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Effect of Different Temperatures and Parameters Analysis of the Storage Life of Fresh Cucumber and Tomato using Controlled Atmosphere Technology

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ABSTRACT

The objectives of this study were to evaluate the effect of different controlled temperatures and analyze the measures and/or parameters of the controlled atmosphere storage for fresh cucumbers and tomatoes. The effect of temperature, relative humidity, gas composition and other impacting factors for fresh cucumbers and tomatoes storage was also analyzed. The storage lives of fruits treated with different temperatures and gas composition treatments (mainly including oxygen and carbon dioxide) was investigated in the present work. Recommendation for the controlled atmosphere storage suggested that optimal controlled atmosphere storage measures and/or parameters for fresh cucumbers and tomatoes were as following temperature (10-13°C, with a variation of ±1°C), relative humidity (90-95%) and maintaining appropriate atmosphere or gas composition (containing 6% oxygen and 15% carbon dioxide).

Key words: Cucumber, tomato, fruit quality, temperature, relative humidity, gas composition, controlled atmosphere storage

INTRODUCTION

Fruits and vegetables are rich in nutrients and provide a variety of vitamins, sugar and/or starch, vegetable protein, amino acids, microelements and other substances necessary for human life and physiological activity. Meanwhile, the fruits and vegetables are daily consumed and they contain many macro-nutrients, micro-nutrients and non-nutrient compounds playing diverse protective roles in the human and animal pathogenesis. As a consequence, people put more and more focus towards the quality, safety, freshness, nutrition and environmental concerns on survival foods. Therefore, there are also more and more requirements for freshness of fruit and fruit-like vegetables (hereinafter referred to as "fruits" in this study for simplicity) and the demand for their supply is increasing. Fresh fruits and vegetables contain high water contents and are generally more perishable than other crops, even after harvest. Preservation of perishable fruits and vegetables is of vital importance and the loss due to lack of proper storage measures is often very high. Thus, the perish-ability of fresh fruits after harvest is an international issue commonly concerned. Fresh fruits have been frequently exported as unpackaged with limited storage and shelf lives. Currently, there are about 25% of the fruit products non-edible due to rot in the storage and transportation process and up to 30% above of decay losses in some post-harvest perishable fruits. Therefore, fruit storage technology is developed to keep the fresh fruit quality and inhibit its deterioration.

Many fresh fruit storage technologies are mainly used to inhibit the fruit's respiration and maintain its bactericidal antimicrobial ability. However, the intensities of fruit's respiration and microbial proliferation are related to environmental temperature, humidity and gas composition during the storage process. For instance, ethylene is one of the products of normal metabolism of plants. Right amount of ethylene would act as plant hormones and promote the organization's respiration and the fruit ripening. The fruit climacteric is usually accompanied with the increased release of ethylene and ethylene affects directly the climacteric frequencies and intensity in turn, while the adjustment of ethylene biosynthesis is intervened by many factors. For example, high temperature promotes the synthesis of ethylene and low temperature prevents the generation of ethylene and delays the fruit maturing process. Therefore, it is suggested to maintain fresh fruits in low temperature, high humidity, low oxygen, high carbon dioxide, low ethylene and sterile environments (without vinyl) and the opposite cases are unfavorable. On the other hand, the impacts of supply and the price differences of fruits between boom and slack seasons are particularly large in the market. For instances, when fruits come into the market, it is easy to form an excess supply with declining prices. When fruits are out of season, it will result in a higher selling price in the off-season due to scarce fruit supply. However, the higher selling price does not necessarily result in well-selling and good income for farmers due to issues of time delay, decay and nutrition loss during fruit transportation and storage before sales. It is important to develop new methods for maintaining and keeping the quality and shelf lives of fresh fruits and vegetables and improve the agricultural product efficiency and economic effectiveness in favor of solving the farmers' income issues. Many measures and considerations are involved in choosing an acceptable atmosphere conditions controlling technology due to the complexity and variety of impacting factors involved within the produce and storage processes, such as fruits' varying respiration rates that are temperature dependent, different optimal storage temperatures and different water content or absorption rates and ethylene releasing etc. (Thompson, 2010). One of the technologies is the Controlled Atmosphere (CA) and refrigeration has been the principal known facilities of successful storage of fresh fruits and vegetables to retain their freshness and flavors. This technology involves either actively or passively controlling the atmosphere conditions surrounding the fruit product within a package made of various types and/or combinations of storage films. Controlled Atmosphere (CA) storage was developed as a result of a research conducted into the quality keeping of preserved fruits (apples). The concept of controlled atmosphere storage was first proposed in the early 1940s and the first commercial usage of CA storage of apples was made in Europe in 1950s (Thompson, 2010).

Thompson (2010) reported that they stored apples in 1% O_2 with an alcohol detector fitted in some places of UK and it sounded an alarm that ethanol fumes were detected because of anaerobic (fermentation) respiration (Thompson, 2010). This enabled the store operator to increase the O_2 level and no damage found done to the fruits. The detector technology was subsequently further developed described a system named "dynamic control of ultra-low oxygen storage", based on headspace analysis of ethanol levels less than 1 ppm and O_2 levels maintained at 0.3-0.7% (Agar *et al.*, 1999; Thompson, 2010). A more recent method of CA storage uses other stress-associated metabolic responses of fruits and vegetables to low O_2 levels. Therefore, modern CA stores use the responses of actual fruits and vegetables being stored as monitors of the atmosphere conditions. The stress was detected and the storage atmosphere is adjusted to relieve the stress of fruits and vegetables stored, usually with a computer maintaining the O_2 levels (Agar *et al.*, 1999). Gorny *et al.* (1998) reported a serial of experiments on the quality changes in fresh-cut and fruit slices affected by factors, such as cultivar, fruit size, storage atmosphere and chemical treatments (Gorny *et al*., 1998, 1999, 2000; Gorny, 2001). Gonzalez-Aguilar *et al*. (2004) found the controlling of temperatures and modified atmosphere packaging had much effect on overall quality of fresh-cut bell peppers. Hodges and Toivonen (2008) also analyzed the quality of fresh-cut fruits and vegetables affected by exposure to abiotic stress. There were few reports about the controlled atmosphere storage and/or modified atmosphere storage or extending the shelf-life of intact fresh fruits after harvest yet (for reviews, see Soliva-Fortuny and Martin-Belloso, 2003; Lin and Zhao, 2007).

Kou *et al*. (2012) introduced measures of extending the shelf life of edible flowers with controlled release of 1-methylcyclopropene and modified atmosphere packaging. Zhu *et al*. (2013) conled genes encoding key enzymes involved in sugar metabolism of apple fruits and analyzed the correlation between sugar contents and gene expression or enzyme activities in fruits stored in air and CA storage. Fernandez-Leon *et al*. (2013) developed and compared the effects of different postharvest strategies (controlled atmosphere and adding 1-MCP) to preserve broccoli quality during storage and shelf life. Gago *et al*. (2013) compared the effects of temperature and CA technology on storage and shelf-life of Rocha pear treated with 1-methylcyclopropene. Martins *et al*. (2013) analyzed the quality of golden papaya stored under controlled atmosphere conditions. Recently, Alturki (2013) reported the technology utilization and effect of modified atmosphere packaging to extend the shelf-life of fresh figs. However, little attention was placed on the experiment on storage and/or preservation of fruits like cucumbers and tomatoes utilizing CA storage. In addition, researchers also found the natural ripening process of apples after harvest could be significantly slowed if the fruits could be stored in an atmosphere that was low in oxygen levels. As a result, particularly sealed rooms were developed into which apples could be placed and then the oxygen removed to enhance the keeping quality of the fruits. Since the inception of CA storage the availability of apples that are firm and crisp has expanded dramatically. The key point of controlled atmosphere storage is to regulate the ambient atmosphere's elements or gas component which is to appropriately increase the concentration of carbon dioxide and reduce that of oxygen. Meanwhile, it is of importance to properly maintain low temperature and proper humidity or moisture evaporation, so as to obtain a good result of fresh fruits' storage. CA technology could act significantly on the suppressing of fruit's respirations, slowing the fruit's ripening and aging processes, inhibiting the decomposition of chlorophyll, reducing the fruit's physiological and infectious diseases and extending the storage period of fruits and vegetables. It is very significant and urgent to carry out studies on storage life of fresh fruits with CA technology for improvement of the product efficiency and sustainable development of modern agriculture.

MATERIALS AND METHODS

Cucumbers and tomatoes: The samples of cucumbers and tomatoes used in this study were obtained from an experimental orchard in Hefei, Anhui province, China. Fruits were harvested and transported to the experiment centre in less than 1.5 h. They were then hydrocooled at a water temperature of 1°C in a 1000 L immersion hydrocooler equipped with a water recirculation system. Then they were grouped into 3-5 commercial ripening stages based on the fruit's size and colour.

Storage conditions: Fruits were packaged in polypropylene punnets and wrapped with macroperforated (mp) film with holes in a refrigerator with an atmosphere analyzer. Storage condition parameters were set as followed: Control groups (without controlled atmosphere) and two controlled atmosphere experimental groups (containing treatments (1) 3 O_2+10% CO_2 (2) 6 O_2+10% CO_2 (3) 8 O_2+10% CO_2 (4) 3 O_2+15% CO_2 (5) 6 O_2+15% CO_2 and (6) 8 O_2+ 15% CO_2 with various temperatures in refrigerator chambers.

Statistical analysis: Statistical analysis of the experiment data was carried out with SPSS 16.0 (SPSS Inc., Chicago, IL, USA).

RESULTS AND DISCUSSION

Effect of controlled temperatures on the storage life of fresh cucumber and tomato under given relative humidity: From Table 1, it was showed that the storage life of fresh cucumbers was 16~25, while the storage life of fresh tomatoes was 17~30 under controlled temperatures (10-16°C) and given relative humidity (90-95%) in CA storage. However, the respiration rates of fruits are temperature dependent and different storage temperatures impact sharply the maturity process and physicochemical changes of fresh fruits. Therefore, the optimum controlled temperatures should be 10-13°C for fresh cucumbers and tomatoes in CA storage. Meanwhile, the reported optimized relative humidity was 85-90%. A few experiments were also done and it's found that the relative humidity variation scope could be wide than this, i.e., 85-95%. Moreover, the combination of relatively low temperature (freezing temperature, e.g., 0°C) and relative high humidity (e.g., 95%) could considerably extend the storage or shelf life of frozen fruits (Table 3). Thus, the essential optimized parameters of CA storage for cucumbers and tomatoes were suggested as following: Temperature (10-13°C, with a variation of ±1°C), relative humidity (90-95%) and maintaining appropriate atmosphere or gas composition, such as 6% oxygen and 15% carbon dioxide. It was also shown that the oxygen was necessary and its concentration should be regulated as below 10%. Otherwise, the fruit will suffer over-aging or hypoxic injury. At the same time, the carbon dioxide should be controlled to avoid carbon dioxide poisoning.

Table 1: Experiment data for fresh cucumbers and tomatoes stored under controlled temperatures (5-16°C) and relative humidity (90-95%)

	Cucumbers' storage and/or shelf-life (day)		Tomatoes' storage and/or shelf-life (day)	
Group No.	Storage temperature (°C)	Controlled temperatures and relative humidity (90-95%)	Storage temperature (°C)	Controlled temperatures and relative humidity (90-95%)
1	5±1	10	5±1	12
2	5±1	11	7±1	13
3	7±1	12	7±1	14
4	10±1	16	10±1	17
5	13±1	~20	13±1	25
6	16±1	~25	16±1	30

Table 2: Experiment data and recommendations for optimum temperature, relative humidity, commercial storage life, temperature and water content for fresh cucumbers and tomatoes

	Parameters				
Fruit variety	Optimum temperature (°C)	Relative humidity (%)	Maximum storage time (day)	Freezing temperature (°C)	Water content (°C)
Cucumber	10-13	95	10-14	-0.5±0.2	96.1
Green ripe tomatoes	12-21	90-95	7-21	-0.6±0.2	93.0
Firm ripe tomatoes	8-10	90-95	28-49	-0.5±0.2	94.1

Table 3: CA storage recommendations for some fresh fruits and vegetables stored in air

Fresh fruit and vegetables product	Atmosphere temperature range (°C)	O_2 (%)	CO_2 (%)
Apple	0-5	1-2	0-3
Apricot	0-5	2-3	2-3
Grapes	0-5	2-5	1-3
Grapefruit	10-15	3-10	5-10
Lemon	10-15	5-10	0-10
Lime	10-15	5-10	0-10
Mango	10-15	3-7	5-8
Orange	5-10	5-10	0-5
Peach	0-5	1-2	3-5
Pear (Asian)	0-5	2-4	0-3
Pear (European)	0-5	1-3	0-3
Plum	0-5	1-2	0-5
Tomatoes (green)	12-20	3-5	2-3
Tomatoes (ripe)	10-15	3-5	3-5
Potato	7	-	-
Mandarin/tangerine	4-7	-	-

Usually a relative humidity of 90-95% is recommended (Source: Gorny, 2001; Gorny *et al.*, 1998, 1999, 2000). Specific CA combination depends on cultivar, temperature and duration of storage. These recommendations are for transport or storage beyond 2 weeks. Exposure to lower O_2 and or high CO_2 concentrations for shorter durations may be used for control of some physiological disorders, pathogens and insects

Mechanism physicochemical changes of fresh cucumber and tomato in controlled atmosphere storage

General mechanism of fruit's quality changes of cucumber and tomato after harvest: Cucumber and tomato are the indispensable staple food of China. Cucumber is a kind of thermophilic plant with delicious and nice taste. For cucumber, its product is a kind of fruits and/or fruit-like vegetables (referred to as "fruit" subsequent to this part), rich in nutrient elements and in favor of reducing the body's blood pressure and cholesterol. In fact, the fruit is proved containing SOD (abbreviation for Super-Oxide Dismutase) which has the efficacy of hairdressing or beauty-keeping, diet-slimming and body-building. The full requirements for fruit quality of fresh cucumber is that it should be uniform dark green in fruit color, tasted fragrant and crisp in texture with hard and smooth surface and no bitter, containing no momordicin and yellow stripe. Usually, it is also selectively short in shape for easy packing, transport and sales.

For tomatoes, it is frequently reported sweet and juicy, containing soluble sugars, organic acids, protein, vitamin A and vitamin C and other nutrients. It is also proved to have the efficacy of clearing heat and promoting fluid, promoting good digestion, lowering cholesterol and slowing the spread of tumor and/or cancer. The requirements for fruit quality of fresh tomato is that it should be unique flavor, crisp in flesh texture and uniform color at the time of mature or near-mature, evenly colored, in darker fruit color, with smooth surface, small fruit pedicle top marks, no edges fold and its fruit shape index being close or equal to 1.0. Moreover, the tomato vines should be hollow woody stems, small round and no longitudinal or ring crack in fruit.

Physiological and biochemical changes in mature cucumber and tomato: When cucumber and tomato are ripe, the fruits will completely enter mature and aging stages after the climacteric periods of fruit aerobic respiratory chains. During those periods, there are various internal transformations of organic substances in the fruits. Meanwhile, photosynthesis related organic substances, including sugars and nitrogen-containing substances, will be transported to the fruit organisms during the plants' development. It should be noted that there is a conversion of sugar into starch and fat to be stored up in fruit and cells. Initially, the conversion amount of starch will reach the maximum levels and then decrease to normal levels. In the process, there are opposite conversions between sugar and starch during the maturing of fruits. In other words, the starch would be converted into small molecular sugars (such as glucose, fructose and sucrose, etc.) under the catalytic action of amylase, resulting in the sweetness of mature fruit. Simultaneously, there are also a lot of citric acids and malic acids in the unripe fruits, leading to the sour taste of fruits after harvest ahead of time. Although, the organic acids produced by respiration in mature fruits could also be transformed into amino acids and proteins and/or peptides, there are rarely proteins or peptides existing in mature fruits.

In the maturing period of fruits, the proto-pectinase's degradation gives rise to soluble pectin which will be decomposed by pectin pectinase to be pectic acids. The pectin and pectic acids could further be decomposed by pectate enzyme or pectin lyase to form galacturonic acids. Meanwhile, the pectin between cells is broken and cell walls will be separated from each other. It is regarded that the formation and decomposition of pectin are relevant to fruits' abscission. In addition, the flesh of mature fruits will become soft and juiciness. Immature fruit contains some bitterness due to its tannin-like substances, while the flavor of ripe fruit or mature fruit taste fragrant and sweet due to its esters, aldehydes and ketones. Young fruit's peel appears to be green due to the action of chlorophyll, while adult fruit's peel will be yellow or red or orange since the chlorophyll has broken down into mature carotenoid or anthocyanin. It is well-known that high temperature and adequate oxygen will be conducive to the formation of anthocyanins. After photosynthesis, the sugar-acid proportion of mature fruits constitutes unique flavors of the fruits.

Impacting factors of fruit quality changes of cucumber and tomato after harvest: During the fruit's maturing period, many growth and development related factors, such as temperature, humidness, oxygen and respiration, act on the fruit quality and give rise to physiological and biochemical changes of cucumber and tomato after harvest.

Aerobic respiration: Many fruits will be ripe indicated by the decomposition of starch into sugar and the color changes from green to red or orange or yellow, without decomposed pectin when they grow to their full sizes in the future accompanied by internal changes during growth and/or development. Thus, the quality of mature fruit will be soft and sweet with bright colors. During the maturation process, fruit goes through a type of special aerobic respiration, i.e., the respiration intensity will be first a bit low, then suddenly rising and abruptly being increased at last. Fruit will entered its mature period after such a cellular changing and turning process of aerobic respiration. This cellular turning process of aerobic respiration peak before fruit maturity would lead to a phenomenon called fruit climacteric (or climacteric fruit).

During these processes above, the aerobic respiration intensity becomes up to 5 times of that before fruit climacteric. It is believed the intensity and strength of fruit climacteric are relevant to the transition time and temperature. Gonzalez-Aguilar *et al.* (2004) found the controlling of temperatures and modified atmosphere packaging had much effect on overall quality of fresh-cut bell peppers. The effect of temperature on respiration mainly lies in the impacts of temperature on the activity of respiratory enzymes. Within a certain range of temperature, the fruit respiration rate

Table 4: CA storage recommendations for some fresh fruits at various temperatures

Fresh fruit product	Atmosphere temperature range (°C)	O_2 (%)	CO_2 (%)	Respiration rates (mg CO_2 kg^{-1} h^{-1})
Apple (sliced)	0-5	<1	-	-
Cantaloupe (cubed)	0-5	3-5	6-15	4.0-31.2
Honeydew (cubed)	0-5	2	10	3.6-10.2
Kiwifruit (sliced)	0-5	2-4	5-10	2.0-6.0
Mango (cubed)	5	2-4	10	-
Orange (sliced)	0-5	14-21	7-10	5.3-5.7
Peach (sliced)	0-5	1-2	5-12	6.0-44.9
Pear (sliced)	0-5	0.5	<10	0.0-10.0
Persimmon (sliced)	0-5	2	12	-
Pomegranate (arils)	0-5	-	15-20	-
Strawberry (sliced)	0-5	1-2	5-10	-
Watermelon (sliced)	3	3	10-20	-

Source: Gorny *et al*. (1998)

will rise along with the increase of temperature but decrease later after reaching the highest peak with optimum temperature (generally 12-15°C, Table 3-4). Aerobic respiration not only consumes the cellular storage of nutrients but also improves the cellular temperature and microbial activity. Hodges and Toivonen (2008) analyzed the quality of fresh-cut fruits and vegetables affected by exposure to aerobic respiration and found the improved cellular temperature led by aerobic respiration will accelerate the deterioration of fruits, resulting in a fair mount of economic loss. Hence, the basic principle of fruit storage, safety and preservation is to reduce the respiration intensity and delay the timeliness of fruit climacteric.

Moisture evaporation: Cucumber and tomato are fruits high in water content. There will be a large amount of water loss, wilting, dry, intender, sensory quality decline loses and edible when they are placed in the circumstances of relatively low humidity under the action of moisture evaporation. Usually a relative humidity of 90-95% is recommended (Gorny, 2001; Gorny *et al.*, 1998, 1999, 2000). Specific CA combination depends on cultivar, temperature and duration of storage and exposure to lower O_2 and or high CO_2 concentrations for shorter durations may be used for control of some physiological disorders, pathogens and insects (Table 3-4).

Fruit maturation: Maturation may also cause the quality changes of fruits. For instance, maturation occurred from down to up in succession in cucumber vines. Therefore, if the mature fruit is not timely harvested, the pulp nutrients will quickly shift to its seed resulting in the fruit quality decreasing. In the case of ripe tomatoes, there are a series of complex biochemical changes in the fruit among its organizations during maturation. The fruit will first turn to red and its hardness gradually reduces, followed by the gradual increase of respiration intensity with high content of cellular ethylene and much production of poly-galacturonic acid. It should be noted that the latter (i.e., poly-galacturonic acid) plays a decisive role in the formation of fruit softening which is a negative impact factor in the storage of fruits and vegetables.

Physiological disorders: The physiological disorders matter indeed in the fruit freshness retaining, storage. There are many influence factors resulting in physiological disorders, such as high and low temperatures, adverse weather, dry and dehydration and insect pests. For instance, in the case of chilling damages, the main factor is low temperature. If cucumber and tomato were in the storage temperatures less than 8°C, fruits could produce a little of sag of plaque or local tissue necrosis. However, temperatures more than 15°C would accelerate the group metamorphic and aging process of cucumbers and tomatoes. On the other side, If the temperature is below the freezing point of cell sap (0.5-0.7°C, Table 1-4), the fruit organization would be full of ice. Subsequently, the fruit freezes with the free water infiltrating in the intercellular space and cell walls, resulting ice crystals and the cellular bioplasm dehydration paradox. Due to ice crystals expanding and cytoplasm water freeze, the organization of cell membrane structure prones to be destroyed by mechanical force. Moreover, the cellular bioplasm dehydration, the increased concentrations of acids and ions would cause the protoplasm damage and degeneration, namely chilling injury.

In another case of respiratory disorders, cucumber and tomato are affected by the deviant concentration of oxygen and carbon dioxide during cellular respiration, the fruits' flavors and colors will be changed and damaged accordingly (Table 3-4). Such as the anoxic injury disorder, it is due to low oxygen with a small amount of brown patches hypoxia or somewhat slight subsidence in the fruit surface. Moreover, long-term hypoxia would lead to respiratory accumulation of alcohol and poisoning cellular soft rot. Another example is the carbon dioxide poisoning caused by excessive carbon dioxide with the fruit's surface and peel producing many small circular concave spots or apparent subsidence fruit bark. The third case is cellular physical injury of cucumber and tomato. When fruits are squeezed or collision damaged, there will be much tissue fluid outflow and loss of nutrients, as well as microbial infection. Simultaneously, the amount of fruit organization ethylene will increase to 10-100 folds of the normal levels which could corrupt fruit organization. There are many other influence factors affecting the quality of fruits too, such as microorganisms and post-harvest growth factors.

Measures suggested for fruit quality control of cucumber and tomato in CA storage after harvest: Through the above analysis, it is obvious that the main damage factors people can regulate and/or control in the process of fruit storage are suitable temperature, humidity, gas composition, microorganisms and the environment conditions causing physical injury.

Fruit's physical damage: For the case of cucumber and tomato, we should take appropriate harvesting methods, methods, appropriate packaging and transport conditions, in order to reduce fruit physical damage.

Atmosphere's relative humidity: The control measures of the relative humidity are aimed to take the approaches and methods reducing water transpiration or evaporation in fruits, such as packaging, waxing and coating which could make a 50% reduction in fruit water loss. These measures can also increase the sense of peel glossiness and color quality of the fruits. There are some other measures to increase environmental humidity, proper ventilation, refrigerator and breeze libraries too.

Atmosphere's temperature: According to the thermal characteristics of cucumber and tomato, these fruits are susceptible to cold injury. Thus, we could take suitable or appropriate control measures to make stable storage temperatures.

Atmosphere or gas composition: The scientific basis for the application of controlled atmosphere technology to the storage of fresh fruits and vegetables has been the subject of considerable research which seems to be progressively increasing and booming (Thompson, 2010). The theory is based on the concept that the natural ripening process of apples after harvest could be significantly slowed in a hypoxia atmosphere. It is the essential of controlled atmosphere technology to reduce oxygen concentration and increase carbon dioxide concentration. High concentration of oxygen is in favor of promoting the fruit ripening and aging processes, while high concentration of carbon dioxide will inhibit the ripening and aging processes of fruits. The combined impact of low oxygen and high carbon dioxide inhibition on fruit ripening is also related to the amount of ethylene release. The conversion of amino trimethylene acid to ethylene needs a certain concentration of oxygen and the decrease of oxygen concentration will inevitably reduce the ethylene release and its impact (Agar *et al*., 1999). For instance, it was reported that when the oxygen concentration was as low as 2.5%, the potency of ethylene would reduce by half and the interaction of ethylene with the receptor site of fruit cellular matrix required some oxygen too. In the extreme cases, the potency of ethylene would be blocked combined with the oxygen concentration less than 8%. More importantly, carbon dioxide is revealed as a competitive inhibitor of fruit ethylene since it could substitute the cellular receptor site for ethylene. Carbon dioxide could also prevent the accumulation of auxin and its efficacy, while the fruit ethylene release needs the promoting of auxin. Therefore, when the concentration of auxin is limited or absent, the production of fruit ethylene will be blocked.

CONCLUSION

The objectives of this study were to evaluate the effect of different controlled temperatures and analyze the parameters of the controlled atmosphere storage for fresh cucumbers and tomatoes. The optimum relative humidity was reported as 85-90%. Meanwhile, the combination of relatively low temperature (e.g., 0°C) and relative high humidity (e.g., 95%) could considerably extend the shelf life of frozen fruits (Table 1-2). Therefore, the essential combination of different parameters of controlled atmosphere storage for cucumber and tomato should be set as following: Temperature (10-13°C, with a variation of ±1°C), relative humidity (90-95%), appropriate gas composition, such as 6% oxygen and 15% carbon dioxide.

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