International Journal of Applied Engineering and Technology ISSN: 2277-212X (Online)
An Open Access, Online International Journal Available at http://www.cibtech.org/jet.htm
2015 Vol. 5 (3) July-September, pp.8-24/Dhineshkumar et al.
Review Article

MODIFIED ATMOSPHERE PACKAGING OF POMEGRANATE ARILS: REVIEW

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ABSTRACT
Minimally processed ready-to-eat pomegranate arils have become popular due to their convenience, high value, unique sensory characteristics, and health benefits. Pomegranate is one of the most important fruit crops in India because of its adaptable nature, high profitability and being cultivated on a commercial scale in India and the fruits are good source of nutrients and bioactive compounds, mainly anthocyanins which exhibit strong chemo-preventive activities such as antimutagenicity, antihypertension, ant oxidative potential and reduction of liver injury. Modified atmosphere packaging (MAP) technology offers the possibility to retard produce respiration rate and extend the shelf life of fresh produce. However, it is important to correlate the permeability properties of the packing films with the respiration rate of the produce, in order to avoid anaerobic conditions which could lead into fermentation of produce and accumulation of ethanol. Although other gases such as nitrous and nitric oxides, sulphur dioxide, ethylene, chlorine, as well as ozone and propylene oxide have also been investigated, they have not been applied commercially due to safety, regulatory, and cost considerations. Successful control of both product respiration and ethylene production and perception by MAP can result in a fruit or vegetable product of high organoleptic quality; however, control of these processes is dependent on temperature control.

Keywords: *Minimal Processing, Modified Atmosphere Packaging, Polyphenols, Pomegranate, Ready-To-Eat, Shelf Life, Total Antioxidant Activity*

INTRODUCTION
Pomegranate Fruit
Pomegranate *(Punica granatum L.)* is one of the most important fruit crops in India because of its adaptable nature, high profitability and being cultivated on a commercial scale in temperate, tropical and subtropical regions of country (Kumar *et al.*, 2012). Its fruits are good source of nutrients and bioactive compounds, mainly anthocyanins which exhibit strong chemo-preventive activities such as antimutagenicity, antihypertension, antioxidative potential and reduction of liver injury (Hertog *et al.*, 1997, Lansky *et al.*, 1998, Lopez-Rubira *et al.*, 2005). The edible part of the pomegranate is called aril which constitutes about 52% of total fruit (w/w), comprising 78% juice and 22% seeds (Kulkarni and Aradhya 2005, Barman *et al.*, 2011). The hard suture (peel) of pomegranate fruits makes it difficult to extract the arils, thus limiting its consumption as fresh fruit. Therefore, production of pomegranate arils in 'ready-to-eat' form would be a convenient and desirable alternative to the consumption of fresh fruits and may further increase pomegranate demand by consumers. Among various factors, selection of variety, ripening stage and storage environment are the major factors that affect storage life of minimally processed produce (Sapers and Miller, 1998). Minimally processed ready-to-eat pomegranate arils have high economic importance due to their convenience, healthiness and their desirable sensory characteristics as compared to whole produce, which poses diffi- culties in extracting the arils (Artes *et al.*, 2007; Caleb *et al.*, 2012; Defilippi *et al.*, 2006). The versatile adaptability, table and therapeutic values and better keeping quality are the features responsible for its cultivation on a wide scale (Dhandar and Singh, 2002). Pomegranate is commercially grown for its sweet-acidic taste of the arils. Other benefits include the combat to some bacterial infections, erectile dysfunction, male infertility,

Alzheimer's disease, obesity. Pomegranate fruit is consumed directly as fresh seeds, but can also be used for making juice, jelly, grenadine or as flavouring and colouring agents. In addition, this species has been proved to possess therapeutic properties, therefore with an economic and ecological importance (Al-Said *et al.*, 2009 and Akbarpour *et al.*, 2010).

Table 1: Nutritional Composition of Pomegranate Fruit

Nutrient	**Unit**	**Value Per100 g**
Proximates		
Water	g	77.93
Energy	kcal	83
Protein	g	1.67
Total lipid (fat)	g	1.17
Carbohydrate, by difference	g	18.70
Fiber, total dietary	g	4.0
Sugars, total	g	13.67
Minerals(mg/100g)		
Calcium, Ca	mg	10
Iron, Fe	mg	0.30
Magnesium, Mg	mg	12
Phosphorus, P	mg	36
Potassium, K	mg	236
Sodium, Na	mg	3
Zinc, Zn	mg	0.35
Vitamins		
Vitamin C, total ascorbic acid	mg	10.2
Thiamin	mg	0.067
Riboflavin	mg	0.053
Niacin	mg	0.293
Vitamin B-6	mg	0.075
Folate, DFE	µg	38
Vitamin B-12	µg	0.00
Vitamin A, RAE	mg	0
Vitamin A, IU	IU	0
Vitamin E (alpha-tocopherol)	mg	0.60
Vitamin D (D2 + D3)	µg	0.0
Vitamin D	IU	0
Vitamin K (phylloquinone)	µg	16.4
Lipids		
Fatty acids, total saturated	g	0.120
Fatty acids, total monounsaturated	g	0.093
Fatty acids, total polyunsaturated	g	0.079
Cholesterol	mg	0

Surce: USDA National Nutrition Database (2010)

Pomegranate fruit Antioxidant activity, as well as suppression of inflammation, may contribute to chemo therapeutic and chemo-preventive utility against cancer. The other potential therapeutic properties of pomegranate are wide-ranging and include treatment and prevention cardiovascular disease, diabetes,

dental conditions, erectile dysfunction, protection from ultraviolet (UV) radiation, infant brain ischemia, Alzheimer's disease, male infertility, arthritis, obesity, etc.

Pomegranate fruit is a rich source of two types of polyphenolic compounds: anthocyanins and hydrolysable tannins, which account for 92% of the antioxidant activity of the whole fruit (Gil *et al.,* 2000). The soluble polyphenol content in pomegranate juice varies between 0.2 and 1.0%, depending on variety (Narr *et al.,* 1996). The seeds are a rich source of lipids; of which comprised of 12% to 20% of total seed weight and characterized by a high content of polyunsaturated (*n*-3) fatty acids such as linolenic, linoleic, and other lipids such as punicic acid, oleic acid, stearic acid, and palmitic acid (Ozgul-Yucel, 2005).

In spite of the numerous health benefits, pomegranate consumption is still limited, due to the difficulties of extracting the arils from the fruit and, the irritation of phenolic metabolites' which stain the hands during preparation of seeds (Gil *et al.,* 1996b). Fruit disorder such as sun burnt husks, splits and cracks, and husk scald on the whole fruit reduces marketability and consumer acceptance (Saxena *et al.,* 1987; Defilippi *et al.,* 2006; Sadeghi and Akbarpour 2009).

However, maintaining the nutritional and microbial quality of pomegranate arils is a major challenge, because, minimally processed arils easily deteriorate in texture, colour, overall quality and a reduction in shelf (Gil *et al.,* 1996a, b). This is due to the active metabolic processes due to endogenous enzymatic activity, enhanced respiration rate with increased production of ethylene (Rolle and Chism, 1987; Ergun and Ergun, 2009), and increased in microbial load, some of which may be potentially harmful to human health (Leistner and Gould, 2002).

Modified Atmosphere Packaging

Modified atmosphere packaging (MAP) of fruit can bring about the lowering of respiration activity, delay in ripening and softening, and a reduced incidence of physiological disorders and decay-causing pathogens (Artés, 1993). In MAP excessive accumulation of CO_2 can cause cell membrane damage and physiological injuries to the product, such as severe enzymatic browning, off flavor development and loss of firmness (Briones *et al.*, 1992).

The purpose of this present paper is to review the use of modified atmosphere packaging to minimally processed or fresh pomegranate arils preservation and identify the future prospects for the development of MAP for pomegranate products.

The ripe pomegranate fruit can be up to five inches wide with a deep red, leathery skin, is grenade-shaped, and crowned by the pointed calyx. The fruit contains many seeds (arils) separated by white, membranous pericarp, and each is surrounded by small amounts of tart, red juice. The physical properties of fruit like weight, whole fruit and aril Colour, juice content and juice dry matter content.(Artes *et al.,* 2000). In addition chemical properties and phytonutrients like vitamin C, total phenolics, total tannins, condensed tannins, total soluble solids, and anthocyanins in the peel and arils of different pomegranate variety have been outlined (Opara *et al.,* 2009).

MAP Gases

The three major gases used in the MAP of foods are oxygen (0_2), nitrogen (N_2) and carbon dioxide (CO_2). For most food products different combinations of two or three of these gases are used, chosen to meet the needs of the specific product. Usually for non-respiring products, where microbial growth is the main spoilage parameter, a 30-60% CO_2 split is used, the remainder being either pure N_2 (for 0_2 sensitive foods) or combinations of N_2 and 0_2. For respiring products levels around 5% CO_2 and 0_2 are usually used with the remainder being N2 in order to minimize the respiration rate.

Several other gases such as carbon monoxide (used to maintain the red colour of red meats), ozone, ethylene oxide, nitrous oxide, helium, neon, argon (increases shelf-lives for some fruits and vegetables), propylene oxide, ethanol vapour (used on some bakery products), hydrogen, sulphur dioxide and chlorine have been used experimentally or on a restricted commercial basis to extend the shelf-life of a number of food products (Day, 1993). However, regulatory constraints, safety concerns and negative effects on sensory quality and/or economic factors hamper the use of these gases. More information about the most promising uses for these gases is given later for the relevant food products.

i) Carbon Dioxide (CO_2)

CO_2 is the most important gas in the MAP of foods, due to its bacteriostatic and finigistatic properties. It inhibits the growth of the many spoilage bacteria and the inhibition rate is increased with increased CO_2 concentrations in the given atmospheres. CO_2 is highly soluble in water and fat, and the solubility increases greatly with decreased temperature. The solubility in water at 0°C and 1 atm is 3.38g CO_2/kg H_2O; however, at 20°C the solubility is reduced to 1.73g CO_2/kg H_2O (Knoche, 1980). Therefore the effectiveness of the gas is always conditioned by the storage temperature, resulting in increased inhibition of bacterial growth as the temperature is decreased (Ogiydziak and Brown, 1982; Gill and Tan, 1980; Haines, 1933).

The concentration of CO_2 in the food is dependent on the product's water and fat content, and on the partial pressure of CO_2 in the atmosphere, according to Henry's law (Ho *et al.*, 1987). Devlieghere *et al.*, (1998a, 1998b) have demonstrated that the growth inhibition of microorganisms in a. modified atmosphere is determined by the concentration of dissolved CO_2 in the product. After the packaging has been opened, the CO_2 is slowly released from the product and continues to exert a. useful preservative effect for a. certain period of time, referred to as CO_2's residual effect (Stammen *et al.*, 1990).

The action of CO_2 on the preservation of foods was originally thought to be caused by the displacement of some or all of the 0_2 available for bacterial metabolism, thus slowing growth (Daniels *et al.*, 1985). However, experiments with storage of bacon and pork showed a considerable increase in shelf-life under pure CO_2 atmospheres, compared to storage in normal air atmospheres (Callow, 1932). The preservative effect was not due to the exclusion of 0_2, since storage in 100% N2 offered no advantage over normal air storage. The same results were also seen on pure cultures of microorganisms isolated from spoiled pork.

A drop in surface pH is observed in modified atmosphere (MA) products due to the acidic effect of dissolved CO_2, but this could not entirely explain all of CO_2's bacteriostatic effects (Coyne, 1933). It was shown that CO_2 was more effective at lower temperatures and that the change in pH caused by the CO_2 did not account for the retardation of growth. In a study on several pure cultures of bacteria. Isolated from fish products, CO_2 atmospheres were found to inhibit the growth of the bacteria markedly, whereas normal growth patterns were observed under air or N_2 atmospheres (Coyne, 1932). It was also observed that bacterial growth was inhibited even after the cultures were removed from the CO_2 atmosphere and transferred to an air environment, interpreted as a residual effect of CO_2 treatment. Bacterial growth was distinctly inhibited when atmospheres with 25% CO_2 were used and almost no growth was observed under higher CO_2 concentrations for four days at 15°C. The obtained results could neither be explained by the lack of 0_2 nor the pH effect.

Coyne suggested the possibility that an intracellular accumulation of CO_2 would upset the normal physiological equilibrium in other ways, i.e. by slowing down enzymatic processes that normally result in the production of CO_2. Thus the effect of CO_2 on bacterial growth is complex and four activity mechanisms of CO_2 on microorganisms have been identified (Farber, 1991; Dixon and Kell, 1989; Daniels *et al.*, 1985; Parkin and Brown, 1982):

1. Alteration of cell membrane functions including effects on nutrient uptake and absorption.
2. Direct inhibition of enzymes or decreases in the rate of enzyme reactions.
3. Penetration of bacterial membranes, leading to intracellular pH changes.
4. Direct changes in the physico-chemical properties of proteins.

A probable combination of all these activities accounts for the bacteriostatic effect. A certain amount (depending on the foodstuff) of CO_2 must dissolve into the product to inhibit bacterial growth (Gill and Penney, 1988). The ratio between the volume of gas and the volume of the food product (G/P ratio) should usually be between 2:1 or 3:1 (volume of gas two or three times the volume of food). This high G/P ratio is also necessary to prevent package collapse because of the CO_2 solubility in wet foods. Dissolved CO_2 fills much less volume compared to CO_2 gas, and after packaging a product in a CO2 atmosphere, under-pressure is developed within the package and package collapse may occur. The CO_2 solubility could also alter the food water-holding capacity and thus increase drip (Davis, 1998). Exudation pads should be used to absorb drip loss from products.

ii) Nitrogen (N_2)

N_2 is an inert and tasteless gas, and is mostly used in MAP as a. filler gas because of its low solubility. N_2 is almost insoluble in water and fat and will not absorb into the food product, and therefore counteracts package collapse as caused by dissolved CO_2. N_2 is used to displace 0_2 from air in packages with 0_2-sensitive products, to delay oxidative rancidity, and as an alternative to vacuum packaging, to inhibit the growth of aerobic microorganisms.

iii) Oxygen (0_2)

The use of 0_2 in MAP is normally set as low as possible to inhibit the growth of aerobic spoilage bacteria. Its presence may cause problems with oxidative rancidity (e.g. fatty fish like salmon and mackerel). However, high levels of 0_2 are used in red meat products to maintain the red colour of the meat; 0_2 (around 30%) in the atmosphere for lean fish species has been used to reduce drip loss and colour changes; for respiring products 0_2 is included in the atmosphere to prevent anaerobic respiration; and recently high levels (80-90%) of 0_2 have shown promising results for extending the shelf-lives of selected fruits and vegetables.

Originally, 0_2 was introduced into the packaging atmosphere of selected products in order to reduce the risk of anaerobic pathogenic bacterial growth, but this process has now been generally discredited (ACMSF, 1992). It is now recognised that the growth of *Clostridium botulinum* in foods does not depend upon the total exclusion of oxygen, nor does the inclusion of 0_2 as a packaging gas ensure that the growth of *C. botulinum* is prevented.

Deterioration of Pomegranate Fruit

i. Weight loss

One of the major problems associated with pomegranate fruit is excessive weight loss which may result in hardening of the husk and browning of the rind and arils (Artés *et al.,* 2000b; Caleb *et al.,* 2012a). Even in the absence of shrivelling, water loss can cause undesirable textual and flavour changes, ultimately resulting to loss of visual appeal. The storage potential of pomegranate fruit at 21°C and 82% RH may not be more than 15 days (Waskar, 2011). However, under refrigerated conditions and high RH, most cultivars can be stored for prolonged periods (Elyatem & Kader, 1984). Storage trials conducted on 'Hicaz' cultivar stored at 6°C showed that weight loss (9%) increased with increasing temperature and prolonged storage duration (Küpper *et al.,* 1995). Al-Mughrabi *et al.,* (1995) observed that weight loss increased with storage temperature and time for 'Taeifi', 'Manfaloti', 'Ganati' pomegranates. The authors reported significantly higher weight loss at 22°C than at 5°C and 10°C, with average weight losses of 18.32%, 21.93% and 32.83% at 5°C, 10°C and 22°C, respectively, after 8 weeks of storage. However, on the contrary, Köksal (1989) studied weight loss on Turkish 'Gok Bahce', the author reported that weight loss in untreated fruit at 5°C (16.5%) were higher than fruit stored at 1°C (8%), 10°C (6.1%) and 21°C (14%) after 4 months storage duration. This clearly showed the importance of low storage conditions in reducing weight loss in pomegranate fruit.

ii. Chilling Injury

The 'Wonderful' pomegranate cultivar has been reported having high susceptibility to chilling injury if stored at temperatures below 5°C, or more than 2 months at 5°C (Elyatem & Kader, 1984; Kader *et al.,* 1984). However, chilling injury may become more noticeable when transferred to 20°C after 2 months of cold storage (Kader, 2006). Mirdehghan *et al.,* (2006a) reported that storage at 2°C plus 3 days shelf-life for 2 weeks results in chilling injury for 'Mollar de Elche'. External symptoms of chilling injury include brown discolouration of fruit peel, cracking, necrotic pitting and increased susceptibility to decay (Elyatem & Kader, 1984). Internal symptoms include reduction in aril colour, aril browning and discolouration of white membrane segments (Elyatem & Kader, 1984; Kader *et al.,* 1984, Köksal, 1989). Depending on cultivar types, pomegranate fruit can be successfully stored for 2 to 7 months between temperatures ranging from 0°C to 10°C (Köksal, 1989; Onur *et al.,* 1992).

Intermittent warming of pomegranate fruits has been reported to reduce chilling injury symptoms and fruit decay (Artés *et al.,* 2000b). Similarly, Mirdehghan & Rahemi (2005) showed that dipping in water at 50°C temperature for 5 min significantly reduced chilling injury for 'Malas Yazdi' and 'Malas Saveh'

stored for 4.5 months at 1.5°C and 85±3% RH. These studies are comparable with Mirdehghan *et al.*, (2006b) who reported that heat treatment such as water dipping at 45°C for 4 min reduced chilling injury symptoms. You-lin & Run-guang (2008) reported that intermittent warming at 15°C for 24 h reduced browning of the husk and could prevent chilling injury when fruits were stored for 120 days for the 'Ganesh' pomegranate.

iii. Husk Scald

Husk scald is a common physiological disorder appearing as a superficial (peel) browning of the husk, which generally develops from the stem end of the fruit and spreads towards the blossom end as severity increases (Ben-Arie & Or, 1986; Defilippi *et al.*, 2006). This disorder is suggested to be due to the oxidation of phenolic compounds on the husk of the fruit when stored at temperatures exceeding 5°C (You-lin & Run-guang, 2008). The severity of scald incidence increases when pomegranates are harvested late in the season, indicating that this disorder may be associated with senescence (Kader, 2006). At advanced stages, scalded areas may become susceptible to decay (Kader, 2006). Pekmezci *et al.*, (1998) reported that scald symptoms become evident after 8 weeks storage at 2°C. For the 'Wonderful', Ben-Arie & Or (1986) reported that husk scald can be effectively controlled when fruit were stored at 2% oxygen at 2°C. However, it was observed that this treatment leads to build-up of ethanol which produced off-flavours in the fruit.

iv. Decay

The major cause limiting the storage potential of pomegranates is the development of decay which are caused by various pathogens such as *Aspergillus* spp, *Cladosporium* spp, *Colletotrichum* spp, *Epicoccum* spp, *Penicillium* spp, *Pestalotia* and *Botrytis cinerea* (Maclean *et al.*, 2011; Caleb *et al.*, 2012a). Several postharvest diseases are mainly associated with pomegranate fruit include gray mold (*Botrytis cinerea*) rot, green mold (*Penicillium digitatum*) rot, blue mold (*P. expansum*) rot and heart (*Aspergillus niger*) rot (Roy & Waskar, 1997; Palou *et al.*, 2007). *B. cinerea* is able to infect stored pomegranates by mycelial spread from infected fruit to adjacent healthy fruit, causing 'nests' of decay. *B. cinerea* mainly infects fruit through the crown (calyx) of young fruit on the tree, remains latent and after harvest forms a characteristic grey mycelium on the affected area under humid conditions (Caleb *et al.*, 2012a). Grey mold rot usually starts from the calyx, spreading onto the skin causing an apparent brown discoloration, making the peel tough and leathery (Ryall & Pentzer, 1974). Furthermore, *B. cinerea* are able to infect stored pomegranates by spreading from infected fruit to adjacent healthy fruit, causing 'nests' of decay (Palou *et al.*, 2007).

In heart rot, with *A. niger* fruit show no external symptoms except for slight abnormal peel colour or soft spot with a blackened mass of arils (Yehia, 2013).

Padule & Keskar (1988) reported that treating pomegranate fruit with aqueous Topsin-M (0.1%) and Bavistin (0.05 - 0.1%) significantly suppressed the growth of *A. niger*. When pomegranate 'Wonderful' were inoculated in the crown with *B. cinerea*, stored for 15 weeks at 7.2°C and 95% RH and treated with an antifungal fludioxonil, decay were shown to be significantly reduced when compared to untreated fruits (Palou *et al.*, 2007). Hence, it is necessary to develop control methods to control postharvest decay and extent the marketing life of pomegranate fruits.

MAP of Pomegranate Fruits and Arils

MAP is a passive or active dynamic process of altering gaseous composition within a package. This is obtained by the interaction between two processes; the respiration rate of the fruit and the transfer of gases through the packaging material, with no more control utilized over the initial gas composition (Kader *et al.*, 1989).

Nevertheless, in MAP, these two processes are relying on many other factors like film thickness and surface area, product weight, free space within the pack, and temperature (Tolle 1962; Charles *et al.*, 2003; Sandhya, 2010).

For example, a limited volume of headspace in the package could tend to an increase in resistance to gas diffusion. Also, metabolic processes like respiration rate and various endogenous enzymatic, and film permeability increases with increase in temperature (Sandhya, 2010). Passively modified atmosphere can

be found inside a package using natural air composition and relying on the produce respiration to attain the desired gas mixture (Kader and Watkins, 2000; Charles *et al.,* 2003; Farber *et al.,* 2003). However, this process takes a longer period of time to reach gas equilibrium steady-state.

According to Cameron *et al.,* (1995), they demonstrated that it can take 2 to 3 weeks to attain a steady-state at low temperatures depending on produce respiration rate and the available gaseous space within the package. If produce respiration rate and film permeability characteristics correlates properly, the desired atmosphere can develop within the hermetic package via the uptake of oxygen and production of carbon dioxide as an end product of respiration. But due to the limited ability to regulate a passively established atmosphere, such as the unavailability of appropriate films which provides both gases diffusion and temperature compensation in order to function effectively (Exama *et al.,* 1993), actively established atmosphere is much preferred compared with passive modification (Kader and Watkins, 2000).

Active MAP involves a quick process of gas flushing or gas replacement or the use of gas-scavenging agents to establish a desired gas mixture within the package (Kader and Watkins, 2000; Charles *et al.,* 2003; Farber *et al.,* 2003), while avoiding a buildup of unsuitable gases. For instance, high solubility of CO2 can result in pack collapse due to the reduction in free-space volume (Sandhya, 2010). Carbondioxide absorbers can prevent a buildup of CO2 gas to deleterious levels, which could occur during passive modified atmosphere packaging (Kader and Watkins, 2000). Excessive accumulation of CO2 can result in cell membrane damage and physiological injuries to the product, such as loss of firmness and severe enzymatic browning (Burton *et al.,* 1987; López-Briones *et al.,* 1992; Varoquaux *et al.,* 1999).

Furthermore, oxygen absorbers can be used to decrease the O2 partial pressure within the package headspace and remove the O2 that diffuses through the film (Gontard, 2000). Also, most oxygen sensitive produce are gas flushed or vacuum packaged to rapidly attain an atmospheric condition of ploy phenolic compounds (Charles *et al.,* 2003).

In MAP, respiration rate is reduced by decreasing O2 concentration. This metabolic response is due to the decrease in the activity of oxidizing enzymes such as polyphenoloxidase, glycolic acid oxidase and ascorbic acid oxidase (Kader, 1986).

Carbon dioxide is a colourless gas, with a slightly pungent smell at a very high concentration. It readily dissolves in water at 1.57 g/kg at 100 kPa and 20 °C, to produce carbonic acid which reduced the pH of the solution (Sandhya, 2010).

Carbon dioxide is the only gas used in MAP that confers a significant level of antimicrobial influence on the product. Microbial growth is retarded at high concentration of carbon dioxide in various products, due to an increased lag phase and generation time during the log phase of microbial growth (Phillips, 1996). Farber (1991), suggested various theories to explain the antimicrobial influence of carbon dioxide on MAP product this include: direct inhibition of enzyme systems or decrease in rate of enzyme reactions; alteration of cell membrane function including uptake and absorption of nutrient; gas penetration of bacterial membranes leading to decrease in intracellular pH; direct changes in the physical and chemical properties of proteins.

Temperature is the most important extrinsic factor in the prevention of fruit ripening. Ripening is observed to correlate with ethylene production rates and these processes are influenced by increase in temperature (Kader, 1980).

Hence to retard ripening, fruits should be stored at a temperature close to 0 °C as possible, without causing chilling injury. However, MAP can be used as a substitute in delaying ripening of fruits. A reduction in oxygen concentration below 8% and/or increase in carbondioxide concentration slow down fruit ripening (Sandhya, 2010).

The degree to which modification of the atmosphere takes place in packages is dependent on other variables such as film permeability to O2 and CO2 and product respiration rate (Beaudry, 1999; Cameron *et al.,* 1994).

Table 2: Properties of Major packaging material

Packaging material	Properties Advantages	Disadvantages
Paper	Strength and rigidity Printability	Opacity
Tinplate	Corrosion resistance Excellent barrier to gases, water vapour, light and odour Heat-treatable Ability to seal hermetically Ductility and formability	Higher barrier to gases Tin toxicty
Tin-free steel	Corrosion resistance Excellent barrier to gases, water vapour, light and odour Heat-treatable Ability to seal hermetically Ductility and formability Less expensive compared to tinplate	Higher barrier to gases
Aluminium foil	Negligible permeability to gases, odours and water vapour Dimensional stability Grease resistance Brilliant appearance Dead folding characteristics	Opacity High barrier to gases
Glass	Formability and rigidity Transparency and UV protection due to colour variation Impermeable to gases, water vapour and odour Chemical resistance to all food products Heat stable	Higher barrier to gases Heavy weight adds to transport cost
Cellulose film (coated)	Strength Attractive appearance Low permeability to water vapour, gases, and odours (coat dependent) Grease resistance Printability	Low permeability barrier
Cellulose acetate	Strength and rigidity Dimensional stability Printability	Glossy appearance
Ethylene vinyl alcohol (EVOH)	Excellent barrier to gases and odour Effective oxygen barrier material	Moisture sensitive barrier
Ethylene vinyl acetate (EVA)	Very good adhesive properties Excellent transparency Heat sealability	Poor gas barrier Poor moisture barrier

Polyethylene	Durability and flexibility Heat sealability Good moisture barrier Chemical resistance Good low-temperature performance Permeable to gases	HDPE; Poor clarity LLDPE; heat sensitive
Polypropylene	Harder, denser and more transparent than polyethylene Better response to heat sealing Excellent grease resistance Good resistance to chemical Higher gas and water vapour barrier compared to polyethylene	
Polyesters (PET/PEN)	Excellent durability and mechanical properties Excellent transparency Good resistance to heat, mineral oil and chemical degradation Adequate barrier to gases, water vapour and odours	
Polyvinyl chloride (PVC)	Strong and transparent Good gas barrier and moderate barrier to water vapour Excellent resistance to chemicals, greases and oils Heat sealability	
Polyvinylidene chloride(PVDC)	Low permeability/high barrier to gases, water vapour and copolymer odors Good resistance to greases and chemicals Heat sealability Usefull in hot filling, retorting and low temperature storage	Low permeability barrier / high gas barrier
Polystyrene	High tensile strength Excellent transparency	Poor barrier to gas and water vapour
Polyamide (nylon-6)	Strong Moderate oxygen barrier, and excellent odour and flavour barrier Good chemical resistance Thermal and mechanical properties similar to PET High temperature performance	Poor water vapour barrier

(Reference: OJ Caleb et al., 2014)

MAP of Minimally Processed Pomegranate Arils

Table 3 gives a summary of MAP on arils of various pomegranate cultivars, highlighting the types of packaging adopted, and the modified atmosphere condition attained in the packages.

Table 3: Summary of modified atmosphere packaging of Pomegranate arils, types of packaging material, MAP composition with temperature and storage days

Type of product	Package film	MA composition (%)		Storage Temperature (^oC)	Storage time in MAP	References
		O_2	CO_2			
Pomegranate fruit (cv. Mollar de Elche)	Unperforated PP; 25 µm thickness	8 6	10 12	2 5	12 weeks	Artés *et al.*, 2000a, b
Pomegranate arils (cv. Mollar de Elche)	Oriented polyproylene (OPP)	188 mL/L OPP-CO2 OPP-N2	22 mL/L 206 mL/L 203 mL/L	1 3 mL/L 4 mL/L	7 days	Gil *et al.*, 1996
Pomegranate arils (cv. Mollar)	Semi-permeable plastic bag	1	30	4	10 days	García *et al.*, 2000
Pomegranate arils (cv. Mollar de Elche)	OPP; 40 µm thickness	12.5 13.5	8.5 7.5	8 4	7 days	Gil *et al.*, 1996a
Pomegranate arils (cv. Mollar de Elche)	Polypropylene basket sealed with BOPP (October)	2–5 kPa	20.1–21.6 kPa	5	15 days	López-Rubira *et al.*, 2005
	Polypropylene basket sealed with BOPP (December)	2–5 kPa	26.9–29.9 kPa			
Pomegranate arils (cv. Wonderful)	BB4 (cryovac based on ethyl vinyl acetate)	1	22	4	14 days	Sepúlveda *et al.*, 2000
	BE (cryovac based on ethyl vinyl acetate)	12	2			
	Perforated polyethylene bags	Not reported				
Pomegranate arils (cv. Primosole)	Polypropylene	6.5	11.4	5	10 days	Palma *et al.*, (2009)

Pomegranate arils	PP tray	Passive MAP	5	18 days	Caleb *et al.*, (2013)
Pomegranate arils	Perforation mediated MAP		5	15 days	Hussain *et al.*, (2015)
Pomegranate arils (cv. Wonderful)	PP Clam shell tray	Passive MAP	5	12 days	Banda *et al.*, (2015)

(Reference: OJ Caleb et al., 2015)

Gil (1996a) investigated the influence of different washing solutions, temperatures, and packaging on the anthocyanins content of minimally processed pomegranate 'Mollar de Elche' seeds. They found no significant differences in the anthocyanin composition after washing with different solutions. However, unpackaged pomegranate seeds stored for 7 days at 8, 4, and 1 °C, were observed to be shriveling, with almost half of the water originally present in the seeds lost during the unpackaged storage.

On the other hand, MAP-stored seeds had a minimal water loss compared with unpackaged. During cold storage in modified atmospheres at 1 °C, an increase in anthocyanin content was observed while a decrease was recorded at 8 and 4 °C. Comparing the perforated oriented polypropylene (OPP) and unperforated OPP package bags, stored with arils at 1 °C for 7 days. They observed that the unperforated OPP bags maintained the pigments better compared with perforated OPP bags. However, when the storage condition was extended for additional 4 days at 4 °C to mimic domestic storage, the seeds were better preserved in the perforated films. In a similar study by Gil *et al.*, (1996b), the best outcomes in quality and appearance were obtained for pomegranate seeds washed with chlorine (100 mg/kg) plus antioxidants (5 g/L ascorbic acid and 5 g/L citric acid) sealed in OPP film, using an initial atmosphere actively modified to 0 mL/L CO2 and 20 mL/L O2 and stored for 7 days at 1 °C. Under this condition, the minimally processed seeds maintained good quality without fungal attacks or off-flavour development. López-Rubira *et al.*, (2005) investigated the effect of harvest time, use of different UV-C radiation and passive MAP storage on sensory, chemical and microbial quality as well as on the shelf life of minimally fresh processed arils extracted from 'Mollar of Elche' pomegranate. They observed that the rate of respiration of fresh processed arils was higher in the late harvest than in the earlier harvested fruit, with an average respiration rate (RR) of 26.55±1.88 and 14.45±2.48 nmol CO2 kg−1 s −1, respectively. No significant differences were observed between the control and UV-C treated arils and there was no observable interaction between the passive MAP and UV-C treatments. Except that the CO_2 accumulation within aril packages was higher in December harvest than those of October, due to their higher RR. However, microbial counts of minimally fresh processed arils increased throughout the shelf life, with mesophilic counts of control arils processed in October slightly higher than those from December. Their anthocyanin content investigation was in agreement with previous report by Gil *et al.*, (1996b). They found no significant change in total anthocyanin content of 'Mollar' arils harvested in early October during MAP storage at 1 °C for 7 days. However, their findings suggested that the shelf life of fresh processed arils is at least 10 days, contrary to 7 days reported by Gil *et al.*, (1996b) for 'Mollar' pomegranate arils harvested in early October and stored at 1 °C under MAP. García *et al.*, (2000) studied the respiratory intensity (RI) of pomegranate 'Mollar' seeds and the gas composition inside both a semi-permeable and an impermeable plastic at a storage temperature of 4 °C for 10 days. They observed a RI of 30.8±0.4 (ml CO_2/kg/h) for the pomegranate seeds which was much lower compared to sliced oranges with 57.05±1 (ml CO_2/kg/h) from their study. In the case of modified atmosphere packages the atmosphere within the semi-permeable plastic was inadequate to prolong the shelf life of the minimally processed and refrigerated pomegranates. The high relative humidity within the packages helps reduce weight loss, maintaining the turgency and texture of the pomegranate seeds. Sepúlveda *et al.*, (2000) investigated the influence of various types of antioxidant solutions and three semi permeable films; two

cryovac, based on ethyl vinyl acetate (BE and BB4) and perforated polyethylene film as control on the quality of minimally processed pomegranate 'var. Wonderful' arils from Chile stored at 4 °C±0.5 for 14 days. A slight browning of arils was observed in all treatments, but this was highest in treatments without antioxidants. The weight loss of arils was lower in the arils packaged in BE and BB4 film and was significantly different from the arils in PE packages. After 14 days, all the treatments with BE and BB4 packages showed a very low total count for mesophilic aerobes, which could be attributed to higher concentration of carbon dioxide inside the packages. The use of semi-permeable films allowed successful storage for 14 days at 4 °C±0.5, with good physical, chemical, and microbiological quality. Additionally, the decrease in microbial growth was in agreement with Gorny (1997), who observed a decrease in the growth of microorganisms with CO2 concentrations between 15% and 20%. Chemical and organoleptic characteristics of minimally processed seeds of pomegranate 'Primosole' were examined after packaging in a 40 µm thick polypropylene film and stored at 5 °C for 10 days by Palma *et al.,* (2009). They observed that a passive modified atmosphere was established within the package, with a progressive increase in CO2 and decrease in O2 level (Table 2). Ethylene concentration increased rapidly to the end of storage, the increase in ethylene was associated with wound injuries on the seeds. Furthermore for their study, no significant changes in chemical properties of analysed juice. However, an increase in titratable acidity was observed in packaged seeds, this increase acidity was attributed to the absorption of CO2 which lowers pH when dissolved in aqueous phase (Malhotra and Prasad, 1999). The use of honey treatments has also been explored in preserving the fresh-like quality of arils and to extend their shelf life. Ergun and Ergun (2009) evaluated the efficacy of varying concentration of 10 and 20% honey dip treatment on the quality and shelf life of minimally processed pomegranate arils of 'Hicaznar' stored at 4 °C in loosely closed plastic containers. It was demonstrated that honey treated arils had brilliant aroma throughout the 10 days storage period, compared with arils treated with water. After 5 days of storage, arils treated with honey solution had a significantly lower rate of softening than control samples. The total aerobic microbial count was lower in honey treated arils compared with the control but the counts increased across all treatment compared with the count immediately after treatment. Microbial quality criteria are often used to determine the acceptability limit and the shelf life of minimally fresh processed produce and this is used as a minimal standard for processed produce having a limited microbial count and free of pathogenic microorganisms (Willcox 1995). Storage of arils under optimal MA have been shown to reduce the risk of *Enterobacteriaceae, latic acid bactria, mesophilic, psychrotrophic,* as well as moulds and yeast counts (Sepúlveda *et al.,* 2000; López-Rubira *et al.,* 2005). Furthermore, since pomegranate arils are stored at lower temperature, the risk of microbial proliferation is reduced. According to Artés *et al.,* (2000a, b), higher levels of decay (mainly due to *Penicillium spp.)* were observed in unpackaged treatments at 5 °C than in those at 2 °C. Similarly, López-Rubira *et al.,* (2005) observed a low count of micro-aerophilic lactic acid bacteria after 10 days of aril storage without any trace of fermentative metabolism.

Factors Affecting Shelf Life during MAP

Two of the most important factors in determining deterioration rate during modified atmosphere packaging are temperature and gas composition.

Decreasing storage temperature causes a reduction in biochemical reaction rates of horticultural products, and thus on respiration rate (Kader, 1986). Biological reactions are resulted to increase two or three times for every 10°C rise in temperature within the temperature range usually used during distribution and marketing chain (Fonceca *et al.,* 2002).

As previously mentioned respiration is widely assumed to be slowed down by decreasing available O_2 and increasing CO_2. Furthermore, if O2 concentration are too low or CO2 too high physiological damages might occur to the product. Therefore MAP should be carefully designed since a system incorrectly designed may be ineffective or even shorten the shelf life of the product. Effective MAP of produce requires consideration of the optimal gas concentration, product respiration rate, gas diffusion through the film, as well as the optimal storage temperature in order to achieve the most benefit for the product and consumer.

In general those products with increased wounding, as in the case of fresh cut produce, will have a high degree of perishability (Fonseca *et al.,* 2002). Cutting and slicing induce chilling injury in the tissue changing its physiology. Cutting rupture the cells, which then de-compartmentalizes and releases cell contents leading to biochemical reactions. The main physiological manifestations that appear due to wounding include increased respiration, ethylene production and accumulation of secondary metabolites (Wiley, 1999). Wounding causes a gradual increase in respiration rate with storage time, until a maximum is reached and then start decreasing to either the value before the wounding or to a higher one. Cutting lead to a 2 to 3 fold increase in respiration rate when compared to that of the whole product (Lee *et al.,* 1995).

Summary and Future Prospects

Even though several benefits of MAP, its application for pomegranate whole fruit and minimally processed arils is still limited due the challenges such as: the choice of polymeric films, as no single polymeric film can offer all the required properties for MAP. Predominantly under unpredictable storage or transit temperature conditions, polymeric film that performs optimally at a given temperature may result in increased rate of respiration or permeability at higher temperature. Limited information is still available on most films' permeability properties at varying storage temperature, and the ability of the polymeric film to withstand mechanical stress during storage and transport, which is critical to MAP of pomegranate in order prevent squashing of the arils and leakage of gases from the package. Moreover, the mechanical capacity of the polymeric film must also be balanced with flexibility and peel-ability for the convenience of consumers.

Accordingly, the potential of mathematical prediction or modelling can be range over towards an optimal MAP for pomegranate whole fruit and arils.

Several novel technologies offer the potential of further improvements in safety and shelf-life of MAP products, including the use of active and smart packaging and hurdle technology. Smart packaging, including time–temperature indicators (TTI), is a technology that appears to have a significant potential, especially with chill stored MAP products (Labuza *et al.,* 1992). To ensure microbial safety, strict temperature control is needed and temperature abuse should be avoided. TTIs could be applied to monitor the temperature and to detect temperature-abused packages.

MAP is still restricted to certain cultivars either because of the profit margin gained from packaging them or due to limited information on the metabolic properties of the other cultivars. As new cultivars are merging for commercial farming, it is expedient to investigate the postharvest physiology for both the newly introduced cultivars and other unstudied cultivars. It was also shown in this review that different pomegranate cultivars responded differently to MAP. Hence, experimental studies should be carried out separately for each cultivar with a more informative output on the metabolic properties (e.g. respiration rates of whole fruits or arils) under various conditions, in order to enable the successful application of the available technology.

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