell pepper. The similar results were reported by Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al*. (1996) in perishable foods and Bahram-Parvar and Lim (2018) in fresh cut onion. The fresh cut onion viz., whole peeled and diced onion registered minimum PLW in the polypropylene bags with freshpaper. This could be due to polypropylene packaging which arrests moisture loss by arresting high humidity inside PP bag and maintain the turgidity. Besides, O2 depletion and CO2 increase occur in PP packs reaching equilibrium and as a result of respiratory activity is slowed down as reported by Dhumal (2001) in Aonla fruits. Also, the extract of fenugreek and spice mixture infusion on freshpaper might have increased freshness of cut produce due to release of volatile compounds arresting the physiological activities as well as inhibiting pathogenic activity as reported by Shukla (2002) in fresh fruits and vegetables and Prasad *et al.* (2000) in perishable substances like fresh fruits and vegetables, meat and dairy products.

4.3.1.3 Decay (%)

The data given in Table 25 and 26 and graphically represented in Fig. 23 and 24 indicated that, no decay was observed up to 15th day of storage in case of pretreated whole peeled onion and up to 12th day of storage in pretreated diced onion. Thereafter, decay percentage increased gradually over the period of storage irrespective of packaging treatments and storage conditions in both types of cut i.e whole peel and diced onion. The percent decay in fresh cut onions i.e. whole peeled and diced, thereafter was significantly influenced by packaging treatments, storage conditions and their interactions.

Even on the 15th day after storage, the percent decay observed in all the packing treatments stored in different storage environments was observed in the range of 0 to 4.62 per cent only in case of whole peeled onion and it was reported to have 0 to 4.51 per cent decay in the pretreated diced onion after 12th day of storage.

Among the packaging treatments, decay was not observed in the fresh cut onions i.e. whole peeled and diced packed in 200 gauge polypropylene bags with freshpaper after 15 and 12 days of storage, respectively. After 15th day of storage, the pretreated whole peeled onion packed in perforated polyethylene terephthalate plastic punnets recorded maximum decay (4.93%) while the pretreated diced onion packaged in polypropylene bags registered highest decay (3.93 %) after 12 days of storage. At the end of storage i.e. after 18th day, the lowest decay (1.82 %) was recorded in pretreated whole peeled onion packaged in polypropylene bags with fresh paper. In case of pretreated diced onion same packaging treatment had minimum percent decay (2.75%). The highest per cent decay of 5.81 and 7.74 per cent was recorded in P_3 (perforated polyethylene terephthalate plastic punnets) packaging treatment in respect of pretreated whole peeled and diced onion, respectively.

With the advancement of the storage period, the decay percentage was increased significantly irrespective of the storage environments under study. As the storage period increased the decay percentage was found to be increased with the slight increase in the storage temperature. After 18 days of storage, the maximum percent decay (3.53 and 5.89 %) was recorded in the pretreated whole peeled and diced onions stored at 7 ± 1^0C (S_2), respectively. In both cut types viz., pretreated whole peeled and diced onion, the lowest percent decay of 3.77 and 5.13 was registered in S_1 storage condition.

Regarding treatment combinations, at the end of storage period i.e. after 18th day, the minimum percent decay (1.29 and 2.35 %) was recorded by pretreated fresh cut onions i.e. whole peeled and diced onion packaged in polypropylene bags with freshpaper and stored at 0 ± 1^0C storage conditions (P_4S_1), respectively.

The per cent decay was not observed in the pretreated fresh cut onions i.e. in whole peeled onion up to 15 days and up to 12 days in case of diced onions. This might be attributed to hexanal vapour producing volatile compounds like (E)-2-hexanal which had antifungal properties and deterrence against postharvest pathogens in wide array of fruits and vegetables as reported by Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears. Also, the hexanal treatment might have caused reduction in ethylene evolution rate in fresh cut onion preventing decay. Similar results were observed by Jincy *et al.* (2017) in mango. In addition to this, the pretreated onions packaged in polypropylene bags with freshpaper recorded minimum decay throughout period of study. This could be due to the effect of the polypropylene bags which might have modified the gaseous atmosphere around the fresh cut produce and controlled the secondary infection by arresting the moisture loss by maintain turgidity as well as the barrier property of the bags as reported by Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al.* (1996) in perishable foods, Bahram-Parvar and Lim (2018) in fresh cut onion, Dhumal (2012) in ready to eat pomegranate arils, Dhumal (2001) in Aonla, Patil (2016) and Kaur (2016) in fresh cut lettuce. Also, the freshpaper incorporation in the bags have played a major role in reduced decay due to the antifungal, antibacterial as well as freshness property of the fenugreek and spice extract as reported by Shukla (2002) in perishable fruits and vegetables. It was also observed that pretreated whole peeled, as well as diced onions packed in polypropylene bags with fresh paper and stored at 0 ± 1^0C, had less decay than other packaging treatments and temperatures. This minimum increase in decay might be due to lower microbial proliferation at lower temperature as reported by Liu and Li (2006) in onion crop and due to the PP bags with freshpaper infused with fenugreek extract as reported by Shukla (2002) in fresh fruits and vegetables and Prasad *et al.* (2000) in perishable fresh fruits and vegetables, meat and dairy products. The increase in storage temperature gradually increases the per cent decay. The results of present study are in conformity with Berno *et al.*, 2014 in purple onions. The water accumulation in packaging material might be responsible for growth of microbes and decay of produce as reported by Almenar *et al.,* 2010 in blueberry. The CO_2 concentration goes beyond its acceptable level in packaging materials, leading to anaerobic respiration and accumulation of ethanol. This might have also resulted in decay as reported by Caleb *et al.* (2012) in pomegranate and Hong and Kim (2004) in onion.

Table 25: Effect of packaging treatments and storage temperatures on percent decay of pretreated whole peeled onion

Treatment combinations	Percent decay	
	Storage period (days)	
	15	18
P_1S_1	3.68	5.09
P_1S_2	4.15	5.53
P_2S_1	1.46	3.22
P_2S_2	2.02	4.14
P_3S_1	4.62	5.49
P_3S_2	5.24	6.12
P_4S_1	0.00	1.29
P_4S_2	0.00	2.35
SE ±	0.0360	0.0613
CD at 1%	0.1515	0.2582
P_1	3.92	5.31
P_2	1.74	3.68
P_3	4.93	5.81
P_4	0.00	1.82
SE ±	0.0255	0.0434
CD at 1%	0.1071	0.1826
S_1	2.44	3.77
S_2	2.85	4.53
SE ±	0.0180	0.0307
CD at 1%	0.0758	0.1291

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

Table 26: Effect of packaging treatments and storage temperatures on percent decay of pretreated diced onion

Treatment combinations	Percent decay		
	Storage period (days)		
	12	15	18
P_1S_1	3.35	4.56	6.37
P_1S_2	4.51	5.49	7.18
P_2S_1	1.49	2.56	4.35
P_2S_2	2.15	3.49	5.19
P_3S_1	3.45	5.57	7.43
P_3S_2	4.16	6.89	8.05
P_4S_1	0.00	1.46	2.35
P_4S_2	0.00	1.95	3.14
SE ±	0.1035	0.0564	0.0197
CD at 1%	0.4356	0.2376	0.0829
P_1	3.93	5.03	6.77
P_2	1.82	3.03	4.77
P_3	3.81	6.23	7.74
P_4	0.00	1.70	2.75
SE ±	0.0732	0.0399	0.0139
CD at 1%	0.3080	0.1680	0.0586
S_1	2.07	3.54	5.13
S_2	2.71	4.46	5.89
SE ±	0.0517	0.0282	0.0098
CD at 1%	0.2178	0.1188	0.0415

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

4.3.2 Chemical Parameters

4.3.2.1 pH and acidity (%)

The data in respect of pH of fresh cut onion i.e. whole peeled and diced onion is presented in Table 27 and 28, respectively. While the data related with the per cent acidity is summarized in Table 29 and 30 for whole peeled as well as diced onion respectively. It is evident from the tables that the initial pH and percent acidity of the onion recorded was 5.28 and 0.33 percent. At all the stages (days) of storage, the pH was significantly influenced by packaging materials and storage environments in both the cut types under study i.e. whole peeled and diced onion. However, the interaction effects were non-significant on 3rd, 6th, 9th and 12th days of storage in both cut types i.e. whole peeled and diced onion. As regards the percent acidity in fresh cut onions i.e. whole peeled and diced, significant effects of packaging material and storage environment were observed except on day 3 and 6 of the storage. The interaction effects were non-significant on 3rd, 6th and 9th days of storage in whole peeled onion and 3rd, 6th, 9th and 12th days of storage in diced onion.

Decreasing trend in pH and increase in per cent acidity was observed irrespective of packaging materials and storage environments under study for both the types of cut. As regards packaging material, at the end of storage period (18 days storage), whole peeled onion packed in polypropylene bags with freshpaper (P_4) recorded minimum change in (4.91) while P_3 treatment registered maximum change in pH (4.79). The whole peeled onion packed in polyethylene terephthalate plastic punnet (P_3) recorded highest acidity (0.76%) while P_4 recorded maximum reduction in acidity (0.64%) after 18 days storage. As regards the diced onion, P_4 (polypropylene bags with freshpaper) registered maximum pH (4.88) with slow increase in acidity (0.66%) and minimum pH was recorded by P_3 (4.76) with maximum increase in acidity (0.78%).

During entire storage period, the whole peeled onion, as well as diced onion stored at S_2 (7±1^{0}C), recorded greater deviation in pH as well as increase in per cent acidity than that of those stored at S_1 (0±1^{0}C). At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0±1^{0}C (S_1) temperature recorded maximum pH of 4.86 and 4.84, respectively. The percent acidity content registered in S_1 storage conditions was 0.67 and 0.69 per cent, respectively for whole peeled and diced onion.

As regards treatment combinations of packaging and storage environments, with the advancement of storage period, decreasing trend in pH and increase in acidity was recorded in both the cut types i.e. whole peeled and diced onion. Non-significant differences in pH and acidity were recorded in both cut types up to 12 days. At the end of storage period, the whole peeled onion and diced onion packaged in polypropylene bag with freshpaper stored at 0±1^{0}C (P_4S_1) had registered minimum deviation in pH (4.93 and 4.90) and acidity (0.62 and 0.63 %),

Table 27: Effect of packaging treatments and storage temperatures on pH of pretreated whole peeled onion

Treatment combinations	pH						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	5.28	5.22	5.18	5.15	5.11	5.07	4.90
P_1S_2		5.18	5.15	5.11	5.07	5.00	4.85
P_2S_1		5.16	5.13	5.09	5.03	4.98	4.81
P_2S_2		5.13	5.11	5.03	4.97	4.93	4.80
P_3S_1		5.16	5.13	5.07	5.00	4.95	4.81
P_3S_2		5.10	5.09	5.02	4.95	4.86	4.77
P_4S_1		5.23	5.19	5.17	5.14	5.11	4.93
P_4S_2		5.20	5.17	5.13	5.08	5.04	4.88
SE ±		0.0093	0.0108	0.0056	0.0058	0.0031	0.0039
CD at 1%		NS	NS	NS	NS	0.0131	0.0163
P_1	5.28	5.20	5.17	5.13	5.09	5.04	4.88
P_2		5.14	5.12	5.06	5.00	4.96	4.81
P_3		5.13	5.11	5.05	4.98	4.91	4.79
P_4		5.21	5.18	5.15	5.11	5.07	4.91
SE ±		0.0066	0.0076	0.0040	0.0041	0.0022	0.0027
CD at 1%		0.0278	0.0321	0.0168	0.0173	0.0093	0.0116
S_1	5.28	5.19	5.16	5.12	5.07	5.03	4.86
S_2		5.15	5.13	5.07	5.02	4.96	4.83
SE ±		0.0047	0.0054	0.0028	0.0029	0.0016	0.0019
CD at 1%		0.0196	0.0227	0.0119	0.0123	0.0066	0.0082

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C

S_2= 7 ± 1^0C

Table 28: Effect of packaging treatments and storage temperatures on pH of pretreated diced onion

Treatment combinations	pH						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	5.28	5.21	5.18	5.13	5.10	5.08	4.87
P_1S_2		5.16	5.13	5.09	5.04	4.97	4.83
P_2S_1		5.18	5.16	5.11	5.08	4.95	4.80
P_2S_2		5.15	5.11	5.06	5.02	4.90	4.75
P_3S_1		5.17	5.16	5.08	5.06	4.93	4.79
P_3S_2		5.15	5.10	5.05	5.00	4.88	4.73
P_4S_1		5.23	5.18	5.15	5.12	5.09	4.90
P_4S_2		5.19	5.15	5.12	5.06	5.02	4.85
SE ±		0.0058	0.0043	0.0053	0.0027	0.0046	0.0194
CD at 1%		NS	NS	NS	NS	0.0023	0.0097
P_1	5.28	5.18	5.16	5.11	5.07	5.02	4.85
P_2		5.16	5.14	5.08	5.05	4.93	4.77
P_3		5.16	5.13	5.07	5.03	4.90	4.76
P_4		5.21	5.16	5.13	5.09	5.06	4.88
SE ±		0.0041	0.0030	0.0038	0.0019	0.0033	0.0016
CD at 1%		0.0172	0.0127	0.0159	0.0080	0.0137	0.0069
S_1	5.28	5.20	5.17	5.12	5.09	5.01	4.84
S_2		5.16	5.12	5.08	5.03	4.94	4.79
SE ±		0.0029	0.0021	0.0027	0.0013	0.0023	0.0012
CD at 1%		0.0122	0.0090	0.0112	0.0056	0.0097	0.0049

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C

S_2= 7 ± 1^0C

Table 29: Effect of packaging treatments and storage temperatures on percent acidity of pretreated whole peeled onion

Treatment combinations	Percent acidity						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	0.33	0.37	0.41	0.46	0.53	0.60	0.65
P_1S_2		0.38	0.43	0.49	0.55	0.66	0.68
P_2S_1		0.37	0.40	0.47	0.57	0.68	0.71
P_2S_2		0.38	0.43	0.49	0.58	0.70	0.75
P_3S_1		0.38	0.43	0.49	0.57	0.69	0.73
P_3S_2		0.40	0.45	0.52	0.60	0.72	0.78
P_4S_1		0.36	0.40	0.43	0.52	0.58	0.62
P_4S_2		0.37	0.42	0.47	0.53	0.64	0.66
SE ±		0.0140	0.0178	0.0108	0.0034	0.0041	0.0032
CD at 1%		NS	NS	NS	0.0144	0.0172	0.0135
P_1	0.33	0.38	0.42	0.47	0.54	0.63	0.66
P_2		0.38	0.42	0.48	0.58	0.69	0.73
P_3		0.39	0.44	0.50	0.59	0.71	0.76
P_4		0.36	0.41	0.45	0.53	0.61	0.64
SE ±		0.0099	0.0126	0.0076	0.0024	0.0029	0.0023
CD at 1%		NS	NS	0.0322	0.0102	0.0122	0.0096
S_1	0.33	0.37	0.41	0.46	0.55	0.64	0.67
S_2		0.38	0.43	0.49	0.57	0.68	0.72
SE ±		0.0070	0.0089	0.0054	0.0017	0.0020	0.0016
CD at 1%		NS	NS	0.0227	0.0072	0.0086	0.0068

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

Table 30: Effect of packaging treatments and storage temperatures on percent acidity of pretreated diced onion

Treatment combinations	Percent acidity						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	0.33	0.38	0.42	0.46	0.55	0.62	0.64
P_1S_2		0.39	0.44	0.51	0.57	0.67	0.69
P_2S_1		0.38	0.43	0.47	0.59	0.68	0.74
P_2S_2		0.40	0.45	0.50	0.63	0.71	0.78
P_3S_1		0.39	0.43	0.49	0.61	0.70	0.76
P_3S_2		0.40	0.47	0.51	0.64	0.73	0.79
P_4S_1		0.36	0.40	0.44	0.53	0.60	0.63
P_4S_2		0.38	0.43	0.47	0.55	0.65	0.68
SE ±		0.0053	0.0069	0.0066	0.0051	0.0035	0.0027
CD at 1%		NS	NS	NS	NS	0.0146	0.0113
P_1	0.33	0.39	0.43	0.49	0.56	0.64	0.66
P_2		0.39	0.44	0.49	0.61	0.70	0.76
P_3		0.39	0.45	0.50	0.63	0.72	0.78
P_4		0.37	0.42	0.46	0.54	0.63	0.66
SE ±		0.0038	0.0048	0.0046	0.0036	0.0025	0.0019
CD at 1%		0.0159	0.0204	0.0195	0.0152	0.0104	0.0080
S_1	0.33	0.38	0.42	0.47	0.57	0.65	0.69
S_2		0.39	0.45	0.50	0.60	0.69	0.74
SE ±		0.0027	0.0034	0.0033	0.0026	0.0017	0.0013
CD at 1%		0.0113	0.0144	0.0138	0.0108	0.0073	0.0056

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

respectively. However, at the end of storage i.e. after 18 days, maximum reduction in pH (4.77 and 4.73) with maximum increase in acidity (0.78 and 0.79 %) was recorded in perforated polyethylene terephthalate plastic punnet packed whole peeled and diced onion stored at 7±1^{0}C.

The organic acids present in onions are glutamic, citric and malic acids. In present study, the non-significant difference in the pH of fresh cut red onion was recorded up to 12 days and significant decrease in pH of onion was noted with the advancement of storage period in both cut types. Significant increase in the titratable acidity of fresh cut whole peeled as well as diced onion was noted in both the storage temperatures. This was due to absorption of CO_2 in aqueous phase, microbial deterioration, action of endogenous enzymes and synthesis of organic acids as observed by Rolle and Chism (1987) in minimally processed fruits and vegetables. The increase in the titratable acidity might be attributed to the greater stress caused due to higher intensity of cut as reported by Berno *et al.* (2014) in fresh cut purple onion. However, the decrease in pH was slow in pretreated fresh cut onion. These results implied that hexanal vapours were effective to delay the breakdown of starch content and delaying senescence. Similar results were reported by Ashwini *et al.* (2018) in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato. As regards packaging treatments, the decrease was slower in PP bags with freshpaper. The maximum retention of acidity and slow deviation in pH in PP bags with freshpaper bags packaging may be attributed to slower rate of transpiration and respiration because of PP barrier and keeping freshlike quality due to fenugreek extract, high humidity and arresting the loss of moisture which reduces rate of utilization of organic acid during respiration as reported by Shukla (2002) in fresh fruits and vegetables, Bahram-Parvar and Lim (2018) in fresh cut onion, Dhumal (2012) in ready to eat pomegranate arils, Dhumal (2001) in Aonla, Patil (2016) and Kaur (2016) in fresh cut lettuce, Angadi and Krishnamurthy (1992) in Mandarins and Singh and Narayana (1995) in Mango. The storage temperature not only regulates all the physiological activities but also affects the physico-chemical changes in fruits and vegetables during storage. The increase in acidity as well as decrease in pH was relatively slow in both the storage temperatures and thus maintained quality of fresh cut onions. This might be due to the refrigeration storage (<7^{0}C) environments which slowed the physiological activities, reduced respiration rate, enzymatic process and microbial activity as reported by Nicolla *et al.* (2009) and Waghmare *et al.* (2013) in fresh cut produce, Zhan *et al.* (2012) in fresh cut broccoli and Sahoo *et al.* (2014) in fresh bell pepper.

4.3.2.2 Total Soluble Solid (^{0}Brix)

Perusal of data (Table 31 and 32) revealed that at the beginning of the storage, TSS of fresh cut onion recorded was 11.50^{0}Brix and it decreased throughout the storage period. The significant differences in TSS were recorded due to packaging materials and storage environments in both cut types of onions. However, the interaction effects were non-significant on 3rd and 6th days of storage in whole peeled and 3rd day of storage in diced onion.

Among various packaging materials, onion packed in polypropylene bags with freshpaper (P_4) recorded minimum change in TSS throughout the storage period than that of onion packed in polyethylene terephthalate plastic punnets. Minimum decrease in TSS (10.48^{0}Brix and 10.46^{0}Brix) was recorded in whole peeled and diced onion packed in polypropylene bags with freshpaper, respectively. The whole peeled onion packed in polyethylene terephthalate plastic punnets recorded minimum TSS (10.39^{0}Brix).

During the entire storage period, the whole peeled and diced onion stored at S_2 (7±1^{0}C) recorded greater deviation in TSS than that of those stored at S_1 (0±1^{0}C). At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0±1^{0}C (S_1) temperature recorded maximum TSS (10.47^{0}Brix and 10.44^{0}Brix), respectively.

As regards different packaging materials and storage temperatures, whole peeled onion packed in polypropylene bags with fresh paper and stored in 0±1^{0}C (P_4S_1) recorded maximum TSS retention throughout the storage period. At the end of storage period i.e. after 18 days of storage, minimum decrease (10.52^{0}Brix) in TSS of whole peeled onion and 10.50^{0}Brix in diced onion were recorded in both cut types of onion packed in polypropylene bags with freshpaper. The diced onion packed in polyethylene terephthalate plastic punnets recorded maximum decrease in TSS (10.38^{0}Brix).

In the present investigation, the decrease in TSS was observed throughout the storage period. This decrease over a period of time could be assigned to the damage caused in the cell structure by cutting process and eliminating part of its content as reported by Berno *et al.* (2014) in fresh cut purple onion and also the consumption of soluble solids as a source of energy reservoir (Brecht *et al.,* 2007). The decompartmentalization of enzymes and substrates altering TSS and flavor might also be responsible as reported by Blanchard *et al.* (1996) in diced yellow onions, Rico *et al.* (2007) and Hodges and Toivonen (2008) in fresh cut fruits and vegetables. The slower changes in TSS can be attributed to the pretreatment with 1 per cent hexanal, lower temperature and higher humidity prevailed in storage, which helped in slow and reduced utilization in respiration and other physiological activities as reported by Nicolla *et al.* (2009) and Waghmare *et al.* (2013) in fresh cut produce, Zhan *et al.* (2012) in fresh cut broccoli and Sahoo *et al.* (2014) in fresh bell pepper. The pretreatment with one percent hexanal might have delayed the breakdown of starch content. Analogous observations in accordance with these findings were reported by Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) in Tomato and Ashwini *et al.* (2018) in banana , Garg *et al.* (1978) in guava, Kaur (2016) and Patil (2016) in fresh cut lettuce. As regards the packaging, the whole peeled and diced onions packaged in PP bags with freshpaper recorded minimum change in TSS throughout the storage

Table 31: Effect of packaging treatments and storage temperatures on total soluble solids (^{0}Brix) of pretreated whole peeled onion

Treatment combinations	TSS (^{0}Brix)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	11.50	11.48	11.28	11.17	10.95	10.71	10.50
P_1S_2		11.44	11.20	11.08	10.88	10.68	10.41
P_2S_1		11.46	11.26	11.15	10.89	10.69	10.45
P_2S_2		11.43	11.18	11.10	10.85	10.62	10.37
P_3S_1		11.44	11.25	11.11	10.86	10.65	10.42
P_3S_2		11.42	11.14	11.08	10.83	10.59	10.35
P_4S_1		11.48	11.30	11.18	10.98	10.76	10.52
P_4S_2		11.45	11.21	11.10	10.92	10.71	10.45
SE ±		0.0102	0.0142	0.0076	0.0036	0.0044	0.0041
CD at 1%		NS	NS	0.0318	0.0153	0.0185	0.0171
P_1	11.50	11.46	11.24	11.12	10.92	10.70	10.46
P_2		11.44	11.22	11.12	10.87	10.66	10.41
P_3		11.43	11.20	11.10	10.85	10.62	10.39
P_4		11.47	11.26	11.14	10.95	10.74	10.48
SE ±		0.0072	0.0100	0.0053	0.0026	0.0031	0.0029
CD at 1%		0.0304	0.0423	0.0225	0.0109	0.0131	0.0121
S_1	11.50	11.47	11.27	11.15	10.92	10.70	10.47
S_2		11.43	11.18	11.09	10.87	10.65	10.39
SE ±		0.0051	0.0071	0.0038	0.0018	0.0022	0.0020
CD at 1%		0.0215	0.0299	0.0159	0.0077	0.0092	0.0085

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C

S_2= 7 ± 1^{0}C

Table 32: Effect of packaging treatments and storage temperatures on total soluble solids (^{0}Brix) of pretreated diced onion

Treatment combinations	TSS (^{0}Brix)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	11.50	11.45	11.24	11.15	10.93	10.68	10.47
P_1S_2		11.42	11.18	11.07	10.86	10.64	10.39
P_2S_1		11.43	11.21	11.15	10.90	10.65	10.40
P_2S_2		11.41	11.17	11.04	10.83	10.60	10.37
P_3S_1		11.40	11.19	11.13	10.87	10.62	10.39
P_3S_2		11.39	11.15	11.00	10.79	10.56	10.34
P_4S_1		11.46	11.26	11.17	10.95	10.73	10.50
P_4S_2		11.43	11.19	11.08	10.90	10.67	10.43
SE ±		0.0055	0.0035	0.0049	0.0039	0.0035	0.0060
CD at 1%		NS	0.0146	0.0208	0.0163	0.0146	0.0252
P_1	11.50	11.44	11.21	11.11	10.90	10.66	10.43
P_2		11.42	11.19	11.09	10.87	10.63	10.39
P_3		11.40	11.17	11.06	10.83	10.59	10.36
P_4		11.44	11.23	11.13	10.93	10.70	10.46
SE ±		0.0039	0.0025	0.0035	0.0027	0.0025	0.0042
CD at 1%		0.0163	0.0104	0.0147	0.0116	0.0104	0.0178
S_1	11.50	11.44	11.22	11.15	10.91	10.67	10.44
S_2		11.41	11.17	11.05	10.85	10.62	10.38
SE ±		0.0027	0.0017	0.0025	0.0019	0.0017	0.0030
CD at 1%		0.0116	0.0073	0.0104	0.0082	0.0073	0.0126

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C

S_2= 7 ± 1^{0}C

period. This could be due to the retardation in rate of loss in moisture by maintaining humidity and freshness inside packaging and maintaining turgidity which resulted in lower utilization of sugar during physiological processes as well as cutting stress. The results of present findings are in conformity with those reported by Shukla (2002) in fresh fruits and vegetables, Bahram-Parvar and Lim (2018) in fresh cut onion, Dhumal (2012) in ready to eat pomegranate arils, Dhumal (2001) in Aonla, Patil (2016) and Kaur (2016) in fresh cut lettuce.

4.3.2.3 Anthocyanins (mg per 100g)

From the data summarized in Table 33 and 34 and graphically represented in Fig. 25 and 26 revealed that at the beginning of the storage, the anthocyanin content in fresh cut red onion was 37.15 mg per 100g. At all the stages (days) of storage, the anthocyanin content in fresh cut onion was significantly influenced by packaging materials and storage environments. However, the interaction effects were non-significant on 3rd, 6th and 9th days of storage in whole peeled and diced onion.

The anthocyanin content was decreased slightly after pretreatment. During storage, slight increase in anthocyanins observed followed by decrease, in the packaging materials and storage environments under study for both the cut types. As regards packaging material, at the end of storage period (18 days storage), whole peeled onion packed in polypropylene bags with freshpaper (P_4) recorded maximum anthocyanins (36.51 mg per 100g) while P_3 recorded minimum anthocyanins (36.43 mg per 100g). The diced onion packaged in the polypropylene bags with freshpaper (P_4) registered maximum anthocyanins (36.49 mg per 100g) and minimum anthocyanins was recorded by P_3 (36.41 mg per 100g).

During entire storage period, the whole peeled onion, as well as diced onion stored at S_2 (7±1^{0}C), recorded slow decrease but continuous and maximum decrease in anthocyanins than that of those stored at S_1 (0±1^{0}C). At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0±1^{0}C (S_1) temperature recorded maximum anthocyanins (36.48 mg per 100g).

As regards treatment combination of packaging and storage environments, with the advancement of storage period, decreasing trend was recorded in both the cut types i.e. whole peeled and diced onion after initial slight increase in anthocyanins. The whole peeled onion and diced onion packaged in polypropylene bag with freshpaper stored at 0±1^{0}C (P_4S_1) had retained highest anthocyanins (36.54 and 36.52 mg per 100g) respectively. However, at the end of storage i.e. after 18 days, maximum reduction in anthocyanins (36.41 and 36.38 mg per 100g) was recorded in perforated polyethylene terephthalate plastic punnet packaged whole peeled and diced onion stored at 7±1^{0}C.

The red colour in onion is attributed to the presence of seven cyanidins and one peonidin glycosides. The major anthocyanins present in large quantity in red onion are cyanidin

Table 33: Effect of packaging treatments and storage temperatures on anthocyanins (mg per 100g) of pretreated whole peeled onion

Treatment combinations	Anthocyanins (mg per 100g)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	37.15	36.60	36.61	36.64	36.59	36.55	36.50
P_1S_2		36.59	36.59	36.61	36.56	36.50	36.47
P_2S_1		36.58	36.60	36.62	36.58	36.50	36.45
P_2S_2		36.57	36.59	36.60	36.55	36.47	36.42
P_3S_1		36.58	36.58	36.61	36.56	36.49	36.44
P_3S_2		36.55	36.58	36.60	36.54	36.45	36.41
P_4S_1		36.60	36.62	36.64	36.61	36.58	36.54
P_4S_2		36.59	36.60	36.62	36.56	36.51	36.48
SE ±		0.0077	0.0073	0.0056	0.0040	0.0055	0.0035
CD at 1%		NS	NS	NS	0.0169	0.0230	0.0146
P_1	37.15	36.60	36.60	36.62	36.57	36.52	36.49
P_2		36.57	36.60	36.61	36.57	36.49	36.44
P_3		36.57	36.58	36.61	36.55	36.47	36.43
P_4		36.60	36.61	36.63	36.58	36.55	36.51
SE ±		0.0054	0.0052	0.0039	0.0028	0.0039	0.0025
CD at 1%		0.0229	0.0219	0.0166	0.0119	0.0163	0.0104
S_1	37.15	36.59	36.60	36.63	36.59	36.53	36.48
S_2		36.57	36.59	36.61	36.55	36.48	36.45
SE ±		0.0039	0.0037	0.0028	0.0020	0.0027	0.0017
CD at 1%		0.0162	0.0155	0.0117	0.0084	0.0115	0.0073

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C

S_2= 7 ± 1^0C

Table 34: Effect of packaging treatments and storage temperatures on anthocyanins (mg per 100g) of pretreated diced onion

Treatment combinations	Anthocyanins (mg per 100g)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	37.15	36.56	36.58	36.61	36.56	36.51	36.50
P_1S_2		36.55	36.55	36.58	36.54	36.48	36.43
P_2S_1		36.53	36.57	36.59	36.53	36.49	36.46
P_2S_2		36.51	36.53	36.56	36.52	36.43	36.41
P_3S_1		36.53	36.55	36.56	36.53	36.47	36.44
P_3S_2		36.49	36.51	36.53	36.50	36.42	36.38
P_4S_1		36.57	36.59	36.62	36.58	36.53	36.52
P_4S_2		36.55	36.57	36.60	36.55	36.49	36.45
SE ±		0.0062	0.0061	0.0085	0.0040	0.0040	0.0041
CD at 1%		NS	NS	NS	0.0167	0.0167	0.0173
P_1	37.15	36.56	36.56	36.60	36.55	36.49	36.47
P_2		36.52	36.55	36.57	36.53	36.46	36.44
P_3		36.51	36.53	36.54	36.52	36.44	36.41
P_4		36.56	36.58	36.61	36.57	36.51	36.49
SE ±		0.0044	0.0043	0.0060	0.0028	0.0028	0.0029
CD at 1%		0.0184	0.0182	0.0253	0.0118	0.0118	0.0122
S_1	37.15	36.55	36.57	36.60	36.55	36.50	36.48
S_2		36.53	36.54	36.57	36.53	36.46	36.42
SE ±		0.0031	0.0031	0.0042	0.0020	0.0020	0.0021
CD at 1%		0.0130	0.0129	0.0179	0.0083	0.0083	0.0086

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)

P_2= Active package lacquered with nanosilver

P_3= Polyethylene terephthalate plastic punnets

P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C

S_2= 7 ± 1^0C

3-glucoside and cyanidin 3-diglucoside as reported by Fuleki (1971) in red onion. The stability of individual anthocyanins was found to be different. The decrease in the anthocyanin content of fresh cut onion was observed in present investigation. This decrease was due to the water solubility of the anthocyanins and slight loss of pigment due to immersion in water as observed by Perez-Gregorio *et al.* (2011) in sliced red onion and Dhumal (2012) in Pomegranate. During early period of storage in all the packaging materials under study, slight increase in anthocyanins was recorded in both cut types. This increase in anthocyanins in later stages of storage was associated with the slow biosynthesis of coloured pigments and/or *de novo* synthesis of anthocyanins at low temperatures as a response against the stress caused by cutting process and low temperature. The anthocyanins increase the tolerance of the vegetables and fruits to refrigeration temperature as reported by Ferreres *et al.* (1996) in shredded red onion, Perez-Greogorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions, Gould and Lister (2006) in fruits and vegetables and Perez-Vicente *et al.* (2004) in pomegranate cv. Mollar. In spite of decrease in anthocyanins the appearance of fresh cut onion was acceptable after the storage period. This could be attributed to the lower storage temperature and PP bags packaging which might have reduced the rate of moisture loss, maintained turgidity and resulted in reduced physiological activities of fresh cut onion. Similar finding was reported by Ferreres *et al.* (1996) in shredded red onion, Dhumal (2012) in ready to eat pomegranate arils cv. Bhagwa. The pretreatment with 1 percent hexanal might have played important role in minimum changes in anthocyanins as reported by Sharma *et al.* (2010) in sweet cherry. Fenugreek and spice extract impregnated freshpaper might have also played important role in maintaining anthocyanins in the package by release of active volatiles and other compounds which maintained freshness of the product by reduced metabolic activities and thereby the consumption of anthocyanins as a source of energy reservoir as stated by Shukla (2002) in fresh fruits and vegetables.

4.3.2.4 Pyruvic acid (µmol/g fresh weight)

The data in Table 35 and 36 and graphically represented by Fig. 27 and 28 indicated that the pyruvic acid content in pretreated fresh cut, at all the stages of storage, was significantly influenced by packaging materials, storage environments and by their interaction. The data indicated that at the beginning of the storage, the pyruvic acid content in the fresh cut red onion was 5.284 µmol/g fresh weight. Decreasing in pyruvic acid was observed irrespective of packaging materials and storage environments under study for both the cut types i.e. whole peeled as well as diced onion.

As regards packaging material, at the end of storage period (18 days storage), pretreated whole peeled onion packed in polyethylene terephthalate plastic punnet (P_3) recorded lowest pyruvic acid (5.083 µmol/g fresh weight) while P_4 recorded minimum reduction in

Table 35: Effect of packaging treatments and storage temperatures on pyruvic acid (µmol/g fresh weight) of pretreated whole peeled onion

Treatment combinations	Pyruvic acid (µmol/g fresh weight)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	5.284	5.281	5.258	5.220	5.165	5.107	5.094
P_1S_2		5.280	5.255	5.218	5.157	5.100	5.090
P_2S_1		5.278	5.253	5.217	5.159	5.103	5.088
P_2S_2		5.276	5.250	5.213	5.153	5.098	5.082
P_3S_1		5.274	5.252	5.215	5.155	5.100	5.086
P_3S_2		5.274	5.247	5.210	5.149	5.093	5.079
P_4S_1		5.283	5.260	5.223	5.168	5.112	5.097
P_4S_2		5.280	5.256	5.219	5.160	5.104	5.093
SE ±		0.00024	0.00034	0.00032	0.00031	0.00048	0.00046
CD at 1%		0.00101	0.00142	0.00134	0.00131	0.00202	0.00194
P_1	5.284	5.280	5.257	5.219	5.161	5.103	5.092
P_2		5.277	5.251	5.215	5.156	5.101	5.085
P_3		5.274	5.249	5.212	5.152	5.096	5.083
P_4		5.282	5.258	5.221	5.164	5.108	5.095
SE ±		0.00017	0.00024	0.00022	0.00022	0.00034	0.00033
CD at 1%		0.00071	0.00100	0.00095	0.00093	0.00143	0.00137
S_1	5.284	5.279	5.255	5.218	5.162	5.105	5.091
S_2		5.277	5.252	5.215	5.155	5.099	5.086
SE ±		0.00012	0.00017	0.00016	0.00016	0.00024	0.00023
CD at 1%		0.00050	0.00071	0.00067	0.00066	0.00101	0.00097

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

Table 36: Effect of packaging treatments and storage temperatures on pyruvic acid (µmol/g fresh weight) of pretreated diced onion

Treatment combinations	Pyruvic acid (µmol/g fresh weight)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	5.284	5.280	5.257	5.219	5.163	5.105	5.093
P_1S_2		5.278	5.252	5.215	5.158	5.100	5.089
P_2S_1		5.277	5.251	5.215	5.156	5.101	5.086
P_2S_2		5.274	5.248	5.210	5.151	5.096	5.080
P_3S_1		5.271	5.250	5.213	5.153	5.098	5.084
P_3S_2		5.268	5.245	5.208	5.147	5.092	5.077
P_4S_1		5.283	5.259	5.221	5.167	5.109	5.094
P_4S_2		5.279	5.253	5.217	5.159	5.102	5.091
SE ±		0.00031	0.00027	0.00035	0.00048	0.00036	0.00051
CD at 1%		0.00130	0.00114	0.00145	0.00202	0.00153	0.00216
P_1	5.284	5.279	5.254	5.217	5.161	5.102	5.091
P_2		5.275	5.250	5.213	5.154	5.098	5.083
P_3		5.270	5.247	5.211	5.150	5.095	5.080
P_4		5.281	5.256	5.219	5.163	5.106	5.093
SE ±		0.00022	0.00019	0.00024	0.00034	0.00026	0.00036
CD at 1%		0.00092	0.00081	0.00103	0.00143	0.00109	0.00153
S_1	5.284	5.278	5.254	5.217	5.160	5.103	5.089
S_2		5.275	5.249	5.213	5.154	5.097	5.084
SE ±		0.00015	0.00014	0.00017	0.00024	0.00018	0.00026
CD at 1%		0.00065	0.00057	0.00073	0.00101	0.00077	0.00108

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge) P_3= Polyethylene terephthalate plastic punnets

P_2= Active package lacquered with nanosilver P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C S_2= 7 ± 1^0C

pyruvic acid (5.095 µmol/g fresh weight). The pretreated diced onion packaged in the polypropylene bags with freshpaper (P_4) registered minimum loss in pyruvic acid (5.093 µmol/g fresh weight).

During entire storage period, the pretreated whole peeled onion, as well as diced onion stored at S_2 (7±1^{0}C), recorded continuous and maximum decrease in pyruvic acid as compared with S_1 stored fresh cut onions. At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0±1^{0}C (S_1) temperature recorded maximum pyruvic acid of 5.091 and 5.089 µmol/g fresh weight respectively.

As regards treatment combination of packagings and storage environments, with the advancement of storage period, decreasing trend was recorded in both the cut types i.e. whole peeled and diced onion. The whole peeled onion and diced onion packaged in polypropylene bag (200 gauge) with freshpaper stored at 0±1^{0}C had retained maximum pyruvic acid content (5.097 and 5.094 µmol/g fresh weight), respectively. However, at the end of storage i.e. after 18 days, minimum pyruvic acid (5.079 and 5.077 µmol/g fresh weight) was recorded in perforated polyethylene terephthalate plastic punnet packaged whole peeled and diced onion stored at 7±1^{0}C.

The decrease in the pyruvic acid content was observed in the pretreated fresh cut onion irrespective of packaging treatments and storage temperatures under study. A lower pyruvic acid content in all the treatment combinations might be attributed to cell disruption, volatization and leaking of substances responsible for pungency, the loss of enzymes, accelerated physiological activities and higher consumption of pyruvic acid as a metabolic substrate as reported by Berno *et al.* (2014) in fresh cut purple onion, Schwimmer and Weston (1961); Anthon and Barrett (2003); Lanzotti (2006); Bretch *et al.* (2007); Bhat *et al.* (2010); Miguel and Durigan (2007) in onions. The PP bag packaging might have caused reduced loss in pyruvic acid by acting as a barrier and thus prevented leaching and volatilization of pyruvates and other flavoring compounds. The effectiveness of PE and PP bags was stated by Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al.* (1996) in perishable foods, Bahram-Parvar and Lim (2018) in fresh cut onion, Dhumal (2012) in ready to eat pomegranate arils, Dhumal (2001) in Aonla, Patil (2016) and Kaur (2016) in fresh cut lettuce. The effectiveness of Fenugreek and spice extract impregnated freshpaper in reducing metabolic activities and keeping product freshlike is reported by Shukla (2002) in fresh fruits and vegetables. The lower temperature during storage might have also played important role in arresting volatilization and leaching of compounds responsible for pungency by lowering down the physiological activities in the packages. The results are in conformity with Ferreres *et al.* (1996) in shredded red onion, Perez-Greogorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions.

4.3.3 In Package Atmosphere (Headspace gas concentrations)

4.3.3.1 Oxygen (%)

Data given in Table 37 and 38 regarding changes in oxygen content of package indicated that oxygen content in the packaged fresh cut onion (whole peeled and diced onion) decreased gradually irrespective of storage conditions. However, in perforated packagings like (P_2 and P_3) the oxygen content was found to constant but less than atmosphere oxygen (Fig. 29 and 30). The oxygen content in pretreated whole peeled and diced onion packages was found to be influenced by packaging treatments and storage environments significantly. The interaction effect between packaging and storage environments irrespective of whole peeled and diced onions found to be significant at all the stages i.e. storage.

As regards packaging under study, the packaging treatments P_1 and P_4 registered significant decrease in oxygen content in headspace. The initial oxygen content in the headspace of packages was ranged from 18.15 to 18.22 per cent. The whole peeled onion packed in semipermeable polypropylene bag with freshpaper registered 1.27 per cent oxygen while P_1 packaging treatment recorded lowest oxygen content in headspace (1.23%). In perforated packagings viz. P_2 and P_3, almost constant but reduced per cent oxygen in the headspace was recorded. At the end of storage i.e. after 18th day, packaging treatment P_2 and P_3 recorded 15.16 and 15.09 per cent oxygen in the headspace. As regards diced onion similar trend was observed in respect of per cent headspace oxygen content. However, the oxygen consumption was at higher pace. The headspace oxygen content at the end of storage period in pretreated diced onion packaged in polypropylene bags with fresh paper (P_4) recorded was 1.19 per cent. The oxygen content in headspace of perforated polyethylene terephthalate plastic punnets packed diced onion was 15.05%.

As the storage period advanced, the per cent oxygen content in headspace in packaged onion (i.e. whole peeled and diced onion) decreased gradually in both storage environments. Among the storage environment under study, packaged fresh cut onions (i.e. whole peeled and diced onion) stored at 0 ± 1^0C recorded relatively slow decrease in oxygen as compared with S_2 storage environment. At the end of storage period, pretreated whole peeled onion stored at S_1 registered 8.22 per cent oxygen in headspace of packages while S_2 (7 ± 1^0C) registered 8.15 per cent oxygen in headspace of packages. As regards the diced onion, storage at 0 ± 1^0C (S_1) temperature recorded maximum per cent headspace oxygen (8.15%) while S_2 recorded 8.07% oxygen in headspace of packages.

As regards interaction effects of packagings and storage environments, under study the gradual decrease in headspace oxygen concentration was recorded by pretreated fresh cut onion i.e. (whole peeled and diced onion). The pretreated whole peeled onions packed in polypropylene bags with fresh paper (P_4S_1) recorded 1.31% headspace oxygen while those

Table 37: Effect of packaging treatments and storage temperatures on percent oxygen of pretreated whole peeled onion

Treatment combinations	Percent Oxygen						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	18.30	11.49	9.63	7.71	5.14	2.88	1.27
P_1S_2	18.26	11.45	9.53	7.58	5.02	2.76	1.19
P_2S_1	18.23	18.14	17.86	17.15	16.76	16.25	15.19
P_2S_2	18.13	18.09	17.78	17.05	16.68	16.18	15.13
P_3S_1	18.19	18.11	17.82	17.11	16.71	16.2	15.11
P_3S_2	18.11	18.03	17.75	17.01	16.62	16.13	15.06
P_4S_1	18.35	11.55	9.65	7.76	5.16	2.94	1.31
P_4S_2	18.28	11.48	9.58	7.63	5.05	2.83	1.23
SE ±	0.0048	0.0049	0.0029	0.0048	0.0034	0.0046	0.0048
CD at 1%	0.0201	0.0208	0.0120	0.0203	0.0142	0.0192	0.0201
P_1	18.28	11.47	9.58	7.65	5.08	2.82	1.23
P_2	18.18	18.12	17.82	17.10	16.72	16.21	15.16
P_3	18.15	18.07	17.79	17.06	16.67	16.16	15.09
P_4	18.32	11.52	9.62	7.70	5.11	2.89	1.27
SE ±	0.0034	0.0035	0.0020	0.0034	0.0024	0.0032	0.0034
CD at 1%	0.0142	0.0147	0.0085	0.0143	0.0100	0.0136	0.0142
S_1	18.27	14.82	13.74	12.43	10.94	9.57	8.22
S_2	18.20	14.76	13.66	12.32	10.84	9.47	8.15
SE ±	0.0024	0.0025	0.0014	0.0024	0.0017	0.0023	0.0024
CD at 1%	0.0101	0.0104	0.0060	0.0101	0.0071	0.0096	0.0101

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C
S_2= 7 ± 1^0C

Table 38: Effect of packaging treatments and storage temperatures on percent oxygen of pretreated diced onion

Treatment combinations	Percent Oxygen						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	18.20	11.45	9.31	7.59	4.90	2.81	1.15
P_1S_2	18.15	11.34	9.23	7.51	4.83	2.69	1.08
P_2S_1	18.20	18.11	17.81	17.11	16.69	16.2	15.14
P_2S_2	18.11	18.03	17.73	17.03	16.6	16.14	15.04
P_3S_1	18.16	18.09	17.78	17.09	16.61	16.15	15.09
P_3S_2	18.09	18.00	17.69	16.98	16.57	16.09	15.01
P_4S_1	18.25	11.49	9.39	7.62	4.98	2.85	1.23
P_4S_2	18.19	11.38	9.27	7.54	4.87	2.73	1.14
SE ±	0.0037	0.0036	0.0035	0.0035	0.0044	0.0037	0.0031
CD at 1%	0.0155	0.0150	0.0145	0.0149	0.0187	0.0155	0.0129
P_1	18.18	11.40	9.27	7.55	4.87	2.75	1.12
P_2	18.16	18.07	17.77	17.07	16.65	16.17	15.09
P_3	18.12	18.05	17.73	17.03	16.59	16.12	15.05
P_4	18.22	11.43	9.33	7.58	4.93	2.79	1.19
SE ±	0.0026	0.0025	0.0024	0.0025	0.0031	0.0026	0.0022
CD at 1%	0.0109	0.0106	0.0103	0.0105	0.0132	0.0109	0.0091
S_1	18.20	14.79	13.57	12.35	10.80	9.50	8.15
S_2	18.13	14.69	13.48	12.26	10.72	9.41	8.07
SE ±	0.0018	0.0018	0.0017	0.0018	0.0022	0.0018	0.0015
CD at 1%	0.0077	0.0075	0.0073	0.0074	0.0093	0.0077	0.0064

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C
S_2= 7 ± 1^0C

packed in perforated polyethylene terephthalate plastic punnets (P_3S_2) recorded 15.06 per cent headspace oxygen. The diced onion packed in polypropylene bags with fresh paper (P_4S_1) recorded 1.23% headspace oxygen while polyethylene terephthalate plastic punnet packaging (P_3S_2) recorded 15.01% headspace oxygen.

Breathing and biodegradable packaging films with appropriate oxygen transmission rates (OTR) and water vapour permeability of packaging materials play an important role in development of equilibrium modified atmosphere (EMA) and quality maintenance in package of fresh cut products during storage (Krasnova and Dukalska, 2012). The gas composition in the headspace of packed pretreated fresh cut onion changed during storage irrespective of packaging treatments and storage temperatures under study. The decrease in the percent oxygen in headspace of packages i.e perforated and unperforated was observed. This might be due to accelerated respiration, other metabolic and physiological processes continued in fresh cut onion in initial phase which later on reduced the respiratory activity with increased ethylene biosynthesis and action. The utilization of the respiratory gases in physiological and metabolic activities might have formed equilibrium modified atmosphere as reported by Bahram-Parvar *et al.* (2018) in onion and Berno *et al.* (2014) in fresh cut onion, Patil (2016) in fresh cut lettuce, Krasnova and Dukalska (2012) in fresh cut mixed salad quality, Kang (2007) in fresh cut lettuce, Kim *et al.* (2005) in fresh cut Romaine lettuce and by Smyth *et al.* (1998) in deciduous fruits. Strict temperature control after processing is needed to reduce wound-induced metabolic activity, as observed in the present study in case of both whole peeled and diced onions stored at 0±1°C and 7±1°C. The similar observations were recorded by Patil (2016) and Kaur (2016) in fresh cut lettuce. The pretreatment with 1 percent hexanal and packaging in PP bags with freshpaper might had slowed down consumption of oxygen for respiratory metabolism due to inhibition PLD activity as reported by Ashwini *et al.* (2018) Golding *et al.,* 1998, 1999; Pathak *et al.,* 2003; Pelayo *et al.,* 2003; Lohini *et al.,* 2004 in banana and Shukla (2002) in fresh fruits and vegetables.

4.3.1.3.2 Carbon dioxide (%)

Data presented in Table 39 and 40 and Fig. 31 and 32 regarding changes in headspace concentration of carbon dioxide in package indicated that carbon dioxide content in the packed fresh cut onion (i.e. whole peeled and diced onion) increased gradually irrespective of storage conditions. However, in perforated packagings like (P_2 and P_3) the carbon dioxide content was minimum. The headspace carbon dioxide content in whole peeled and diced onion packages was influenced by packaging treatments, storage environments and their interactions significantly.

As regards packagings under study, the packaging treatments P_1 and P_4 registered significant increase in carbon dioxide concentration in headspace of the packages. The initial carbon dioxide content in the headspace of packages was ranged from 0.03 to 0.62%. The whole peeled onion packed in semipermeable polypropylene bag with freshpaper registered 4.28% carbon dioxide while P_1 packaging treatment recorded lowest carbon dioxide content in headspace (4.36%) at the end of storage period. In perforated packagings, almost constant per cent carbon dioxide in the headspace was recorded in both cut types. At the end of storage i.e. after 18th day of storage, packaging treatments P_2 and P_3 recorded 1.22 and 1.35 per cent carbon dioxide in the headspace. As regards diced onion similar trend was observed in respect of per cent headspace carbon dioxide content. The headspace carbon dioxide content at the end of storage period, diced onion polypropylene bags with fresh paper (P_4) was 4.66 per cent.

As the storage period advanced, the per cent carbon dioxide content in headspace in packaged onion (i.e. whole peeled and diced onion) increased gradually in both storage environments. Among the storage environments under study, packaged fresh cut onion (i.e. whole peeled and diced onion) stored at S_1 (0 ± 1^0C) recorded relatively slow increase in carbon dioxide as compared with S_2. At the end of storage period, whole peeled onion stored at S_1 registered 2.74% carbon dioxide in headspace of packages while S_2 (7 ± 1^0C) registered 2.87% carbon dioxide in headspace of packages. As regards the diced onion, storage at 0 ± 1^0C (S_1) temperature recorded 2.98% carbon dioxide in headspace while S_2 storage recorded 3.11% carbon dioxide in headspace of packages.

As regards interaction effect of packagings and storage environments under study, the gradual decrease in headspace carbon dioxide concentration was recorded by pretreated fresh cut onion (i.e. whole peeled and diced onion). The pretreated whole peeled onion packed in polypropylene bags with fresh paper (P_4S_1) recorded 4.20% headspace carbon dioxide while polyethylene terephthalate plastic punnets (P_3S_2) recorded 1.41% headspace carbon dioxide. The pretreated diced onion packed in polypropylene bags with fresh paper (P_4S_1) recorded 4.56% headspace carbon dioxide while polyethylene terephthalate plastic punnets (P_3S_2) recorded 1.49% headspace carbon dioxide.

In the present investigation, the decrease in the headspace carbon dioxide concentration was observed irrespective of the packaging materials and storage environments under study. The pretreatment with hexanal might have helped in reduction of metabolic activity by reducing PLD activity as reported by Ashwini *et al.* (2018) Golding *et al.,* 1998,1999; Pathak *et al.,* 2003; Pelayo *et al.,*2003; Lohini *et al.,* 2004 in banana and Shukla (2002) in fresh fruits and vegetables. Also, the barrier properties of PP bags, as well as inclusion of freshpaper in PP bags for extension of shelf life, are reported by Shukla (2002) in fresh fruits and vegetables. The lower temperature storage might have also played important role in arresting the respiratory activities at low rate by reducing other physiological and biochemical alteration. The similar results were reported by Patil (2016) and Kaur (2016) in fresh cut lettuce. The utilization of the

Table 39: Effect of packaging treatments and storage temperatures on percent carbon dioxide of pretreated whole peeled onion

Treatment combinations	Percent carbon dioxide						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	0.46	1.05	1.15	1.59	2.76	3.51	4.29
P_1S_2	0.63	1.13	1.24	1.73	2.86	3.86	4.43
P_2S_1	0.02	0.08	0.20	0.54	0.84	1.08	1.15
P_2S_2	0.03	0.11	0.34	0.72	1.05	1.15	1.28
P_3S_1	0.02	0.10	0.36	0.63	1.02	1.21	1.30
P_3S_2	0.03	0.15	0.48	0.86	1.11	1.33	1.41
P_4S_1	0.38	0.98	1.09	1.52	2.68	3.42	4.20
P_4S_2	0.59	1.04	1.16	1.69	2.98	3.56	4.36
SE ±	0.0035	0.0054	0.0052	0.0058	0.0047	0.0069	0.0051
CD at 1%	0.0149	0.0226	0.0218	0.0244	0.0196	0.0290	0.0215
P_1	0.54	1.09	1.19	1.66	2.81	3.68	4.36
P_2	0.03	0.10	0.27	0.63	0.95	1.12	1.22
P_3	0.03	0.13	0.42	0.75	1.07	1.27	1.35
P_4	0.48	1.01	1.13	1.61	2.83	3.49	4.28
SE ±	0.0025	0.0038	0.0037	0.0041	0.0033	0.0049	0.0036
CD at 1%	0.0105	0.0160	0.0154	0.0172	0.0138	0.0205	0.0152
S_1	0.22	0.55	0.70	1.07	1.83	2.30	2.74
S_2	0.32	0.61	0.80	1.25	2.00	2.48	2.87
SE ±	0.0018	0.0027	0.0026	0.0029	0.0023	0.0034	0.0025
CD at 1%	0.0074	0.0113	0.0109	0.0122	0.0098	0.0145	0.0107

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

Table 40: Effect of packaging treatments and storage temperatures on percent carbon dioxide of pretreated diced onion

Treatment combinations	Percent Carbon dioxide						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	0.53	1.09	1.23	1.73	2.89	3.76	4.72
P_1S_2	0.72	1.23	1.36	1.84	3.02	3.87	4.87
P_2S_1	0.03	0.16	0.32	0.63	0.95	1.16	1.27
P_2S_2	0.04	0.23	0.47	0.81	1.11	1.24	1.34
P_3S_1	0.04	0.2	0.43	0.71	1.16	1.27	1.38
P_3S_2	0.05	0.26	0.51	0.92	1.23	1.38	1.49
P_4S_1	0.42	1.03	1.17	1.63	2.73	3.62	4.56
P_4S_2	0.63	1.12	1.29	1.75	3.09	3.79	4.76
SE ±	0.0162	0.0092	0.0090	0.0028	0.0130	0.0028	0.0042
CD at 1%	0.0682	0.0387	0.0378	0.0117	0.0547	0.0117	0.0177
P_1	0.62	1.16	1.30	1.79	2.96	3.81	4.80
P_2	0.04	0.20	0.40	0.72	1.03	1.20	1.30
P_3	0.05	0.23	0.47	0.82	1.20	1.33	1.43
P_4	0.52	1.08	1.23	1.69	2.91	3.71	4.66
SE ±	0.0115	0.0065	0.0064	0.0020	0.0092	0.0020	0.0030
CD at 1%	0.0482	0.0274	0.0268	0.0083	0.0387	0.0083	0.0125
S_1	0.25	0.62	0.79	1.18	1.93	2.45	2.98
S_2	0.36	0.71	0.91	1.33	2.11	2.57	3.11
SE ±	0.0081	0.0046	0.0045	0.0014	0.0065	0.0014	0.0021
CD at 1%	0.0341	0.0194	0.0189	0.0059	0.0274	0.0059	0.0088

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

respiratory gases in physiological and metabolic activities might have formed equilibrium modified atmosphere as reported by Bahram-Parvar *et al.* (2018) in onion and Berno *et al.* (2014) in fresh cut onion, Patil (2016) in fresh cut lettuce, Krasnova and Dukalska (2012) in fresh cut mixed salad quality, Kang (2007) in fresh cut lettuce, Kim *et al.* (2005) in fresh cut Romaine lettuce and by Smyth *et al.* (1998) in iceberg lettuce.

4.3.3.3 Ethylene (ppm)

Perusal of data given in Table 41 and 42 and graphically represented in Fig. 33 and 34 regarding changes in headspace concentration of ethylene in packages indicated that ethylene concentration in the packaged pretreated fresh cut onion (whole peeled and diced onion) increased gradually irrespective of storage conditions. The headspace concentration of ethylene in pretreated whole peeled and diced onion packages was found to be influenced by packaging treatments and storage environments significantly. The interaction effects between packaging and storage environments in respect of both i.e. pretreated whole peeled and diced onions were found to be significant at all the stages i.e. storage.

The significant increase in the concentration of ethylene in headspace of packages was observed. The initial ethylene concentration in the packages of pretreated whole peeled as well as diced onion was ranged in between 7.08 to 7.61 ppm. The pretreated whole peeled onion packed in semipermeable polypropylene bag with freshpaper registered 14.97 ppm ethylene while P_1 packaging treatment recorded highest ethylene content in package (15.02 ppm) at the end 18^{th} day of storage. At the end of storage i.e. after 18^{th} day of storage, packaging treatment P_2 and P_3 recorded 15.07 and 15.11 ppm ethylene in the headspace of packages. As regards, diced onion similar trend was observed irrespective of packaging treatment under study. On 18^{th} day of storage, the headspace concentration of ethylene in pretreated diced onion packed in polypropylene bags with fresh paper (P_4) recorded was15.93 ppm. The maximum ethylene content in headspace of package was recorded in polyethylene terephthalate plastic punnets (16.06 ppm).

As the storage period advanced, the ethylene concentration in headspace of packaged onion (i.e. whole peeled and diced onion) increased gradually in both storage environments. At the end of storage period, whole peeled onion stored at S_1 registered 15.01 ppm ethylene in headspace of packages while S_2 (7 ± 1^0C) registered 15.08 ppm ethylene in headspace of packages. As regards the diced onion at 0 ± 1^0C (S_1) temperature recorded minimum ethylene content (15.96 ppm) while S_2 recorded 16.03 ppm ethylene in headspace of packages.

As regards interaction effects of packagings and storage environments under study, the gradual increase in headspace ethylene concentration was recorded by pretreated fresh cut onion (i.e. whole peeled and diced onion). The pretreated whole peeled onions packed in polypropylene bags with fresh paper (P_4S_1) recorded 14.94 ppm ethylene in headspace while

Table 41: Effect of packaging treatments and storage temperatures on ethylene (ppm) of pretreated whole peeled onion

Treatment combinations	Ethylene (ppm)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	7.15	7.78	9.14	9.40	12.00	12.66	15.00
P_1S_2	7.20	7.79	9.18	9.43	12.06	12.79	15.05
P_2S_1	7.18	7.83	9.21	9.49	12.26	13.80	15.03
P_2S_2	7.22	7.87	9.24	9.55	12.43	13.96	15.11
P_3S_1	7.20	7.84	9.23	9.51	12.31	13.87	15.07
P_3S_2	7.24	7.87	9.26	9.58	12.48	14.02	15.15
P_4S_1	7.08	7.71	9.10	9.35	11.98	12.62	14.94
P_4S_2	7.18	7.76	9.18	9.39	12.03	12.73	15.01
SE ±	0.0046	0.0036	0.0051	0.0056	0.0043	0.0060	0.0042
CD at 1%	0.0192	0.0153	0.0213	0.0235	0.0180	0.0254	0.0177
P_1	7.18	7.79	9.16	9.41	12.03	12.73	15.02
P_2	7.20	7.85	9.23	9.52	12.35	13.88	15.07
P_3	7.22	7.86	9.25	9.54	12.39	13.95	15.11
P_4	7.13	7.74	9.14	9.37	12.00	12.68	14.97
SE ±	0.0032	0.0026	0.0036	0.0039	0.0030	0.0043	0.0030
CD at 1%	0.0136	0.0109	0.0151	0.0166	0.0127	0.0179	0.0125
S_1	7.15	7.79	9.17	9.44	12.14	13.24	15.01
S_2	7.21	7.82	9.22	9.49	12.25	13.38	15.08
SE ±	0.0023	0.0018	0.0025	0.0028	0.0021	0.0030	0.0021
CD at 1%	0.0096	0.0077	0.0106	0.0117	0.0090	0.0127	0.0088

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

Table 42: Effect of packaging treatments and storage temperatures on ethylene (ppm) of pretreated diced onion

Treatment combinations	Ethylene (ppm)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	7.36	8.95	10.12	11.37	13.19	13.94	15.94
P_1S_2	7.45	8.71	10.16	11.40	13.29	14.07	16.00
P_2S_1	7.47	8.98	10.19	11.46	14.28	15.08	15.97
P_2S_2	7.58	9.03	10.22	11.52	14.49	15.24	16.06
P_3S_1	7.55	9.01	10.21	11.48	14.36	15.15	16.02
P_3S_2	7.61	9.05	10.24	11.55	14.57	15.30	16.10
P_4S_1	7.27	8.93	10.08	11.32	13.09	13.90	15.89
P_4S_2	7.38	8.98	10.16	11.36	13.23	14.01	15.96
SE ±	0.0054	0.0050	0.0055	0.0037	0.0056	0.0058	0.0034
CD at 1%	0.0229	0.0210	0.0232	0.0156	0.0235	0.0246	0.0144
P_1	7.41	8.83	10.14	11.38	13.24	14.01	15.97
P_2	7.52	9.00	10.21	11.49	14.39	15.16	16.01
P_3	7.58	9.03	10.23	11.52	14.47	15.23	16.06
P_4	7.33	8.96	10.12	11.34	13.16	13.95	15.93
SE ±	0.0038	0.0035	0.0039	0.0026	0.0039	0.0041	0.0024
CD at 1%	0.0162	0.0148	0.0164	0.0110	0.0166	0.0174	0.0102
S_1	7.41	8.97	10.15	11.41	13.73	14.52	15.96
S_2	7.51	8.94	10.20	11.46	13.90	14.66	16.03
SE ±	0.0027	0.0025	0.0028	0.0019	0.0028	0.0029	0.0017
CD at 1%	0.0114	0.0105	0.0116	0.0078	0.0117	0.0123	0.0072

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

polyethylene terephthalate plastic punnets (P_3S_2) recorded 15.15 ppm ethylene. The pretreated diced onion packed in polypropylene bags with fresh paper (P_4S_1) recorded 15.89 ppm ethylene content in headspace while polyethylene terephthalate plastic punnets (P_3S_2) recorded 16.10 ppm ethylene content.

The gradual increase in the ethylene concentration in the headspace of packages was recorded irrespective of all the treatments under study. This accelerated rate of ethylene concentration could be attributed to the cuts and impacts which increased the surface area, increased rate of respiration and accelerated deterioration as reported by Hong and Kim (2004) in onion and Berno *et al.* (2014) in fresh cut onion. The reduced respiratory activity in later stages might have resulted in increased ethylene biosynthesis and action by synthesis of volatiles stimulating anaerobic respiration, off-flavour production and even microbial growth as reported by Mattos *et al*. (2013). The rate of ethylene evolution might have slowed down in all the treatments under study due to application of hexanal which could have reduced PLD activity as reported by Sharma *et al.* 2010 in sweet cherry, Ashwini *et al.* (2018) Golding *et al.*, 1998,1999; Pathak *et al.*, 2003; Pelayo *et al.*,2003; Lohini *et al.*, 2004 in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato. The beneficial effects of polyethylene and polypropylene packaging in extending the shelf-life of fresh and fresh cut fruits by acting as a barrier for exchange of gases and arresting respiratory and other metabolic activities have been reported by Sahoo *et al* (2014) in bell pepper, Yommi and Aguiero (2011) in fresh bunched spinach and Piagentini and Guemes (2002) in fresh cut spinach. The inclusion freshpaper inside package might have absorbed the ethylene gas generated in packages, as well as release of volatiles from fenugreek extract, might have resulted in delayed senescence as reported by Shukla (2002) in fresh fruits and vegetables. The lower temperature storage might have also played important role in arresting the respiratory activities at low rate by reducing other physiological and biochemical alteration. Thus, slow release of ethylene in headspace. The similar results were reported by Patil (2016) and Kaur (2016) in fresh cut lettuce.

4.3.4 Microbial limit tests

4.3.4.1 Total microbial count (log cfu g^{-1})

Data in Table 43 and 44 indicated that at the beginning of the storage, total aerobic count of fresh onion recorded was 6.04 log cfu per gram. After the pretreatment with 1 percent hexanal, the total aerobic count in the whole peeled onion and diced onion was reduced to 3.18 and 3.32 log cfu per gram. Total aerobic count in fresh cut whole peeled as well as diced onion was significantly influenced by packaging materials, storage temperatures and their interactions. It is evident from the data that, with the advancement of the storage period, the total microbial load in both types of cut onion increased gradually irrespective of packaging treatment and storage environment.

Table 43: Effect of packaging treatments and storage temperatures on total microbial count (log cfu g^{-1}) of pretreated whole peeled onion

Treatment combinations	Total microbial count (log cfu g^{-1})		
	Storage periods (days)		
	Initial before treatment	Initial after treatment	Final
P1S1	6.04	3.18	6.12
P1S2			6.76
P2S1			6.04
P2S2			6.50
P3S1			8.18
P3S2			8.60
P4S1			5.04
P4S2			5.40
SE ±			0.0221
CD at 1%			0.0930
P1			6.44
P2			6.27
P3			8.39
P4			5.22
SE ±			0.0156
CD at 1%			0.0657
S1			6.35
S2			6.82
SE ±			0.0110
CD at 1%			0.0465

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_3= Polyethylene terephthalate plastic punnets
P_2= Active package lacquered with nanosilver
P_4= Polypropylene bags with fresh paper

Storage temperatures

$S_1 = 0 \pm 1^0C$
$S_2 = 7 \pm 1^0C$

Table 44: Effect of packaging treatments and storage temperatures on total microbial count (log cfu g^{-1}) of pretreated diced onion

Treatment combinations	Total microbial count (log cfu g^{-1})		
	Storage periods (days)		
	Initial before treatment	Initial after treatment	Final
P1S1	6.04	3.32	6.52
P1S2			7.06
P2S1			6.36
P2S2			6.94
P3S1			8.88
P3S2			9.11
P4S1			5.56
P4S2			5.94
SE ±			0.0205
CD at 1%			0.0864
P1			6.79
P2			6.65
P3			8.99
P4			5.75
SE ±			0.0145
CD at 1%			0.0611
S1			6.83
S2			7.26
SE ±			0.0103
CD at 1%			0.0432

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_3= Polyethylene terephthalate plastic punnets
P_2= Active package lacquered with nanosilver
P_4= Polypropylene bags with fresh paper

Storage temperatures

$S_1 = 0 \pm 1^0C$
$S_2 = 7 \pm 1^0C$

As regards the packaging treatments, at the end of storage i.e. after 18th day, the lowest total aerobic count (5.22 log cfu/gram) was recorded in pretreated whole peeled onion packaged in polypropylene bags with fresh paper. In case of pretreated diced onion same packaging treatment registered minimum total aerobic count (5.75 log cfu/gram). The maximum microbial load of 8.39 and 8.99 log cfu/gram was recorded in P_3 (perforated polyethylene terephthalate plastic punnets) packaging treatment in respect of pretreated whole peeled and diced onion respectively.

With the advancement of the storage period, the total aerobic count was found to be increased significantly irrespective of the storage environments under study. After 18 days of storage, the maximum total aerobic count (6.82 and 7.26 log cfu/gram) was recorded in the pretreated whole peeled and diced onions stored at 7±1^{0}C (S_2) respectively. In both cut types viz., pretreated whole peeled and diced onion, the lowest total aerobic count of 6.35 and 6.83 log cfu per gram was registered in S_1 storage condition.

Regarding treatment combinations, at the end of storage period i.e. after 18th day, the minimum total aerobic count (5.04 and 5.56 log cfu/gram) was recorded by pretreated fresh cut onions i.e. whole peeled and diced onion packaged in polypropylene bags with freshpaper and stored at 0±1^{0}C storage conditions (P_4S_1) respectively.

In the present investigation, the initial total aerobic count of untreated onion was reduced drastically after pretreatment with 1 percent hexanal. This was due to sanitation and washing out of microbes as well as due to hexanal vapour producing volatile compounds like (E)-2-hexanal which had antifungal properties and deterrence against postharvest pathogens in wide array of fruits and vegetables as reported by Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears. The minimum microbial count in case of polypropylene bags with freshpaper may be attributed to the antifungal and antimicrobial property of fenugreek and spice extract impregnated freshpaper along with the barrier property of PP bags arresting microbial growth due to increase in CO_2 gas inside package by modification of atmosphere as reported by Shukla (2002) in perishable fruits and vegetables, Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al.* (1996) in perishable foods, Bahram-Parvar and Lim (2018) in fresh cut onion, Dhumal (2012) in ready to eat pomegranate arils, Dhumal (2001) in Aonla, Patil (2016) and Kaur (2016) in fresh cut lettuce. It was also observed that pretreated whole peeled, as well as diced onions packed in polypropylene bags with fresh paper and stored at 0±1^{0}C, registered minimum total aerobic count than other treatment combination. This minimum load of microbes might be due to lower microbial proliferation at lower temperature as reported by Liu and Li (2006) in onion crop and due to the PP bags with freshpaper infused with fenugreek extract as reported by Shukla (2002) in fresh fruits and vegetables and Prasad *et al* (2000) in perishable substances like fresh fruits and vegetables, meat and dairy products. Our results are in conformity with Berno *et al.,* 2014 in purple onions. However, the water accumulation in packaging material might be responsible for growth of microbes and decay of produce as reported by Almenar *et al.*, 2010 in blueberry. The CO_2 concentration goes beyond its acceptable level in packaging materials, leading to anaerobic respiration and accumulation of ethanol leading to availability fermented substrate for the growth of microorganisms. This might have also resulted into increase in total aerobic count in product decay as reported by Caleb *et al.* (2012) in pomegranate and Hong and Kim (2004) in onion.

4.3.5 Sensorial Analysis (Visible Quality Markers)

4.3.5.1 Colour, appearance and flavour (In package and out package)

With the advancement of storage period, decreasing trend in score for colour (Table 45 and 46), appearance (Table 47 and 48) and flavour (Table 49 and 50) of pretreated onions i.e. whole peeled and diced onion was recorded irrespective of packaging materials and storage environments.

Among the various packaging materials and storage environments, fresh cut onion packed in polypropylene bags with freshpaper and stored at S_1 had maximum score for colour, appearance and flavour than those packed in perforated polyethylene terephthalate plastic punnet and stored in S_2 storage environment. The initial score of 9.00 was recorded for colour, appearance and flavor of both cut types onion. The whole peeled onion and diced onion packed in polypropylene bags with freshpaper and stored 0 ± 1^0C at recorded the highest score for colour (6.38 and 6.28), flavor (6.28 and 6.24) and appearance (6.34 and 6.25), respectively. However, whole peeled and diced onion packed in perforated polyethylene terephthalate plastic punnet registered lowest score for the colour (6.06 and 6.00), flavor (6.04 and 6.01) and appearance (6.04 and 6.02) at the end of the storage period i.e after 18^{th} of storage.

The quality of the fresh cut onion and the rejection or acceptance of the fresh cut produce is dependent on the colour, flavor, texture (appearance) and nutritional value as reported by Barrett *et al.* (2010) in fresh cut fruits and vegetables and Bahram-Parvar and Lim (2017) in fresh cut onion. The decrease in score of colour and appearance of the fresh cut onion irrespective of packaging treatment and storage environment might be attributed to the loss of anthocyanins as well as texture due to chemical and biochemical reactions responsible for onion discolouration as reported by Ferreres *et al.* (1996) in in shredded red onion, Perez-Gregorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions, Gould and Lister (2006) in fruits and vegetables and Perez-Vicente *et al.* (2004) in pomegranate cv. Mollar. The maximum score for sensory properties was recorded in the pretreated fresh cut onion i.e. whole peeled and diced onion packed in polypropylene bags with fresh paper and stored in 0 ± 1^0C. This might be due to the barrier property of PP bags arresting moisture and maintaining turgidity in package and also due to antimicrobial, antifungal and antiviral property of fenugreek impregnated freshpaper inside

Table 45: Effect of packaging treatments and storage temperatures on colour (score) of pretreated whole peeled onion

Treatment combinations	Colour (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.84	8.60	7.81	7.20	6.70	6.30
P_1S_2	9.00	8.77	8.45	7.71	7.11	6.62	6.18
P_2S_1	9.00	8.80	8.35	7.55	7.15	6.57	6.15
P_2S_2	9.00	8.72	8.21	7.29	7.08	6.49	6.11
P_3S_1	9.00	8.75	8.30	7.45	6.98	6.53	6.09
P_3S_2	9.00	8.62	8.16	7.22	6.88	6.44	6.06
P_4S_1	9.00	8.86	8.62	7.89	7.23	6.75	6.38
P_4S_2	9.00	8.82	8.45	7.74	7.15	6.66	6.28

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

$S_1 = 0 \pm 1^0C$
$S_2 = 7 \pm 1^0C$

Table 46: Effect of packaging treatments and storage temperatures on colour (score) of pretreated diced onion

Treatment combinations	Colour (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.75	8.55	7.71	7.13	6.63	6.24
P_1S_2	9.00	8.70	8.32	7.65	7.02	6.56	6.15
P_2S_1	9.00	8.70	8.26	7.45	7.10	6.51	6.10
P_2S_2	9.00	8.66	8.17	7.23	7.00	6.39	6.07
P_3S_1	9.00	8.67	8.21	7.32	6.91	6.41	6.03
P_3S_2	9.00	8.58	8.10	7.17	6.82	6.36	6.00
P_4S_1	9.00	8.77	8.55	7.75	7.18	6.69	6.28
P_4S_2	9.00	8.72	8.38	7.64	7.07	6.60	6.23

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

$S_1 = 0 \pm 1^0C$
$S_2 = 7 \pm 1^0C$

Table 47: Effect of packaging treatments and storage temperatures on appearance (score) of pretreated whole peeled onion

Treatment combinations	Appearance (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.85	8.60	7.81	7.17	6.80	6.26
P_1S_2	9.00	8.78	8.49	7.76	7.11	6.69	6.20
P_2S_1	9.00	8.78	8.55	7.65	7.10	6.40	6.15
P_2S_2	9.00	8.72	8.48	7.57	6.97	6.34	6.07
P_3S_1	9.00	8.76	8.47	7.51	6.98	6.37	6.09
P_3S_2	9.00	8.70	8.39	7.42	6.80	6.31	6.04
P_4S_1	9.00	8.88	8.62	7.89	7.20	6.88	6.34
P_4S_2	9.00	8.82	8.57	7.74	7.15	6.76	6.24

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

$S_1 = 0 \pm 1^0C$
$S_2 = 7 \pm 1^0C$

Table 48: Effect of packaging treatments and storage temperatures on appearance (score) of pretreated diced onion

Treatment combinations	Appearance (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.80	8.53	7.76	7.12	6.75	6.20
P_1S_2	9.00	8.77	8.40	7.72	7.09	6.66	6.16
P_2S_1	9.00	8.75	8.50	7.60	7.05	6.35	6.08
P_2S_2	9.00	8.70	8.42	7.52	6.91	6.30	6.03
P_3S_1	9.00	8.74	8.39	7.47	6.95	6.32	6.05
P_3S_2	9.00	8.68	8.31	7.38	6.71	6.24	6.02
P_4S_1	9.00	8.85	8.57	7.83	7.14	6.80	6.25
P_4S_2	9.00	8.79	8.50	7.70	7.11	6.67	6.18

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_3= Polyethylene terephthalate plastic punnets
P_2= Active package lacquered with nanosilver
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C
S_2= 7 ± 1^0C

Table 49: Effect of packaging treatments and storage temperatures on flavour (score) of pretreated whole peeled onion (In package and out package)

Treatment combinations	Flavour (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.85	8.60	7.81	7.17	6.7	6.23
P_1S_2	9.00	8.80	8.49	7.71	7.11	6.62	6.17
P_2S_1	9.00	8.78	8.55	7.55	7.10	6.57	6.11
P_2S_2	9.00	8.72	8.48	7.29	6.97	6.49	6.09
P_3S_1	9.00	8.76	8.47	7.45	6.98	6.53	6.07
P_3S_2	9.00	8.70	8.39	7.22	6.80	6.44	6.04
P_4S_1	9.00	8.88	8.62	7.89	7.20	6.75	6.28
P_4S_2	9.00	8.84	8.57	7.74	7.15	6.66	6.22

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_3= Polyethylene terephthalate plastic punnets
P_2= Active package lacquered with nanosilver
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C
S_2= 7 ± 1^0C

Table 50: Effect of packaging treatments and storage temperatures on flavour (score) of pretreated diced onion (In package and out package)

Treatment combinations	Flavour (score)						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.80	8.53	7.71	7.12	6.63	6.18
P_1S_2	9.00	8.79	8.40	7.65	7.09	6.56	6.13
P_2S_1	9.00	8.73	8.50	7.45	7.05	6.51	6.07
P_2S_2	9.00	8.65	8.42	7.23	6.91	6.39	6.05
P_3S_1	9.00	8.70	8.39	7.32	6.95	6.41	6.02
P_3S_2	9.00	8.63	8.31	7.17	6.71	6.36	6.01
P_4S_1	9.00	8.82	8.57	7.75	7.14	6.69	6.24
P_4S_2	9.00	8.80	8.50	7.64	7.11	6.60	6.18

'-' indicates termination of treatments

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_3= Polyethylene terephthalate plastic punnets
P_2= Active package lacquered with nanosilver
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^0C
S_2= 7 ± 1^0C

package which keeps and preserves the freshlike quality of produce as reported by Shukla (2002) in fruits and vegetables, Kaur (2016) and Patil (2016) in fresh cut lettuce. The beneficial effects of polyethylene and polypropylene packaging in extending the shelf-life of fresh and fresh cut fruits have been reported by Sahoo *et al* (2014) in bell pepper, Yommi and Aguiero (2011) in fresh bunched spinach and Piagentini and Guemes (2002) in fresh cut spinach. The low storage temperature and pretreatment with 1 percent hexanal might have also played role in arresting the chemical and biochemical reactions and thus reducing loss in anthocyanins and pyruvic acid as a result of this could have registered maximum score for sensory properties as reported by Sharma *et al.* (2010) in sweet cherry, Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears.

4.2.5.2 Overall acceptability

With the advancement of storage period, overall acceptability of the pretreated fresh cut onion viz., whole peel and diced onion decreased irrespective of the packaging treatment, storage environment and their interactions (Table 51 and 52). The data pertaining to overall acceptability of pretreated whole peeled as well as diced onion is graphically presented in Fig. 35 and 36. At all the stages (days) of storage, the overall acceptability was significantly influenced by packaging materials, storage temperatures and their interactions in both the cut types under study i.e. whole peeled and diced onion.

At the end of storage period i.e. after 18 days, whole peeled onion packed in polypropylene bags with freshpaper (P_4) recorded highest score (6.29) while P_3 recorded lowest score (6.07). The diced onion packaged in the polypropylene bags with freshpaper (P_4) registered maximum acceptability score (6.23) throughout the storage period of 18 days.

During entire storage period, the whole peeled onion, as well as diced onion stored at S_2 (7 ± 1^0C), recorded maximum decrease in score of overall acceptability than that of those stored at S_1 (0 ± 1^0C). At the end of storage period i.e. after 18 days, the whole peeled onion and diced onion stored at 0 ± 1^0C (S_1) temperature recorded maximum score of 6.20 and 6.14, respectively.

As regards treatment combination of packagings and storage environments, with the advancement of storage period, slow but constant decrease was recorded in both the cut types i.e. whole peeled and diced onion. The whole peeled and diced onion packaged in polypropylene bag (200 gauge) with freshpaper stored at 0 ± 1^0C had retained maximum overall acceptability (6.33 and 6.26), respectively throughout the storage period of 18 days. However, at the end of storage i.e. after 18 days, minimum acceptability scores (6.05 and 6.01) were recorded in perforated polyethylene terephthalate plastic punnet packaged whole peeled and diced onion stored in S_2 environment.

Table 51: Effect packaging treatments and storage temperatures on overall acceptability (score) of pretreated whole peeled onion

Treatment combinations	Overall acceptability						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.85	8.60	7.81	7.18	6.73	6.26
P_1S_2		8.78	8.46	7.72	7.11	6.64	6.18
P_2S_1		8.79	8.48	7.58	7.12	6.51	6.14
P_2S_2		8.72	8.39	7.38	7.01	6.44	6.09
P_3S_1		8.76	8.41	7.47	6.98	6.48	6.08
P_3S_2		8.67	8.31	7.29	6.83	6.40	6.05
P_4S_1		8.87	8.62	7.89	7.21	6.79	6.33
P_4S_2		8.82	8.53	7.74	7.15	6.69	6.25
SE ±		0.0048	0.0048	0.0051	0.0062	0.0036	0.0052
CD at 1%		0.0201	0.0201	0.0216	0.0263	0.0151	0.0217
P_1	9.00	8.82	8.53	7.77	7.15	6.69	6.22
P_2		8.75	8.44	7.48	7.07	6.48	6.11
P_3		8.72	8.36	7.38	6.91	6.44	6.07
P_4		8.85	8.57	7.82	7.18	6.74	6.29
SE ±		0.0034	0.0034	0.0036	0.0044	0.0025	0.0036
CD at 1%		0.0142	0.0142	0.0153	0.0186	0.0107	0.0153
S_1	9.00	8.82	8.53	7.69	7.12	6.63	6.20
S_2		8.75	8.42	7.53	7.02	6.54	6.14
SE ±		0.0024	0.0024	0.0026	0.0031	0.0018	0.0026
CD at 1%		0.0101	0.0101	0.0108	0.0131	0.0076	0.0108

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

Table 52: Effect packaging treatments and storage temperatures on overall acceptability (score) of pretreated diced onion

Treatment combinations	Overall acceptability						
	Storage period (days)						
	0	3	6	9	12	15	18
P_1S_1	9.00	8.78	8.54	7.73	7.12	6.67	6.21
P_1S_2		8.75	8.37	7.67	7.07	6.59	6.15
P_2S_1		8.73	8.42	7.50	7.07	6.46	6.08
P_2S_2		8.67	8.34	7.33	6.94	6.36	6.05
P_3S_1		8.70	8.33	7.37	6.94	6.38	6.03
P_3S_2		8.63	8.24	7.24	6.75	6.32	6.01
P_4S_1		8.81	8.56	7.78	7.15	6.73	6.26
P_4S_2		8.77	8.46	7.66	7.10	6.62	6.20
SE ±		0.0055	0.0052	0.0036	0.0049	0.0054	0.0057
CD at 1%		0.0233	0.0219	0.0153	0.0206	0.0226	0.0239
P_1	9.00	8.77	8.45	7.70	7.10	6.63	6.18
P_2		8.70	8.38	7.42	7.01	6.41	6.07
P_3		8.67	8.29	7.30	6.84	6.35	6.02
P_4		8.79	8.51	7.72	7.13	6.68	6.23
SE ±		0.0039	0.0037	0.0026	0.0035	0.0038	0.0040
CD at 1%		0.0165	0.0155	0.0109	0.0146	0.0160	0.0169
S_1	9.00	8.76	8.46	7.59	7.07	6.56	6.14
S_2		8.71	8.35	7.48	6.96	6.47	6.10
SE ±		0.0028	0.0026	0.0018	0.0024	0.0027	0.0028
CD at 1%		0.0117	0.0110	0.0077	0.0103	0.0113	0.0120

Packaging treatments

P_1= Polypropylene bags (200 gauge)
P_2= Active package lacquered with nanosilver
P_3= Polyethylene terephthalate plastic punnets
P_4= Polypropylene bags with fresh paper

Storage temperatures

S_1= 0 ± 1^{0}C
S_2= 7 ± 1^{0}C

The overall acceptability of the fresh and fresh cut produce depends on the retention of colour, flavor, appearance and nutritional qualities of produce. The packaging material and the storage environment affects the overall acceptability of the produce as reported by Kaur (2016) in fresh cut lettuce. In the present investigation, overall acceptability was reduced fresh cut onion i.e. whole peeled and diced packaged in polypropylene bags with freshpaper and over the period of storage time irrespective of packaging treatment. However, the pretreated stored in 0 ± 1^0C registered maximum score for all the sensorial attributes and overall acceptability in comparison with other packaging materials and storage environments. This could be assigned to the PP bags packaging and its barrier property which might have decreased O_2 content and increase in CO_2 content in the packet and maintenance of turgidity as reported by Blanchard *et al.*, 1996 in onions as well as due to antimicrobial, antifungal and antiviral property of fenugreek impregnated freshpaper inside package which keeps and preserves the freshlike quality of produce as reported by Shukla (2002) in fruits and vegetables, Kaur (2016) and Patil (2016) in fresh cut lettuce. The beneficial effects of polyethylene and polypropylene packaging in extending the shelf-life of fresh and fresh cut fruits have been reported by Sahoo *et al.* (2014) in bell pepper, Yommi and Aguiero (2011) in fresh bunched spinach and Piagentini and Guemes (2002) in fresh cut spinach. The low storage temperature and pretreatment with 1 per cent hexanal could be the other reason for retaining overall acceptability of fresh cut produce as reported by Sharma *et al.* (2010) in sweet cherry, Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears. The results are in conformity with those reported by Piercy *et al.* (2012) in fresh cut onions, Liu and Li (2006) in sliced onion, Howard *et al.* (1994) in diced onions. Cantwell and Suslow (2002) in minimally processed products, O'Connor-Shaw *et al.* (1994) in minimally processed muskmelon cv. Honey Dew and Dhumal (2012) in pomegranate.

4.4 Effectiveness of Modified Atmosphere Packaging and Storage Temperatures on Pre-treated Fresh cut Red Onion

The two forms of fresh cut onion viz., whole peeled and diced onion pre-treated with 1% hexanal were undertaken to study the effectiveness of modified atmosphere packaging and different storage temperatures. The fresh cut onions were packaged in 200 gauge polypropylene bags. The data pertaining to physico-chemical parameters, headspace gas concentrations, sensorial observations and microbial test limits are presented and discussed hereunder suitable headings.

4.4.1 Physical Parameters

4.4.1.1 Percent moisture

The data in respect of per cent moisture content in fresh cut onion (i.e. whole peeled and diced onion) are summarized in Table 53 and 54 and graphically represented in a Fig.

37 and 38. Initial per cent moisture content in pretreated fresh cut onion was 88.15. As regards interaction effect of MAP treatments and storage temperatures, non-significant differences were recorded in both the types of cut up to 12th day of storage. Thereafter, interactions were found to be significant in both pretreated cut types till the end of storage. As regards, the effect of MAP treatment, at all the stages of storage i.e. days, the significant differences were noted in both types of cut. The storage temperatures under study recorded non-significant differences up to 12 days of storage in case of whole peeled onion while in case of diced onion the non-significant effect was noted only after 12th day of storage.

Table 53: Effect of modified atmosphere packaging and storage temperatures on percent moisture of whole peeled onion

Treatment Combinations	Moisture (%)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	88.15	88.08	87.97	87.85	87.59	86.95	85.88	-
M_1S_2		88.06	87.95	87.83	87.56	86.90	85.84	-
M_2S_1		88.12	88.07	87.98	87.65	87.18	86.85	85.93
M_2S_2		88.11	88.06	87.95	87.63	87.14	86.81	85.89
M_3S_1		88.12	88.08	88.00	87.65	87.23	86.90	86.00
M_3S_2		88.12	88.08	87.97	87.63	87.18	86.86	85.96
M_4S_1		88.11	88.03	87.93	87.62	87.14	86.82	85.89
M_4S_2		88.10	88.00	87.91	87.60	87.09	86.78	85.84
M_5S_1		88.11	88.06	87.96	87.64	87.15	86.85	85.91
M_5S_2		88.11	88.06	87.93	87.59	87.11	86.82	85.88
M_6S_1		88.09	88.02	87.90	87.60	86.98	85.91	-
M_6S_2		88.09	88.00	87.87	87.58	86.93	85.89	-
M_7S_1		87.64	85.88	-	-	-	-	-
M_7S_2		87.60	85.84	-	-	-	-	-
M_8S_1		88.04	86.65	85.73	-	-	-	-
M_8S_2		88.00	86.59	85.68	-	-	-	-
SE ±		0.0221	0.0272	0.0237	0.0199	0.0073	0.0060	0.0072
CD at 1%		NS	NS	NS	NS	0.0303	0.0251	0.0302
M_1	88.15	88.07	87.96	87.84	87.58	86.92	85.86	-
M_2		88.12	88.07	87.97	87.64	87.16	86.83	85.91
M_3		88.12	88.08	87.98	87.64	87.20	86.88	85.98
M_4		88.10	88.01	87.92	87.61	87.11	86.80	85.86
M_5		88.11	88.06	87.94	87.61	87.13	86.84	85.90
M_6		88.09	88.01	87.88	87.59	86.95	85.90	-
M_7		87.62	85.86	-	-	-	-	-
M_8		88.02	86.62	85.70	-	-	-	-
SE ±		0.0156	0.0192	0.0167	0.0140	0.0051	0.0043	0.0051
CD at 1%		0.0650	0.0801	0.0697	0.0585	0.0214	0.0177	0.0213
S_1	88.15	88.04	87.59	87.62	87.62	87.10	86.53	85.93
S_2		88.02	87.57	87.59	87.56	87.06	86.50	85.89
SE ±		0.0078	0.0096	0.0084	0.0070	0.0026	0.0021	0.0026
CD at 1%		NS	NS	NS	NS	0.0107	0.0089	0.0107

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Among all the MAP treatments, M_3 (0.5% O_2 + 10% CO_2) retained significantly maximum per cent moisture (85.98 and 85.91) after 21 days of storage in pretreated whole peeled and diced onion respectively. While MAP with super atmospheric oxygen i.e. 100%

oxygen recorded minimum per cent moisture (85.86 and 85.79) after 6 days of storage in pretreated whole peeled and diced onion, respectively.

As regards storage environments under study, the maximum retention of per cent moisture was observed in S_1 (0 ± 1^0C) storage as compared to S_2 storage environment. The whole peeled onion stored at S_1 recorded 85.93 per cent moisture at the end of 21st day of storage while same treatment registered 85.89 per cent moisture in the diced onion.

As regards treatment combination of MAP and storage environments, relatively slow but constant decrease in per cent moisture was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered maximum per cent moisture of 86.00 and 85.93 per cent in pretreated whole peeled and diced onion after 21 days of storage, respectively.

Table 54: Effect of modified atmosphere packaging and storage temperatures on percent moisture of diced onion

Treatment Combinations	Percent Moisture							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	88.15	88.05	87.95	87.8	87.56	86.92	85.85	-
M_1S_2		88.03	87.92	87.78	87.54	86.89	85.82	-
M_2S_1		88.09	88.05	87.95	87.62	87.15	86.83	85.90
M_2S_2		88.07	88.02	87.90	87.60	87.11	86.79	85.87
M_3S_1		88.10	88.06	87.98	87.64	87.17	86.85	85.93
M_3S_2		88.09	88.04	87.95	87.62	87.12	86.81	85.89
M_4S_1		88.08	88.02	87.91	87.59	87.07	86.78	85.87
M_4S_2		88.06	88.00	87.88	86.55	87.04	86.74	85.84
M_5S_1		88.09	88.03	87.93	87.60	87.11	86.82	85.89
M_5S_2		88.06	88.00	87.89	87.56	87.08	86.78	85.85
M_6S_1		88.07	87.99	87.82	87.58	86.96	85.88	-
M_6S_2		88.05	87.95	87.79	87.55	86.91	85.85	-
M_7S_1		87.60	85.82	-	-	-	-	-
M_7S_2		87.57	85.76	-	-	-	-	-
M_8S_1		88.02	86.60	85.68	-	-	-	-
M_8S_2		87.97	86.56	85.64	-	-	-	-
SE ±		0.0103	0.0128	0.0122	0.2528	0.0066	0.0058	0.0031
CD at 1%		NS	NS	NS	NS	0.0273	0.0243	0.0129
M_1	88.15	88.04	87.94	87.79	87.55	86.90	85.83	-
M_2		88.08	88.03	87.93	87.61	87.13	86.81	85.88
M_3		88.10	88.05	87.97	87.63	87.14	86.83	85.91
M_4		88.07	88.01	87.89	87.07	87.05	86.76	85.85
M_5		88.08	88.01	87.91	87.58	87.09	86.80	85.87
M_6		88.06	87.97	87.81	87.57	86.93	85.86	-
M_7		87.59	85.79	-	-	-	-	-
M_8		88.00	86.58	85.66	-	-	-	-
SE ±		0.0073	0.0090	0.0086	0.1788	0.0046	0.0041	0.0022
CD at 1%		0.0304	0.0376	0.0360	0.7451	0.0193	0.0172	0.0091
S_1	88.15	88.01	87.57	87.58	87.60	87.06	86.50	85.89
S_2		87.99	87.53	87.55	87.40	87.02	86.46	85.86
SE ±		0.0037	0.0045	0.0043	0.0894	0.0023	0.0021	0.0011
CD at 1%		0.0152	0.0188	0.0180	NS	0.0097	0.0086	0.0046

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Water loss in vegetables is determined by many factors, the most important of which is the resistance exerted by the outer periderm or cuticle movement of water vapour due to transpiration. However, produce cuttings, results in resistance reduction of these barriers to transpiration. Fresh cut products are highly susceptible to moisture loss and physiological weight loss because internal tissues are exposed to atmospheric conditions. In this study, the percent moisture was significantly influenced by MAP treatments and storage temperatures. However, the maximum percent moisture was recorded in M_3 (0.5% O_2 + 10% CO_2). Also, the samples were stored under low temperature, so dehydration was not a major problem. The low oxygen environment with higher CO_2 concentration in packages might have lowered the respiration and other metabolic processes thus resulting from lower utilization of internal water in plant tissues. The similar results were reported by Bennik *et al.* (1998), Hong *et al.* (2000) in onion, Patil (2016) and Kaur (2016) in fresh cut lettuce. The beneficial effects of polyethylene and polypropylene packaging in extending the shelf-life of fresh and fresh cut fruits have been reported by Sahoo *et al.* (2014) in bell pepper, Yommi and Aguiero (2011) in fresh bunched spinach and Piagentini and Guemes (2002) in fresh cut spinach.

4.4.1.2 Percent physiological loss in weight

The observations recorded on per cent physiological loss in weight of minimally processed onion i.e. whole peeled and diced onion are summarized in Table 55 and 56 and graphically represented in a Fig. 39 and 40. The data revealed that physiological loss in weight of fresh onion i.e. whole peeled and diced onion was significantly influenced by MAP treatments at all the stages of growth. However, as regards storage temperatures under study, the non-significant effects were recorded on the 6, 9 and 12th day after storage in whole peeled onion. The diced onions recorded non-significant effect of storage temperatures only on 3rd day after storage. As regards interaction effects of MAP treatments and storage environments, the whole peeled onion recorded non-significant difference up to 12th day of storage while diced onion recorded significant differences on 18 and 21st day of storage. Increase in physiological loss in weight was recorded in both cut types irrespective of the treatments under study.

Among all the MAP packagings, M_3 (0.5% O_2 + 10% CO_2) registered significantly minimum per cent physiological loss in weight (0.65 and 0.67) after 21 days of storage in pretreated whole peeled and diced onion respectively. While MAP with super atmospheric oxygen i.e. 100% oxygen recorded maximum per cent physiological loss in weight (0.50 and 0.60) after 6 days of storage in pretreated whole peeled and diced onion, respectively.

As regards storage temperatures, the minimum physiological loss in weight was observed in S_1 (0 ± 1^0C) storage. The whole peeled onion stored at S_1 recorded 0.65 per cent physiological loss in weight at the end of 21[st] day of storage while same treatment registered 0.69 per cent physiological loss in weight in the diced onion.

As regards treatment combination of MAP treatments and storage environments relatively slow but constant increase in per cent physiological loss in weight was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered minimum physiological loss in weight of 0.63 and 0.66 per cent in pretreated whole peeled and diced onion after 21 days of storage, respectively.

Table 55: Effect of modified atmosphere packaging and storage temperatures on percent physiological loss in weight of whole peeled onion

Treatment combinations	Percent physiological loss in weight						
	Storage period (days)						
	3	6	9	12	15	18	21
M_1S_1	0.34	0.37	0.41	0.47	0.48	0.57	-
M_1S_2	0.36	0.41	0.45	0.47	0.49	0.59	-
M_2S_1	0.30	0.34	0.36	0.39	0.45	0.55	0.64
M_2S_2	0.30	0.37	0.40	0.39	0.47	0.58	0.67
M_3S_1	0.30	0.32	0.36	0.38	0.44	0.56	0.63
M_3S_2	0.30	0.32	0.38	0.38	0.45	0.60	0.66
M_4S_1	0.32	0.35	0.39	0.44	0.49	0.59	0.68
M_4S_2	0.33	0.40	0.42	0.46	0.50	0.61	0.71
M_5S_1	0.32	0.34	0.38	0.42	0.47	0.58	0.67
M_5S_2	0.33	0.38	0.40	0.43	0.48	0.61	0.70
M_6S_1	0.34	0.35	0.41	0.45	0.45	0.58	-
M_6S_2	0.36	0.41	0.43	0.47	0.49	0.60	-
M_7S_1	0.42	0.50	-	-	-	-	-
M_7S_2	0.42	0.51	-	-	-	-	-
M_8S_1	0.40	0.45	0.56	-	-	-	-
M_8S_2	0.40	0.46	0.63	-	-	-	-
SE ±	0.0029	0.0357	0.0391	0.0372	0.0045	0.0051	0.0055
CD at 1%	NS	NS	NS	NS	0.0186	0.0214	0.0228
M_1	0.35	0.39	0.43	0.47	0.49	0.58	-
M_2	0.30	0.35	0.38	0.39	0.46	0.57	0.66
M_3	0.30	0.32	0.37	0.38	0.45	0.58	0.65
M_4	0.32	0.38	0.40	0.45	0.50	0.60	0.69
M_5	0.33	0.36	0.39	0.42	0.48	0.59	0.68
M_6	0.35	0.38	0.42	0.46	0.47	0.59	-
M_7	0.42	0.50	-	-	-	-	-
M_8	0.40	0.46	0.54	-	-	-	-
SE ±	0.0020	0.0253	0.0277	0.0263	0.0032	0.0036	0.0039
CD at 1%	0.0085	0.1053	0.1153	0.1097	0.0131	0.0151	0.0161
S_1	0.34	0.38	0.41	0.42	0.46	0.57	0.65
S_2	0.35	0.41	0.43	0.43	0.48	0.60	0.68
SE ±	0.0010	0.0126	0.0138	0.0132	0.0016	0.0018	0.0019
CD at 1%	0.0043	NS	NS	NS	0.0066	0.0075	0.0081

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

The metabolic and physiological processes like respiration and transpiration accelerated the physiological weight loss of fresh and fresh cut fruits and vegetables during storage. The respiration releases water and carbon dioxide via oxidation of carbohydrates and thus reduces dry matter content (Zhan *et al.*, 2012). Fresh cut products due to exposure of

Table 56: Effect of modified atmosphere packaging and storage temperatures on percent physiological loss in weight of diced onion

Treatment combinations	Percent physiological loss in weight						
	Storage period (days)						
	3	6	9	12	15	18	21
M_1S_1	0.36	0.40	0.45	0.50	0.53	0.64	-
M_1S_2	0.39	0.44	0.48	0.52	0.57	0.67	-
M_2S_1	0.32	0.36	0.39	0.43	0.48	0.58	0.68
M_2S_2	0.33	0.37	0.41	0.46	0.54	0.63	0.70
M_3S_1	0.32	0.35	0.38	0.41	0.46	0.58	0.66
M_3S_2	0.33	0.37	0.40	0.46	0.53	0.62	0.69
M_4S_1	0.34	0.38	0.43	0.49	0.56	0.65	0.73
M_4S_2	0.34	0.42	0.45	0.53	0.59	0.69	0.77
M_5S_1	0.34	0.36	0.40	0.47	0.52	0.59	0.71
M_5S_2	0.35	0.41	0.42	0.51	0.56	0.65	0.75
M_6S_1	0.36	0.38	0.43	0.47	0.51	0.62	-
M_6S_2	0.38	0.42	0.46	0.50	0.55	0.65	-
M_7S_1	0.46	0.57	-	-	-	-	-
M_7S_2	0.48	0.63	-	-	-	-	-
M_8S_1	0.44	0.52	0.63	-	-	-	-
M_8S_2	0.45	0.56	0.68	-	-	-	-
SE ±	0.0150	0.0124	0.0122	0.0141	0.0114	0.0054	0.0041
CD at 1%	NS	NS	NS	NS	NS	0.0227	0.0170
M_1	0.38	0.42	0.47	0.51	0.55	0.65	-
M_2	0.33	0.37	0.40	0.45	0.51	0.60	0.69
M_3	0.33	0.36	0.39	0.44	0.50	0.60	0.67
M_4	0.34	0.40	0.44	0.51	0.58	0.67	0.75
M_5	0.35	0.39	0.41	0.49	0.54	0.62	0.73
M_6	0.37	0.40	0.45	0.49	0.53	0.63	-
M_7	0.47	0.60	-	-	-	-	-
M_8	0.45	0.54	0.66	-	-	-	-
SE ±	0.0106	0.0087	0.0086	0.0100	0.0080	0.0038	0.0029
CD at 1%	0.0443	0.0364	0.0360	0.0415	0.0335	0.0160	0.0120
S_1	0.37	0.42	0.44	0.46	0.51	0.61	0.69
S_2	0.38	0.45	0.47	0.50	0.56	0.65	0.73
SE ±	0.0053	0.0044	0.0043	0.0050	0.0040	0.0019	0.0014
CD at 1%	NS	0.0182	0.0180	0.0207	0.0168	0.0080	0.0060

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

internal tissues to atmospheric conditions are prone to register maximum PLW. In the present investigation, slow increase in PLW was observed in all MAP treatments and storage environments. The similar observation were reported by Miguel and Durigan (2007) in onion, Han *et al.*, 2010 in fresh cut onion, Conesa *et al.*, 2007 in fresh cut bell peppers. However, the rate of increase was very slow in both storage temperatures. This might be due to the refrigeration storage (<7^0C) environments which slowed the respiration rate, enzymatic process and microbial activity as reported by Nicolla *et al.* (2009) and Waghmare *et al.* (2013) in fresh cut produce, Zhan *et al.* (2012) in fresh cut broccoli and Sahoo *et al.* (2014) in fresh bell pepper. The similar results were reported by Hong and Kim (2004) in fresh cut spring onion; Guilbert *et al.* (1996) in perishable foods and Bahram-Parvar and Lim (2018) in fresh cut onion. The minimum PLW was recorded in the M_3 (0.5% O_2 + 10% CO_2) treatment. This could be due to the absence of oxygen arresting the respiration and thus reduced utilization of carbohydrates with retained dry matter content in the fresh cut product as reported by Zhan *et al.* (2012) in fresh cut broccoli, Patil (2016) and Kaur (2016) in fresh cut lettuce and Kale (2017) in fresh cut muskmelon. The loss in weight during storage was observed in fresh cut onion.

4.4.1.3 Percent decay

The results of per cent decay in fresh cut onion (i.e. whole peeled and diced onion) packaged in polypropylene bags with MAP and stored at different temperatures are summarized in Table 57 and 58 and graphically represented in a Fig. 41 and 42. It is evident from the tables that the per cent decay in fresh cut onions i.e. whole peeled and diced was significantly influenced by the MAP treatments, storage temperatures and their interactions throughout the storage period. An increasing trend in per cent decay of whole peeled and diced onion was observed irrespective of MAP treatments and storage environments under study. No decay was recorded up to 9 days of storage in both cut types in various MAP treatments except M_7 and M_8 with super atmospheric oxygen. The MAP treatments with M_7 and M_8 observed decay from day 3 of storage.

Among all the MAP packagings, M_3 (0.5% O_2 + 10% CO_2) significantly minimum decay of 4.47 and 4.91 per cent after 21 days of storage was recorded in pretreated whole peeled and diced onion, respectively. While MAP with super atmospheric oxygen i.e. 100% oxygen recorded maximum decay (32.21 and 40.29 %) after only 6 days of storage in pretreated whole peeled and diced onion respectively.

It is clear from the data that, minimum per cent decay was observed in S_1 (0 ± 1^0C) storage than the S_2 (7 ± 1^0C). The whole peeled onion stored at S_1 recorded 4.98 per cent decay at the end of 21st day of storage while same treatment registered 5.41 per cent decay in the diced onion.

As regards treatment combination of MAP treatments and storage environments relatively slow but constant increase in per cent decay was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered minimum per cent decay 4.43 and 4.85 in pretreated whole peeled and diced onion after 21 days of storage respectively. While whole peeled and diced onions packed in M_7S_2 recorded maximum decay of 32.28 and 40.42 per cent, respectively. The treatment was terminated after 6th day of storage due to maximum decay percentage.

Minimally processed food products readily deteriorate in quality, especially in colour and texture, as a result of endogenous enzymatic interactions, enhanced respiration and attack of microorganisms. This can be prevented by a combined use of antioxidants and surfactants washings, MAP with high CO_2 levels and refrigeration. MAP is the replacement of air in a pack with single or mixture of gases. Generally, atmosphere low in O_2 and high in CO_2 influence the metabolism of packed product being packed and reduce the activity of decay

Table 57: Effect of modified atmosphere packaging and storage temperatures on percent decay of whole peeled onion

Treatment combinations	Percent decay						
	Storage period (days)						
	3	6	9	12	15	18	21
M_1S_1	0.00	0.00	0.00	2.06	3.98	6.85	-
M_1S_2	0.00	0.00	0.00	2.24	4.16	7.05	-
M_2S_1	0.00	0.00	0.00	0.00	2.26	3.59	4.78
M_2S_2	0.00	0.00	0.00	0.00	2.38	3.73	4.90
M_3S_1	0.00	0.00	0.00	0.00	2.16	3.27	4.43
M_3S_2	0.00	0.00	0.00	0.00	2.23	3.41	4.51
M_4S_1	0.00	0.00	0.00	0.00	3.37	4.88	5.69
M_4S_2	0.00	0.00	0.00	0.00	3.58	5.02	5.83
M_5S_1	0.00	0.00	0.00	0.00	3.19	4.24	5.02
M_5S_2	0.00	0.00	0.00	0.00	3.31	4.37	5.16
M_6S_1	0.00	0.00	0.00	1.85	3.87	6.55	-
M_6S_2	0.00	0.00	0.00	2.09	4.02	6.74	-
M_7S_1	6.18	32.15	-	-	-	-	-
M_7S_2	6.23	32.28	-	-	-	-	-
M_8S_1	4.26	15.26	30.26	-	-	-	-
M_8S_2	4.39	15.38	30.41	-	-	-	-
SE ±	0.0097	0.0107	0.0093	0.0110	0.0108	0.0132	0.0120
CD at 1%	0.0406	0.0447	0.0387	0.0458	0.0449	0.0548	0.0500
M_1	0.00	0.00	0.00	2.15	4.07	6.95	-
M_2	0.00	0.00	0.00	0.00	2.32	3.66	4.84
M_3	0.00	0.00	0.00	0.00	2.19	3.34	4.47
M_4	0.00	0.00	0.00	0.00	3.47	4.95	5.76
M_5	0.00	0.00	0.00	0.00	3.25	4.30	5.09
M_6	0.00	0.00	0.00	1.97	3.95	6.64	-
M_7	6.20	32.21	-	-	-	-	-
M_8	4.32	15.32	30.33	-	-	-	-
SE ±	0.0069	0.0076	0.0066	0.0078	0.0076	0.0093	0.0085
CD at 1%	0.0287	0.0316	0.0274	0.0324	0.0318	0.0388	0.0354
S_1	1.30	5.93	4.32	0.65	3.14	4.89	4.98
S_2	1.33	5.96	4.34	0.72	3.28	5.05	5.10
SE ±	0.0034	0.0038	0.0033	0.0039	0.0038	0.0047	0.0042
CD at 1%	0.0144	0.0158	0.0137	0.0162	0.0159	0.0194	0.0177

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

causing organisms, which in turn increase storability or shelf life of the product. Storage temperature controls respiratory activity, transpiration, decay, fermentation and development of microbial pathogens and minimizes the physiological losses and increases shelf life of fresh food as well as processed products. The increased decay was observed in present investigation irrespective of the MAP treatments and storage temperatures under study. However, the decay percentage was lower in the MAP treatment with low oxygen content and CO_2 enriched atmosphere. It is also influenced by the lower storage temperature. This might be due to arresting the respiration rate and other metabolic process due to lack of oxygen in the packages and low temperatures lowering down metabolic processes as reported by Blanchard *et al.* (1996) in diced onion and Baskaran *et al.* (2015) in minimally processed onion. The MAP treatments with super atmospheric oxygen resulted in complete decay of fresh cut onion at both the storage conditions. This might be attributed to the increased respiration as reported by Hong *et al.* (2000) in fresh cut green onions and Blanchard (1996) in yellow diced onions. However, contradictory results are reported by Han *et al.* (2010) in fresh cut onion and Allende *et al.* (2002) in fresh processed mixed salads. The deterioration occurs progressively during storage in fresh cut onion and was caused due to the activity of microorganisms that thrived in product. The results are in conformity with Liu and Li (2006) in sliced onions, Baskaran *et al.* (2015) in minimally processed onions. The low storage temperature might have arrested the physiological activities and growth of the microorganisms, thus recorded lower per cent decay. The similar results were obtained by Carolina A. *et al.* (2007) in minimally processed onions, Dhumal (2012) in ready to eat pomegranate arils, Patil (2016) and Kaur (2016) in fresh cut lettuce.

Table 58: Effect of modified atmosphere packaging and storage temperatures on percent decay of diced onion

Treatment combinations	Percent decay						
	Storage period (days)						
	3	6	9	12	15	18	21
M_1S_1	0.00	0.00	0.00	2.67	5.43	7.81	-
M_1S_2	0.00	0.00	0.00	2.83	5.67	7.96	-
M_2S_1	0.00	0.00	0.00	2.98	3.68	4.57	5.15
M_2S_2	0.00	0.00	0.00	3.12	3.78	4.69	5.29
M_3S_1	0.00	0.00	0.00	2.84	3.57	3.91	4.85
M_3S_2	0.00	0.00	0.00	2.93	3.65	4.06	4.98
M_4S_1	0.00	0.00	0.00	3.24	4.11	5.31	6.12
M_4S_2	0.00	0.00	0.00	3.39	4.29	5.58	6.28
M_5S_1	0.00	0.00	0.00	3.05	3.89	4.95	5.55
M_5S_2	0.00	0.00	0.00	3.23	4.07	5.09	5.63
M_6S_1	0.00	0.00	0.00	2.29	4.56	7.59	-
M_6S_2	0.00	0.00	0.00	2.38	4.71	7.76	-
M_7S_1	9.21	40.29	-	-	-	-	-
M_7S_2	9.35	40.42	-	-	-	-	-
M_8S_1	7.35	22.29	38.55	-	-	-	-
M_8S_2	7.59	22.48	38.72	-	-	-	-
SE ±	0.0137	0.0101	0.0060	0.0125	0.0097	0.0086	0.0109
CD at 1%	0.0572	0.0423	0.0252	0.0521	0.0403	0.0357	0.0453
M_1	0.00	0.00	0.00	2.75	5.55	7.88	-
M_2	0.00	0.00	0.00	3.05	3.73	4.63	5.21
M_3	0.00	0.00	0.00	2.89	3.61	3.98	4.91
M_4	0.00	0.00	0.00	3.31	4.20	5.44	6.20
M_5	0.00	0.00	0.00	3.14	3.98	5.02	5.59
M_6	0.00	0.00	0.00	2.34	4.64	7.67	-
M_7	9.28	40.35	-	-	-	-	-
M_8	7.47	22.38	38.63	-	-	-	-
SE ±	0.0097	0.0072	0.0043	0.0088	0.0068	0.0061	0.0077
CD at 1%	0.0404	0.0299	0.0178	0.0369	0.0285	0.0252	0.0320
S_1	2.07	7.82	5.51	2.84	4.20	5.69	5.41
S_2	2.12	7.86	5.53	2.98	4.36	5.86	5.54
SE ±	0.0049	0.0036	0.0021	0.0044	0.0034	0.0030	0.0038
CD at 1%	0.0202	0.0149	0.0089	0.0184	0.0142	0.0126	0.0160

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

4.4.2 Chemical Parameters

4.4.2.1 pH and acidity (%)

The data in respect of pH of pretreated fresh cut onion i.e. whole peeled and diced onion packaged in different MAPs and stored at different storage temperatures is presented in Table 59 and 60 respectively. While the data related with the change in per cent acidity is summarized in Table 61 and 62 for whole peeled as well as diced onion respectively. It is evident from the data that the initial pH and per cent acidity of the fresh cut red onion recorded was 5.26 and 0.30 per cent respectively. At all the stages (days) of storage, the pH was significantly influenced by MAP treatments and storage environments in both the cut types under

Table 59: Effect of modified atmosphere packaging and storage temperatures on pH of whole peeled onion

Treatment combinations	pH							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	5.26	5.23	5.16	5.08	4.95	4.86	4.75	-
M_1S_2		5.23	5.13	5.05	4.91	4.83	4.71	-
M_2S_1		5.25	5.20	5.15	5.06	4.96	4.87	4.77
M_2S_2		5.25	5.18	5.13	5.05	4.93	4.84	4.73
M_3S_1		5.26	5.21	5.15	5.08	4.98	4.89	4.77
M_3S_2		5.26	5.20	5.15	5.06	4.95	4.85	4.74
M_4S_1		5.25	5.17	5.11	5.00	4.91	4.83	4.74
M_4S_2		5.24	5.14	5.10	4.98	4.91	4.81	4.71
M_5S_1		5.25	5.18	5.14	5.04	4.94	4.85	4.75
M_5S_2		5.24	5.16	5.13	5.04	4.93	4.83	4.73
M_6S_1		5.23	5.16	5.10	4.98	4.86	4.75	-
M_6S_2		5.23	5.13	5.07	4.96	4.83	4.72	-
M_7S_1		5.21	5.02	-	-	-	-	-
M_7S_2		5.18	5.01	-	-	-	-	-
M_8S_1		5.25	5.12	4.89	-	-	-	-
M_8S_2		5.25	5.08	4.83	-	-	-	-
SE ±		0.0161	0.0086	0.0118	0.0085	0.0057	0.0055	0.0060
CD at 1%		NS	NS	NS	NS	0.0237	0.0228	0.0249
M_1	5.26	5.23	5.14	5.07	4.93	4.84	4.73	-
M_2		5.25	5.19	5.14	5.06	4.95	4.85	4.75
M_3		5.26	5.20	5.15	5.07	4.97	4.87	4.75
M_4		5.24	5.15	5.11	4.99	4.91	4.82	4.73
M_5		5.25	5.17	5.14	5.04	4.93	4.84	4.74
M_6		5.23	5.14	5.08	4.97	4.84	4.73	-
M_7		5.20	5.01	-	-	-	-	-
M_8		5.25	5.10	4.86	-	-	-	-
SE ±		0.0114	0.0061	0.0083	0.0060	0.0040	0.0039	0.0042
CD at 1%		NS	0.0252	0.0347	0.0249	0.0168	0.0161	0.0176
S_1	5.26	5.24	5.15	5.09	5.02	4.92	4.82	4.76
S_2		5.23	5.13	5.06	5.00	4.89	4.79	4.73
SE ±		0.0057	0.0030	0.0042	0.0030	0.0020	0.0019	0.0021
CD at 1%		NS	0.0126	0.0173	0.0125	0.0084	0.0081	0.0088

'-' indicates termination of treatments

MAP treatments

- M_1= Air/passive MAP with no vacuum
- M_2= Combination of 2% O_2 + 10% CO_2
- M_3= Combination of 0.5% O_2 + 10% CO_2
- M_4= Combination of 3% O_2 + 10% CO_2
- M_5= Combination of 0.5% O_2 + 5% CO_2
- M_6= 100% N_2 flushing
- M_7= 100% O_2 flushing
- M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

- S_1= $0^0C \pm 1^0C$
- S_2= $7^0C \pm 1^0C$

study i.e. whole peeled and diced onion except on the day 3 of the storage. However, the interaction effects were non-significant on 3rd, 6th, 9th and 12th days of storage in whole peeled and 3rd, 6th, 9th, 12th and 15th days of storage in diced onion. At all the stages (days) of storage, the acidity was also significantly influenced by MAP treatments in both the cut types under study i.e. whole peeled and diced onion. It is seen from the data that the per cent acidity in fresh cut onions i.e. whole peeled and diced, was significantly influenced by storage environments except on day 6, 9 and 12 of the storage in whole peeled onion and day 3 of the storage in diced onion. The interaction effects were non-significant on 3rd, 6th, 9th and 12th days of storage in whole peeled onion and 3rd, 6th, 9th, 12th and 15th days of storage in diced onion.

Decreasing trend in pH and increase in per cent acidity was observed irrespective of MAP treatments and storage environments under study for both the cut types. As regards MAP treatments, at the end of storage period i.e. 21 days after storage, M_3 (0.5% O_2 + 10% CO_2) retained significantly maximum with minimum changes in pH (4.75 and 4.74) in pretreated whole peeled and diced onion respectively. While MAP treatment M_5 (0.5% O_2 + 5% CO_2) recorded 4.74 and 4.71 pH after 21 days of storage in pretreated whole peeled and diced onion

Table 60: Effect of modified atmosphere packaging and storage temperatures on pH of diced onion

Treatment combinations	pH							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	5.26	5.20	5.15	5.06	4.93	4.82	4.72	-
M_1S_2		5.22	5.11	5.03	4.90	4.79	4.69	-
M_2S_1		5.24	5.18	5.14	5.04	4.93	4.84	4.74
M_2S_2		5.23	5.17	5.11	5.02	4.89	4.80	4.71
M_3S_1		5.25	5.19	5.14	5.06	4.96	4.86	4.75
M_3S_2		5.22	5.18	5.12	5.03	4.92	4.81	4.73
M_4S_1		5.23	5.15	5.09	4.99	4.89	4.81	4.71
M_4S_2		5.22	5.13	5.07	4.96	4.87	4.78	4.69
M_5S_1		5.24	5.15	5.12	5.02	4.91	4.83	4.72
M_5S_2		5.22	5.13	5.09	5.00	4.89	4.79	4.70
M_6S_1		5.22	5.15	5.08	4.96	4.84	4.74	-
M_6S_2		5.20	5.14	5.05	4.92	4.81	4.72	-
M_7S_1		5.20	4.99	-	-	-	-	-
M_7S_2		5.17	4.95	-	-	-	-	-
M_8S_1		5.22	5.09	4.86	-	-	-	-
M_8S_2		5.20	5.05	4.81	-	-	-	-
SE ±		0.0148	0.0129	0.0096	0.0086	0.0095	0.0054	0.0034
CD at 1%		NS	NS	NS	NS	NS	0.0227	0.0142
M_1	5.26	5.21	5.13	5.05	4.92	4.81	4.70	-
M_2		5.24	5.18	5.13	5.03	4.91	4.82	4.72
M_3		5.24	5.19	5.13	5.05	4.94	4.83	4.74
M_4		5.23	5.14	5.08	4.98	4.88	4.79	4.70
M_5		5.23	5.14	5.11	5.01	4.90	4.81	4.71
M_6		5.21	5.15	5.07	4.94	4.83	4.73	-
M_7		5.19	4.97	-	-	-	-	-
M_8		5.21	5.07	4.84	-	-	-	-
SE ±		0.0105	0.0091	0.0068	0.0061	0.0067	0.0038	0.0024
CD at 1%		NS	0.0380	0.0284	0.0252	0.0279	0.0160	0.0101
S_1	5.26	5.23	5.13	5.07	5.00	4.89	4.80	4.73
S_2		5.21	5.11	5.04	4.97	4.86	4.76	4.70
SE ±		0.0052	0.0046	0.0034	0.0030	0.0033	0.0019	0.0012
CD at 1%		NS	0.0190	0.0142	0.0126	0.0139	0.0080	0.0050

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

respectively. Among all the MAP packagings, M_3 (0.5% O_2 + 10% CO_2) recorded significantly maximum per cent acidity (0.65 and 0.66%) with minimum changes after 21 days of storage in pretreated whole peeled and diced onion, respectively. The MAP treatment with super atmospheric oxygen i.e. 100% oxygen recorded maximum changes in per cent acidity (0.50 and 0.64 %) after 6 days of storage in pretreated whole peeled and diced onion, respectively.

Table 61: Effect of modified atmosphere packaging and storage temperatures on percent acidity of whole peeled onion

Treatment combinations	Percent acidity							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	0.30	0.34	0.37	0.41	0.47	0.48	0.57	-
M_1S_2		0.36	0.41	0.45	0.47	0.49	0.59	-
M_2S_1		0.30	0.34	0.36	0.39	0.45	0.55	0.65
M_2S_2		0.30	0.37	0.40	0.39	0.47	0.58	0.67
M_3S_1		0.30	0.32	0.36	0.38	0.44	0.56	0.64
M_3S_2		0.30	0.32	0.38	0.38	0.45	0.60	0.66
M_4S_1		0.32	0.35	0.39	0.44	0.49	0.59	0.68
M_4S_2		0.33	0.40	0.42	0.46	0.50	0.61	0.71
M_5S_1		0.32	0.34	0.38	0.42	0.47	0.58	0.67
M_5S_2		0.33	0.38	0.40	0.43	0.48	0.61	0.70
M_6S_1		0.34	0.35	0.41	0.45	0.45	0.58	-
M_6S_2		0.36	0.41	0.43	0.47	0.49	0.60	-
M_7S_1		0.42	0.50	-	-	-	-	-
M_7S_2		0.42	0.51	-	-	-	-	-
M_8S_1		0.40	0.45	0.56	-	-	-	-
M_8S_2		0.40	0.46	0.53	-	-	-	-
SE ±		0.0029	0.0357	0.0391	0.0372	0.0045	0.0051	0.0055
CD at 1%		NS	NS	NS	NS	0.0186	0.0214	0.0228
M_1	0.30	0.35	0.39	0.43	0.47	0.49	0.58	-
M_2		0.30	0.35	0.38	0.39	0.46	0.57	0.66
M_3		0.30	0.32	0.37	0.38	0.45	0.58	0.65
M_4		0.32	0.38	0.40	0.45	0.50	0.60	0.69
M_5		0.33	0.36	0.39	0.42	0.48	0.59	0.68
M_6		0.35	0.38	0.42	0.46	0.47	0.59	-
M_7		0.42	0.50	-	-	-	-	-
M_8		0.40	0.46	0.54	-	-	-	-
SE ±		0.0020	0.0253	0.0277	0.0263	0.0032	0.0036	0.0039
CD at 1%		0.0085	0.1053	0.1153	0.1097	0.0131	0.0151	0.0161
S_1	0.30	0.34	0.38	0.41	0.42	0.46	0.57	0.65
S_2		0.35	0.41	0.43	0.43	0.48	0.60	0.68
SE ±		0.0010	0.0126	0.0138	0.0132	0.0016	0.0018	0.0019
CD at 1%		0.0043	NS	NS	NS	0.0066	0.0075	0.0081

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

During entire storage period, the whole peeled onion, as well as diced onion stored at S_2 (7 ± 1^0C), recorded greater deviation in pH with increase in per cent acidity than that of those stored at S_1 (0 ± 1^0C). At the end of storage period i.e. after 21 days, the whole peeled onion and diced onion stored at 0 ± 1^0C (S_1) temperature recorded stable pH of 4.76 and 4.73, respectively. The per cent acidity content in fresh cut onion registered in S_1 storage condition was 0.65 and 0.68 per cent, respectively for whole peeled and diced onion.

As regards treatment combinations of MAP treatments and storage environments, with the advancement of storage period, decreasing trend in pH and increase in acidity was recorded in both the cut types i.e. whole peeled and diced onion. At the end of storage period, the whole peeled onion and diced onion packaged with treatment combination M_3S_1 had registered minimum deviation in pH (4.77 and 4.75) and acidity (0.64 and 0.65%) respectively.

An increase of acidity decreases in fruits and vegetables quality during storage period (Khuram *et al.*, 2015). The slight increase in per cent acidity and decrease in pH was recorded in MAP packages stored at different temperatures in both cut types of onion. This was due to absorption of CO_2 in aqueous phase, microbial deterioration, action of endogenous enzymes and synthesis of organic acids as observed by Rolle and Chism (1987) in minimally processed fruits and vegetables. However, the minimum change in the per cent acidity was

Table 62: Effect of modified atmosphere packaging and storage temperatures on percent acidity of diced onion

Treatment combinations	Percent acidity							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	0.30	0.36	0.39	0.43	0.52	0.56	0.61	-
M_1S_2		0.39	0.42	0.47	0.55	0.6	0.64	-
M_2S_1		0.32	0.36	0.39	0.42	0.48	0.59	0.66
M_2S_2		0.34	0.38	0.41	0.46	0.53	0.62	0.68
M_3S_1		0.33	0.37	0.40	0.43	0.49	0.60	0.65
M_3S_2		0.35	0.39	0.41	0.46	0.52	0.63	0.67
M_4S_1		0.35	0.405	0.47	0.46	0.53	0.66	0.71
M_4S_2		0.36	0.43	0.49	0.49	0.55	0.68	0.75
M_5S_1		0.34	0.37	0.42	0.44	0.51	0.63	0.66
M_5S_2		0.36	0.4	0.45	0.48	0.54	0.65	0.72
M_6S_1		0.36	0.38	0.46	0.53	0.55	0.63	-
M_6S_2		0.38	0.43	0.49	0.56	0.59	0.66	-
M_7S_1		0.47	0.62	-	-	-	-	-
M_7S_2		0.5	0.65	-	-	-	-	-
M_8S_1		0.44	0.55	0.65	-	-	-	-
M_8S_2		0.46	0.59	0.69	-	-	-	-
SE ±		0.0151	0.0147	0.0139	0.0118	0.0133	0.0037	0.0047
CD at 1%		NS	NS	NS	NS	NS	0.0152	0.0194
M_1	0.30	0.38	0.41	0.45	0.54	0.58	0.62	-
M_2		0.33	0.37	0.40	0.44	0.51	0.60	0.67
M_3		0.34	0.38	0.41	0.45	0.51	0.61	0.66
M_4		0.36	0.42	0.48	0.48	0.54	0.67	0.73
M_5		0.35	0.39	0.44	0.46	0.53	0.64	0.70
M_6		0.37	0.41	0.48	0.55	0.57	0.64	-
M_7		0.49	0.64	-	-	-	-	-
M_8		0.45	0.57	0.67	-	-	-	-
SE ±		0.0106	0.0104	0.0098	0.0084	0.0094	0.0026	0.0033
CD at 1%		0.0444	0.0432	0.0409	0.0348	0.0391	0.0108	0.0137
S_1	0.30	0.37	0.43	0.46	0.47	0.52	0.62	0.68
S_2		0.39	0.46	0.49	0.50	0.56	0.64	0.70
SE ±		0.0053	0.0052	0.0049	0.0042	0.0047	0.0013	0.0016
CD at 1%		NS	0.0216	0.0205	0.0174	0.0196	0.0054	0.0069

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

recorded in the M_3 treatment. This may be attributed to the low O_2 and/ or high CO_2 atmosphere which can retard decomposition of organic acids in plant tissue. The results are in conformity with numerous studies conducted by Carolina A. *et al.* (2007) in Onions cv. Superex, Baskaran *et al.* (2015) in minimally processed onion, Sanchez-Moreno *et al.* (2004) in onions, Aguayo *et al.* (2007), Koh *et al.* (2017), Aguayo *et al.* (2003) and Lamikanra *et al*. (2000) in fresh cut muskmelon. The increase in the acidity and decrease in pH of pretreated fresh cut onion could be due to the CO_2, which might have played a role in decreasing cell pH because of dissociation of carbonic acid to bicarbonate and hydrogen ions as reported by Holcroft and Kader (1999) in strawberry and Aguayo *et al.* (2007) in Amarillo melons. The storage temperature not only regulates all the physiological activities but also affects the physico-chemical changes in fruits and vegetables during storage. The increase in acidity as well as decrease in pH were relatively slow in both the storage temperatures and thus maintained quality of fresh cut onions. This might be due to the refrigeration storage (<7^0C) environments which slowed the physiological activities, reduced respiration rate, enzymatic process and microbial activity as reported by Baskaran *et al.* (2015) in minimally processed onions, Nicolla *et al.* (2009) and Waghmare *et al.* (2013) in fresh cut produce, Zhan *et al.* (2012) in fresh cut broccoli and Sahoo *et al.* (2014) in fresh bell pepper.

4.4.2.2 Total soluble solids (^{0}Brix)

The data regarding changes in total soluble solids of fresh cut onion (i.e. whole peeled and diced onion) are summarized in Table 63 and 64. As regards interaction effects of MAP treatment and storage environment on whole peeled and diced onion, non-significant effects were observed up to 6 and 9 days of storage, respectively. Thereafter significant effects in both pretreated cut types were noted till the end of storage. The effect of MAP treatments was found to be significant in both cut types at all the stages of storage. The effect of storage environments was found to be non-significant in both cut types at 3^{rd} day of storage. Decreasing trend in TSS of whole peeled and diced onion was observed irrespective of MAP treatments and storage environments under study.

Among the MAP treatments tried, M_3 (0.5% O_2 + 10% CO_2) recorded significantly maximum TSS (10.41^0Brix and 10.39^0Brix) after 21 days of storage in pretreated whole peeled and diced onion, respectively. While MAP packaging M_5 (0.5% O_2 + 5% CO_2) recorded TSS 10.37^0Brix and 10.35^0Brix after 21 days of storage in pretreated whole peeled and diced onion respectively.

As regards storage environments under study, the minimum deviation in TSS was observed in S_1 (0 ± 1^0C) storage. The whole peeled onion stored at S_1 recorded TSS 10.40^0Brix at the end of 21^{st} day of storage while same treatment registered TSS 10.39^0Brix in the diced onion.

As regards treatment combination of MAP treatments and storage environments, relatively slow but constant decrease in TSS was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered maximum TSS 10.43^0Brix and 10.41^0Brix in pretreated whole peeled and diced onion after 21 days of storage, respectively.

The decrease in TSS of fresh cut onion was reported due to the increase of the respiration rate of the product during storage. The similar report was given by Carolina A. *et al.* (2007) in Onions cv. Superex and Aguayo *et al.* (2003) in fresh cut muskmelon. The MAP treated onions with low oxygen content did not cause much change in the TSS content over initial. The similar results were reported by Sanchez-Moreno *et al.* (2004) in onions. MAP treated fresh cut onion retained significantly higher total soluble solids than normal atmosphere. This was in harmony with the study by Sanchez-Moreno *et al.* (2004) and Baskaran *et al.* (2015)

Table 63: Effect of modified atmosphere packaging and storage temperatures on total soluble solids (°Brix) of whole peeled onion

Treatment combinations	Total soluble solids (°Brix)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	11.54	11.53	11.30	11.22	10.80	10.68	10.46	-
M_1S_2		11.52	11.25	11.15	10.77	10.65	10.43	-
M_2S_1		11.48	11.32	11.20	10.99	10.75	10.53	10.41
M_2S_2		11.48	11.27	11.13	10.90	10.70	10.49	10.38
M_3S_1		11.48	11.28	11.26	10.88	10.75	10.55	10.43
M_3S_2		11.47	11.26	11.22	10.85	10.68	10.50	10.39
M_4S_1		11.50	11.31	11.24	10.83	10.70	10.50	10.40
M_4S_2		11.49	11.29	11.21	10.80	10.65	10.47	10.36
M_5S_1		11.47	11.28	11.20	10.81	10.69	10.48	10.39
M_5S_2		11.46	11.25	11.19	10.78	10.65	10.43	10.35
M_6S_1		11.49	11.29	11.18	10.80	10.67	10.44	-
M_6S_2		11.49	11.27	11.16	10.76	10.63	10.40	-
M_7S_1		11.52	11.19	-	-	-	-	-
M_7S_2		11.51	11.16	-	-	-	-	-
M_8S_1		11.52	11.22	11.15	-	-	-	-
M_8S_2		11.50	11.18	11.09	-	-	-	-
SE ±		0.0141	0.0134	0.0094	0.0063	0.0083	0.0063	0.0070
CD at 1%		NS	NS	0.0393	0.0262	0.0344	0.0262	0.0290
M_1	11.54	11.52	11.27	11.18	10.78	10.66	10.44	-
M_2		11.48	11.29	11.16	10.94	10.72	10.51	10.39
M_3		11.47	11.27	11.24	10.87	10.71	10.53	10.41
M_4		11.49	11.30	11.23	10.82	10.67	10.48	10.38
M_5		11.47	11.26	11.19	10.79	10.67	10.46	10.37
M_6		11.49	11.28	11.17	10.78	10.65	10.42	-
M_7		11.51	11.18	-	-	-	-	-
M_8		11.51	11.20	11.12	-	-	-	-
SE ±		0.0100	0.0094	0.0067	0.0044	0.0058	0.0044	0.0049
CD at 1%		0.0416	0.0394	0.0278	0.0185	0.0244	0.0185	0.0205
S_1	11.54	11.50	11.27	11.21	10.85	10.71	10.49	10.40
S_2		11.49	11.24	11.16	10.81	10.66	10.45	10.37
SE ±		0.0050	0.0047	0.0033	0.0022	0.0029	0.0022	0.0025
CD at 1%		NS	0.0197	0.0139	0.0093	0.0122	0.0093	0.0102

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

in onions, Erkan *et al.* (2004) in apple fruits. The slight decrease in TSS was also recorded by Baskaran *et al.* (2015) in onions, Selcuk and Erkan (2014) in sweet pomegranate, Peano *et al.* (2014) in strawberry, Majidi *et al.* (2011) in tomato. The decrease in the TSS content of fresh cut onion irrespective of MAP treatment and storage temperatures was most likely as a result of the use of this compound during the respiratory process for metabolism maintenance with considerable mass loss, ultimately leading to the accumulation of solids and decompartmentalization of enzymes and substrates altering TSS and flavours, as reported by Blanchard *et al.* (1996) in yellow diced onion, Silva *et al.*, 2009 in atemoyas, Rico *et al.* (2007) and Hodges and Toivonen (2008) in fresh cut fruits and vegetables. The low temperatures might have also played an important role in minimum changes in TSS content as reported by Carolina *et al.* (2007) in Onions cv. Superex, Blanchard *et al.* (1996) in yellow diced onion, Baskaran *et al.* (2015) in onion, Nicolla *et al.* (2009) and Waghmare *et al.* (2013) in fresh cut produce, Zhan

Table 64: Effect of modified atmosphere packaging and storage temperatures on total soluble solids (°Brix) of diced onion

Treatment combinations	Total soluble solids (°Brix)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	11.54	11.51	11.28	11.20	10.78	10.65	10.44	-
M_1S_2		11.50	11.23	11.14	10.75	10.63	10.42	-
M_2S_1		11.47	11.31	11.18	10.97	10.73	10.52	10.39
M_2S_2		11.46	11.25	11.12	10.89	10.68	10.47	10.35
M_3S_1		11.47	11.27	11.24	10.86	10.73	10.53	10.41
M_3S_2		11.46	11.25	11.21	10.83	10.67	10.47	10.38
M_4S_1		11.49	11.30	11.22	10.80	10.68	10.47	10.39
M_4S_2		11.48	11.28	11.19	10.77	10.63	10.42	10.34
M_5S_1		11.45	11.26	11.19	10.78	10.67	10.46	10.37
M_5S_2		11.44	11.24	11.17	10.75	10.62	10.40	10.33
M_6S_1		11.48	11.28	11.17	10.76	10.64	10.42	-
M_6S_2		11.47	11.26	11.14	10.73	10.60	10.39	-
M_7S_1		11.51	11.17	-	-	-	-	-
M_7S_2		11.50	11.15	-	-	-	-	-
M_8S_1		11.51	11.19	11.13	-	-	-	-
M_8S_2		11.50	11.17	11.06	-	-	-	-
SE ±		0.0144	0.0121	0.0124	0.0067	0.0065	0.0081	0.0057
CD at 1%		NS	NS	NS	0.0279	0.0271	0.0336	0.0239
M_1	11.54	11.51	11.26	11.17	10.77	10.64	10.43	-
M_2		11.47	11.28	11.15	10.93	10.70	10.50	10.37
M_3		11.47	11.26	11.22	10.84	10.70	10.50	10.39
M_4		11.49	11.29	11.21	10.78	10.65	10.45	10.36
M_5		11.45	11.25	11.18	10.76	10.64	10.43	10.35
M_6		11.48	11.27	11.16	10.74	10.62	10.41	-
M_7		11.51	11.16	-	-	-	-	-
M_8		11.51	11.18	11.10	-	-	-	-
SE ±		0.0102	0.0086	0.0088	0.0047	0.0046	0.0057	0.0041
CD at 1%		0.0423	0.0356	0.0365	0.0197	0.0192	0.0238	0.0169
S_1	11.54	11.49	11.26	11.19	10.82	10.68	10.47	10.39
S_2		11.48	11.23	11.15	10.78	10.64	10.43	10.35
SE ±		0.0051	0.0043	0.0044	0.0024	0.0023	0.0029	0.0020
CD at 1%		NS	0.0178	0.0182	0.0099	0.0096	0.0119	0.0085

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

et al. (2012) in fresh cut broccoli, Sahoo *et al.* (2014) in fresh bell pepper and Dhumal (2012) in ready to eat pomegranate arils.

4.4.2.3 Anthocyanins (mg per 100g)

The results of anthocyanin content in fresh cut onion (i.e. whole peeled and diced onion) are summarized in Table 65 and 66 and graphically represented in a Fig. 43 and 44. Initial anthocyanin content in pretreated fresh cut onion recorded was 37.18 mg per 100g. As regards interaction effects of MAP treatment and storage environment on whole peeled and diced onion, non-significant effects up to 9th and 12th days of storage were recorded, respectively. Thereafter, significant effects in both pretreated cut types were noted till the end of storage. The effect of MAP treatments and storage environments were found to be significant in both cut types at all the stages of storage. The effect of storage environments was found to be non-significant in whole peeled onion at 6th, day of storage. Initially increasing trend was observed in anthocyanin

Table 65: Effect of modified atmosphere packaging and storage temperatures on anthocyanins of whole peeled onion

Treatment combinations	Anthocyanins (mg per 100g)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	37.18	36.77	36.84	36.85	36.73	36.60	36.53	-
M_1S_2		36.75	36.81	36.81	36.70	36.55	36.49	-
M_2S_1		36.79	36.88	36.91	36.83	36.75	36.62	36.53
M_2S_2		36.79	36.85	36.89	36.80	36.72	36.60	36.51
M_3S_1		36.79	36.88	36.93	36.85	36.77	36.64	36.55
M_3S_2		36.78	36.86	36.90	36.81	36.74	36.60	36.52
M_4S_1		36.79	36.85	36.87	36.79	36.70	36.52	36.45
M_4S_2		36.76	36.87	36.85	36.74	36.64	36.49	36.42
M_5S_1		36.80	36.85	36.88	36.80	36.70	36.56	36.48
M_5S_2		36.76	36.82	36.85	36.76	36.66	36.52	36.45
M_6S_1		36.83	36.86	36.85	36.75	36.62	36.55	-
M_6S_2		36.78	36.83	36.83	36.71	36.59	36.52	-
M_7S_1		36.74	36.55	-	-	-	-	-
M_7S_2		36.71	36.51	-	-	-	-	-
M_8S_1		36.75	36.65	36.58	-	-	-	-
M_8S_2		36.73	36.61	36.55	-	-	-	-
SE ±		0.0099	0.0478	0.0087	0.0060	0.0062	0.0058	0.0052
CD at 1%		NS	NS	NS	0.0251	0.0258	0.0243	0.0215
M_1	37.18	36.76	36.82	36.83	36.71	36.58	36.51	-
M_2		36.79	36.86	36.90	36.81	36.74	36.61	36.52
M_3		36.78	36.87	36.91	36.83	36.75	36.62	36.54
M_4		36.77	36.86	36.86	36.77	36.67	36.50	36.44
M_5		36.78	36.84	36.86	36.78	36.68	36.54	36.47
M_6		36.80	36.85	36.84	36.73	36.60	36.54	-
M_7		36.72	36.53	-	-	-	-	-
M_8		36.74	36.63	36.56	-	-	-	-
SE ±		0.0070	0.0338	0.0169	0.0043	0.0044	0.0041	0.0037
CD at 1%		0.0292	0.1409	0.0255	0.0177	0.0182	0.0172	0.0152
S_1	37.18	36.78	36.79	36.84	36.79	36.69	36.57	36.50
S_2		36.75	36.77	36.81	36.75	36.65	36.53	36.48
SE ±		0.0035	0.0061	0.0031	0.0021	0.0022	0.0021	0.0018
CD at 1%		0.0146	NS	0.0128	0.0089	0.0091	0.0086	0.0076

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

content of whole peeled and diced onion and thereafter decrease in anthocyanin content was registered with advancement of storage period irrespective of MAP treatments and storage environments under study.

Among all the MAP packagings, M_3 (0.5% O_2 + 10% CO_2) retained significantly maximum anthocyanin content (36.54 and 36.47 mg per 100g) after 21 days of storage in pretreated whole peeled and diced onion respectively. While MAP with super atmospheric oxygen i.e. 100% oxygen recorded minimum anthocyanin content (36.53 and 36.49 mg per 100g) after 6 days of storage in pretreated whole peeled and diced onion respectively.

As regards storage environments under study, the maximum retention of anthocyanin content was observed in S_1 (0 ± 1^0C) storage. The whole peeled onion stored at S_1 recorded 36.50 mg per 100g anthocyanin content at the end of 21[st] day of storage while same treatment registered 36.47 mg per 100g anthocyanin content in the diced onion.

Table 66: Effect of modified atmosphere packaging and storage temperatures on anthocyanins of diced onion

Treatment combinations	Anthocyanins (mg per 100g)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	37.18	36.75	36.80	36.84	36.72	36.59	36.51	-
M_1S_2		36.73	36.77	36.80	36.70	36.53	36.45	-
M_2S_1		36.78	36.85	36.89	36.80	36.71	36.60	36.49
M_2S_2		36.76	36.83	36.85	36.76	36.67	36.55	36.42
M_3S_1		36.77	36.86	36.91	36.82	36.74	36.60	36.50
M_3S_2		36.75	36.84	36.87	36.77	36.69	36.56	36.44
M_4S_1		36.77	36.83	36.85	36.76	36.68	36.48	36.43
M_4S_2		36.75	36.80	36.82	36.71	36.62	36.44	36.40
M_5S_1		36.79	36.83	36.85	36.77	36.67	36.53	36.45
M_5S_2		36.75	36.81	36.83	36.74	36.63	36.48	36.40
M_6S_1		36.80	36.83	36.84	36.73	36.60	36.53	-
M_6S_2		36.76	36.79	36.81	36.70	36.56	36.47	-
M_7S_1		36.73	36.50	-	-	-	-	-
M_7S_2		36.70	36.47	-	-	-	-	-
M_8S_1		36.73	36.62	36.53	-	-	-	-
M_8S_2		36.71	36.58	36.48	-	-	-	-
SE ±		0.0150	0.0125	0.0124	0.0103	0.0058	0.0071	0.0085
CD at 1%		NS	NS	NS	NS	0.0243	0.0295	0.0356
M_1	37.18	36.74	36.79	36.82	36.71	36.56	36.48	-
M_2		36.77	36.84	36.87	36.78	36.69	36.57	36.46
M_3		36.76	36.85	36.89	36.80	36.71	36.58	36.47
M_4		36.76	36.82	36.84	36.74	36.65	36.46	36.42
M_5		36.77	36.82	36.84	36.76	36.65	36.50	36.43
M_6		36.78	36.81	36.83	36.72	36.58	36.50	-
M_7		36.72	36.49	-	-	-	-	-
M_8		36.72	36.60	36.51	-	-	-	-
SE ±		0.0106	0.0088	0.0087	0.0073	0.0041	0.0050	0.0060
CD at 1%		0.0442	0.0368	0.0364	0.0304	0.0172	0.0208	0.0252
S_1	37.18	36.77	36.77	36.82	36.77	36.66	36.54	36.47
S_2		36.74	36.74	36.78	36.73	36.61	36.49	36.42
SE ±		0.0053	0.0044	0.0044	0.0036	0.0021	0.0025	0.0030
CD at 1%		0.0221	0.0184	0.0182	0.0152	0.0086	0.0104	0.0126

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

As regards treatment combination of MAP treatments and storage environments, increase in anthocyanin content was observed initially and thereafter decrease in anthocyanin content was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered maximum anthocyanin content of 36.55 mg per 100g and 36.50 mg per 100g in pretreated whole peeled and diced onion after 21 days of storage respectively.

The anthocyanins in the red fresh cut onions were found to be increased initially during storage and thereafter decreased throughout the storage period. However, after pretreatment it was found to be decreased in the present investigation. This decrease was due to the water solubility of the anthocyanins and slight loss of pigment due to immersion in water as observed by Perez-Gregorio *et al.* (2011) in sliced red onion and Dhumal (2012) in pomegranate. During early period of storage in all the treatments under study, slight increase in anthocyanins was recorded in both cut types. This increase in anthocyanins in later stages of storage was associated with the slow biosynthesis of coloured pigments and/or *de novo* synthesis of anthocyanins at low temperatures as a response against the stress caused by cutting process and low temperature. The anthocyanins increase the tolerance of the vegetables and fruits to refrigeration temperature as reported by Ferreres *et al.* (1996) in shredded red onion, Perez-Greogorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions, Gould and Lister (2006) in fruits and vegetables and Perez-Vicente *et al.* (2004) in pomegranate cv. Mollar. The MAP treatments with low oxygen content and high CO_2 coupled with low storage temperatures have been reported to have minimum changes in anthocyanin content of fresh cut onion. The similar results were reported by Sanchez-Moreno *et al.* (2004) and Baskaran *et al.* (2015) in onions.

4.4.2.4 Pyruvic Acid (µmol/g fresh weight)

The data regarding per cent acidity in fresh cut onion (i.e. whole peeled and diced onion) is depicted in Table 67 and 68 and graphically represented in Fig. 45 and 46. Initial pyruvic acid in pretreated fresh cut onion was 5.286 µmol/g fresh weight. As regards interaction effects of MAP treatment and storage environment in both types of cut i.e. whole peeled and diced onion, non-significant effect was found up to 9th days of storage. Thereafter significant effects in both pretreated cut types were noted till the end of storage. The effect of MAP treatments and storage environment was found to be significant in both cut types at all the stages of storage. Decreasing trend in pyruvic acid content of whole peeled and diced onion was observed irrespective of MAP treatments and storage environments under study.

Among all the MAP packagings, M_3 treatment (0.5% O_2 + 10% CO_2) retained significantly maximum pyruvic acid (5.088 and 5.087 µmol/g fresh weight) after 21 days of storage in pretreated whole peeled and diced onion, respectively. While MAP packaging M_4 (3%

O_2 + 10% CO_2) retained significantly minimum pyruvic acid (5.083 and 5.081 µmol/g fresh weight) after 21 days of storage in pretreated whole peeled and diced onion, respectively.

As regards storage environments under study, the maximum retention of pyruvic acid content was observed in S_1 (0±1^{0}C) storage. The whole peeled onion stored at S_1 recorded 5.087 µmol/g fresh weight pyruvic acid at the end of 21st day of storage while same treatment registered 5.085 µmol/g fresh weight pyruvic acid in the diced onion. The whole peeled onion stored at S_2 recorded 5.084 µmol/g fresh weight pyruvic acid at the end of 21st day of storage while same treatment registered 5.082 µmol/g fresh weight pyruvic acid in the diced onion.

Table 67: Effect of modified atmosphere packaging and storage temperatures on pyruvic acid (µmol/g fresh weight) of whole peeled onion

Treatment combinations	Pyruvic acid (µmol/g fresh weight)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	5.286	5.283	5.249	5.220	5.220	5.105	5.091	-
M_1S_2		5.280	5.246	5.217	5.166	5.103	5.089	-
M_2S_1		5.286	5.253	5.227	5.165	5.111	5.097	5.086
M_2S_2		5.284	5.250	5.225	5.162	5.109	5.096	5.083
M_3S_1		5.286	5.253	5.230	5.166	5.112	5.100	5.090
M_3S_2		5.285	5.251	5.228	5.163	5.109	5.098	5.087
M_4S_1		5.286	5.251	5.226	5.163	5.108	5.096	5.085
M_4S_2		5.283	5.249	5.224	5.159	5.107	5.093	5.082
M_5S_1		5.286	5.253	5.226	5.165	5.110	5.097	5.088
M_5S_2		5.283	5.249	5.225	5.160	5.107	5.094	5.086
M_6S_1		5.284	5.250	5.224	5.161	5.106	5.095	-
M_6S_2		5.282	5.247	5.221	5.157	5.104	5.091	-
M_7S_1		5.279	5.228	-	-	-	-	-
M_7S_2		5.276	5.222	-	-	-	-	-
M_8S_1		5.281	5.241	5.215	-	-	-	-
M_8S_2		5.277	5.238	5.211	-	-	-	-
SE ±		0.0010	0.0008	0.0007	0.0011	0.0009	0.0005	0.0005
CD at 1%		NS	NS	NS	0.0047	NS	0.0019	0.0020
M_1	5.286	5.281	5.248	5.218	5.193	5.104	5.090	-
M_2		5.285	5.251	5.226	5.164	5.110	5.096	5.084
M_3		5.286	5.252	5.229	5.164	5.110	5.099	5.088
M_4		5.284	5.250	5.225	5.161	5.107	5.095	5.083
M_5		5.284	5.251	5.225	5.162	5.109	5.095	5.087
M_6		5.283	5.248	5.222	5.159	5.105	5.093	-
M_7		5.278	5.225	-	-	-	-	-
M_8		5.279	5.239	5.213	-	-	-	-
SE ±		0.0007	0.0006	0.0005	0.0008	0.0006	0.0003	0.0003
CD at 1%		0.0029	0.0025	0.0020	0.0034	0.0026	0.0014	0.0014
S_1	5.286	5.284	5.247	5.224	5.173	5.108	5.096	5.087
S_2		5.281	5.244	5.222	5.161	5.106	5.093	5.084
SE ±		0.0003	0.0003	0.0002	0.0004	0.0003	0.0002	0.0002
CD at 1%		0.0015	0.0012	0.0010	0.0017	0.0013	0.0007	0.0007

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= 0^{0}C ± 1^{0}C
S_2= 7^{0}C ± 1^{0}C

As regards treatment combination of MAP treatments and storage environments relatively slow but constant decrease in pyruvic acid content was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered maximum pyruvic acid (5.090 µmol/g fresh weight and 5.088 µmol/g fresh weight) in pretreated whole peeled and diced onion after 21 days of storage respectively.

Table 68: Effect of modified atmosphere packaging and storage temperatures on pyruvic acid (µmol/g fresh weight) of diced onion

Treatment combinations	Pyruvic acid (µmol/g fresh weight)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	5.286	5.282	5.247	5.219	5.217	5.103	5.089	-
M_1S_2		5.280	5.245	5.215	5.165	5.100	5.086	-
M_2S_1		5.285	5.251	5.225	5.162	5.108	5.095	5.084
M_2S_2		5.283	5.249	5.223	5.159	5.107	5.093	5.080
M_3S_1		5.286	5.251	5.228	5.164	5.109	5.097	5.088
M_3S_2		5.284	5.250	5.226	5.160	5.106	5.095	5.086
M_4S_1		5.285	5.248	5.225	5.161	5.106	5.094	5.082
M_4S_2		5.282	5.246	5.221	5.157	5.103	5.090	5.080
M_5S_1		5.285	5.251	5.224	5.162	5.108	5.095	5.086
M_5S_2		5.283	5.247	5.222	5.158	5.104	5.092	5.083
M_6S_1		5.283	5.248	5.222	5.160	5.105	5.093	-
M_6S_2		5.281	5.246	5.220	5.155	5.102	5.090	-
M_7S_1		5.277	5.226	-	-	-	-	-
M_7S_2		5.275	5.219	-	-	-	-	-
M_8S_1		5.280	5.240	5.213	-	-	-	-
M_8S_2		5.275	5.237	5.209	-	-	-	-
SE ±		0.00121	0.00108	0.00105	0.00117	0.00048	0.00043	0.00047
CD at 1%		NS	NS	NS	0.00486	0.00201	0.00178	0.00194
M_1	5.286	5.281	5.246	5.217	5.191	5.101	5.087	-
M_2		5.284	5.250	5.224	5.160	5.107	5.094	5.082
M_3		5.285	5.251	5.227	5.162	5.107	5.096	5.087
M_4		5.284	5.247	5.223	5.159	5.104	5.092	5.081
M_5		5.284	5.249	5.223	5.160	5.106	5.093	5.084
M_6		5.282	5.247	5.221	5.157	5.103	5.091	-
M_7		5.276	5.223	-	-	-	-	-
M_8		5.278	5.239	5.211	-	-	-	-
SE ±		0.00086	0.00076	0.00074	0.00083	0.00034	0.00030	0.00033
CD at 1%		0.00356	0.00318	0.00308	0.00344	0.00142	0.00126	0.00137
S_1	5.286	5.283	5.245	5.222	5.171	5.106	5.093	5.085
S_2		5.280	5.242	5.219	5.159	5.103	5.091	5.082
SE ±		0.00043	0.00038	0.00037	0.00041	0.00017	0.00015	0.00016
CD at 1%		0.00178	0.00159	0.00154	0.00172	0.00071	0.00063	0.00069

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

The decrease in the pyruvic acid content was observed in the pretreated fresh cut onions with different MAP treatments and storage temperatures. A lower pyruvic acid content in all the treatment combinations might be attributed to cell disruption, volatization and leaking of substances responsible for pungency, degradation of volatiles, the loss of enzymes, accelerated physiological activities and higher consumption of pyruvic acid as a metabolic substrate as reported by Berno *et al.* (2014) in fresh cut purple onion, Schwimmer and Weston (1961); Anthon and Barrett (2003); Lanzotti (2006); Bretch *et al.* (2007); Bhat *et al.* (2010); Howard *et al.* (1994) and Miguel and Durigan (2007) in onions. However, MAP treatments and lower storage temperatures under study observed minimum deviation in pyruvic acid as compared with other treatments. Similar results were reported by Blanchard *et al.* (1996) in yellow diced onions.

The lower temperature during storage might have also played important role in arresting volatization and leaching of compounds responsible for pungency by lowering down the physiological activities in the packages. The results are in conformity with Carolina *et al.* (2007) in Onions cv. Superex, Ferreres *et al.* (1996) in shredded red onion, Perez-Gregorio *et al.* (2011) in sliced onion, Bahram-Parvar and Lim (2018) in fresh cut onions.

4.4.3 In Package Atmosphere (Headspace gas concentrations)

4.4.3.1 Oxygen (%)

Data given in Table 69 and 70 regarding changes in oxygen content of MAP packages indicated that oxygen content in the packed fresh cut onion (whole peeled and diced onion) decreased gradually irrespective of storage conditions. However, in MAP packagings with reduced oxygen content like M_3, the oxygen content was found to be almost constant but less than atmosphere oxygen (Fig. 47 and 48). The oxygen concentration in the headspace of

Table 69: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of percent oxygen in whole peeled onion

Treatment combinations	Percent oxygen							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	18.70	12.55	10.44	8.32	6.18	3.45	2.76	-
M_1S_2	18.70	12.61	10.50	8.28	6.11	3.37	2.70	-
M_2S_1	2.00	1.96	1.78	1.65	1.44	1.15	0.88	0.56
M_2S_2	2.00	1.98	1.80	1.69	1.56	1.20	0.95	0.59
M_3S_1	0.50	0.50	0.50	0.50	0.30	0.25	0.20	0.18
M_3S_2	0.50	0.50	0.54	0.59	0.33	0.28	0.26	0.23
M_4S_1	3.00	2.95	2.85	2.32	1.95	1.26	1.12	0.85
M_4S_2	3.00	2.95	2.88	2.39	1.98	1.29	1.18	0.88
M_5S_1	0.50	0.50	0.47	0.47	0.33	0.28	0.26	0.20
M_5S_2	0.50	0.50	0.49	0.47	0.39	0.29	0.27	0.24
M_6S_1	0.00	0.00	0.28	0.25	0.23	0.11	0.09	-
M_6S_2	0.00	0.00	0.31	0.28	0.25	0.24	0.15	-
M_7S_1	100.00	10.26	2.16	-	-	-	-	-
M_7S_2	100.00	10.38	2.25	-	-	-	-	-
M_8S_1	80.00	13.15	8.36	2.23	-	-	-	-
M_8S_2	80.00	13.27	8.43	2.31	-	-	-	-
SE ±	0.0060	0.0054	0.0034	0.0070	0.0074	0.0087	0.0086	0.0063
CD at 1%	NS	0.0227	0.0142	0.0293	0.0306	0.0361	0.0357	0.0262
M_1	18.70	12.58	10.47	8.30	6.14	3.41	2.73	-
M_2	2.00	1.97	1.79	1.67	1.50	1.17	0.91	0.58
M_3	0.50	0.50	0.52	0.54	0.31	0.26	0.23	0.20
M_4	3.00	2.95	2.86	2.35	1.96	1.28	1.15	0.86
M_5	0.50	0.50	0.48	0.47	0.36	0.28	0.27	0.22
M_6	0.00	0.00	0.29	0.26	0.24	0.18	0.12	-
M_7	100.00	10.32	2.21		-	-	-	-
M_8	80.00	13.21	8.40	2.27	-	-	-	-
SE ±	0.0043	0.0038	0.0024	0.0050	0.0052	0.0061	0.0061	0.0044
CD at 1%	0.0178	0.0160	0.0101	0.0207	0.0217	0.0255	0.0252	0.0185
S_1	25.59	5.23	3.35	2.25	1.73	1.08	0.88	0.45
S_2	25.59	5.27	3.40	2.29	1.77	1.11	0.91	0.48
SE ±	0.0021	0.0019	0.0012	0.0025	0.0026	0.0031	0.0030	0.0022
CD at 1%	NS	0.0080	0.0050	0.0104	0.0108	0.0128	0.0126	0.0093

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

fresh cut onion bags was significantly influenced by MAP treatments, storage environment and their interactions. The rate of oxygen reduction varied depending on the oxygen content in the MAP packages.

As regards MAP treatments under study, the MAP treatments, the drastic reduction in the headspace oxygen concentration was recorded in the packages containing super atmospheric oxygen. The MAP treatment M_7 registered 2.21 and 2.39% headspace concentration of oxygen in whole peeled as well as diced onion, respectively. In the whole peeled onion, MAP packagings with 0.5% O_2 + 10% CO_2 registered 0.20 per cent oxygen in headspace while M_4 (3% O_2 + 10% CO_2) packaging treatment recorded 0.86 per cent oxygen headspace at the end of storage period i.e. after 21days. The same MAP treatments recorded 0.24 and 0.91 per cent oxygen in the headspace of the diced onion packages. The packages flushed with super-atmospheric oxygen were terminated after 6 and 9 days of storage in both cut types.

As the storage period advanced, the headspace concentration of per cent oxygen in MAP packaged fresh cut onion (i.e. whole peeled and diced onion) decreased gradually in both storage environments. Among the storage environment, MAP packaged fresh cut onion (i.e. whole peeled and diced onion) stored at 0 ± 1^0C recorded relatively slow decrease in oxygen as compared with S_2. At the end of storage period, pretreated whole peeled onion stored at S_1 registered 0.45 per cent oxygen in headspace of MAP packages while S_2 (7 ± 1^0C) registered 0.48 per cent oxygen in headspace of MAP packages. As regards the diced onion stored at 0 ± 1^0C (S_1) temperature recorded maximum per cent headspace oxygen (0.48%) while S_2 recorded 0.53 per cent oxygen in headspace of MAP packages.

As regards interaction effects of MAP treatments and storage environments under study, the gradual decrease in headspace oxygen concentration was recorded by pretreated fresh cut onion i.e. (whole peeled and diced onion). The whole peeled onion packaged with 0.5% O_2 + 10% CO_2 and stored at 0 ± 1^0C (M_3S_1) recorded 0.18 per cent headspace oxygen while treatment combination M_4S_2 recorded 0.88 per cent oxygen in headspace. The diced onion packed with 0.5% O_2 + 10% CO_2 and stored at 0 ± 1^0C (M_3S_1) recorded 0.21 per cent headspace oxygen while treatment combination M_4S_2 recorded 0.93 per cent headspace oxygen.

The headspace concentration changes in oxygen content inside fresh cut onion packages are graphed in Fig. 49 and 50 as a function of storage time. The oxygen levels decreased in the packages irrespective of the MAP treatment and the storage temperature under study. The modified atmosphere composition in the headspace of package of fresh cut onion during storage changed. This might be due to accelerated respiration, other metabolic and physiological processes continued in fresh cut onion in initial phase which later on reduced the respiratory activity with increased ethylene biosynthesis and action. The utilization of the respiratory gases in physiological and metabolic activities might have formed equilibrium modified atmosphere, thus depressing the inhibitory effect to respiration rate as reported by Han *et al.* (2010) in fresh cut onion, Liu and Li (2006) in MAP sliced onion, Bahram-Parvar *et al.* (2018) in onion and Berno *et al.* (2014) in fresh cut onion, Patil (2016) in fresh cut lettuce, Krasnova and Dukalska (2012) in fresh cut mixed salad quality, Kang *et al.* (2007) in fresh cut lettuce, Kim *et al.* (2005) and Mattos *et al.* (2013) on Crisp head lettuce in fresh cut Romaine lettuce and by Smyth *et al.* (1998) in deciduous fruits. Strict temperature control after processing is needed to reduce wound-induced metabolic activity, as observed in the present study in case of both whole peeled and diced onions stored at 0±1°C and 7±1°C. The similar observations were recorded by Patil (2016) and Kaur (2016) in fresh cut lettuce. The barrier properties of used packaging films might have also played role in bringing the equilibrium of gases inside packages as reported by Krasnova *et al.* (2012) in fresh cut mixed salad quality and Kim *et al.* (2005) in defatted soybean meal quality during storage.

Table 70: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of percent oxygen in diced onion

Treatment combinations	Percent oxygen							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	18.72	12.58	10.48	8.35	6.21	3.48	2.79	-
M_1S_2	18.74	12.63	10.56	8.42	6.27	3.54	2.85	-
M_2S_1	2.00	1.97	1.81	1.69	1.46	1.19	0.92	0.60
M_2S_2	2.00	1.99	1.83	1.73	1.53	1.24	0.98	0.65
M_3S_1	0.50	0.50	0.48	0.45	0.35	0.27	0.25	0.21
M_3S_2	0.50	0.49	0.49	0.47	0.38	0.30	0.28	0.26
M_4S_1	3.00	2.97	2.86	2.34	1.98	1.34	1.18	0.88
M_4S_2	3.00	2.98	2.89	2.41	2.02	1.30	1.24	0.93
M_5S_1	0.50	0.50	0.48	0.48	0.36	0.31	0.29	0.24
M_5S_2	0.50	0.50	0.49	0.48	0.41	0.33	0.31	0.27
M_6S_1	0.00	0.10	0.32	0.28	0.25	0.15	0.12	-
M_6S_2	0.00	0.15	0.38	0.32	0.29	0.23	0.19	-
M_7S_1	100.00	10.55	2.35	-	-	-	-	-
M_7S_2	100.00	10.64	2.42	-	-	-	-	-
M_8S_1	80.00	13.26	8.46	2.29	-	-	-	-
M_8S_2	80.00	13.47	8.57	2.35	-	-	-	-
SE ±	0.0037	0.0098	0.0083	0.0096	0.0086	0.0089	0.0086	0.0072
CD at 1%	NS	0.0410	0.0346	0.0399	0.0357	0.0369	0.0357	0.0300
M_1	18.73	12.61	10.52	8.39	6.24	3.51	2.82	-
M_2	2.00	1.98	1.82	1.71	1.50	1.22	0.95	0.63
M_3	0.50	0.50	0.49	0.46	0.37	0.29	0.27	0.24
M_4	3.00	2.98	2.88	2.38	2.00	1.32	1.21	0.91
M_5	0.50	0.50	0.49	0.48	0.39	0.32	0.30	0.26
M_6	0.00	0.13	0.35	0.30	0.27	0.19	0.16	-
M_7	100.00	10.60	2.39	-	-	-	-	-
M_8	80.00	13.36	8.51	2.32	-	-	-	-
SE ±	0.0026	0.0070	0.0059	0.0068	0.0061	0.0063	0.0061	0.0051
CD at 1%	0.0108	0.0290	0.0245	0.0282	0.0252	0.0261	0.0252	0.0212
S_1	25.59	5.30	3.40	2.27	1.77	1.12	0.93	0.48
S_2	25.59	5.36	3.45	2.31	1.82	1.16	0.98	0.53
SE ±	0.0013	0.0035	0.0029	0.0034	0.0030	0.0031	0.0030	0.0025
CD at 1%	NS	0.0145	0.0122	0.0141	0.0126	0.0130	0.0126	0.0106

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

4.4.3.2 Carbon dioxide (%)

The headspace concentration changes in carbon dioxide inside the fresh cut onion packages are presented hereunder in Table 71 and 72 and are graphed in Fig. 49 and 50 as a function of storage time. The CO_2 levels increased in the air treatment packages while it reduced in CO_2 enriched packages till it reaches equilibrium. The carbon dioxide concentration in the headspace of fresh cut onion bags was significantly influenced by MAP treatments, storage environment and their interactions in both the types of cut. The rate of change in carbon dioxide concentration varied depending on the MAP content of the packages.

Table 71: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of percent carbon dioxide in whole peeled onion

Treatment combinations	Percent carbon dioxide							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	1.15	1.29	2.68	4.95	5.89	7.12	7.45	-
M_1S_2	1.17	1.32	2.73	5.00	5.94	7.19	7.50	-
M_2S_1	10.00	8.15	7.19	7.06	6.89	6.76	5.84	5.47
M_2S_2	10.00	8.19	7.31	7.15	6.96	6.85	5.91	5.53
M_3S_1	10.00	8.1	7.23	7.11	6.92	6.81	5.86	5.36
M_3S_2	10.00	8.23	7.27	7.12	6.94	6.83	5.91	5.45
M_4S_1	10.00	7.76	7.33	7.19	7.02	6.81	5.92	5.55
M_4S_2	10.00	7.81	7.38	7.21	7.05	6.89	5.98	5.58
M_5S_1	5.00	5.15	6.08	5.49	4.99	4.77	4.51	3.56
M_5S_2	5.00	5.19	6.13	5.58	5.08	4.82	4.56	3.62
M_6S_1	0.00	0.01	0.19	0.69	1.05	1.76	2.06	-
M_6S_2	0.00	0.03	0.25	0.73	1.10	1.85	2.12	-
M_7S_1	0.00	1.52	2.06	-	-	-	-	-
M_7S_2	0.00	1.56	2.13	-	-	-	-	-
M_8S_1	20.00	9.53	8.02	7.15	-	-	-	-
M_8S_2	20.00	9.58	8.09	7.23	-	-	-	-
SE ±	0.0143	0.0051	0.0024	0.0048	0.0089	0.0061	0.0073	0.0060
CD at 1%	NS	0.0211	0.0100	0.0199	0.0372	0.0255	0.0304	0.0251
M_1	1.16	1.30	2.70	4.98	5.91	7.15	7.47	-
M_2	10.00	8.17	7.25	7.10	6.93	6.81	5.88	5.50
M_3	10.00	8.16	7.25	7.12	6.93	6.82	5.88	5.41
M_4	10.00	7.78	7.35	7.20	7.04	6.86	5.95	5.56
M_5	5.00	5.17	6.11	5.53	5.03	4.79	4.54	3.59
M_6	0.00	0.02	0.22	0.71	1.07	1.80	2.09	-
M_7	0.00	1.54	2.09	-	-	-	-	-
M_8	20.00	9.55	8.06	7.19	-	-	-	-
SE ±	0.0101	0.0036	0.0017	0.0034	0.0063	0.0043	0.0052	0.0043
CD at 1%	0.0423	0.0149	0.0071	0.0141	0.0263	0.0180	0.0215	0.0177
S_1	7.02	5.19	5.10	5.66	5.46	5.67	5.27	4.98
S_2	7.02	5.24	5.16	5.72	5.51	5.74	5.33	5.04
SE ±	0.0051	0.0018	0.0008	0.0017	0.0032	0.0022	0.0026	0.0021
CD at 1%	NS	0.0075	0.0035	0.0071	0.0131	0.0090	0.0108	0.0089

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

As regards MAP treatments under study, the increase in the headspace concentration of carbon dioxide was recorded in passive MAP treatment i.e. air flushed, N_2 flushed as well as in super atmospheric oxygen in fluxed MAP packages. However, the MAP packages enriched with CO_2 recorded reduction in the headspace concentration of CO_2 in both the cut types i.e. whole peeled and diced onion, till it reaches equilibrium. The whole peeled onion packed in M_3 (3% O_2 + 10% CO_2) registered 5.41 per cent carbon dioxide while M_5 (0.5% O_2 + 5% CO_2) packaging treatment recorded 3.59 per cent carbon dioxide content in headspace at the 21st day of storage. The same treatments carried out in case of the diced onion, registered 5.47 and 3.66 per cent carbon dioxide at the end of storage period i.e. after 21st day of storage. The MAP packaging with super atmospheric oxygen (M_7) recorded 2.09 and 2.13 per cent carbon dioxide at the end of storage period i.e. after 6th day of storage.

As regards storage temperatures under study, the change in the headspace concentration of the carbon dioxide was observed in both cut types, until the equilibrium in the package is reached. Among the storage environments, MAP packaged fresh cut onion (i.e. whole peeled and diced onion) stored at 0 ± 1^0C recorded relatively slow change in carbon dioxide as compared with S_2. The slight increase in temperature was found to accelerate the change in headspace concentration of carbon dioxide. At the end of storage period, whole peeled onion stored at S_1 registered 4.98 per cent carbon dioxide in headspace of MAP packages while S_2 (7 ± 1^0C) registered 5.94 per cent carbon dioxide in headspace of MAP packages. As regards the diced onion stored at 0 ± 1^0C (S_1) temperature recorded 5.04 per cent headspace carbon dioxide while S_2 recorded 5.11 per cent carbon dioxide in headspace of MAP packages.

As regards interaction effects of MAP treatments and storage environments under study, the whole peeled onion packaged with 0.5% O_2 + 10% CO_2 and stored at 0 ± 1^0C (M_3S_1) recorded 5.36 per cent headspace carbon dioxide. The diced onion packaged with 0.5% O_2 + 10% CO_2 and stored at 0 ± 1^0C (M_3S_1) recorded 5.43 per cent headspace carbon dioxide.

In the present investigation, the changes in the headspace concentration of carbon dioxide were recorded in both types of fresh cut onion irrespective of MAP treatments and storage temperatures. Minimally processed food products readily deteriorate in quality, especially in colour and texture, as a result of endogenous enzymatic interactions and attack of microorganisms. This can be prevented by combined use of postharvest treatments, modified atmosphere packaging (MAP) with high CO2 levels and refrigeration. The increase in the headspace concentration of CO2 was recorded in the O2 enriched packages as well as air flushed package. However, decrease in CO2 concentration was recorded CO2 enriched MAP packages. Rapid consumption of oxygen and evolution of CO2 was noticed. This might be due to high rate of physiological activities like respiration, polyphenol oxidase activities and transpiration losses as reported by Liu and Li (2006) in sliced onions, Martin-Belloso *et al.* (2006) in fresh cut fruits and vegetables and by Manolopoulou *et al.* (2010) in fresh cut Romaine lettuce. The extended shelf life in fresh cut onions i.e. whole peeled and diced onions may be attributed the equilibrium of the O2 and CO2 in the packages retarding browning and spoilage which further delayed of exponential growth phase of microbes and maintained fresh appearance. Similar results were reported by Bai *et al.* (2001) in fresh cut muskmelon, Oliveria *et al.* (2015) in fresh cut fruits and vegetables, Zhang *et al.* (2013) in fresh cut honeydew muskmelon, Aguayo *et al.* (2007) in fresh cut cantaloupes. Storage temperature controls respiratory activity, transpiration, decay, fermentation and development of microbial pathogens and minimizes the physiological losses and increases shelf-life of fresh-food as well as processed products. In present study, MAP conditions at low temperatures might have maintained cell turgidity, prevented microbiological deterioration, creation of anaerobic condition, restricted availability of free oxygen, reduction in respiration rate by maintaining the CO2 concentration in the headspace of packages as evidenced by Liu and Li (2006) in MAP sliced onions, Kaur (2016) and Patil (2016) in fresh cut lettuce, Aguayo *et al.* (2007) in fresh cut cantaloupe and Dhumal (2012) in ready-to-eat fresh pomegranate arils.

Table 72: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of percent carbon dioxide in diced onion

Treatment combinations	Percent carbon dioxide							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	1.18	1.31	2.72	4.98	5.92	7.16	7.49	-
M_1S_2	1.20	1.35	2.76	5.03	5.95	7.21	7.53	-
M_2S_1	10.00	8.23	7.43	7.28	7.08	6.96	5.99	5.49
M_2S_2	10.00	8.29	7.48	7.33	7.19	7.05	6.09	5.57
M_3S_1	10.00	8.20	7.39	7.21	7.03	6.91	5.93	5.43
M_3S_2	10.00	8.27	7.43	7.29	7.13	6.99	6.02	5.52
M_4S_1	10.00	7.79	7.42	7.17	7.08	6.93	5.94	5.61
M_4S_2	10.00	7.85	7.49	7.26	7.15	6.98	6.02	5.67
M_5S_1	5.00	5.18	6.11	5.53	5.06	4.81	4.59	3.62
M_5S_2	5.00	5.22	6.19	5.61	5.11	4.87	4.53	3.69
M_6S_1	0.00	0.02	0.23	0.76	1.10	1.83	2.12	-
M_6S_2	0.00	0.05	0.28	0.81	1.16	1.92	2.17	-
M_7S_1	0.00	1.58	2.11	-	-	-	-	-
M_7S_2	0.00	1.63	2.16	-	-	-	-	-
M_8S_1	20.00	9.58	8.08	7.21	-	-	-	-
M_8S_2	20.00	9.63	8.13	7.29	-	-	-	-
SE ±	0.0037	0.0017	0.0052	0.0051	0.0048	0.0062	0.0048	0.0064
CD at 1%	NS	0.0071	0.0215	0.0214	0.0201	0.0258	0.0201	0.0266
M_1	1.19	1.33	2.74	5.01	5.94	7.19	7.51	-
M_2	10.00	8.26	7.45	7.30	7.14	7.01	6.04	5.53
M_3	10.00	8.23	7.41	7.25	7.08	6.95	5.98	5.47
M_4	10.00	7.82	7.46	7.22	7.11	6.96	5.98	5.64
M_5	5.00	5.20	6.15	5.57	5.09	4.84	4.56	3.66
M_6	0.00	0.04	0.25	0.78	1.13	1.88	2.15	-
M_7	0.00	1.61	2.13	-	-	-	-	-
M_8	20.00	9.61	8.11	7.25	-	-	-	-
SE ±	0.0026	0.0012	0.0037	0.0036	0.0034	0.0044	0.0034	0.0045
CD at 1%	0.0108	0.0050	0.0152	0.0151	0.0142	0.0182	0.0142	0.0188
S_1	7.02	5.24	5.19	5.73	5.54	5.77	5.34	5.04
S_2	7.03	5.29	5.24	5.80	5.62	5.84	5.39	5.11
SE ±	0.0013	0.0006	0.0018	0.0018	0.0017	0.0022	0.0017	0.0023
CD at 1%	NS	0.0025	0.0076	0.0075	0.0071	0.0091	0.0071	0.0094

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

4.4.3.3 Ethylene (ppm)

Data given in Table 73 and 74 and graphically represented in Fig. 51 and 52 regarding changes in headspace concentration of ethylene in MAP packages indicated that ethylene content in the packaged fresh cut onion (whole peeled and diced onion) increased gradually irrespective of storage conditions. The headspace concentration of ethylene in pretreated whole peeled onion and diced onion packages were found to be significantly influenced by MAP treatments, storage environments and their interaction effects throughout the storage period.

Table 73: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of ethylene (ppm) in whole peeled onion

Treatment combinations	Ethylene (ppm)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	6.85	7.55	8.93	9.65	10.91	12.79	13.51	-
M_1S_2	6.89	7.66	9.02	9.73	10.98	12.86	13.62	-
M_2S_1	3.61	5.39	7.21	8.83	9.61	11.08	12.11	13.18
M_2S_2	3.67	5.43	7.28	8.95	9.69	11.19	12.21	13.29
M_3S_1	3.53	5.36	7.15	8.79	9.56	11	12.05	12.98
M_3S_2	3.55	5.39	7.23	8.85	9.65	11.13	12.13	13.07
M_4S_1	3.76	5.56	7.32	8.93	9.72	11.18	12.26	13.41
M_4S_2	3.83	5.64	7.41	9.02	9.81	11.29	12.38	13.49
M_5S_1	3.65	5.48	7.25	8.88	9.66	11.13	12.18	13.36
M_5S_2	3.71	5.52	7.31	8.98	9.76	11.25	12.27	13.47
M_6S_1	6.11	7.45	8.85	9.41	10.83	12.65	13.43	-
M_6S_2	6.16	7.53	8.98	9.49	10.89	12.74	13.49	-
M_7S_1	8.15	11.43	13.84	-	-	-	-	-
M_7S_2	8.23	11.55	13.91	-	-	-	-	-
M_8S_1	7.85	10.86	12.06	13.75	-	-	-	-
M_8S_2	7.91	10.93	12.14	13.82	-	-	-	-
SE ±	0.0087	0.0105	0.0020	0.0051	0.0058	0.0056	0.0067	0.0080
CD at 1%	NS	0.0437	0.0084	0.0211	0.0243	0.0235	0.0279	0.0331
M_1	6.87	7.61	8.98	9.69	10.94	12.83	13.56	-
M_2	3.64	5.41	7.25	8.89	9.65	11.13	12.16	13.23
M_3	3.54	5.38	7.19	8.82	9.60	11.07	12.09	13.02
M_4	3.79	5.60	7.37	8.97	9.76	11.23	12.32	13.45
M_5	3.68	5.50	7.28	8.93	9.71	11.19	12.22	13.42
M_6	6.14	7.49	8.91	9.45	10.86	12.69	13.46	-
M_7	8.19	11.49	13.87	-	-	-	-	-
M_8	7.88	10.90	12.10	13.78	-	-	-	-
SE ±	0.0062	0.0074	0.0014	0.0036	0.0041	0.0040	0.0047	0.0056
CD at 1%	0.0257	0.0309	0.0059	0.0149	0.0172	0.0166	0.0197	0.0234
S_1	5.44	7.39	9.08	9.74	10.05	11.64	12.59	13.23
S_2	5.49	7.46	9.16	9.83	10.13	11.74	12.68	13.33
SE ±	0.0031	0.0037	0.0007	0.0018	0.0021	0.0020	0.0024	0.0028
CD at 1%	0.0129	0.0154	0.0030	0.0075	0.0086	0.0083	0.0099	0.0117

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

As regards MAP treatments under study, the MAP treatment M_3 registered significantly minimum increase in ethylene content in headspace. The whole peeled onion packed in MAP packaging with 0.5% O_2 + 10% CO_2 registered 13.02 ppm ethylene while M_4

(3% O_2 + 10% CO_2) packaging treatment recorded highest ethylene content in headspace (13.45 ppm) at the end of 21^{st} day of storage. In case of diced onion, MAP packagings with 0.5% O_2 + 10% CO_2 registered 14.09 ppm ethylene while M_4 (3% O_2 + 10% CO_2) packaging treatment recorded highest ethylene content in headspace (14.75 ppm) at the end of 21^{st} day of storage.

As the storage period advanced, the per cent ethylene content in headspace in MAP packaged onion (i.e. whole peeled and diced onion) increased gradually in both storage environments. At the end of storage period, whole peeled onion stored at S_1 registered 13.23 ppm ethylene in headspace of MAP packaged onion while S_2 (7 ± 1^0C) registered 13.33 ppm ethylene in headspace of MAP packed fresh cut onions. As regards the diced onion, the packagings stored at 0 ± 1^0C (S_1) temperature recorded minimum ethylene content (14.40 ppm) while S_2 recorded 14.52 ppm ethylene in headspace of MAP packages after 21 days of storage.

As regards interaction effects of MAP treatments and storage environments under study, the gradual increase in headspace ethylene concentration was recorded by pretreated fresh cut onion i.e. (whole peeled and diced onion). As regards, whole peeled onion M_3S_1 combination recorded minimum ethylene (13.48 ppm) while M_4S_2 recorded maximum ethylene content (13.79 ppm). The diced onion packaged with 0.5% O_2 + 10% CO_2 and stored at 0 ± 1^0C (M_3S_1) recorded 13.55 ppm ethylene while M_4S_2 treatment combination recorded maximum ethylene content (13.81 ppm).

The gradual increase in the ethylene concentration in the headspace of packages was recorded irrespective of all the treatments under study. This accelerated rate of ethylene concentration could be attributed to the cuts and impacts which increased the surface area, increased rate of respiration and accelerated deterioration as reported by Hong and Kim (2004) in onion and Berno *et al.* (2014) in fresh cut onion. The ethylene biosynthesis is relatively very less in various MAP packagings. This might be due to the occurrence of climacteric peak of ethylene production in early hours after minimal processing and the can be correlated with the change in respiration rate as reported by Liu and Li (2006) in sliced onions, Allende *et al.* (2004) in minimally processed baby spinach, Kim *et al.* (2005) and Mattos *et al.* (2013) in minimally processed lettuce. The low oxygen concentration in package could be the reason for gradual increase in ethylene concentration over the storage period as reported by Patil (2016), Kaur (2016), Lopez-Galvez *et al.* (1997), Cameron *et al.* (1995) and Smyth *et al.* (1998) in minimally processed lettuce. The rate of ethylene accumulation in the headspace of package was slower in the whole peeled onion treated with hexanal solution. These results implied that hexanal vapors were effective to delay the senescence due to PLD inhibitory action leading to maintaining freshness of the product and reduction in ethylene production. The exogenous application of hexanal slows down the lipogeneses in the skin which could have assisted in delayed softening process and slowing down ethylene evolution. The data closely coincided with those reported by

Sharma *et al.* 2010 in sweet cherry, Ashwini *et al.* (2018), Golding *et al.*, 1998, 1999; Pathak *et al.*, 2003; Pelayo *et al.*, 2003; Lohani *et al.*, 2004 in banana, Krammes *et al.* (2003), Mir *et al.* (2004) and Opiyo and Ying (2005) for tomato. Ethylene production in fresh cut onion with passive MAP packagings was higher than for those kept in low O_2 or elevated CO_2. The results are in conformity with Agar *et al.*, 1999 in fresh cut kiwi fruit. The rate of ethylene accumulation was relatively slow in all the MAP packages and this might be attributed to the low storage temperature. The similar results were reported by Blanchard *et al.* (1996) in yellow diced onion, Dhumal (2012) in ready to eat pomegranate arils, Patil (2016) and Kaur (2016) in fresh cut lettuce.

Table 74: Effect of modified atmosphere packaging and storage temperatures on headspace concentration of ethylene (ppm) in diced onion

Treatment combinations	Ethylene (ppm)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	7.05	7.75	9.18	10.47	11.15	13.10	14.83	-
M_1S_2	7.13	7.82	9.25	10.56	11.24	13.18	14.91	-
M_2S_1	3.96	5.75	7.59	9.05	9.91	11.18	12.46	14.33
M_2S_2	4.07	5.82	7.65	9.17	10.03	11.29	12.58	14.45
M_3S_1	3.88	5.63	7.46	8.96	9.88	11.08	12.36	14.02
M_3S_2	3.94	5.71	7.53	9.08	9.97	11.17	12.43	14.15
M_4S_1	4.18	5.91	7.71	9.28	10.11	11.51	12.68	14.71
M_4S_2	4.24	5.98	7.83	9.36	10.23	11.67	12.75	14.79
M_5S_1	4.10	5.80	7.65	9.12	10.07	11.35	12.53	14.55
M_5S_2	4.17	5.89	7.72	9.23	10.18	11.47	12.60	14.68
M_6S_1	6.57	7.60	9.11	10.35	11.02	12.96	14.81	-
M_6S_2	6.65	7.71	9.19	10.42	11.14	13.08	14.88	-
M_7S_1	9.36	12.69	15.11	-	-	-	-	-
M_7S_2	9.47	12.78	15.23	-	-	-	-	-
M_8S_1	9.18	11.38	13.12	14.97	-	-	-	-
M_8S_2	9.27	11.49	13.21	15.08	-	-	-	-
SE ±	0.0041	0.0012	0.0029	0.0060	0.0048	0.0074	0.0068	0.0052
CD at 1%	0.0170	0.0052	0.0120	0.0252	0.0201	0.0309	0.0283	0.0215
M_1	7.09	7.79	9.22	10.52	11.20	13.14	14.87	-
M_2	4.01	5.79	7.62	9.11	9.97	11.24	12.52	14.39
M_3	3.91	5.67	7.50	9.02	9.93	11.13	12.40	14.09
M_4	4.21	5.94	7.77	9.32	10.17	11.59	12.71	14.75
M_5	4.13	5.85	7.68	9.18	10.13	11.41	12.57	14.62
M_6	6.61	7.66	9.15	10.39	11.08	13.02	14.85	-
M_7	9.41	12.74	15.17	-	-	-	-	-
M_8	9.22	11.44	13.17	15.03	-	-	-	-
SE ±	0.0029	0.0009	0.0020	0.0043	0.0034	0.0052	0.0048	0.0037
CD at 1%	0.0120	0.0037	0.0085	0.0178	0.0142	0.0219	0.0200	0.0152
S_1	6.03	7.81	9.62	10.32	10.36	11.86	13.28	14.40
S_2	6.12	7.90	9.70	10.41	10.47	11.98	13.36	14.52
SE ±	0.0014	0.0004	0.0010	0.0021	0.0017	0.0026	0.0024	0.0018
CD at 1%	0.0060	0.0018	0.0043	0.0089	0.0071	0.0109	0.0100	0.0076

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

4.4.4 Microbial limit tests

4.4.4.1 Total aerobic count (log cfu g^{-1})

The results of total microbial count in fresh cut onion (i.e. whole peeled and diced onion) are summarized in Table 75 and 76. As regards MAP treatments, storage environment and their interaction effects on whole peeled and diced onion, the significant results were observed throughout the storage period. The total aerobic count in pretreated whole peeled, as well as diced onions, was increased over the initial irrespective of MAP treatments and storage environments under study.

Table 75: Effect of modified atmosphere packaging and storage temperatures on total microbial count (log cfu g^{-1}) of whole peeled onion

Treatment combinations	Total microbial count (log cfu g^{-1})		
	Storage periods (days)		
	Initial before treatment	Initial after treatment	Final
M_1S_1	6.68	3.59	8.50
M_1S_2			8.64
M_2S_1			5.88
M_2S_2			6.02
M_3S_1			5.39
M_3S_2			5.60
M_4S_1			6.77
M_4S_2			6.86
M_5S_1			6.11
M_5S_2			6.34
M_6S_1			7.75
M_6S_2			7.90
M_7S_1			9.78
M_7S_2			10.10
M_8S_1			9.85
M_8S_2			9.97
SE ±			0.0252
CD at 1%			0.1051
M_1	6.68	3.59	8.57
M_2			5.95
M_3			5.50
M_4			6.81
M_5			6.22
M_6			7.82
M_7			9.94
M_8			9.91
SE ±			0.0178
CD at 1%			0.0744
S_1	6.68	3.59	7.50
S_2			7.68
SE ±			0.0089
CD at 1%			0.0372

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Among all the MAP packagings, pretreated fresh cut onions viz., whole peeled and diced onion packaged in M_3 (Combination of 0.5% O_2 + 10% CO_2) registered significantly minimum total aerobic count (5.50 and 6.49 log CFU g^{-1}) even after 21 days of storage respectively. While MAP with super atmospheric oxygen i.e. 100% oxygen recorded maximum total microbial count (9.94 and 11.99 log cfu g^{-1}) after 6 days of storage in pretreated whole peeled and diced onion respectively.

As regards storage environments under study, the lowest microbial count was observed in S_1 (0 ± 1^0C) storage. The whole peeled onion stored at S_1 recorded 7.50 log cfu g^{-1} at the end of 21st day of storage while same treatment registered 8.78 log cfu g^{-1} total microbial count in the diced onion.

Table 76: Effect of modified atmosphere packaging and storage temperatures on total microbial count (log cfu g^{-1}) of diced onion

Treatment combinations	Total microbial count (log cfu g^{-1})		
	Storage periods (days)		
	Initial before treatment	Initial after treatment	Final
M_1S_1	6.68	3.89	10.13
M_1S_2			10.25
M_2S_1			6.79
M_2S_2			6.96
M_3S_1			6.41
M_3S_2			6.58
M_4S_1			7.58
M_4S_2			7.80
M_5S_1			7.22
M_5S_2			7.35
M_6S_1			9.06
M_6S_2			9.29
M_7S_1			11.94
M_7S_2			12.04
M_8S_1			11.14
M_8S_2			11.30
SE ±			0.0154
CD at 1%			0.0641
M_1	6.68	3.89	10.19
M_2			6.87
M_3			6.49
M_4			7.69
M_5			7.29
M_6			9.18
M_7			11.99
M_8			11.22
SE ±			0.0109
CD at 1%			0.0453
S_1	6.68	3.89	8.78
S_2			8.94
SE ±			0.0054
CD at 1%			0.0227

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

As regards treatment combination of MAP treatments and storage environments, increase in total microbial count over the initial count was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered minimum total microbial count of 5.39 log cfu g^{-1} and 6.41 log cfu g^{-1} in pretreated whole peeled and diced onion after 21 days of storage, respectively.

In the present study, the initial total aerobic count of untreated onion was reduced drastically after the pretreatment with 1 per cent hexanal. The antifungal and antimicrobial effects of hexanal are reported by Park *et al.* (1998) in onions and garlic, Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears. The initial microbial load was increased at the end of the storage period. The similar results were reported by Baskaran *et al.* (2015) in minimally processed onion, Nguyen-The (1991) in ready to use vegetables. The microbial population was slowed down in the pretreated whole peeled and diced onion under modified atmosphere as compared to air. The super atmospheric oxygen also resulted in maximum microbial count. This might be attributed to the rapid reduction of the O_2 content in the package resulting fast decay and browning as reported by Day (1989) in diced onion and Blanchard *et al.* (1996) in diced yellow onions. The minimum microflora was recorded in the carbon dioxide enriched packages. This could be due to the fungistatic effect of CO_2 and extension of lag phase or the germination time during the log phase, particularly in the absence of O_2 by delaying respiration. The results are in conformity with those obtained by Clarks and Takacs (1980), Davidson *et al.* (1983), Garg *et al.* (1990) in diced onion, Blanchard *et al.* (1996) in yellow diced onion, Carlin *et al.* (1990) in shredded carrot, Patil (2016), Kaur (2016) in fresh cut lettuce and Dhumal (2012) in ready to eat pomegranate arils. The inhibition or slow microbial growth on fresh cut onions was probably due to the presence of the antifungal and antimicrobial thiopropanal-*S*-oxide as well as low temperature storage as reported by Blanchard *et al.* (1996) in yellow diced onion.

4.4.5 Sensorial Analysis (Visible Quality Markers)

4.4.5.1 Colour, appearance and flavour (In package and out package)

With the advancement of storage period, visual and sensory markers like colour (Table 77 and 78), appearance (Table 79 and 80) and flavour (Table 81 and 82) of pretreated onions i.e. whole peeled and diced onion showed decreasing trend in score irrespective of MAP treatments and storage environments.

Among the various MAP treatments and storage environments, M_3S_1 (MAP containing 0.5% O_2 + 10% CO_2) had maximum score for colour, appearance and flavour. The same treatment recorded the highest score for colour (6.08 and 6.06), flavour (6.08 and 6.05) and appearance (6.08 and 6.05) in case of whole peeled and diced onions respectively. However, the lowest score for sensorial parameters like colour (6.02 and 6.00), flavour (6.03 and 6.00) and appearance (6.03 and 6.00) was recorded by M_4S_2 at the end of the storage period i.e. after 21st days of storage respectively. The treatment combinations M_7S_1 and M_7S_2 registered lowest score for colour, appearance and flavour in both the types of cut at the end of 6th day of storage.

Table 77: Effect of modified atmosphere packaging and storage temperatures on colour (score) of whole peeled onion

Treatment combinations	Colour (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.42	7.80	7.40	6.80	6.30	6.02	-
M_1S_2	9.00	8.33	7.60	7.20	6.60	6.20	6.00	-
M_2S_1	9.00	8.85	8.50	7.70	7.50	6.60	6.29	6.08
M_2S_2	9.00	8.83	8.40	7.60	7.30	6.40	6.26	6.05
M_3S_1	9.00	8.86	8.50	7.90	7.50	6.70	6.30	6.08
M_3S_2	9.00	8.78	8.50	7.90	7.30	6.60	6.28	6.07
M_4S_1	9.00	8.65	8.30	7.60	7.40	6.50	6.20	6.04
M_4S_2	9.00	8.56	8.10	7.60	7.00	6.30	6.18	6.02
M_5S_1	9.00	8.76	8.40	7.80	7.40	6.50	6.26	6.05
M_5S_2	9.00	8.72	8.30	7.70	7.10	6.40	6.23	6.03
M_6S_1	9.00	8.53	8.10	7.50	6.90	6.30	6.05	-
M_6S_2	9.00	8.48	8.00	7.30	6.70	6.17	6.03	-
M_7S_1	9.00	8.04	5.73	-	-	-	-	-
M_7S_2	9.00	7.72	5.67	-	-	-	-	-
M_8S_1	9.00	8.54	6.90	5.80	-	-	-	-
M_8S_2	9.00	8.43	6.50	5.72	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Table 78: Effect of modified atmosphere packaging and storage temperatures on colour (score) of diced onion

Treatment combinations	Colour (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.40	7.76	7.35	6.76	6.27	6.01	-
M_1S_2	9.00	8.30	7.57	7.16	6.54	6.16	6.00	-
M_2S_1	9.00	8.80	8.46	7.63	7.48	6.57	6.24	6.05
M_2S_2	9.00	8.76	8.37	7.59	7.25	6.34	6.20	6.03
M_3S_1	9.00	8.82	8.43	7.85	7.44	6.64	6.24	6.06
M_3S_2	9.00	8.75	8.40	7.82	7.23	6.55	6.22	6.04
M_4S_1	9.00	8.60	8.25	7.54	7.35	6.43	6.13	6.01
M_4S_2	9.00	8.51	8.07	7.51	6.96	6.24	6.10	6.00
M_5S_1	9.00	8.73	8.31	7.76	7.36	6.44	6.21	6.03
M_5S_2	9.00	8.68	8.24	7.64	7.02	6.34	6.15	6.00
M_6S_1	9.00	8.47	8.00	7.45	6.81	6.25	6.03	-
M_6S_2	9.00	8.45	7.95	7.24	6.63	6.15	6.01	-
M_7S_1	9.00	7.95	5.56	-	-	-	-	-
M_7S_2	9.00	7.69	5.44	-	-	-	-	-
M_8S_1	9.00	8.50	6.85	5.76	-	-	-	-
M_8S_2	9.00	8.39	6.46	5.65	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

The decrease in colour, flavour and appearance was noticed in all the MAP treatment stored at different storage temperatures. The visual and sensorial qualities were better in low temperature stored fresh cut onions. The results are in conformity with Baskaran *et al.* (2015) in onions, Patil (2016) and Kaur (2016) in fresh cut lettuce. The deviation in the sensorial and visual quality markers of pretreated fresh cut onions may be attributed to the minimal processing, loss of surface water, soft textured appearance, yellowing, loss of translucence and loss of pyruvic acid as reported by Blachard *et al.* (1996) in yellow diced onion and Baskaran *et al.* (2015) in minimally processed onions and Liu and Li (2006) in fresh cut onion. High CO_2 in MAP packagings coupled with low temperature might have caused reduced respiration rates of fresh cut onion, slowed down metabolic activities and microbial growth, creation of anaerobic conditions and off-flavour development in fresh cut onion. Thus, resulted in maximum score for

Table 79: Effect of modified atmosphere packaging and storage temperatures on appearance (score) of whole peeled onion

Treatment combinations	Appearance (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.42	7.82	7.30	6.80	6.30	6.03	-
M_1S_2	9.00	8.33	7.63	7.20	6.60	6.20	6.02	-
M_2S_1	9.00	8.87	8.54	7.60	7.50	6.60	6.25	6.10
M_2S_2	9.00	8.83	8.47	7.40	7.30	6.40	6.16	6.03
M_3S_1	9.00	8.84	8.54	7.70	7.50	6.70	6.27	6.08
M_3S_2	9.00	8.72	8.42	7.50	7.30	6.60	6.23	6.05
M_4S_1	9.00	8.66	8.36	7.50	7.40	6.50	6.20	6.05
M_4S_2	9.00	8.57	8.17	7.40	7.25	6.30	6.12	6.03
M_5S_1	9.00	8.73	8.41	7.50	7.40	6.50	6.18	6.06
M_5S_2	9.00	8.71	8.33	7.30	7.10	6.40	6.15	6.02
M_6S_1	9.00	8.56	8.12	7.30	6.90	6.30	6.03	-
M_6S_2	9.00	8.52	8.06	7.17	6.70	6.10	6.00	-
M_7S_1	9.00	8.04	5.73	-	-	-	-	-
M_7S_2	9.00	7.95	5.65	-	-	-	-	-
M_8S_1	9.00	8.56	6.96	5.75	-	-	-	-
M_8S_2	9.00	8.43	6.53	5.69	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Table 80: Effect of modified atmosphere packaging and storage temperatures on appearance (score) of diced onion

Treatment combinations	Appearance (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.38	7.78	7.24	6.73	6.23	6.01	-
M_1S_2	9.00	8.27	7.57	7.16	6.55	6.17	6.00	-
M_2S_1	9.00	8.81	8.48	7.53	7.41	6.49	6.20	6.07
M_2S_2	9.00	8.78	8.41	7.36	7.24	6.31	6.13	6.02
M_3S_1	9.00	8.79	8.48	7.62	7.44	6.66	6.25	6.05
M_3S_2	9.00	8.68	8.39	7.45	7.23	6.52	6.21	6.03
M_4S_1	9.00	8.60	8.31	7.44	7.32	6.45	6.17	6.03
M_4S_2	9.00	8.52	8.14	7.31	7.20	6.35	6.10	6.00
M_5S_1	9.00	8.67	8.36	7.43	7.34	6.41	6.14	6.05
M_5S_2	9.00	8.64	8.26	7.24	7.02	6.33	6.10	6.00
M_6S_1	9.00	8.48	8.05	7.24	6.81	6.20	6.02	-
M_6S_2	9.00	8.41	8.00	7.10	6.63	6.05	6.00	-
M_7S_1	9.00	7.98	5.65	-	-	-	-	-
M_7S_2	9.00	7.93	5.55	-	-	-	-	-
M_8S_1	9.00	8.50	6.87	5.62	-	-	-	-
M_8S_2	9.00	8.37	6.48	5.58	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

sensorial attributes. The similar results were also observed by Hong *et al.* (2000) in minimally processed green onions, Carolina *et al.* (2007) in onions cv. Superex, Sanchez-Moreno *et al.* (2004) and Baskaran *et al.* (2015) in onions, Falah *et al.* (2015), Silveira *et al.* (2011), Silveira *et al.* (2010), Aguayo *et al.* (2003) in fresh cut muskmelon, Ergun and Ergun (2009) in pomegranate arils cv. Hicaznar and Dhumal (2012) in ready to eat fresh pomegranate arils.

Table 81: Effect of modified atmosphere packaging and storage temperatures on flavour (score) of whole peeled onion

Treatment combinations	Flavour (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.42	7.82	7.30	6.80	6.30	6.03	-
M_1S_2	9.00	8.33	7.63	7.20	6.60	6.20	6.02	-
M_2S_1	9.00	8.87	8.54	7.63	7.51	6.58	6.25	6.07
M_2S_2	9.00	8.84	8.47	7.50	7.32	6.40	6.16	6.03
M_3S_1	9.00	8.84	8.54	7.72	7.53	6.72	6.27	6.08
M_3S_2	9.00	8.72	8.52	7.56	7.36	6.59	6.23	6.05
M_4S_1	9.00	8.66	8.36	7.49	7.39	6.52	6.20	6.05
M_4S_2	9.00	8.57	8.17	7.38	7.21	6.36	6.12	6.03
M_5S_1	9.00	8.73	8.41	7.52	7.38	6.51	6.18	6.06
M_5S_2	9.00	8.69	8.33	7.43	7.29	6.40	6.15	6.02
M_6S_1	9.00	8.56	8.12	7.30	6.90	6.30	6.05	-
M_6S_2	9.00	8.52	8.06	7.17	6.70	6.20	6.03	-
M_7S_1	9.00	8.04	5.58	-	-	-	-	-
M_7S_2	9.00	7.78	5.45	-	-	-	-	-
M_8S_1	9.00	8.56	6.96	5.62	-	-	-	-
M_8S_2	9.00	8.43	6.53	5.48	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Table 82: Effect of modified atmosphere packaging and storage temperatures on flavour (score) of diced onion

Treatment combinations	Flavour (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.37	7.76	7.25	6.73	6.25	6.02	-
M_1S_2	9.00	8.27	7.59	7.15	6.52	6.14	6.00	-
M_2S_1	9.00	8.82	8.48	7.56	7.48	6.46	6.20	6.04
M_2S_2	9.00	8.80	8.40	7.43	7.27	6.35	6.11	6.02
M_3S_1	9.00	8.78	8.51	7.62	7.48	6.67	6.23	6.05
M_3S_2	9.00	8.70	8.47	7.51	7.31	6.51	6.17	6.03
M_4S_1	9.00	8.65	8.32	7.43	7.34	6.45	6.15	6.02
M_4S_2	9.00	8.53	8.15	7.32	7.17	6.29	6.08	6.00
M_5S_1	9.00	8.68	8.34	7.45	7.35	6.43	6.12	6.03
M_5S_2	9.00	8.65	8.29	7.38	7.26	6.34	6.08	6.00
M_6S_1	9.00	8.52	8.08	7.25	6.84	6.24	6.04	-
M_6S_2	9.00	8.47	8.02	7.12	6.64	6.13	6.01	-
M_7S_1	9.00	8.02	5.52	-	-	-	-	-
M_7S_2	9.00	7.75	5.39	-	-	-	-	-
M_8S_1	9.00	8.53	6.92	5.56	-	-	-	-
M_8S_2	9.00	8.40	6.48	5.43	-	-	-	-

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

4.4.5.2 Overall Acceptability

The results of overall acceptability (score) of pretreated fresh cut onion (i.e. whole peeled and diced onion) and packaged in different MAP conditions and stored at different storage temperatures are summarized in Table 83 and 84 and graphically represented in Fig. 53 and 54. The significant effects of MAP treatments, storage environment and their interactions were recorded throughout the storage period in both cut types i.e. whole peeled and diced onion. The overall acceptability in respect of fresh cut onion i.e. whole peeled and diced onion decreased over the period of time irrespective of MAP treatments and storage environments under study.

Table 83: Effect of modified atmosphere packaging and storage temperatures on overall acceptability (score) of whole peeled onion

Treatment combinations	Overall acceptability (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.42	7.81	7.33	6.8	6.3	6.03	-
M_1S_2		8.33	7.62	7.20	6.6	6.2	6.01	-
M_2S_1		8.86	8.53	7.64	7.5	6.59	6.26	6.08
M_2S_2		8.83	8.45	7.50	7.31	6.4	6.19	6.04
M_3S_1		8.85	8.53	7.77	7.51	6.71	6.28	6.08
M_3S_2		8.74	8.48	7.65	7.32	6.6	6.25	6.06
M_4S_1		8.66	8.34	7.53	7.4	6.51	6.2	6.04
M_4S_2		8.57	8.15	7.46	7.15	6.32	6.14	6.01
M_5S_1		8.74	8.41	7.61	7.39	6.5	6.21	6.06
M_5S_2		8.71	8.32	7.48	7.16	6.4	6.18	6.02
M_6S_1		8.55	8.11	7.37	6.9	6.3	6.04	-
M_6S_2		8.51	8.04	7.21	6.7	6.16	6.02	-
M_7S_1		8.04	5.68	-	-	-	-	-
M_7S_2		7.82	5.59	-	-	-	-	-
M_8S_1		8.55	6.94	5.72	-	-	-	-
M_8S_2		8.43	6.52	5.63	-	-	-	-
SE ±		0.0100	0.0112	0.0046	0.0089	0.0089	0.0081	0.0056
CD at 1%		0.0417	0.0467	0.0194	0.0369	0.0369	0.0336	0.0235
M_1	9.00	8.38	7.72	7.27	6.7	6.25	6.02	-
M_2		8.85	8.49	7.57	7.41	6.5	6.23	6.06
M_3		8.8	8.50	7.71	7.42	6.66	6.27	6.07
M_4		8.62	8.24	7.49	7.28	6.42	6.17	6.02
M_5		8.73	8.37	7.54	7.28	6.45	6.2	6.04
M_6		8.53	8.07	7.29	6.8	6.23	6.03	-
M_7		7.93	5.63	-	-	-	-	-
M_8		8.49	6.73	5.68	-	-	-	-
SE ±		0.0071	0.0079	0.0033	0.0063	0.0063	0.0057	0.0040
CD at 1%		0.0295	0.0330	0.0137	0.0261	0.0261	0.0238	0.0166
S_1	9.00	8.58	7.79	7.28	7.25	6.49	6.17	6.06
S_2		8.49	7.64	7.16	7.04	6.35	6.13	6.03
SE ±		0.0035	0.0040	0.0016	0.0031	0.0031	0.0029	0.0020
CD at 1%		0.0147	0.0165	0.0068	0.0130	0.0130	0.0119	0.0083

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

Among all the MAP packagings, M_3 (0.5% O_2 + 10% CO_2) retained significantly maximum score for overall acceptability of 6.07 and 6.04 after 21 days of storage in pretreated whole peeled and diced onion, respectively. However, M_4 MAP packagings (3% O_2 + 10% CO_2)

registered significantly minimum score for overall acceptability (6.02 and 6.01) after 21 days of storage in pretreated whole peeled and diced onion respectively. The MAP treatment M_7 (100 % O_2) was terminated on the 6th day of storage as it recorded 5.63 and 5.52 scores for overall acceptability in respect of whole peeled onion and diced onion respectively.

As regards storage environments under study, the maximum score for overall acceptability was observed in S_1 (0 ± 1^0C) storage. The whole peeled onion stored at S_1 recorded score 6.06 at the end of 21st day of storage while same treatment registered score 6.04 in the diced onion. The whole peeled onions stored at S_2 recorded score 6.03 at the end of 21st day of storage while same treatment registered score 6.01 in the diced onion.

Table 84: Effect of modified atmosphere packaging and storage temperatures on overall acceptability (score) of diced onion

Treatment combinations	Overall acceptability (score)							
	Storage period (days)							
	0	3	6	9	12	15	18	21
M_1S_1	9.00	8.38	7.77	7.28	6.74	6.25	6.01	-
M_1S_2		8.28	7.58	7.16	6.54	6.16	6.00	-
M_2S_1		8.81	8.47	7.57	7.46	6.51	6.21	6.05
M_2S_2		8.78	8.39	7.46	7.25	6.33	6.15	6.02
M_3S_1		8.80	8.47	7.70	7.45	6.66	6.24	6.05
M_3S_2		8.71	8.42	7.59	7.26	6.53	6.20	6.03
M_4S_1		8.62	8.29	7.47	7.34	6.44	6.15	6.02
M_4S_2		8.52	8.12	7.38	7.11	6.29	6.09	6.00
M_5S_1		8.69	8.34	7.55	7.35	6.43	6.16	6.04
M_5S_2		8.66	8.26	7.42	7.10	6.34	6.11	6.00
M_6S_1		8.49	8.04	7.31	6.82	6.23	6.03	-
M_6S_2		8.44	7.99	7.15	6.63	6.11	6.01	-
M_7S_1		7.98	5.58	-	-	-	-	-
M_7S_2		7.79	5.46	-	-	-	-	-
M_8S_1		8.51	6.88	5.65	-	-	-	-
M_8S_2		8.39	6.47	5.55	-	-	-	-
SE ±		0.0100	0.0072	0.0085	0.0089	0.0089	0.0063	0.0047
CD at 1%		0.0417	0.0302	0.0353	0.0373	0.0369	0.0262	0.0194
M_1	9.00	8.33	7.67	7.22	6.64	6.21	6.00	-
M_2		8.80	8.43	7.52	7.36	6.42	6.18	6.03
M_3		8.76	8.44	7.64	7.36	6.60	6.22	6.04
M_4		8.57	8.20	7.42	7.23	6.37	6.12	6.01
M_5		8.68	8.30	7.48	7.23	6.39	6.14	6.02
M_6		8.47	8.01	7.23	6.73	6.17	6.02	-
M_7		7.89	5.52	-	-	-	-	-
M_8		8.45	6.68	5.60	-	-	-	-
SE ±		0.0071	0.0051	0.0060	0.0063	0.0063	0.0044	0.0033
CD at 1%		0.0295	0.0213	0.0249	0.0264	0.0261	0.0185	0.0137
S_1	9.00	8.54	7.73	7.22	7.19	6.42	6.13	6.04
S_2		8.45	7.58	7.10	6.98	6.29	6.09	6.01
SE ±		0.0035	0.0026	0.0030	0.0032	0.0031	0.0022	0.0016
CD at 1%		0.0147	0.0107	0.0125	0.0132	0.0130	0.0093	0.0069

'-' indicates termination of treatments

MAP treatments

M_1= Air/passive MAP with no vacuum
M_2= Combination of 2% O_2 + 10% CO_2
M_3= Combination of 0.5% O_2 + 10% CO_2
M_4= Combination of 3% O_2 + 10% CO_2
M_5= Combination of 0.5% O_2 + 5% CO_2
M_6= 100% N_2 flushing
M_7= 100% O_2 flushing
M_8= Combination of 80% O_2 + 20% CO_2

Storage temperatures

S_1= $0^0C \pm 1^0C$
S_2= $7^0C \pm 1^0C$

As regards treatment combinations of MAP treatments and storage environments relatively slow but constant decrease in overall acceptability was recorded in both the cut types with advancement of storage period. The treatment combination M_3S_1 registered maximum overall acceptability score of 6.08 and 6.05 in pretreated whole peeled and diced onion after 21 days of storage respectively.

The ratings of overall acceptability may be attributed to decreased O_2 content and increase in CO_2 content in the packet as reported by Blanchard *et al.*, 1996 in onions. The yellowing, loss of translucence, microbial development, changes in physico-chemical composition, change in headspace gas concentration, decrease in anthocyanin content as well as pyruvic acid content in the fresh cut onions over the period of storage time might have contributed to the decrease in overall acceptability of fresh cut onions. The results are in conformity with those reported by Blanchard *et al.* (1996) in yellow diced onions, Baskaran *et al.* (2015) in minimally processed onions, Berno *et al.* (2014), Piercy *et al.* (2012) in fresh cut onions, Liu and Li (2006) in sliced onion, Howard *et al.* (1994) in diced onions, Escalano *et al.* (2007), Hamza *et al.* (2007) and Barriga *et al.* (2006) in minimally processed lettuce at cold storage conditions. The shelf life and acceptability of diced onion stored in MAP were limited due to development of off-odours, pink discolouration and proliferation of spoilage organisms. The similar results were reported by Howard *et al.* (1994) and Day (1989) in onions. In the present investigation, low O_2 combined with high CO_2 and low temperature provided better sensory quality. The similar results were reported by Carolina *et al.* (2007) in Onions cv. Superex and Kale (2017) in muskmelon. The low storage temperature and pretreatment with 1 per cent hexanal could be the other reason for retaining overall acceptability of fresh cut produce as reported by Sharma *et al.* (2010) in sweet cherry, Anusuya *et al.* (2016) in mango, Gardini *et al.* (1997) and Sholberg and Randall (2007) in apples and pears.

4.5 Economics of Packaged Fresh Cut Onion

The cost of production of minimally processed red onion is presented in Table 85, 86 and 87. It was observed that the cost of production varied with postharvest treatments in case of different types of cut and with packaging while in case of MAP packagings it was varied with flushing with gases.

Per packet cost of production of minimally processed onion ranged from ₹ 4.10 to ₹ 4.45. The treatment T_3 (1% hexanal EFF-nano emulsion) which was found superior in terms of physicochemical parameters, sensory attributes and microbial limit tests gave cost of production of ₹ 4.20 per bag (Table 85). As regards the packaging materials used, per bag cost of production varied from ₹ 5.57 to ₹ 45.17. The best packaging treatment, P_4 recorded maximum cost of production (₹ 45.17). The costs are high due to high cost of freshpaper and active packaging bags. This cost may be reduced if the process is carried out on commercial basis. Among the MAP treatments, per bag cost of production varied from ₹ 5.57 to ₹ 6.08 (Table 87).

These costs are for laboratory (small) scale processing of fresh cut onions. It may still be reduced during mechanization of process for mass production.

Table 85: Economics of fresh cut red onions

Particulars	Rate (₹)	T_1		T2		T3		T4		T5		T6		T7		T8		T9	
		Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)
Onion	10/ Kg	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65	6.5 Kg	65
Polypropylene bags (200 guage)	147/ 500 bags	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4	32 bags	9.4
Distilled water	60/L	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30
Sodium hypochlorite	840/ 5L	-	-	20 ml	3.36	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Enhanced Freshness Formulation	750/ L	-	-	-	-	5 ml	3.75	10 ml	7.5	-	-	-	-	-	-	-	-	-	-
Hydrogen peroxide	60/ L	-	-	-	-	-	-	-	-	30 ml	1.8			-	-	-	-	-	-
Sophorolipid	390/ 200 ml	-	-	-	-	-	-	-	-	-	-	5 ml	9.75	-	-	-	-	-	-
Calcium lactate	1372/ Kg	-	-	-	-	-	-	-	-	-	-	-	-	5 g	6.86	-	-	-	-
Nisin	1250/ 100g	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.025 g	0.32	-	-
Citric acid	963/ 500g	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5 g	9.63	-	-
UV-C radiation	0.20/ bags	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	32 bags	6.4
Muslin cloth	15/mt	1 mt	15	1 mt	15	1 mt	15	1 mt	15	1 mt	15	1 mt	15	1 mt	15	1 mt	15	1 mt	15
Total cost (A)	-	-	119.4	-	122.8	-	122.2	-	126.9	-	121.2	-	129.2	-	126.3	-	129.4	-	125.8
Labour, electricity, fuel, rent etc. (10% of total cost)	-	-	11.94	-	12.28	-	12.22	-	12.69	-	12.12	-	12.92	-	12.63	-	12.94	-	12.58
Total cost	For 32 bags		131.3		135.0		134.4		139.6		133.3		142.1		138.9		142.3		138.4
Cost of production /bag	**-**	**-**	**4.10**	-	**4.22**	-	**4.20**	-	**4.36**	-	**4.17**	-	**4.44**	-	**4.34**	-	**4.45**	-	**4.32**

Table 86: Economics of packaged fresh cut red onions

Particulars	Rate (₹)	P1		P2		P3		P4	
		Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)
Onion	10/Kg	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35
Distilled water	60/L	500 ml	30	500 ml	30	500 ml	30	500 ml	30
Enhanced Freshness Formulation	750/ L	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75
Muslin cloth	15/mt	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5
Polypropylene bags (200 guage)	147/ 500 bags	16 bags	4.704	-	-	-	-	16 bags	4.704
Active packaged lacquered with nanosilver	499/ 20 bags	-	-	16 bags	399.2	-	-	-	-
Polyethylene terephthalate plastic punnets	2/ punnet	-	-	-	-	16 punnets	32	-	-
Fresh paper	1152/ 8 sheets	-	-	-	-	-	-	4 sheets	576
Total cost (A)	-	-	80.95	-	475.45	-	108.25	-	657.0
Labour, electricity, fuel, rent etc. (10% of total cost)	-	-	8.10	-	47.55	-	10.83	-	65.70
Total cost	For 16 bags or punnets		89.05	-	523.00	-	119.08	-	722.6
Cost of production /bag	**-**	**-**	5.57	**-**	**32.69***	**-**	7.44	**-**	**45.17***

*The costs are high due to high cost of freshpaper and active packaging bags. This cost may be reduced if the process is carried out on commercial basis.

Table 87: Economics of MAP packaged fresh cut red onions

Particulars	Rate (₹)	M1		M2		M3		M4		M5		M6		M7		M8	
		Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)	Quantity	Amount (₹)
Onion	10/ Kg	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35	3.5 Kg	35
Distilled water	60/L	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30	500 ml	30
Enhanced Freshness Formulation	750/ L	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75	5 ml	3.75
Polypropylene bags (200 guage)	147/ 500 bags	16 bags	4.704	16 bags	4.704	16 bags	4.704	16 bags	4.704	16 bags	4.704	16 bags	4.704	16 bags	4.704	16 bags	4.704
Muslin cloth	15/ mt	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5	0.5 mt	7.5
MAP gases (O_2 gas flushing)	0.10/ bag	-	-	16 bags	1.6	16 bags	1.6	16 bags	1.6	16 bags	1.6	-	-	18 bags	3.6	19 bags	4.6
MAP gases (CO_2 gas flushing)	0.18/ bag	-	-	16 bags	2.88	16 bags	2.88	16 bags	2.88	16 bags	2.88	-	-	-	-	16 bags	2.88
MAP gases (N_2 gas flushing)	0.12/ bag	-	-	16 bags	1.92	16 bags	1.92	16 bags	1.92	16 bags	1.92	16 bags	1.92	-	-	-	-
Total cost (A)	-	-	80.95		87.35		87.35		87.35	-	87.35	-	82.87	-	84.55	-	88.43
Labour, electricity, fuel, rent etc. (10% of total cost)	-	-	8.10	-	8.74	-	8.74	-	8.74	-	8.74	-	8.29	-	8.46	-	8.84
Total cost	For 16 bags		89.05	-	96.09	-	96.09	-	96.09	-	96.09	-	91.16	-	93.01	-	97.28
Cost of production/ bag	**-**	**_**	**5.57**	**-**	**6.01**	**-**	**6.01**	**-**	**6.01**	**-**	**6.01**	**-**	**5.70**	**-**	**5.81**	**-**	**6.08**

5. SUMMARY AND CONCLUSION

The present investigation entitled, "Investigations on the minimal processing of red onion", was carried out in three different parts in laboratory of Post-harvest Technology, Horticulture section, RCSM College of Agriculture, Kolhapur during 2016-2017. In the first part, effectiveness of nine different post-harvest treatments was studied on the shelf life stability of four different types of cut onion. In the second part, fresh-cut onions i.e. whole peeled as well as diced onions treated with the best post-harvest treatment from the first part were packed in four different packaging materials and stored in two different storage temperature for further studies while in the third part pretreated fresh-cut onions (whole peeled and diced onions) packed in polypropylene bags were evaluated for the effectiveness of eight different modified atmosphere packagings treatments in two different storage temperatures for the extension of shelf life. The results obtained are summarized hereunder.

The data on initial analysis of red onion bulbs of cultivar Baswant-780 revealed that average weight of the bulbs was 67.70 g and had 88.24 per cent moisture, 5.28 pH, 0.38 per cent acidity, 11.5^0Brix TSS with 37.20 mg/100g anthocyanins and 5.242 µmol per g fresh weight of pyruvic acid. The total aerobic count in bulb recorded was 8.72 log cfu per g.

The four different pretreated types of cut i.e. sliced, diced, shredded and whole peeled onions were evaluated for post-harvest behavior during storage at $0\text{-}5^0$C. The fresh-cut onions were given nine different post-harvest treatments with organic and inorganic chemicals and irradiations. The different types of fresh cut red onion can be stored up to 15-18 days by applying different postharvest treatments. Untreated fresh cut onion packed in polypropylene bags gave shelf life up to 12 days only. However, fresh cut red onion pretreated with 1% hexanal (EFF- nano emulsion) was found to be the best treatment to enhance the shelf life of fresh-cut red onion up to 18 days. The treatment T_3 (1% hexanal) followed by T_2 (2% hexanal) had maximum sensorial qualities like colour, flavour, appearance and registered highest overall acceptability among the postharvest treatments studied. Among the various types of cut under study, the whole peeled onion gave the best results than sliced, shredded and diced onion. As regards treatments combinations, the whole peeled onion treated with 1% hexanal (EFF- nano emulsion) (A_4T_3) packed in polypropylene bags stored at $0\text{-}5^0$C recorded minimum changes in pH, total soluble solids, titratable acidity, anthocyanin, pyruvic acid of fresh-cut red onion, headspace gas concentrations and also restricted microbial growth. It also recorded minimum moisture loss, physiological loss in weight and had minimum decay.

The changes in physico-chemical parameters of fresh-cut onion were slow in whole peeled onion pretreated with 1% hexanal under refrigerated storage ($0\text{-}5^0$C). Decrease in percent moisture, pH, TSS, anthocyanin and pyruvic acid was observed in all treatments irrespective of types of cut and post-harvest treatments. The maximum percent decay was observed in diced onion treated with distilled water (control). The changes in headspace gas concentrations were minimum in whole peeled onion treated with T_3 (1% hexanal) and stored at 0-5^{0}C while the maximum changes in oxygen, carbon dioxide concentrations and ethylene release were recorded in control treatment followed by UV-C radiation treated diced onion. The untreated diced onion registered maximum decay with fast changes in the physico-chemical parameters and had registered highest microbial count.

Among packaging materials tried, fresh-cut onion i.e. whole peeled as well as diced onions packed in polypropylene bags with freshpaper (P_4) gave shelf life up to 18 and 15 days, respectively without much changes in physico-chemical parameters and had minimum microbial population. As regards the storage environments, the storage of fresh cut onion at 0±1^{0}C (S_1) recorded the better quality than the storage at 7±1^{0}C (S_2). The whole peeled onion packed in polypropylene bags with freshpaper and stored at 0±1^{0}C (P_4S_1) recorded maximum value of moisture (86.12%), pH (4.93), TSS (10.52^{0}Brix), anthocyanins (36.54 mg per 100g), and pyruvic acid (5.097 μmol/g fresh weight) with minimum change in titratable acidity. The diced onions packed in polypropylene bags with freshpaper and stored at 0±1^{0}C (P_4S_1) had extended the shelf life up to 15 days by retaining physico-chemical parameters with minimum changes in headspace gas concentration and registered maximum score for sensorial characters.

Decrease in moisture, pH, total soluble solids, anthocyanin and pyruvic acid of fresh-cut red onion and increase in PLW, decay and acidity were noticed in both the storage environments i.e. 0±1^{0}C and 7±1^{0}C. The changes in headspace gas concentrations like decrease in oxygen, increase in carbon dioxide and ethylene were recorded in all treatment combinations. The minimum changes in headspace gas concentrations were recorded in fresh cut onions packed in polypropylene bags with freshpaper (P_4) and stored at 0±1^{0}C (S_1).

For the MAP experiment, the treatment T_3 (1% hexanal) was selected for pretreatment of fresh-cut onion. The pretreated fresh cut onions i.e. whole peeled and diced onions were packed in polypropylene bags with eight different packagings separately. MAP with 0.5% oxygen plus 10% carbon dioxide flushing and MAP with 2% oxygen plus 10% carbon dioxide flushing extended shelf life of pretreated fresh-cut onion up to 21 days when stored at 0±1^{0}C. Pretreated fresh-cut onion i.e. whole peeled and diced onions packed in polypropylene bags superatmoxpheric oxygen (100% oxygen flushing) recorded shelf life up to 6 days only. As regards other MAP treatments, control (air/passive MAP) treatment recorded maximum decrease in physico-chemical and sensorial parameters with rapid increase in microbial count at 7±1^{0}C storage and could be stored up to 18 days. Decrease in percent moisture, pH, TSS, anthocyanin and pyruvic acid and sensory parameters while increase in PLW, decay, acidity, ethylene and microbial count was recorded in all MAP conditions. The MAP treatment, M_3 (0.5% O_2 plus

10% CO_2) recorded minimum changes in physico-chemical parameters, headspace gas concentrations and minimum microbial count at 0±1^{0}C in both whole peeled and diced onion.

Conclusion

1. Treatment combination of whole peeled onion pretreated with 1% hexanal (EFF- nano emulsion) and packed in 200 gauge polypropylene bags restricted the microbial growth with minimum changes in physico-chemical attributes, headspace gas concentrations of packages and maintained or enhanced colour, flavour and appearance and extended shelf life up to 18 days at 0-5^{0}C.
2. Among the different types of cut under study, whole peeled onion retained physico-chemical attributes and maintained fresh like quality throughout the storage period i.e. 18 days. While pretreated diced onions could be stored up to 12 days only. The intensity of cut had influenced the shelf life of cut onion during storage.
3. The pretreatments with hexanal (1% and 2%) and Nisin (50μg-mL^{-1}) + citric acid (1% w/v) were the potential tool to control the growth of microorganisms in fresh cut onion.
4. The shelf life of pretreated whole peeled onion packed in polypropylene bags with freshpaper and stored at 0±1^{0}C can be extended upto 18 days by minimum change in physico-chemical, biochemical, headspace gas concentration, sensory qualities and restricting the microbial growth while the shelf life of pretreated diced onions packed in polypropylene bags with freshpaper and stored at 0±1^{0}C can be increased up to 15 to 18 days by maintaining fresh like qualities.
5. The fresh cut onions packed in polypropylene bags with freshpaper retained freshness and flavour due to its infusion and or impregnation with fenugreek and other spice extracts.
6. Shelf life of fresh-cut onion stored at lower temperature (0±1^{0}C) retained its quality and shelf life as compared to slightly higher temperatures (7±1^{0}C) with best pretreatment (1% hexanal) and packaging material (polypropylene bags with freshpaper) and it also registered minimum changes in the headspace gases (i.e. oxygen, carbon dioxide and ethylene) concentrations up to 18 days.
7. Modified atmosphere packaging with 0.5% O_2 plus 10% CO_2 flushing or with 2% O_2 plus 10% CO_2 flushing extended the shelf life of pretreated fresh cut onions i.e. whole peeled as well as diced onions up to 21 days at low storage temperature 0±1^{0}C by restricting microbial growth, decay with minimum changes in headspace gas concentrations and enhanced sensorial parameters with minimum changes in physico-chemical attributes.

Future Line of Research Work

India ranks second in the onion production. However, the seasonal price fluctuation is the major threat to the onion production industry. The processing, preservation and value addition by suitable means could be the best and major thrust area to stabilize the market of onions. In India, the minimal processing of fresh onion is very rare. Minimally processed onion is offering convenience to the consumer in preparation of various culinary dishes. Presently only ready-to-cook peeled multiplier onion is available in Indian market which has limited shelf life up to 2-3 days. Due to change in consumers lifestyle over the decade, demand for ready-to-use (RTU) onions has notably increased with onions among the fine most commonly sold vegetables in western countries. Minimal processing, pretreatments to increase shelf life and modified atmosphere packaging of fresh-cut onion present more scope in future. The intelligent packaging system like MAP and SMART packaging with polypropylene bags with freshpaper should be thoroughly studied with different combinations. Similarly, the active packaging with quality of absorbing/adsorbing the volatiles released during metabolic processes and releasing them whenever required is a need of time to increase the fresh like quality of produce. The Indian varieties suitable for minimal processing are needed to be screened for the purpose. There is need to develop low cost automation in peeling and cutting of onion like vegetable with novel products.

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7. APPENDICES

APPENDIX- I

Performa for Sensory Evaluation of Minimal Processing of Red Onion

Name of the experiment :
Packaging material :
Storage condition : **Days after storage** :
Name of the judge : **Date of evaluation** :

Sr. No.	**Sample code**	**Parameters**			
		Colour	**Flavour (in and out package)**	**Appearance**	**Overall acceptability**

Maximum score 9 for each parameter

Date: **Signature of Judge**

Sensory score rating using 9 point Hedonic scale as given by Amerine *et al.* (1965).

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

When average score is more than 5.5, then product is acceptable in the market.

8. VITAE

MS. HOLIKATTI NIKITA SHIVAKUMAR

MASTER OF SCIENCE (AGRICULTURE)

IN

HORTICULTURE (VEGETABLE SCIENCE)

2018

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