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THE SHELF LIFE AND IN PACKAGE COOKING OF READY-TO-EAT FRESH ASPARAGUS IN MICROWAVEABLE MAP AND VSP TRAY SYSTEMS

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THE SHELF LIFE AND IN PACKAGE COOKING OF READY-TO-EAT FRESH ASPARAGUS IN MICROWAVEABLE MAP AND VSP TRAY SYSTEMS

By

Patnarin Benyathiar

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ABSTRACT

THE SHELF LIFE AND IN PACKAGE COOKING OF READY-TO-EAT FRESH ASPARAGUS IN MICROWAVEABLE MAP AND VSP TRAY SYSTEMS

By

Patnarin Benyathiar

Asparagus (*Asparagus officinalis* L.) is one of the most popular cuisine vegetables. To assess the quality as a packed ready-to-eat product, fresh green asparagus (Michigan and Peru) was cut to the length of 6 inches, sanitized with sodium hypochlorite and then packed in commercially available microwaveable modified atmosphere packaging (MAP) and vacuum skin packaging (VSP) trays. Weight loss, moisture content, pH, O_2/CO_2 content in the package headspace, microbial growth and sensory shelf life (odor, color, texture and overall quality) were analyzed throughout the storage time. Michigan asparagus was packed and stored at 1°C and 8°C, 80% RH for 18 storage days. The sensory results showed that the shelf life of asparagus stored under MAP was longer than that stored under VSP. MAP of asparagus, stored at 1°C and 8°C was able to maintain product quality through 18 days and 15 days, respectively, whereas the VSP package maintained product quality for only 9 days at 1°C and 3 days at 8°C. Asparagus was also stored at a commercial storage temperature (4°C, 80% RH) for 21 days. The MAP system maintained asparagus quality throughout the 21 days while the VSP system maintained product quality until day 18. Microwave cooking time and power level affected the quality of the cooked asparagus. Either 2 or 3 min cooking time at full power was satisfactory for the MAP while 2 min at full or medium power was satisfactory for VSP.

This thesis is dedicated to

My parents, Suchint Benyathian and Sopit Benyathian, my sister Asaya Benyathian and my grandparents

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1. INTRODUCTION

This thesis has been divided into three chapters. Chapter one focuses on the shelf life of fresh Michigan asparagus using two different techniques: modified atmosphere packaging (MAP) and vacuum skin packaging (VSP), and the effect of two different storage temperatures: 1°C and 8°C on the quality of fresh asparagus. Chapter two focuses on the shelf life of fresh asparagus in modified atmosphere packaging (MAP) and vacuum skin packaging (VSP) microwaveable tray systems at a commercial storage temperature of 4 °C. In chapter three, the effect of cooking time on the quality of cooked fresh cut asparagus in modified atmosphere packaging (MAP) and vacuum skin packaging (VSP) microwaveable trays at 4° C was studied. A consumer sensory acceptance test comprising the following attributes: aroma, appearance/color, texture, flavor and overall acceptability, was used to evaluate the quality of cooked asparagus at different cooking times and temperatures. The appearance of product in these two different packaging techniques was also considered important for the marketing of fresh asparagus.

1.1 Asparagus Harvest

Asparagus belongs to the Lily family (Asparagus *officinalis* L.) and has been cultivated for over 2000 years. However, the original habitat in which asparagus was grown is cloudy. Asparagus was first known by Greeks and Romans, and means sprout or shoot in Greek, and was first domesticated by the Macedonians about 200 B.C (MAAB 2005).

Asparagus crowns are planted about a foot deep in sandy, clay-loam, peat or muck solids with a pH 6.0-6.8. Generally, asparagus is planted from seeds and the first harvesting begins after the third year of transplanting when crowns have been well established and the plants have developed a strong fibrous root system (MAAB 2005). The edible part of asparagus is the young shoot, commonly called the spear. For green asparagus, spears are cut when their height is eight or ten inches above the soil in early summer by hand snapping or cutting with a special long-handled knife below the soil surface (Hexamer 1901). Due to its perishable nature, asparagus has to be cooled immediately by storing at 0°C (32°F) to 2°C (35.6°F), 95% RH, or through hydrocooling after harvesting to remove the field heat. Asparagus can be affected by chilling injury if stored at 0°C for more than 10 days, resulting in limp, wilted stalks and darkened spots near the tips (Lutz and Hardenburg 1968; Mills 2001; Luo and others 2006)

1.2 Asparagus Market

There are two varieties of asparagus in today's marketplace based on the color of the spears: green and white asparagus. Green asparagus is more popular in the US market than white asparagus, which is widely eaten in Europe

and Japan (MAAB 2005). According to the world asparagus report (2004 Food and Agriculture Organization (FAO) of the United Nations and FAS/China), the United States is ranked third in asparagus production. In 2005, cultivated land in the U.S. in asparagus production was 54,000 acres which yielded 90,200 tons of asparagus (World Horticultural Trade & U.S. Export Opportunities 2005). The three largest asparagus producing states in the U.S. are California, Washington and Michigan, according to the USDA (2006), as indicated in Table 1.1 (Peirce 1987; MAAB 2005; USDA 2006).

Table 1.1: The regional production of asparagus including fresh market and processed from 2005 to 2006 (Kleweno 2006; USDA 2007).

State	Area Harvested		Area for Harvest 2007	Yield Per Acre		Production	
	2005	2006		2005	2006	2005	2006
	Acres			Cwt.		1,000 Cwt.	
California	24,100	24,000	23,000	32	25	770	600
Washington	13,000	9,000	7,500	41	42	532	378
Michigan	12,200	11,700	11,500	19	22	232	257
TOTAL	49,300	44,700	42,000	31	28	1,534	1,235

1.3 Characteristics of Fresh Green Asparagus

Asparagus has a pencil shape, which translates into a long green spear with tight scale-like leaves and compact tips. The grading of asparagus is based on its freshness (including color of spears and tips), length, diameter of stalks and the amount of bruises (MAAB 2005). The definition of freshness from the USDA is that "the stalk is not limp or flabby". The characteristics of high-quality fresh green asparagus are its firm, fairly straight and shiny deep green stalks or bluish green stalks with a minimum of white stems, and tightly closed and compact tips. It should also be disease free (UCCE 2006), and the third quarter

of the stalk length should be green (Lipton 1990; U.S. Department of Agriculture 1997). According to the United States standards for grading of fresh asparagus, the spear size is identified by its diameter, measuring at a point approximately 1 inch from the butt. The 5 asparagus spear sizes are shown in Table 1.2 and Figure 1.1.

Table 1.2: The sizes of asparagus spears used in grading (U.S. Department of Agriculture 1997)

Sizes of Asparagus Spears	Diameter
Very small spears	less than 5/16 inch
Small spears	5/16 – less than 8/16 inch
Medium	8/16 – less than 11/16 inch
Large	11/16 – less than 14/16 inch
Very large	14/16 and more

Figure 1.1: The small, medium and large size grades of fresh asparagus spears

1.4 Nutritional Value of Fresh Asparagus

Asparagus is one of the most nutritionally well-balanced and most consumed vegetables in the world. It has a high fiber level and a wealth of nutrients, and very low sodium and calorie content. Additionally, asparagus is an excellent source of vitamin A, vitamin B, vitamin C, carotenoids, folic acid,

potassium, copper, and zinc (California Asparagus Commission 2007) as shown in Table 1.3. Several published research papers describe the benefits of folic acid as being necessary in blood cell formation, reduction of neural tube birth defects and protection against liver disease (MAAB 2005).

Table 1.3: The nutritional value of green asparagus (Rubatzky and Yamaguchi 1997)

Composition	Percent (%)	Composition	Percent (%)
Water	92.2	Vitamin B1	0.20
Calories	22	Vitamin B2	0.14
Carbohydrate	3.8	Niacin	2
Protein	2.60	Calcium (Ca)	22
Fat	0.21	Phosphorus (P)	67
Fiber	0.77	Potassium (K)	271
Ash	0.79	Sodium (Na)	2
Vitamin A	950	Magnesium (Mg)	18
Vitamin C	33	Iron (Fe)	0.8

1.5 Packaging of Asparagus

Due to its high metabolic (respiration) rate, asparagus deteriorates very rapidly after harvesting. Thus, controlled atmospheric storage (CAS), an agriculture storage method, is used to extend the shelf life of fresh asparagus by constantly monitoring and adjusting the oxygen (O_2) and carbon dioxide (CO_2) level within a gas-tight storage chamber. Modified atmosphere packaging (MAP) can also be used to maintain the freshness of fresh produce.

Modified atmosphere packaging (MAP) (Figure 1.2) is a packaging technique used to create a balance between the produce respiration and the gas permeability of polymeric packaging films to create an optimum atmosphere. In general, there are 2 types of modified atmosphere packaging: active and passive. An active modified atmosphere package is established by flushing out the initial

atmosphere within the package and then replacing it with a gas mixture, usually nitrogen, oxygen and carbon dioxide. This technique is used for O_2-sensitive products such as fresh-cut lettuce or potatoes to slow down enzymatic browning (Charles and others 2003). A passive modified atmosphere package depends on the product respiration and the permeability of the package to adjust the atmosphere in the package passively (Farber and Dodds 1995).

Vacuum skin packaging (VSP) (Figure 1.2) is a newer packaging technique which can be used for fresh produce to maintain its freshness and extend its shelf life. It is established by evacuating the air and sealing the package without deliberate replacement with any gas mixture.

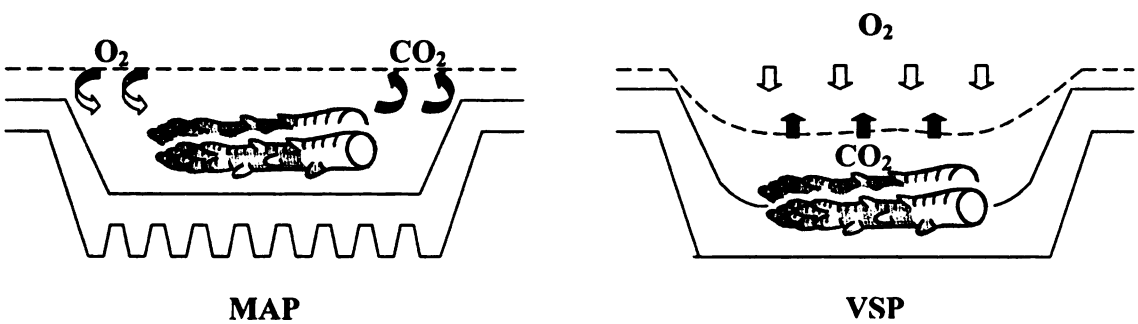

Figure 1.2: A schematic representing modified atmosphere packaging and vacuum skin packaging systems

In this study, both passive modified atmosphere packaging (MAP) and vacuum skin packaging were used to maintain the shelf life of fresh cut asparagus at 1°C, 4°C and 8°C.

The overall objective of this work was to determine the shelf life of fresh asparagus using two different packaging techniques and three storage-temperature combinations. Other objectives included the verification of the cooking time and temperature for these microwaveable products and to examine

the feasibility of these packages for fresh asparagus in the market. This work will help to develop packaged fresh-cut asparagus as a value added, ready-to-eat product using microwavable packaging.

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2 Literature Review

2.1 Michigan asparagus

Asparagus (*Asparagus officinalis* L.), a unique perennial vegetable, is a member of the lily family (Liliaceae) (Hexamer 1901; Peirce 1987), and is one of the most consumed vegetables in the world. The United States ranks third in the world's biggest asparagus producers and consumers of fresh asparagus with 102,780 tons in 2004, behind China (587,500 tons) and Peru (186,000 tons) (World Horticultural Trade & U.S. Export Opportunities 2005). The principal production and consumption in the U.S. market is green asparagus (Luo and others 2006).

After California and Washington, Michigan ranks third in the U.S. in total asparagus production with approximately 7,700,000 lbs. of asparagus, worth 18 million dollars annually on farmland mostly near the Lake Michigan shoreline in both the west and southwest areas (Hart and Shelby or between South Haven and Benton Harbor) of the state because of the moderate temperatures and loamy soils (MAAB 2005; USDA 2006). In addition, asparagus also ranks third as the most important Michigan vegetable crop, behind cucumbers and snap beans (Taylor 1979). Unlike asparagus from other states, Michigan asparagus is harvested traditionally by hand-snapping above the ground. This snap method not only requires less labor but also makes the product tender and tasty, resulting in one of the best asparagus in the United States. The growing season for Michigan asparagus is very short, starting from late April through July, as illustrated in Table 2.1 (MDA 2007).

Table 2.1: The yearly harvest seasons of Asparagus in North America and South America (Benson 2005)

Country	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
N. America												
Canada (Ont))					******	******						
Costa Rica	******	******	******	******	******	******	******	******	******	******	******	******
El Salvador	******	******	******	******	******	******	******	******	******	******	******	******
Guatemala	******	******	******	******	******	******	******	******	******	******	******	******
Honduras	******	******	******	******	******	******	******	******	******	******	******	******
Mexico	******	******	******	******		******	******	******	******	******	******	******
Nicaragua	******	******	******	******	******	******	******	******	******	******	******	******
Panama	******								******	******	******	******
U.S.A												
California	**	******	******	******	******	****						
Washington				******	******	******						
Michigan				**	******	******	**					
S. America												
Argentina								***	******	******	******	******
Brazil	******	******	******								******	******
Chile								**	******	******	******	**
Colombia	******	******	******	******	******	******	******	******	******	******	******	******
Ecuador	******						******	******				******
Peru	******	******	******	******	******	******	******	******	******	******	******	******
Uruguay									******	******	******	***

2.2 Michigan asparagus market

The marketplace for fresh Michigan asparagus is in the northeast and midwest and is affected by product preference, preparation technique and consumption habits (Behe 2006). There are many value added products made from asparagus in today's market such as pickled asparagus, canned asparagus and frozen spear/cut asparagus. According to a strategic plan for the Michigan asparagus industry which was presented at a Michigan State University workshop (2000), in 1998 total fresh market asparagus was reported to be 4,000,000 lbs. with a value of $2.6 million, while processed asparagus accounted for 24,000,000 lbs. with a value of $14.9 million. In 2000, the Michigan Asparagus Advisory Board demonstrated that only 15% of the harvest is purchased as fresh asparagus in the fresh vegetable section of the grocery store and/or at a roadside market. 85% of the yield is sold for food processing, about 38% of which goes to frozen (cuts & tips or spears) and 62% as canned asparagus (cuts & tips or spears). However, market researchers from MSU showed that the per capita consumption of fresh asparagus is increasing at a rate greater than other fresh vegetables while the consumption of processed asparagus is unchanged or declining. Hausbeck and others (2002) reported that the consumption of fresh asparagus in the U.S. market has increased at a compound annual growth rate of 14% since 1996. The world consumption of fresh asparagus grew rapidly from 1997 to 2005 and this growth was more than canned and frozen asparagus (Table 2.2) (IAS 2007).

Table 2.2: The percent consumption of asparagus spears utilized as fresh, canned and frozen in 1997, 2001 and 2005 (Benson 2005)

Countries	Fresh			Can			Frozen		
	2005	2001	1997	2005	2001	1997	2005	2001	1997
Asia									
China	38	25	1	30	55	90	32	20	9
India	100	5		0	95		0	0	
Indonesia	100	100	100	0	0	0	0	0	0
Iran	100			0			0		
Japan	100	97	90	0	3	10	0	0	0
Korea	100			0			0		
Malasia	100	100	100	0	0	0	0	0	0
Pakistan	100			0			0		
Philippines	100	100	100		0	0		0	0
Thailand	100	98		0	2		0	0	
Europe									
Austria	100		100	0	0	0	0	0	0
Belgium	100			0	2		0	0	
Bulgania	100			0			0		
Cyprus	100		100	0	0	0	0	0	0
Czech Rep	100		100	0	0	0	0	0	0
Denmark	100		100	0	0	0	0	0	0
Frence	100		100	0	0	0	0	0	0
Germany	99		100	0	0	0	1	0	0
Greece	100		100	0	0	0	0	0	0
Hungary	100		100	0	0	0	0	0	0
Israel	100			0			0		
Italy	99		100	0	0	0	1	0	0
Netherlands	100		100	0	0	0	0	0	0
Norway	100			0			0		
Poland	90		90	9	10	0	1	0	0
Portugal	100		100	0	0	0	0	0	0
Romania	100		100	0	0	0	0	0	0
Slovakia	100			0			0		
Slovinia	100			0			0		
Spain	70		90	20	5	5	10	5	5
Switzerland	100		100	0	0	0	0	0	0
Turkey	100			0			0		
United Kingdom	100		100	0	0	0	0	0	0

Table 2.2 (continued)

Countries	Fresh			Can			Frozen		
	2005	2001	1997	2005	2001	1997	2005	2001	1997
North America									
Canada (Ont.)	100	88		0	12		0	0	
Costa Rica	100	100	100	0	0	0	0	0	0
El Salvador	100	100	100	0	0	0	0	0	0
Guatemala	100	100	100	0	0	0	0	0	0
Honduras	100	100	100	0	0	0	0	0	0
Mexico	100	90	90	0	0	0	0	10	10
Nicaragua	100	100	100	0	0	0	0	0	0
Panama	100	100	100	0	0	0	0	0	0
United States		45	50		50	40		5	10
California	100	99	99	0	1	1	0	0	0
Washington	65			30			5		
Michigan	20			40			40		
South America									
Argentina	65	70	70	20	30	30	15	0	0
Chile	25	50	35	0	0	10	75	50	55
Colombia		30	30		70	70		0	10
Ecuador	100	90	90	0	10	10	0	0	0
Peru	60	45	35	30	50	60	10	5	5
Uruguay		80	80		0	0		20	20
Africa									
Egypt	100	100		0	0		0	0	
Morocco	100	100		0	0		0	0	
South Africa	55	33		45	67		0	0	
Tunisia	100	100		0	0		0	0	
Zimbabwe			100			0			0
Australian Area									
Australia	95	90		5	10		0	0	
New Zealand	40	35		55	50		5	15	

2.3 Pathogenic microorganisms and degradation of asparagus

The presence and contamination by parasites, pathogenic and spoilage microorganisms including bacteria, yeast and mold on fresh produce can happen in the field before and/or during harvest, and during postharvest handling, processing, packing and distribution (Zagory 1999). Viruses are also important

risk microbes (Beuchat 1998). The presence of spoilage and pathogenic microorganisms on whole and fresh-cut produce can increase the risk of foodborne disease outbreaks and spoilage, leading to a reduction in fresh produce quality and creating a safety risk.

In the U.S., most of the known foodborne illness outbreaks are reported by consumers who suspect a relationship with the food that they have eaten and the disease they have (Guzewich and Salsbury 2001). Data from the Foodborne Outbreak Surveillance System for 1973 through 1997 shows that the epidemiologic investigation of a produce-implicated illness outbreak, occurring in two or more cases of the same illness, is associated with uncooked fruits, raw vegetables, salad and juice (Sivapalasingam and others 2004). More than 50% of the sources of foodborne illness outbreaks in the U.S. are unknown between 1973 - 1987 and 1988 -1992. Between 1995 and 1998, nine foodborne disease outbreaks caused by *Salmonella* or E.coli O157:H plagued Michigan, Missouri, California, Washington, Arizona, and Nevada. These epidemics injured more than 1234 people who consumed fresh vegetable sprouts, especially from alfalfa and clover seed (Buck and others 2003). Every year approximately 6 to 8 million people in the U.S. are affected by foodborne diseases that cause the death of 9,000 people and cost 5 billion U.S dollars (Altekruse and others 1997). Consequently, food safety and human pathogens are an increasingly important consumer health concern.

Common microorganisms found in vegetables are Pseudomonas (especially members of the *P. fluorescens* and *P. syringae* groups, and

Xanthomonas campestris), *Erwinia*, coryneforms, lactic acid bacteria, (spore formers, coliforms, micrococci), *Salmonella* spp., *Shigella* spp, *Y. enterocolitica*, *E. coli* O157:H7, *L. monocytogenes*, *C. botulinum*, *B. cereus,* yeasts and molds (FDA/CFSAN 2004). Molds that are related to the spoilage of vegetables included *Botrytis, Alternaria, Sclerotinia, Colletotrichum, Rhizopus, Phomopsis, Ceratocystis, Geothrichum, Cladosporium, Rhizoctonia, Phytophthora, Perenospora*, *Bremia, Aspergillus, Penicillium, Fusarium*, and *Mycosphaerella.* Some microorganisms which cause spoilage of vegetables can produce toxic metabolites, whereas others are human pathogens which can cause a serious health condition (Tournas 2005). Both bacteria and fungi are able to spoil fresh produce by secreting pectolytic enzymes which can soften and disintegrate plant tissues. As a result, that tissue is broken down and will be mushy, which is referred to as rot. For most vegetables, spoilage can be caused by either fungi or bacteria when the pH ranges between 5.0 and 7.0, while the spoilage of most fruits is caused by fungi when the pH is lower than 4.5 (Forsythe and Hayes 1998). Normally, fresh produce has particular characteristics, which influence the types of spoilage and pathogens which may be present. For example, large numbers of Lactobacillus and other lactic acid bacteria have been found on carrots while apples have large numbers of yeasts (Zagory 1999).

For asparagus, the most common postharvest microbial diseases are bacterial soft rot, Fusarium rot and Phyrophthora rot. The soft rot caused by *Erwinia carotovora* is the most important asparagus market disease. These bacteria can enter into the plant tissue from cut or bruised parts, causing watery,

slimy spears and producing a foul odor. Fusarium rot, which is caused by various *Fusarium* species, makes asparagus spears soften and discolor. White, fluffy mycelium may also appear on the asparagus spears. The main characteristic of the Phytophthora rot disease which is caused by several *Phytophthora* species is wet lesions on the spears usually in the area between the bottom of the tips and butt ends. *Penicillium* and *Botrytis cinerea* are also important organisms which affect asparagus (Tournas 2005). In addition, *Aeromonas* is a bacterial pathogen that has been found to cause the spoilage of asparagus (Buck and others 2003) as shown in Table 2.3.

Table 2.3: Some microorganisms which cause spoilage in asparagus (ASHRAE 2002)

Microorganisms	**Types of spoilage**	**Syndrome**
Bacteria		
Erwinia carotovora	Soft rot bacteria	Mushy, soft, water-soaked areas on tips and cut ends of asparagus
Aeromonas		
Fungi		
B. cinerea	Gray mold rot	
Geotrichum candidum	Sour rot	
Fusarium	Fusarium rot	Water-soaked areas, changing stalks through yellow to brown color, principally on asparagus tips; white to pink delicate mold
Phytophthora	Phytophthora rot	Large, water-soaked, or brownish wound at the side of cut asparagus stalks.

2.4 Sanitation for fresh-cut asparagus

Raw fresh fruits and vegetables must be washed and sanitized before packing to reduce the number of pathogens which may cause infection, and to maintain the fresh produce quality. Hazard Analysis Critical Control Point (HACCP) programs have been developed to control contamination and outbreaks of foodborne diseases and to reduce the risk of illness related to consumption of fresh fruits and vegetables. Hygienic processing operations and sanitization is essential in the food industry, especially for fresh-cut produce because of the interruption of the natural protective skin, which can result in increased pathogen growth. Unsanitary equipment, processing surfaces and working areas, and inappropriate handling can also lead to an increase in the population of microorganisms on fresh produce, affecting the quality and safety of the product (Brackett 1992). The reduction or elimination of the microbial load on fresh-cut fruits and vegetables depends on the types of fresh produce and natural microorganisms (Senter and others 1985). Contact time between product and sanitizer, concentration of sanitizer and pH also affect the effectiveness of sanitizer (Pirovani and others 2004). Several methods have been used to decrease the populations of microorganisms and have different advantages and disadvantages even if they provide the same result in cleaning and disinfection as demonstrated in Table 2.4 (Troller 1993; Parish and others 2003).

Table 2.4: Sanitization methods used to eliminate/reduce the presence of microorganisms on fresh whole and cut produce (Troller 1993; Parish and others 2003)

Sanitizer Compound	Advantage	Disadvantage	Comments on current use	Comments on research
Hypochlorite	• Inexpensive • Easy to use • Broad spectrum of activity	• Corrosive • Flavor/odor • May irritate skin • Sensitive to temperature, light, air, metals and organic materials • pH dependent • Some resistance by bacterial spores and protozoan oocysts	• Commonly used in the 50-200 ppm with a 1-2 min contact time. • Usefulness on many produce commodities has been investigated	• Very high concentrations may not eliminate pathogens on produce • Commonly used concentrations produce a maximum 1-2 log reduction on many commodities.
Iodine	• Noncorrosive • Easy to use • Broad spectrum of activity • Nonirritating [Iodophor less volatile than iodine]	• Flavor/odor • Forms purple compound with starch • Stains commodities and equipment • Corrosive above 50°C • Moderately expensive	• Commonly used on food contact surfaces and equipment • No direct contact use on produce	• May have significant sporicidal capacity • Possible usefulness on some whole produce deserves investigation

Table 2.4 (continued)

Sanitizer Compound	Advantage	Disadvantage	Comments on current use	Comments on research
Quaternary ammonium compounds	• Noncorrosive • Nonirritating • No flavor/odor • Colorless • Stable at high temperature • Good penetrating ability • Relatively stable to organic compounds • Leaves residual	• Ineffective against Gram-negative bacteria • Film formation • Organisms may develop resistance • Limited usefulness at low pH (< 6 pH) • Not compatible with soaps or anionic detergents • Costly	• Commonly used on food contact surfaces and equipment	• As effective as chlorine at reducing populations of Xanthomonas campestris pathovar vesicatoria • Reduced native orange-surface microflora 95% compared to 60% reduction on control fruit
Acid-anionics	• Noncorrosive • Easy to use • Nonirritating • Broad spectrum of activity against vegetative cells	• Effective at low pH level (1.9-2.5 pH) hence corrosive • Antimicrobial effect dependent upon type of acid and strain of microorganism	• Acidification to preserve foods commonly used • Acid sprays on meat carcasses commercially used • Phosphoric acid/anionic compound commonly used on citrus at about 200 ppm	• Lemon juice and vinegar may be useful for limited household sanitation of produce • Organic acids studied for use on several produce commodities for control of native population as well as specific pathogens • Peracetic acid concentrations up to 200 ppm effectively used on whole and cut produce.

Table 2.4 (continued)

Sanitizer Compound	Advantage	Disadvantage	Comments on current use	Comments on research
Hydrogen Peroxide	• Sporicidal • Rapid breakdown to nontoxic products	• Possible effects on product color (browning or bleaching)	• Limited industry use on food contact surfaces and packaging	• Vapor and aqueous dips (1-5% range) studied on numerous produce commodities • Variable effectiveness reported by researchers
Trisodium Phosphate	• Less corrosive than most other compounds	• Listeria relatively resistant • Have very high pH (11-12 pH)	• Occasional use on fresh-market citrus • Authorized for use on raw poultry	• Concentrations between 1 and 15% yielded reductions in pathogen population from 0-6 log

Chlorine (hypochlorite) is a very powerful oxidizing agent and one of the most widely used sanitizers in the food industry. Chlorine was first discovered in 1774 by Carl Wilhelm Scheele (Betz Laboratories Inc. 1980). In 1894, chloride was used to treat water in Germany and in the early 1930s it was added to wash water for food processing equipment in the U.S. After World War II, chloride was recognized to reduce microbial counts in food products. This was the start of the use of chlorination in food processing (Troller 1993). The main benefits of using chlorine are not only that it is a convenient and inexpensive sanitizer for use against many foodborne pathogens but it can efficiently kill a broad range of pathogens and microorganisms as well. Moreover, chlorine leaves very little residue or film on the product's surfaces (Ritenour and others 2000; Ritenour and others 2002). The bactericidal action of chlorine is not fully understood. In theory, bacterial cells are killed by the irreversible chemical reaction of chlorine which affects the bacteria cell's enzyme systems (Betz Laboratories Inc. 1980) while others claim that the bacteria present in water are destroyed as a consequence of breathing problems caused by the activity of the chlorine.

Two types of tests are available to test for chlorine, total chlorine and available chlorine. Total chlorine means the total available and combined chlorine in the water which is still able to disinfect and oxiditize organic matter. Conversely, available chlorine, also known as reactive chlorine and free chlorine, refers only to the amount of any chlorine forms available for oxidative reaction and disinfection. Thus, available chlorine does not include chlorine which is combined with ammonia or other less readily available chlorine forms such as

chloramines which have weak antimicrobial activity (Betz Laboratories Inc. 1980; Suslow 1997; Suslow 2000).

Chlorine is available in several different forms. Three main commercial forms of chlorine are approved for use by the U.S. Environment Protection Agency (EPA): Chlorine gas (Cl_2), calcium hypochlorite ($CaCl_2O_2$) and sodium hypochlorite (NaOCl) (Suslow 2000; Ritenour and others 2002).

Sodium hypochlorite (NaOCl) is commonly used by the food industry as a disinfectant to reduce the initial microbiological load since it has powerful activity against sport-forming resistant microbes. Sodium hypochlorite is usually used in available concentrations as 5.25 or 12.75% active ingredient. Chlorine is very soluble in water. When sodium hypochlorite is added to water, a chemical reaction occurs to separate it into three forms of the chlorinated water: a mixture of chlorine gas (Cl_2), hypochlorous acid (HOCl) and hypochlorite ions (OCl^-). In the chlorine water, hypochlorous acid (HOCl) is a much more effective bactericide than the hypochlorite ion. Thus, hypochlorous acid is the form of chlorine that will kill pathogens (Suslow 1997; Parish and others 2003).

$$NaOCl + H_2O \leftrightarrow (HOCl) + Na^+ + OH^-$$

$$HOCl \leftrightarrow H^+ + (OCl^-)$$

$$HOCl + HCl \leftrightarrow H_2O + (Cl_2)$$

The amount of hypochlorous acid and hypochlorite ion in the chlorine water is related to the pH of the water. Generally, sodium hypochlorite rapidly increases the pH of the water to above 7.5. As shown in Table 2.5 and Figure 2.1, at a pH of 4.5 – 5.5, 100 % of chloride exists as hypochlorous acid (HOCL) and is

very effective but is also very corrosive to equipment and its activity is rapidly lost. At a pH of around 6.0 to 6.5, 98-95% of chlorine (hypochlorous acid) is still able to be effective against microorganisms. At a pH of 7, about 78 - 80% of the chlorine is available as hypochlorous acid and at a pH of 7.5 only about 50% exists as hypochlorous acid. When the pH of the chlorine solution (in water) is above 8, the hypochlorous acid acts slowly and is only slightly effective against pathogens. Therefore, the pH is an essential factor, affecting the efficiency of chlorine and determines the amount of chlorine to be added to reduce the growth of bacteria. Thus, the higher the pH, the more chlorine is required to kill pathogens in a water system (Troller 1993; Suslow 1997; Suslow 2000; Sargent and others 2000 ; Ritenour and others 2002).

In general, pH values between 6.0 and 7.5 are used in sanitizer solutions because they not only yield acceptable chlorine efficacy to kill pathogens, but as well reduces the corrosion of equipment (Parish and others 2003). Suslow (1997) recommended that a pH of between 6.5 and 7.5 is the best compromise of activity and stability. Consequently, both pH and free chlorine must be carefully controlled and measured when sodium hypochlorite is used in water (Plotto and Narciso 2006). Also, the chlorine water must be changed more frequently because water not only becomes dirty from build up of organic matter but accumulation of salt can occur due to continuous adding of sanitizer.

Table 2.5: The effect of varying pH on the activity of chlorine forms in water (UCANR 1997)

pH of process water	Approximate % of chloride as HOCL	Approximate % of chloride as OCL^-
3.5	90	0
4.0	95	0
4.5	100	Trace
5.0	100	Trace
5.5	100	Trace
6.0	98	2
6.5	95	5
7.0	78	22
7.5	50	50
8.0	22	78
8.5	15	85
9.0	4	96
9.5	2	98
10.0	0	100

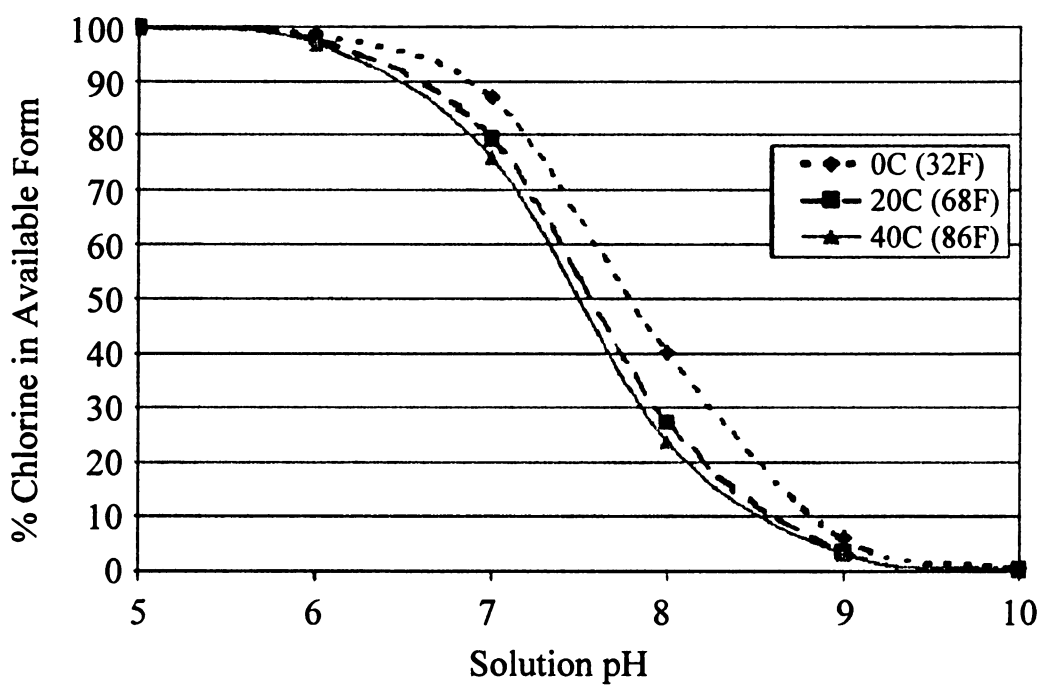

Figure 2.1: The percent of available chlorine at different pHs and water temperatures (University of Florida 2000)

Fresh fruits and vegetables have different natural pathogens and varying microbial loads. The sensitivity of microorganisms to chlorine is also different. For

example, bacteria are usually more sensitive to chlorine than mold spores. The ability of chlorine to control microbial growth on produce is also dependent upon the concentration of chlorine and contact time of produce in a chlorine water solution (Suslow 1997; Suslow 2000; Parish and others 2003).

The current IFAS recommendation for using chlorine to sanitize fresh fruits and vegetables is 100 – 150 parts per million (ppm) of available chlorine with controlled water pH between 6.5 –7.5. Rienour and others (2000), Sarget and others (2000) and Parish and others (2003) reported that the amount of liquid chloride and hypochlorite needed to sanitize fresh produce and processing equipment is 50 – 200 ppm for 1 – 2 minutes contact time with pH values between 6.0 and 7.5. The temperature of the sanitizing water should be at least 10°C (50°F), higher than the temperature of the produce to decrease the penetrative opportunity of microorganisms. The product sensitivity to bleaching, however, needs to be considered as it affects consumer acceptance and product quality since the toleration level of fresh produce to the concentration of chlorine is different.

Generally, microbial population reduction data have been shown as logarithms rather than percentages as $\log_{10}$ (CFU/g) values. Log reductions of 1, 2, 3, 4, 5 are equal to percentage reductions of 90%, 99%, 99.9%, 99.99%, and 99.999%, respectively (Sapers 2001). Several research papers have shown that chlorine can generally reduce the initial microbial counts around 1 to 2 log units (Cherry 1999; Parish and others 2003).

Park and Beuchat (1999) showed that sanitation with 2000 ppm sodium hypochlorite for 3 minutes can reduce the population of E.coli O157:H7 or salmonellae inoculated on the surfaces of cantaloupe and honeydew melons between 2.6 and 3.8 log CFUs compared to water wash control, but this treatment was less effective when applied to asparagus spears. The use of 1% hydrogen peroxide (H_2O_2) with whole cantaloupes, honeydew melons, and asparagus spears was less effective at reducing the levels of inoculated salmonellae and *E. coli* O157:H7 than hypochlorite, acidified sodium chlorite or peracetic acid-containing sanitizer. Suslow (1997), however, found that chlorine concentrations exceeding 250 ppm may affect the asparagus and celery surface by creating light-brown pits, the appearance of bell peppers was not effected. For asparagus, around 125 – 250 ppm is recommended, as shown in Table 2.6.

Table 2.6: Chlorine concentrations generally recommended for postharvest sanitation of fresh fruits and vegetables (Suslow 1997)

Vegetables & Fruits	Total Available Chlorine (mg/L)
Artichoke	100 – 150
Asparagus	125 – 250
Bell Peppers	150 – 400
Broccoli	100 – 150
Brussel sprouts	100 – 150
Cabbage (shredded)	100 – 150
Carrots	100 – 200
Cauliflower	100 – 150
Celery	100 – 150
Sweet corn	75 – 100
Chopped leafy greens	100 – 150
Cucumbers	100 – 150
Garlic (peeled)	75 – 150
Lettuce-Iceberg (whole and shredded)	100 – 150
Mushrooms	100 – 150
Green Onions	100 – 150
Peppers (chili or bell)	250 – 400
Potatoes (red or brown)	200 – 300
Potatoes (white)	100 – 250
Pumpkins	100 – 200
Radishes	50 – 150
Spinach	75 – 100
Sweet Potatoes	100 – 150
Squash (all types)	75 – 100
Tomatoes	200 – 350
Turnips	100 – 200
Yams	100 – 200
Apples	100 – 150
Cherries	75 – 100
Grapefruit	100 – 150
Kiwi	75 – 100
Lemon	40 – 75
Oranges	100 – 200
Peaches, Nectarines and Plums	75 – 150
Pears	200 – 300
Prunes	100 – 150

ppm = parts per million (1ppm = 1ug /ml = 1mg/l)

2.5 Innovation packaging of fresh-cut asparagus

Fresh-cut produce is an increasingly popular product and has been successful in the market as a ready-to-eat product due to the consumer's interest in convenience, functional nutrition and healthy food. Consequently, the fresh-cut fruit and vegetable industry is growing rapidly (Garrett 2002). According to the International Fresh-Cut Produce Association (IFPA 2003), U.S. fresh-cut produce rose approximately from $5 billion in 1994 to $10-12 billion in 2000. Fresh vegetable consumption grew from 162 pounds in 1987 to 196 pounds in 2000 (Calvin and others 2001). Several organizations including WHO, FAO, USDA and EFSA have suggested that consumption of fresh fruits and vegetables can help to reduce the risk of cardiovascular disease and cancer (Allende and others 2006).

Unlike other food products, fresh-cut fruits and vegetables still breathe after harvesting since the living plant tissues in fresh fruits and vegetable are still alive and continue the process of respiration. Respiration is a basic plant reaction by which plants take in oxygen (O_2) and give out carbon dioxide (CO_2). During respiration, plant materials such as carbohydrates, proteins and fats are broken down by oxygen from air into simple end products (carbon dioxide and water) with a release of energy as explained by the chemical reaction:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

The respiration rate of harvested produce depends on the deterioration and shelf life of fresh fruits and vegetables, causing the loss of food value, flavor and weight. Thus, high rates of respiration are associated with short shelf life

(FAO 1989; Wilson and others 1999). Different types of fresh produce vary in their respiration rate depending upon species, variety, growth, harvest and storage history. Thus, fresh fruits and vegetables are classified according to their respiration rate as indicated in Table 2.7.

Asparagus is a vegetable which has a very high respiration rate as shown in Table 2.7 and 2.8. It has a high metabolic rate: > 60 mg CO_2/kg/h (Fallik and Aharoni 2004) and the spears deteriorate rapidly. According to the USDA, fresh asparagus is very perishable and deteriorates above 41°F (5°C). Papadopoulou (2001) found that the respiratory activity and ethylene production of green asparagus rose after harvest because of the wounding stress from cutting.

Table 2.7: Classification of horticultural crops according to respiration rate (Fallik and Aharoni 2004)

Class	**Respiration Rate at 5°C (mg CO_2/Kg-hr)**	**Commodities**
Very low	< 5	Dates, Nuts, Dry fruits
Low	5 – 10	Apple, Celery, Citrus fruits, Garlic, Grape, Kiwi, Onion, Persimmon, Pineapple, Potato, Sweet Potato, Watermelon
Moderate	10 – 20	Apricot, Cabbage, Cantaloupe, Carrot, Cherry, Cucumber, Fig, Gooseberry, Lettuce, Nectarine, Olive, Peach, Pear, Pepper, Plum, Tomato, Banana
High	20 – 40	Avocado, Cauliflower, Lima bean, Raspberry
Very high	40 – 60	Artichoke, Bean sprouts, , Green onion, Snap beans
Extremely high	> 60	Asparagus, Mushroom, Parsley, Peas, Sweet corn, Broccoli

Table 2.8: The respiration rates of fresh vegetables (CO_2 production in mg/kg/h) at different storage temperatures (Kader 1992)

Produce	Temperature (°C)				
	0	5	10	15	20
Asparagus	28	44	63	105	127
Calabrese	42	58	105	200	240
Brussels sprouts	17	30	50	75	90
Lettuce	9	11	17	26	37
Tomatoes	6	9	15	23	30
Onions	-	-	6	-	6
Potatoes	-	-	4	-	6

The characteristics of fresh-cut produce such as respiration, lack of protective skin and damaged tissue from processing make it a very perishable product. To market fresh-cut asparagus in the fresh-cut marketplace, improvements in processing technologies and in packaging techniques are needed to prolong its shelf life.

2.5.1 Modified atmosphere packaging (MAP)

Concern about the preservation of the postharvest quality of fresh fruits and vegetables is increasing. Since fresh produce still respires after harvest, resulting in aging and spoilage, the key to extend its shelf life is to slow down its respiration rate. Several research papers have shown that elevating the carbon dioxide (CO_2) gas concentration and decreasing the oxygen (O_2) gas concentration helps to inhibit the natural respiration of fresh produce, ethylene biosynthesis and aerobic microbial growth (Gonzalez-Meler and others 1996).

The first scientific research on the effect of modified atmosphere on harvested horticultural products was done by J.E. Berard in the 1800s (Dilley

1990) and the effect of atmosphere on fruit ripening was studied in 1820 (Floros 1990). The first implementation of this valuable packaging technique was around 1922 in London, England, by focusing on the effect of different concentrations of carbon dioxide and oxygen on the germination and growth of fruit-rotting fungi at different temperatures (Brown 1922). Later, in 1930, several research studies were done to investigate the effect of different concentrations of carbon dioxide and storage temperature as related to microbial inactivation on fresh meat surfaces such as beef, pork, bacon, fish and lamb (Ooraikul and Stiles 1991). The first models used to describe the gas exchange characteristics in MAP were published in the 1960s. In the US., MAP of fresh-cut fruits and vegetables has been a popular and fast growing packing technique since the 1990s (Blakistone 1998). Tomatoes, peppers, apples and leeks are successful examples of fresh produce using MAP to extend the shelf life, without harmful effect on the product quality (Geeson 1988).

Consumer demand for ready-to-eat fresh produce is rapidly increasing, especially for the group of consumers who are concerned about convenience, residues of pesticides, additives and preservatives. Modified atmosphere packaging (MAP) has become a useful technology for the purpose of extending the storage shelf life and increasing the commercial value of fresh fruits and vegetables enclosed in the packages (Moleyar and Narasimham 1994; Amanatidou and others 1999).

Modified atmosphere packaging (MAP) is a technique in which an alteration in the gaseous composition surrounding the product takes place to prolong the shelf life of the product by creating a gas atmosphere inside the package. A wide-range of polymer film styles are used to preserve the freshness and quality of fresh fruits and vegetables (Thompson 1998). MAP uses the simple method of gas flushing to remove the air inside the package and then replaces it with the desired gases. No further control of the initial composition in the package is necessary. There are three main gases used in MAP to control and extend the shelf life of products: carbon dioxide (CO_2), oxygen (O_2) and nitrogen (N_2). The choice of gas depends upon the product type (Coles and others 2003). Research studies show that superatmospheric O_2 concentrations may have no effect in reducing respiration rates and ethylene production depending on the commodity, maturity and ripeness stage, time and temperature of storage. However, high O_2 concentrations inhibit the growth of some bacteria and fungi and they are much more effective when combined with CO_2 gas (15-20 kPa) (Kader 2000). Amanatidou and others (1999) reported that the inhibitory effect on microbial growth of ready-made salads is extremely variable when a high level of only one gas, O_2 or CO_2, is used. The growth of microorganisms is significantly reduced when the two gases are applied in combination.

Fresh fruits and vegetables have their own specific characteristics and behave differently depending upon the gas composition in the package. Due to the active respiration of fresh produce, chemical reactions and microbial activity, the gaseous composition inside the package changes constantly and is often

difficult to predict and control (Ahvenainen 1996). Atmospheres with too low oxygen levels and/or too high carbon dioxide concentrations can cause fermentation which is linked to the development of off-flavors and/or tissue injury, resulting in accelerated deterioration (Kader 1989b). A study on fresh broccoli showed a low O_2 level helps to retard yellowing of broccoli; however, undesirable flavor and odor develops when the O_2 level goes below 0.25 KPa O_2 at 5°C. The browning of sliced lettuce is retarded when O_2 is below 1 kPa at 5°C but fermentation begins when the O_2 falls below 0.3-0.5 kPa. Thus, 0.5 to 1 kPa of O_2 is recommended to decrease the browning of lettuce, without causing induction of fermentation (Cameron and others 1995).

To avoid adverse physiological damage or undesirable effects and to improve the storability, it is, therefore, important for package designers to understand the requirements of fresh fruits and vegetables and their safe levels of O_2 and CO_2. Several researchers have reviewed the limit levels of O_2 and CO_2. When the O_2 level drops below the O_2 tolerance value and/or the CO_2 level increases above the CO_2 tolerance level, damage and injury symptoms may occur, as shown in Tables 2.9, 2.10 and 2.11. For fresh asparagus, the tolerance level of CO_2 concentration is less than 10% at 3-6°C and less than 15% at 0-3°C storage temperatures. O_2 levels less than 10% lead to discoloration of asparagus (Kader 1989a; Saltveit 1989; Ooraikul and Stiles 1991; Kader A.A. 1993.). The recommended levels of O_2 and CO_2 to use to maintain the quality attributes of fresh asparagus are 21% O_2 (air) and 5-10% CO_2 at a storage temperature of 0-5°C as indicated in Table 2.12 (Kader 1985).

Table 2.9: Threshold levels of O_2 and CO_2 concentration causing injury to fruits and vegetables and typical injury symptoms (Kader 1989a; Kader 1993; Thompson 1998)

Crops	CO_2 injury level	CO_2 injury symptoms	O_2 injury level	O_2 injury symptoms
Asparagus	> 10 % at 3-6°C > 15 % at 0-3°C	Increased elongation, weight gain & sensitivity to chilling and pitting	< 10%	Discoloration
Avocado	> 15 %	Skin browning, off flavor	< 1%	Internal flesh breakdown, off flavor
Banana	> 7 %	Green fruit softening, undesirable texture and flavor	< 1%	Dull yellow or brown skin discoloration, failure to ripen, off flavor
Green bean	> 7 % more than 24 hrs.	Off-flavor	< 5 % more than 24 hrs.	Off-flavor
Cabbage	> 10 %	Discoloration of inner leaves	< 2 %	Off-flavor, increased sensitivity to freezing
Cucumber	> 5% at 8°C > 10% at 5°C	Increased softening, chilling injury, surface discoloration and pitting	< 1 %	Off-odor, breakdown and increased chilling injury
Mango	> 10 %	Softening, off–flavor	< 2 % (< 5 %)	discoloration of skin, grayish flesh color, off-flavor

Table 2.10: O_2 thresholds causing injury for horticultural crops held at typical storage temperatures [adapted from Beaudry (2000)]

O_2 (kPa)	Commodities
0.5 or less	Chopped green leaf, red leaf, Romaine and iceberg lettuce, spinach, sliced pear, broccoli, mushroom
1	Broccoli florets, chopped butterhead lettuce, sliced apple, brussels sprouts, cantaloupe, cucumber, crisphead lettuce, onion bulbs, apricot, avocado, banana, cherimoya, atemoya, sweet cherry, cranberry, grape, kiwifruit, litchi, nectarine, peach, plum, rambutan, sweetsop
1.5	Most apples, most pears
2	Shredded and cut carrots, artichoke, cabbage, cauliflower, celery, bell and chili pepper, sweet corn, tomato, blackberry, durian, fig, mango, olive, papaya, pineapple, pomegranate, raspberry, strawberry
2.5	Shredded cabbage, blueberry
3	Cubed or sliced cantaloupe, low permeability apples and pears, grapefruit, persimmon
4	Sliced mushrooms
5	Green snap beans, lemon, lime, orange
10	Asparagus
14	Orange sections

Table 2.11: CO_2 pressure thresholds causing injury for horticultural crops (Beaudry 2000; Watkins 2000)

CO_2 (kPa)	Commodity
2	Lettuce (crisphead), pear
3	Artichoke, tomato
5	Apple (most cultivars), apricot, cauliflower, cucumber, grape, olive, orange, peach (clingstone), potato, pepper (bell)
7	Banana, bean (green snap), kiwi fruit
8	Papaya
10	Asparagus, brussels sprouts, cabbage, celery, grapefruit, lemon, lime, mango, nectarine, peach (freestone), persimmon, pineapple, sweet corn
15	Avocado, broccoli, lychee, plum, pomegranate, sweetsop
20	Cantaloupe (muskmelon), durian, mushroom, rambutan
25	Blackberry, blueberry, fig, raspberry, strawberry
30	Cherimoya

Table 2.12: Recommended MA conditions for vegetables (Kader 1985; Aharoni 2004; Han 2005)

Commodity	Temperature range (°C)	Modified Atmosphere	
		% Oxygen (O_2)	% Carbon dioxide (CO_2)
Asparagus	0-5	20 (Air)	5-10
Bean, Snap	5-10	2-3	5-10
Bell pepper	8-12	3-5	0
Broccoli	0-5	1-2	5-10
Brussels sprouts	0-5	1-2	5-7
Cabbage	0-5	3-5	5-7
Cauliflower	0-5	2-5	2-5
Corn	0-5	2-4	10-20
Cucumber	8-12	3-5	0
Lettuce	0-5	2-5	0
Mushroom	0-5	20 (Air)	10-15
Spinach	0-5	20 (Air)	10-20
Tomatoes			
Mature-green	12-20	3-5	0
Partly ripe	8-12	3-5	0

2.5.2 Vacuum skin packaging (VSP)

Vacuum packaging is a packaging technique that can help to preserve the freshness and extend the shelf life of products by removing the air inside the package and then hermetically sealing them in a high barrier film. Vacuum packaging has been commonly used for many dry foods and fresh meats since the 1960s. In the U.S., vacuum packaging has been heavily used with poultry, processed meats and cured cheeses. Around 1960, the Cryovac company created barrier shrink film vacuum packaging to prolong the freshness of red meat (Blakistone 1998).

Vacuum skin packaging (VSP) uses the same technique as vacuum packaging but it applies a themoformable film to seal over the product against a rigid backboard. This is widely used to prolong the storage shelf life of meats (Tewari 2002). Vacuum packaging can also be used to package fresh produce. However, vacuum skin packaging has not been widely used with fresh fruits and vegetables. More research is needed in this area to ensure the quality of fresh packed produce.

Vacuum packaging can help to retard the growth of aerobic microorganisms, resulting in decreased spoilage. Vacuum packaging significantly extended the shelf-life of sliced carrots at 4°C from 5 to 8 days and retarded microbial growth compared with non-vacuum packed carrots (Buick and Damoglou 2006). Generally, vacuum packaging helps to preserve product appearance better than MAP (Beltran and others 2005). The effect of MAP and vacuum packaging on the quality of chilled potato strips showed that potato strips

dipped in a 10% ascorbic acid solution and packed in a fiber tray lined with Surlyn-PVdC-Surlyn under MAP (5% O_2 and 10% CO_2) at 5°C inhibited enzymatic discoloration for 1 week while product under vacuum packaging had minimum discoloration of chilled potato strips up to 2 weeks at the same storage temperature (O' Beirne and Ballantyne 1987).

The gaseous atmosphere in vacuum packed fresh produce changes during storage because it is impossible to remove all of the air from the package (about 0.3 – 3% of air remains after sealing) and because of the respiration of microorganisms and the fresh produce (Irtwange 2006). Applying high vacuum pressure can cause bruising of fresh produce while low vacuum pressure may not lower the O_2 content in the initial headspace sufficiently (Blakistone 1998). A suitable vacuum pressure must be used with fragile products such as fresh produce.

2.5.3 Film

Plastics are a commonly used packaging material for many food packaging applications because of ease of forming, light weight, clarity, strength and good heat sealing ability. Unlike other products, fresh-cut produce can still breathe. Thus, respiration is a big concern when plastic films are used to protect and extend the shelf life of fresh products.

There are 3 groups of films currently used in the fresh produce industry: monolayer, laminated, and co-extruded films. Generally, the films used with MAP are multilayer structures which are made from several layers of different types of plastic using co-extrusion, lamination or coating technologies to achieve needed

properties. MAP laminated films are usually made from polyethylene (PE), polypropylene (PP), polyamide (nylons), polyethylene terephthalate (PET), polyvinyl chloride (PVC), polyvinylidene chloride (PVDC) and ethylene vinyl alcohol (EVOH). For rigid and semi-rigid packaging, PP, PET, PVC and expanded polystyrene are used to create tray containers for MAP (Blakistone 1998; Coles and others 2003) as illustrated in Table 2.13.

Table 2.13: Typical polymeric plastic materials for MAP containers (Coles and others 2003)

Plastic material	Application
UPVC/PE	Thermoformed base tray
PET/PE	Thermoformed base tray
XPP/EVOH/PE	Thermoformed base tray
PS/EVOH/PE	Thermoformed base tray
PET/EVOH/PE	Thermoformed base tray
PVDC coated PP/PE	Lidding film
PVDC coated PET/PE	Lidding film
PA/PE	Lidding film
PA/PE	Flow warp film
PA/ionomer	Flow warp film
PA/EVOH/PE	Flow warp film
PET	Pre-formed base tray
PP	Pre-formed base tray
UPVC/PE	Pre-formed base tray

The most important barrier characteristic that polymeric films need for MAP and vacuum packaging is their permeability to oxygen, carbon dioxide, and nitrogen or argon (Han 2005). Permeability is "the diffusion or molecular exchange of gases, vapors or liquid permeates across a plastic material" (Hernandez 1997). The rate of gas transmission through a perforated film is the sum of gas diffusion through any perforations in the film and the gas permeation through the polymeric film. In general, the total gas exchange through a

perforated film is much greater than the gas permeation through the plastic film (Fishman and others 1996; Mir and Beaudry 2001).

Permeable plastic film has been developed for use with fresh produce to control the gas exchange between the package head space and the external environment (Zagory 1998). Plastic films help to moderate moisture loss, slow down produce senescence and diminish product quality degradation (Schlimme and Rooney 1994).

Using a suitable polymeric film is necessary for both MAP and vacuum packaging to maintain quality of fresh-cut fruits and vegetables because of product respiration rates. The choices of film permeability, thus, depend on the respiration rates of the fresh produce (Kader 1989b; Paine and Paine 1992; Day 1993). Table 2.14 and 2.15 show the permeability of O_2, CO_2, N_2 and water vapor of different types of polymeric films for use with fresh produce at room temperature. However, knowing the oxygen transmission rates at refrigerated temperatures may provide more realistic permeability rate information for films used in refrigerated storage conditions (Day 1993).

The permeation rates of the film rely on the partial pressure of the CO_2 and O_2 gases (Paine and Paine 1992; Zagory 1998). Semi-permeable polymeric films are the most popular barriers used to create modified atmosphere (Talasila and others 1995). Presently, most of the films used for MAP are suitable only for the low and medium respiring commodities. Produce with high respiration rates may need other film combinations and/or perforated films, to provide sufficient flux of O_2 and CO_2 (Kader 1989b; Exama and others 1993).

Microperforation of films to create small holes can be used to allow greater gas movement across the package membrane (Mir and Beaudry 2001). Microporous films have been developed by mixing polymer resin with inert inorganic materials such as $CaCO_3$ and SiO_2 for the purpose of creating very high gas transmission rates. Gas permeability can be controlled by adjusting the particle size of the filler and degree of stretching obtained. In general, the average pore size diameter is 0.14 – 1.4 μm (Mizutani and others 1993) for methods such as FreshHold®, which was developed by Hercules (Hercules, Wilmington, DE) (Zagory and Kader 1988; Roming and Nazir 2004). Microperforated film has also been developed to achieve very high gas transmission rates, using holes in the general range of 40-200 μm. For example, P-plus, developed by Sidlaw (Sidlaw Packaging P-plus, Bristol, UK) and now owned by Printpack (Printpack Inc, Atlanta, GA) has this technology (Zagory and Kader 1988; Roming and Nazir 2004).

Metallocene technology uses single-site catalyst (SSC) polymers that can control molecular weight density and distribution. This technology helps to create flexible plastics with very high oxygen transmission rates, low moisture vapor transmission rates, clarity, strength and low seal initiation temperature. For instance, polyolefin plastomer film (POP) created by Dow Chemical Co. and Exxon Chemical Co., has high O_2 and CO_2 permeability that can facilitate the packaging of fresh-cut produce (Young and Wooster 1996; Hernandez 1997; Zagory 1998). Commercial films have also been developed to have higher gas transmission, ethylene-vinyl acetate, low density polyethylene (Elvax, Dupont,

Wilimington, DE), styrene butadiene block copolymer films (K-Resin, Phillips Chemical Co., Houston, TX) and ultra low density ethylene octene copolymer films (Attane series, Dow Chemical Co., Midland, MI) (Roming and Nazir 2004).

Microperforated films (P-plus) have been shown to extend the storage shelf life of various fresh fruits and vegetables such as asparagus, cherry tomatoes, peppers, brussel sprouts, sweet corn, leeks, pears (Geeson 1988), Iceberg lettuce (Ballantyne and others 1988) and mushroom (Lopez-Briones and others 1993). Peeled white asparagus packed in P-plus 160 under MAP at 4°C had longer shelf life than that packed in perforated PVC (Simon and others 2004). This was shown to be the same for borage, a vegetable from the north of Spain, packed in P-plus film and PVC (Gimenez and others 2003). Studies of shredded carrots packed in oriented polypropylene (OPP), polyether block amide (DP) with hydrophilic coating, Pebax (OSM) and P-plus bags at 3°C and 8°C also showed that the P-plus film (CO_2 permeability of 29 × 10^3 $mL.m^{-2}.d^{-1}.atm^{-1}$, O_2 permeability of 25 × 10^3 $mL.m^{-2}.d^{-1}.atm^{-1}$) protected the product the best and retarded its deterioration. These studies also found that the deterioration of the product was related to the depletion of O_2 rather than the increase of CO_2 inside the package (Barry-Ryan and others 2000). The effect of film thickness on product shelf life has been studied on honey peach fruit packed in a LDPE bag (thickness 15, 25, 40 μm) and stored under a MAP composition of 6% O_2 and 3% CO_2 at 2°C. The results showed that the honey peach maintained its color and texture during 40 days of storage, and that the thickness of the LDPE film significantly affected the product quality (Jianshen and others 2007).

Although a permeable film can help to extend product shelf life, either low, medium or high-barrier films can contribute to problems associated with absence of oxygen. This is because film properties tend to be more permeable to CO_2 than O_2 (CO_2 2 to 6 or 8 times higher than O_2), resulting in diffusion of CO_2 gas through the package wall faster than the diffusion of O_2 gas into the package (Zagory 1998; Mir and Beaudry 2001). When the oxygen level inside the package approaches or reaches the zero level, anaerobic respiration occurs and causes product deterioration. For instance, perforated polypropylene (PP) helped to preserve the ripeness and nutritional value of MAP strawberries though it does affect their color and flavor (Sanz and others 1999). Fresh-cut spinach packed in monooriented polypropylene (OPP) and LDPE bags under MAP at 4°C and 90% RH maintained weight but lost chlorophyll. An off-odor developed in the product packed in OPP bags (Piagentini and others 2002).

Rigid plastic trays have been widely used for fresh-cut fruit and vegetables because of their mechanical properties. However, the trays are impermeable which reduces the surface area for gas exchange. The appropriate design of a package can allow the produce to breathe. Therefore, the ratio of product weight and headspace/surface area needs to be balanced (Zagory 1998). Some research studies have shown that gas equilibrium inside the package, at low temperature, will reach steady-state in about 2 to 3 weeks depending on the void volume and the respiration rates of the products (Cameron and others 1995).

The development of permeable films continues. Recently, biodegradable films have been used in MAP applications. Corn zein film was used as a

biodegradable material to extend the shelf life of fresh broccoli under MAP. The research showed that product packed in zein films plasticized with oleic acid and coated with tung oil, and stored under MAP at 5°C kept its freshness (color and firmness) during 6 days of storage (Rakotonirainy and others 2001).

Table 2.14: Permeability of polymeric films for fresh produce (Zagory and Kader 1988; Aharoni 2004)

Film Type	Permeability ($cc/m^2/mil/day$ at 1 atm)		
	CO_2	O_2	$CO_2:O_2$ Ratio
Polyethylene (low density)	7,700 - 77,000	3,900 - 13,000	2.0 - 5.9
Polyvinylchloride	4,263 - 8,138	620 - 2,248	3.6 - 6.9
Polypropylene	7,700 - 21,000	1,300 - 6,400	3.3 - 5.9
Polystyrene	10,000 - 26,000	2,600 - 7,700	3.4 - 3.8
Polyester	180 - 390	52 - 130	3.0 - 3.5
Saran	52 - 150	8 - 26	5.8 - 6.5

Table 2.15: Polymeric film types used for packaging of MAP produce

Film	Permeability (cm^3/m^2.d.atm for 25 μm film at 25 °C)			Water vapor transmission, g/m^2/day/atm (38 °C and 90%relative humidity)
	O_2	N_2	CO_2	
Ethylene-vinyl alcohol (EVOH)	3-5	–	–	16-18
Polyvinylidene chloride coated (PVdC)	9-15	–	20-30	–
Polyethylene, LD	7800	2800	42000	18
Polyethylene, HD	2600	650	7600	7-10
Polypropylene	1,300 - 6,400	–	7,700 - 21,000	
Polypropylene cast	3700	680	10000	10-12
Polypropylene, oriented	2000	400	8000	6-7
Polypropylene, oriented, PVdC coated	10-20	8-13	35-50	4-5
Rigid PVC	150-350	60-150	450-1000	30-40
Plasticized PVC	500-30000	300-10000	1500-46000	15-40
Ethylene vinyl acetate (EVA)	12500	4900	50000	40-60
Polystyrene, oriented	5000	800	18000	100-125
Polyurethane (polyester)	800-1500	600-1200	7000-25000	400-600
PvdC-PVC copolymer (Saran)	8-25	2-2.6	50-150	1.5-5.0
Polyamide (Nylon-6)	40	14	150-190	84-3100
Microperforated (MP)	>15,000[4]	–	–	–
Microporous (MPOR)	>15,000[4]	–	–	Variable

2.6 Storage and temperature

Temperature is another important factor that affects the metabolic rate of fresh produce, and the success of MAP and vacuum packaging in extending the shelf life and quality retention of horticultural products during storage. Too high a temperature accelerates respiration, browning and microbial growth. Low temperature in combination with MAP can successfully reduce the respiration rate, ethylene production and pigment degradation and retard the growth of microorganisms, all of which delay product spoilage (Kader 1989b; Ooraikul and Stiles 1991; Heard 2002; Ternorio and others 2005).

Temperature affects not only the respiratory rate of fresh fruits and vegetables but film permeability as well. When temperature increases above the optimum level, the respiration rate of produce increases resulting in an increase in CO_2 level and depletion of O_2 (Exama and others 1993). With an increase in temperature from 0°C to 15°C, there is a 4 to 6 fold increase in respiration of most fruits and vegetables. When temperature increases, the respiration rate of fresh produce increases at a rate of 2 or 3 times that of the increased permeability of LDPE and 30 times the rate (LDPE) with perforations (1-mm perforation in a 0.0025 mm (1 mil) thick LDPE film) (Beaudry and others 1992; Cameron and others 1994; Lakakul 1999; Mir and Beaudry 2001). The permeability of O_2 and CO_2 through LDPE film increases when the temperature increases from 5°C to 35°C (Charles and others 2005). Since CO_2 permeability increases more than O_2 permeability, when temperature increases, the respiratory rate increases, resulting in increased CO_2 production and increased

O_2 consumption. The decline in O_2 levels inside the package causes fermentation, resulting in off-odor development due to the production of ethanol and acetaldehyde from anaerobic respiration (Phillips 1996).

Inappropriate temperature control can lead to the deterioration of fresh produce and the potential for anaerobic microbial growth such as C. *botulinum* which causes serious foodborne illness. Storage at 10°C or above is adequate for most foodborne bacteria to grow and produce toxin on fresh cut vegetables. While high temperatures accelerate the spoilage of fresh produce, low temperature can sometimes cause chilling injury. Each produce species varies in its sensitivity level to temperature, both in terms of respiration and chilling injury. Fluctuating temperatures or changes in temperature should be avoided since they cause moisture condensation inside the package, thus stimulating microbial spoilage (Zagory and Kader 1988). To avoid temperature abusive conditions, it is necessary to understand the specific requirements of fresh produce related to temperature.

Fresh asparagus is a perishable vegetable which can be injured by refrigeration. The deterioration of asparagus occurs rapidly when storage temperature rises above 2°C (36°F) resulting in loss of sweetness, tenderness, flavor and vitamin C. Asparagus is also damaged by chilling injury when the temperature falls below 0°C (32°F). The recommended storage temperature for asparagus is around 0 to 2°C (32-36°F) at 95 to 100% RH under controlled atmosphere (CA) and MAP as shown in Tables 2.16 and 2.17 (ASHRAE 2002).

Storage temperature affects the shelf life of fresh-cut asparagus under MAP and vacuum packaging. Fresh asparagus packaged under MAP at 2°C had longer shelf life (26 days) than when stored at 10°C (14 days) or Non-MAP storage at 2°C (9-12 days) (Villanueva and others 2005). Ternorio and others (2004) also found that MAP at 2°C was successful in preserving asparagus shelf life and its color including that from carotenoids and chlorophylls through 26-33 days. MAP at 10°C extended the product quality only 20 days, and only 14 days at 2°C under non-MAP conditions. The use of MAP for fresh asparagus also helps to reduce the loss of moisture and anthocyanins (Siomos and others 2000).

Table 2.16: The optimum storage condition of whole fruits and vegetables for MAP (Powrie and Skura 1991; Day 1993; Exama and others 1993; Moleyar and Narasimham 1994; Smith and Ramaswamy 1996; Farber and others 2003)

Commodity	Respiration Rate (at 5°C, mg CO_2/kg/h)	Gas Tolerance		Optimum		Recommended Storage Temperature	Approximate Storage Shelf life
		Maximum % CO2	Maximum % O2	%CO2	%O2		
Artichoke	-	2	3	2-3	2-3	0-5	29 days
Asparagus	>60	14	5	10-14	Air	1-5	21 days
Beans, snap	40-60	10	2	5-10	2-3	5-10	7-10 days
Bell pepper	10-20	2	3	0	3-5	8-12	2-3 weeks
Broccoli	>60	10	1	5-10	1-2	0-5	2-3 months
Brussels sprouts	40-60	5	2	5-7	1-2	0-5	2-3 months
Cabbage	10-20	5	2	3-6	2-3	0-5	6-12 months
Carrot	10-20	5	5	3-4	5	0-5	4-5 months
Cauliflower	20-40	5	2	2-5	2-5	0-5	2-3 months
Chili pepper	10-20	2	3	5	3	8-12	N/A
Corn, sweet	>60	15	2	10-20	2-4	0-5	N/A
Cucumber	4	10	3	0	3-5	8-12	14-21 days
Lettuce	10-20	2	2	0	1-3	0-5	3-4 weeks
Mushroom	>60	15	1	5-15	3-21	0-5	3-4 days
Onion	5-10	-	-	0	1-2	0-5	8 months
Potato	5-10	-	-	none	none	4-12	N/A
Spinach	>60	15	-	10-20	Air	0-5	2-3 weeks
Tomato (mature)	10-20	2	3	0	3-5	12-20	2 weeks
Tomato (ripe)	10-20	2	3	3-5	3-5	10-15	N/A

Table 2.17: Optimal transit temperatures for various vegetables (USDA 1995; UCANR 1997)

Commodities	Desirable Transit Temperature (°F)	Suggested Thermostat Setting (°F)	Highest Freezing Point (°F)
Artichokes	32	33	29.8
Asparagus	32 – 35	35	30.9
Lima beans	37 – 41	37	31.0
Snap beans	40 – 45	45	30.7
Beets (topped)	32	34	30.4
Broccoli	32	34	30.9
Brussels sprouts	32	34	30.6
Cabbage	32	34	30.4
Cantaloupes	36 – 41	37	29.8
Carrots	32	33	29.5
Cauliflower	32	34	30.6
Celery	32	34	31.1
Sweet corns	32	34	30.9
Cucumbers	50 – 55	50	31.1
Eggplant	46 – 54	50	30.6
Green leaves	32	34	-
Honeydew melon	45 – 50	45	30.4
Lettuce	32	34	31.6
Onions	32 – 39	35	30.6
Green onions	32	34	30.4
Green peas	32	34	30.9
Sweet peppers	45 – 50	46	30.7
Potatoes			
Early crop	50 – 60	50	30.9
Late crop	39 – 50	40	30.9
Radishes	32	34	30.7
Spinach	32	34	31.5
Squash (summer)	41 – 50	41	31.1
Squash (winter)	50 – 55	50	30.5
Sweet potatoes	55 - 61	55	29.7
Tomatoes			
Mature green	55 - 70	55	30.9
Pink	50	50	30.6
Watermelons	50 - 60	50	31.3

2.7 Sensory quality of fresh-cut asparagus

The appearance of fresh-cut fruits and vegetables is the most important factor considered by consumers when buying produce. After harvest, the physiology of fresh fruits and vegetables changes over time. Eventually the product reaches its maturity stage and then senescence occurs due to respiration resulting in changes in appearance, odor, color, flavor and texture which cause the loss of the fresh-like quality. In addition, cutting results in broken cells which also hasten the degradation of fresh products. Although MAP is widely used to increase the shelf life of fresh-cut products, undesirable changes such as discoloration, off-odor and off-flavors can occur during storage and reduce the product quality (Kader 1986).

Aroma, color and texture can be used to represent the freshness of fresh produce. Moisture loss, mechanical damage and microbial spoilage are involved in the degradation of fresh-cut produce (Piagentini and others 2002). Most fresh-cut produce research has focused on browning, discoloration, flavor, texture and microbial growth and their effect on product shelf life. Analytical analysis has been used to measure color, aroma and texture of the fresh fruits and vegetables. It, however, is able to determine only visual or chemical properties. Thus, use of human senses can help to judge the product quality more precisely (Abbott and others 1997).

Sensory analysis is a scientific method which uses the human senses (sight, smell, taste, touch or hearing) to efficiently assess product quality and shelf life (ASTM 1992). Assessing product sensory characteristics requires

different tests depending on the objective, such as development of a new product, product matching, improvement and cost reduction, raw material change and storage stability (Hutchings 1994). Consumer tests are the most effective test technique for product preference and acceptance, and generally require 50 – 100 panelists. A typical 9-point hedonic scale is often used, while discrimination tests can be used to detect the difference in similar products. Descriptive analysis methods measure both the qualitative and quantitative sensory aspects of products by using a trained panel (recommended minimum number of panelists is 5) (Meilgaard and others 1991; Baldwin 2002). Sensory evaluation cannot be fully unbiased; however, bias can be minimized by use of a well designed experiment and scoring system, and by enhanced training of the panelists (Hutchings 1994).

For ready-to-eat products, fresh produce is cut and packed into a package. The proper selection of the plastic film as a packaging material is crucial to the shelf life of the product. The permeability of the film can help to maintain the quality of the fresh produce by lessening the degradation of chlorophyll and other pigments, and to reduce browning and microbial growth by creating and maintaining an atmosphere inside the package during storage (Cartaxo and others 1997; Watada 1997; Senesi and others 1999; Bett 2002). Since the product is packed, consumers are able to evaluate the product quality only by its appearance and hence it is the key factor in making a purchase decision. Most research on product quality of fresh-cut produce is centered on the visual and

quality appearance (Beaulieu and Baldwin 2002) of the product and color is the most critical feature of its visual appearance.

Fruits and vegetables have their own unique color. The progressive color of some fresh fruits and vegetables changes from green to yellow (cucumbers, broccoli, asparagus and bananas), while some change from green to red or orange (tomatoes, strawberries, cherries and oranges). These color changes demonstrate the ripeness and eventual degradation of the produce. Like other green vegetables, the green color of the asparagus stalk is representative of its freshness color due to chlorophyll. Chlorophyll synthesis involves the transformation of protochlorophyllide into chlorophyllide and later to chlorophyll. Most likely, the degradation of chlorophyll is caused by chlorophyllase resulting in the development of chlorophyllide which can be converted into yellow and brown compounds and then into colorless compounds (Schouten and Van Kooten 2000). Browning, caused by oxidation of phenols and catalyzed by polyphenol oxidase enzymes, can produce off-flavor. It can also result in loss of quality in some fresh-cut products such as potatoes, avocado, lettuce, and apples (Whitaker 1995; Bett 2002).

Aroma and flavor can be characterized as components of the sensory quality of fresh produce. They are critical to the consumer repurchase (Beaulieu and Baldwin 2002). Unlike other food products, fresh-cut fruits and vegetables still continue to respire after harvest. With one purpose of MAP being shelf life extension, control of the O_2/CO_2 inside the package is critical since O_2 is consumed during respiration while CO_2 elevates. The concentration of O_2 and

CO_2 determines the metabolic rate of the plant tissue. An O_2 concentration less than 2% or CO_2 concentration more than 5% may change the metabolic reactions within the living tissue from aerobic to anaerobic respiration, causing fermentation that creates undesirable odors and flavors and thereby reduces the shelf life of the product (Powrie and Skura 1991; Farber and others 2003; Saltveit 2003). When O_2 levels in MAP decrease below the tolerance level of fresh produce such as in fresh-cut green asparagus spears (Baxter and Waters 1991), potatoes (Beltran and others 2005) and broccoli (Dan and others 1997), off-flavor develops due to anaerobic respiration. To assess the aroma and flavor sensory qualities of fresh fruits and vegetables, raw, fermented and rotten odor/flavor notes are used as attributes as shown in Table 2.18 (Bett 2002).

Table 2.18: Descriptors with definitions and references for odor/flavor of fresh fruits and vegetables (Bett 2002)

Aroma/Flavor Attributes	Description	Reference
Raw	Aroma associated with unprocessed and/or uncooked product	Fresh fruit or vegetable
Fermented	Aroma associated with fermented fruits or vegetables	Fermented apple juice or WONF 3RA654 (McCormick)
Deteriorated/ rotten	Aroma associated with rotten, deteriorated, decayed fruit/material	Rotten fruit or vegetables (specific)

Texture is an important factor in characterizing the freshness of fresh fruits and vegetables. Physical characteristics, including the structural elements, can be assessed by the look of the product, by sensation of touch to the hand and/or in the mouth (Bourne 1982; Abbott 2004). Generally, consumers perceive the texture of fresh produce by squeezing the product (Voisey and Crete 1973;

Rosenthal 1999). The touch/feel helps consumers to determine its actual product quality. Products soften because of pectolytic activity and cellulose breakdown, resulting in moisture loss, wilt and wrinkled appearance (Lieberman 1981). The structural, physiological and biochemical characteristics of fresh fruits and vegetables and their varying stages of development are used to evaluate textural characteristics. Many terms are used to describe the sensory texture of fruits and vegetables such as hard, firm, soft, crunchy, crisp, limp, mealy, tough, leathery, melting, gritty, stringy, dry and juicy (Abbott 2004). Different fruits and vegetables are comprised of different tissues which differ in strength and biological properties. Hence, different product sections need to be considered individually when measuring the texture. For example, crispness/toughness is a principal attribute of asparagus caused by fiber content and fiber lignification (Lipton 1990). The crispness/toughness of asparagus spears stored under MAP in semi-permeable film at 6°C has been shown to degrade faster than the color and hence can be used as a measurable parameter to evaluate the sensory quality (Albanesea and others 2007).

2.8 Microbiological safety of fresh-cut asparagus

Microbial spoilage affects product quality and shelf life. The growth of microorganisms leads to deterioration, and can lead to a principle food safety concern. Raw fruits and vegetables can be contaminated with microorganisms in the field, through processing, and packing and in transportation, all of which can lead to human foodborne disease. In the fresh-cut produce industry, bacterial total count and coliform numbers can be used as indicators of a product's

sanitation and quality (Heard 2002) even though some researchers recommend not to use coliform numbers to indicate contamination with fecal pathogens (Beuchat 1998; Nguyen-The and Carlin 2000).

Unlike some food processing techniques such as freezing and canning, fresh-cut products are processed without heat treatment to maintain the freshness of the product (Heard 2002). In most cases, the type of pathogen and spoilage microorganisms found on fresh-cut produce and raw crops are similar (Nguyen-The and Carlin 2000). Contamination of fresh-cut products may occur in the field and/or in processing. Washing fruits and vegetables after cutting or trimming helps to reduce the pathogen and spoilage load (Sinigaglia 1999). However, only 1 log reduction in microbial numbers is achieved by washing with water (Nguyen-The and Carlin 1994). Washing fresh fruits and vegetables with water and the addition of a disinfectant such as chlorine can help to reduce the microbial load further (1-2 log reduction) (Cherry 1999; Parish and others 2003).

MAP and vacuum packaging techniques can help to extend the shelf life of fresh produce, but can also allow the development of pathogens even when the product is stored at low temperature due to long storage and/or inappropriate package headspace gas composition (Brackett 2000; FDA 2001). Thus, microbiological safety is a serious concern for the fresh-cut produce industry using either MAP or vacuum packaging.

Much research has been done on *L. monocytogenes* as a contaminant of fresh produce stored under MAP. *Listeria monocytogenes* is a critical foodborne bacterial pathogen, and can grow and survive at refrigeration temperature. In

1989, a zero tolerance policy was enforced for *L. monocytogenes* in food by the U.S. Department of Agriculture and U.S. Food and Drug Adminstration (Altekruse and others 1997). *L. monocytogenes* is a concern as a pathogenic contaminate in ready-to-eat foods such coleslaw, milk (after pasteurization) and MAP produce (Schuchat and others 1991; NACMCF 1999). It has been reported that *L. monocytogenes* inoculated on fresh broccoli, asparagus and cauliflower packed under MAP composed of 3%CO_2, 18 % O_2 and 79% N_2 at 10°C for 10 days was unaffected (Berrang and others 1989). However, the population of *L. monocytogenes* on trimmed, fresh green asparagus stored under MAP at 2°C and 4°C, and then increased to 8°C at the rate of 0.038°C/hour (Castillejo Rodriguez 2000).

Aeromonas hydrophila has been found on a variety of foods and there is concern that it is a foodborne pathogen in fresh-cut fruits and vegetables. Under MAP (11-18% O_2, 3-10% CO_2 and 97% N_2), the shelf life of fresh broccoli, asparagus and cauliflower was extended from 8-21 days at 4°C and 15°C. CO_2 levels of more than 50% have been reported to inhibit the growth of *L. monocytogenes* and *A. hydrophila*. However, CO_2 levels this high can injure products (Bennik and others 1995).

Microbial growth on fresh asparagus in vacuum packaging has been reported. During a 21-day storage period at 2°C 80% RH, the total *Enterobacteriaceae* counts (2.5×10^2 CFU/g), and yeast and mold (10 CFU/g) on asparagus packed in Poliskin-X bags under vacuum packaging was lower than the *Enterobacteriaceae* counts (7.3×10^4 CFU/g), and yeast and mold (2.3×10^4

CFU/g) counts on asparagus packed in low density polyethylene bags under MAP. Anaerobic psychrotrophs were found in both vacuum packaged (basically lactic acid bacteria of the Lactobacillus genus) and MAP (principally Coryneforms, Pseudomonas and Acinetobacter anitratus) (Osuna and others 1995).

There is potential growth of *Clostridium botulinum* on fresh-cut produce under MAP and vacuum packaging since *C. botulinum* can grow in an anaerobic environment (Zagory 1995). Several research studies have found that fresh products were grossly spoiled before the botulinal toxin produced by *C. botulinum* was detected in the product. For example, shredded carrots and green beans (Hao and others 1998), romaine lettuce and shredded cabbage (Petran and others 1995), and cantaloupe and honeydew (Larson and Johnson 1999) have all shown this result. However, research with onions and butternut squash packed under MAP at 5°C (41°F) for 21 days and 25°C (77°F) for 6 days showed that both nonproteolytic and proteolytic strains of *C. botulinum* appeared when toxin was detected (Austin and others 1998). Thus, the production of toxin by *C. botulinum* varies with the vegetable (FDA 2001). It has been claimed that the overall occurrence of *C. botulinum* spores in pre-cut fresh vegetables under MAP at 4°C (39.2°F) at retail suppliers in the U.S. is low, only 0.36% (1 of 337) (Lilly and others 1996). This pathogen is difficult to grow and cannot produce toxin in the product stored at a temperature below 12°C, pH below 4.6, a water activity below 0.95 and NaCl concentrations above 10% (Lund and Peck 2000).

Escherichia coli (*E* .coli) O157:H7 is another serious foodborne pathogen which causes food-poisoning. *E. coli* O157:H7 can contaminate fresh fruits and

vegetables during harvesting, processing and packing (FDA 2001). It has been found that the CO_2 concentration of shredded iceberg lettuce in MAP using 4 different gas mixture ratios (O_2:CO_2:N_2): 0:10:90, 3:0:97, 5:30:65, and 20:0:80, and stored at 13°C and 22°C had no significant effect on the growth of *E. coli* O157:H7 at both temperatures (Diaz and Hotchkiss 1996). It was also found that shredded lettuce, sliced cucumber, and shredded carrot packed under MAP containing 3% O_2, 0.3% CO_2 and 97% N_2 at 5, 12, and 21°C had no effect on the development of *E. coli*, psychrotrophs, or mesophiles. The reduction in pH of the vegetables allows the growth of *E. coli* O157:H7 and other microorganisms (Abdul-Raouf and others 1993).

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3 THE SHELF LIFE OF FRESH-CUT MICHIGAN ASPARAGUS PACKED IN MAP AND VSP MICROWAVEABLE TRAY SYSTEMS AT 1°C AND 8°C STORAGE TEMPERATURES

Abstract

Asparagus (*Asparagus officinalis* L.) is a perennial vegetable of the lily family (Liliaceae). The world consumption and the proportion eaten as fresh asparagus grew rapidly from 1997 to 2005 and was more than was canned or frozen. Fresh asparagus is a very perishable crop because of its high post-harvest metabolic rate. In order for Michigan (currently ranked 3rd in the nation for asparagus production) asparagus to remain competitive, the industry needs to focus on value addition to help Michigan asparagus growers in a global asparagus marketplace. Modified atmosphere packaging (MAP) has been used successfully to extend shelf life of fresh fruits and vegetables by reducing their respiration rate. Vacuum skin packaging (VSP) can also be used with fresh produce to increase product shelf life by creating a micro-atmosphere around the product. The objective of this study was to determine the quality and shelf life of fresh-cut Michigan asparagus packed for the retail market in MAP and VSP microwaveable tray systems. Pre-trimmed, cleaned, 6-inch fresh asparagus spears were packed in microwaveable tray systems using passive MAP and VSP techniques. Both systems were heat-sealed with highly permeable films provided by commercial manufacturers, and stored at 1°C and 8°C. To evaluate product shelf life and quality, three packages from each treatment were selected randomly every third day and evaluated for weight loss, moisture content, pH, O_2/CO_2 content in the package headspace, microbial growth and sensory quality.

MAP and VSP techniques and storage temperature affected the quality and shelf life of fresh-cut Michigan asparagus. Based on sensory scores, the shelf life of asparagus stored under MAP at 1°C and 8°C, 80% RH (18 days at 1°C, 15 days at 8°C) was longer than that stored under VSP at the same temperatures (9 days at 1°C and 3 days at 8°C). MAP at 1°C resulted in product with the highest quality and longest shelf life.

3.1 Introduction

Asparagus (*Asparagus officinalis* L.) is one of the most highly consumed vegetables. Green asparagus is the popular edible form in the US market (Luo 2006). Michigan ranks third in the nation for asparagus production and produces up to 25 million pounds annually (Michigan Asparagus Advisory Board; MDA 2005; World Horticultural Trade & U.S. Export Opportunities 2006).

Asparagus is a highly perishable crop because of its high metabolic (respiration) postharvest rate, >60 mg CO_2/kg/h (Fallik 2004). Modified atmosphere packaging (MAP) is a preservation technique which can maintain the product's storage shelf life. MAP can reduce the respiration rate of fresh produce, ethylene production and moisture loss, and help to maintain the product's nutritional value and edibility by adjusting gas atmosphere inside the package, in conjunction with a wide-range of permeable polymeric films to preserve freshness and quality (Thompson 1998).

Commodities vary in their respiration rate and in their tolerance to the amount of available O_2 and CO_2. Fresh asparagus has a high metabolic rate and its tolerance level to CO_2 is less than 10% concentration at 3-6°C and less than

15% at 0-3°C. O_2 levels less than 10% lead to discoloration (Kader 1989a; Saltveit 1989; Ooraikul 1991; Kader 1993). The recommended modified atmosphere levels of O_2 and CO_2 to preserve the shelf life of fresh asparagus is 20% O_2 and 5-10% CO_2 (Kader 1985).

Vacuum skin packaging (VSP) is another technique which can maintain freshness and extend the shelf life of fresh produce using a themoformable film to vacuum-seal the product against a rigid backboard (Tewari 2002). It can retard the growth of microorganisms, resulting in a decrease in spoilage (Buick 2006). Generally, vacuum packaging helps to preserve product appearance better than MAP (Beltran 2005). However, the published research using vacuum packaging with fresh produce is minimal.

Controlling respiration is a big challenge in designing packages for fresh-cut produce. Permeable films have been developed to use with MAP and vacuum packaging to allow the product inside the package to breathe. Permeable films can help to prevent moisture loss, decelerate produce senescence, reduce degradation of product quality and preserve the shelf life of produce (Schlimme 1994). Permeable plastic films have been created by many manufacturers for use with fresh produce to control gas transmission rates and gas exchange between the package head space and the external environment (Zagory 1998). However, the choice of film permeability depends on the respiration rate of the fresh produce (Kader 1989b; Paine 1992; Day 1993).

Temperature is also a key factor in maintaining the shelf life of fresh produce as it affects the metabolic activity of the product (Kader 1989b). Low

temperature can help to maintain product freshness by delaying its metabolic reactions and pigment degradation, and by retarding microbial growth (Kader 1989b; Ooraikul 1991; Heard 2002; Ternorio M.D. 2005).

The main objectives of this study were 1) to determine the shelf life of fresh-cut Michigan asparagus packed in two commercially available permeable films and microwavable tray systems: a microwaveable Dupont® tray and a microwaveable Cryovac® tray using two different techniques: modified atmosphere packaging (MAP) and vacuum skin packaging (VSP), and 2) to determine the effect of different storage temperatures (1°C and 8°C) on the shelf life of fresh packaged asparagus.

3.2 Materials and Methods

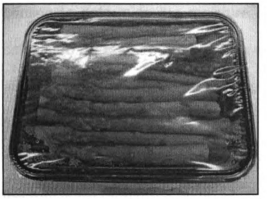
3.2.1 Sanitation, packaging and storage

Fresh, green Michigan asparagus was provided by the Michigan Asparagus Advisory Board from 3 different locations (from the middle of May to the middle of June). After arrival, fresh asparagus was rapidly transported to a chamber (3°C) in laboratory facilities at the School of Packaging (Packaging Building) and the Trout Food Science and Human Nutrition building. Asparagus spears were washed with tap water and deionized distilled water to remove soil, debris and other contamination and then sanitized by dipping in a 100 ppm sodium hypochlorite solution (Cleaner and Sanitizer, Johnson® CRS, US) for 1 minute and then rinsed twice with distilled water. The medium to large diameter spears were sorted, dried off with sanitized paper toweling (using UV light for 20-30 minutes) and trimmed to a length of 6 inches. Trimmed fresh asparagus

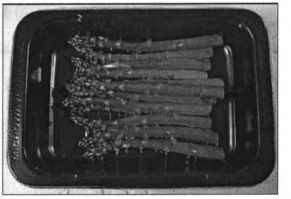
spears were then packed in the microwaveable containers. Two types of packaging techniques were used: modified atmosphere packaging (MAP) and vacuum skin packaging (VSP). A Multivac T-200 machine (Multivac, Inc., Kansas City, MO.) was used for both techniques. Products were then stored in controlled chambers at 1°C and 8°C, 80% RH for 18 days. The asparagus used for the MAP and VSP treatments were from different harvest times. Fresh-cut asparagus packaged in MAP and VSP trays are shown in Figure 3.1.

Modified Atmosphere Packaging (MAP): 453 g (1 lb) of pre-trimmed spears were packed in the Dupont® microwaveable trays (5¼ in×7½ in×1½ in, Polypropylene, Dupont®, Dura Fresh™, Wilmington, DE). A passive modified atmosphere was established and heat-sealed in medicated air containing 21% O_2, and 0.03 % CO_2, over a pressure of 80 psi. A lidding film from Dupont® was used to seal the containers (Appeel Lidding Sealant Resin 004, 2.5 mils thickness, O_2 permeability of 7.75 cc.mil/in^2.day.atm and CO_2 permeability of 8.0 cc.mil/in^2.day.atm).

Vacuum Skin Packaging (VSP): The vacuum skin packaging technique was used to pack the samples in Cryovac® microwaveable trays (4½ in × 6¾ in × 1¼ in, CS966-B2, Cryovac®, Simple Steps™, Duncan, SC). Each tray contained 133 g (0.29 lb) of asparagus spears and was vacuum-sealed with a Cryovac® lidding film (3 mils thickness, O_2 permeability of 10.64 cc.mil/in^2.day.atm and CO_2 permeability of 60.77 cc.mil/in^2.day.atm). The quantity of spears packed in to the Cryovac® containers was lower because of the limitations of the VSP system.



MAP tray



VSP tray

Figure 3.1: Fresh-cut Michigan asparagus packed in a MAP tray and a VSP tray

3.2.2 Product Evaluation

Product analysis was conducted on the stored samples by taking three trays of each packaging type and temperature, using a 3 day frequency. Triplicate analyses of each parameter for each of the trays were done on the samples. The process is illustrated in Appendix A.

3.2.2.1 Weight loss

For every 3 day evaluation, three MAP trays and three VSP trays from the two storage temperatures were weighed to determine the weight loss over the storage time using a precision balance scale (NSF®, Arlington, VA). The weight loss from the product trays for each evaluation period was calculated from the average weight of three samples of each storage temperature.

3.2.2.2 Moisture Content

Whole spears were chopped into small pieces (about 1 inch), and a sample weight of 15 - 16 g was placed into an aluminum pan. Aluminum pans containing the chopped asparagus were placed in a vacuum oven (524 Treas, Precision Scientific) at 100°C (212°F) for 4 hours and then reweighed after

cooling to determine the moisture content (AOAC 1984). Moisture content was calculated on a wet basis which is expressed as the loss in weight of asparagus after drying compared to the product fresh weight.

3.2.2.3 Headspace gas analysis

Oxygen (O_2) and carbon dioxide (CO_2) concentrations in the headspace of the tray were monitored using an O_2/CO_2 gas analyzer (Illinois 6600 Head Space Analyzer, Illinois Instruments, Inc., Johnsburg, IL). To avoid gas exchange with the surrounding atmosphere during quantification, a septum (septum PPL-193456, Illinois Instruments, Inc., Johnsburg, IL) was placed onto the film surface of the packages.

3.2.2.4 pH analysis

Whole asparagus spears were randomly selected from each treatment. 15 g of product were blended in a blender and made up to a final volume of 100 ml using Milli Q water. The pH of the solution was measured using a pH-meter (Corning 440 benchtop pH meter, Corning®, NC).

3.2.2.5 Microbial analysis

Asparagus spears were randomly selected from each packaging system and storage condition. 25 g of sample were placed into a sterile Whirl-Pack® Sampling bag (6 a 9 inch polyethylene bag, Whirl-Pack™, Nasco, Fort Atkinson, WI) and then homogenized with 100 ml of sterile 0.1% peptone water (Bacto Peptone, Difco™, Becton Dickinson and Company, USA) in a stomacher (Seward Stomacher 400 lab system, Seward Medical, London, UK) for 2 minutes at high speed. Serial dilutions (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} and 10^{-5}) were made from 1 ml of the

asparagus/fluid mixture with 9 ml of sterile 0.1% peptone water in sterile tubes. Duplicate samples of each treatment were plated on the following specific media (APHA 1984; Villanueva M.J. 2005), as shown below, using an automatic spiral plating machine (AutoPlate 4000, Spiral Biotech®, Inc., MA). Microbial plate counts were determined as average values of duplicate measurements and reported as logarithmic values of colony-forming units per gram of sample (Log $_{10}$ CFU/g).

- Total count bacteria was determined by spiral-plating 0.1 ml of the diluted samples in duplicate on Trypticase Soy Agar or TSAYE-C (Difco™, Becton Dickinson and Company, USA) containing 0.6% yeast extract and 100 ppm cyclohexamide (Sigma-Aldrich Co., St. Louis, MO). TSAYE-C plates were counted after 2-3 days of incubation at 35°C. Ranges of total count bacteria were 25-250 per plate.
- Yeasts and molds were determined by spiral-plating 0.1 ml samples on potato dextrose agar (PDA) (Difco™, Becton Dickinson and Company, USA) containing 20 ppm streptomycin (Sigma) and 50 ppm ampicillin (Sigma-Aldrich Co., St. Louis, MO). PDA plates were counted after 3-7 days of incubation at 23°C (room temperature). Countable ranges of yeast and mold were 15-150 per plate.
- *E. coli* and coliforms were determined by spiral-plating 1 ml of samples on 3M Petri films (3M Petrifilm™, MN). The films were counted after 24 hours of incubation at 35°C.

3.2.2.6 Sensory evaluation

According to the green asparagus quality guideline (Michigan Asparagus

Advisory Board 2005), the appearance of fresh, green Michigan asparagus should be a dark green-violet color with a firm texture and tightly closed and compact heads and tips. The stalks should be straight, and tender with shiny stem appearance. Visual and organoleptic characteristics of the samples were monitored to determine quality attributes and product shelf life during storage using a 9-12 member trained panel. MSU students (age between 26-30 years) served as panelists and were selected on the basis of their ability to detect specific product attributes (including odor, color and texture). All panelists participated in the training which was conducted over a 4 month period.

Standard asparagus color and quality scales were created according to the characteristics of fresh Michigan asparagus and its deterioration features including stalk and tip sections, odor and texture. Fresh product was used in training in addition to unacceptable product (the end of the shelf life) in order to give the panelists a range of attribute intensities.

Color, odor, texture (crispness/freshness) and overall quality were evaluated using a 5-point category scale, where 5 represented the best (fresh) and 1 was the worst (spoiled). The sensory testing was conducted in the Sensory Laboratory, Trout Food Science and Human Nutrition building at Michigan State University. Statistical analysis of the sensory data was performed using the statistical software program, SAS version 8.01.

3.3 Results and Discussion

3.3.1 Weight Loss

Loss of weight from both tray systems during 18 days storage at two temperatures is shown in Table 3.1. Weight loss of the products was observed in both treatments and both storage conditions. The loss in weight of fresh-cut asparagus in the MAP system was lower than that in the VSP system at both storage temperatures. The loss of product weight in both packaging systems was slower at 1°C than at 8°C. However, the difference in weight loss was not substantial. The loss of product weight was delayed due to the water vapor barrier protection from the polypropylene based microwaveable tray materials and a lidding film which is also a good water vapor barrier.

Table 3.1: The moisture content of fresh-cut Michigan asparagus stored at 1°C and 8°C, 80% RH under MAP and VSP systems during 18 days storage

Samples	Days	% Weight Loss		% Moisture Content	
		1°C	8°C	1°C	8°C
MAP	0	0.00±0.00	0.00±0.00	93.32±0.43	93.32±0.43
	3	0.00±0.00	0.00±0.00	93.30±0.24	93.00±0.60
	6	0.00±0.00	0.00±0.00	93.28±0.44	92.83±0.66
	9	0.00±0.00	0.00±0.00	93.25±0.59	93.25±0.36
	12	0.00±0.00	0.18±0.14	93.26±0.31	93.19±0.73
	15	0.14±0.16	0.30±0.13	93.20±0.50	93.14±0.47
	18	0.18±0.14	0.30±0.13	93.17±0.56	93.10±0.68
VSP	0	0.00±0.00	0.00±0.00	93.69±0.43	93.69±0.43
	3	0.00±0.00	0.00±0.00	93.64±0.36	93.64±0.26
	6	0.00±0.00	0.13±0.32	93.60±0.33	93.55±0.31
	9	0.00±0.00	0.25±0.38	93.58±0.33	93.54±0.40
	12	0.25±0.39	0.62±0.56	93.57±0.29	93.54±0.46

3.3.2 Moisture Content

The moisture content of fresh Michigan asparagus on day 0, prior to storage, was approximately 93.32%. A decrease in moisture content of the samples packed in both MAP trays and VSP trays at 1°C and 8°C was observed. In the MAP system, loss of moisture content at 1°C (0.15%) was slightly less than that at 8°C (0.23%) over the storage time as illustrated in Table 3.1 and Figure 3.2.

Loss in moisture content of asparagus packed in the VSP system at 1°C and 8°C also occurred as shown in Table 3.1 and Figure 3.3. Loss of moisture content from the VSP of product at 8°C (0.16%) was almost the same as that at 1°C (0.13%) over the storage time.

There was no significant difference ($p>0.05$) in moisture loss during storage for MAP at 1°C and also at 8°C. The same result was found for VSP at 1°C and 8°C. There was no significant difference ($p>0.05$) between the two storage temperatures for each treatment on the same evaluation day. The moisture content of fresh-cut asparagus in MAP and VSP and stored at 1°C and 8°C remained satisfactory over the entire storage time.

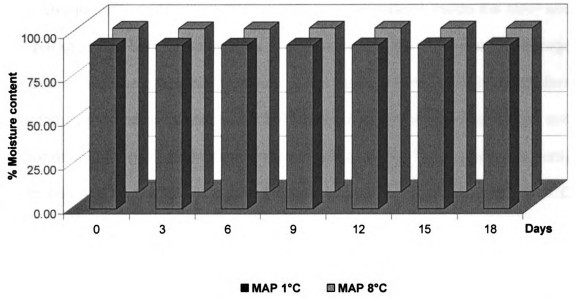


Figure 3.2: Moisture content of fresh-cut Michigan asparagus stored in MAP at 1°C and 8°C, 80% RH during storage

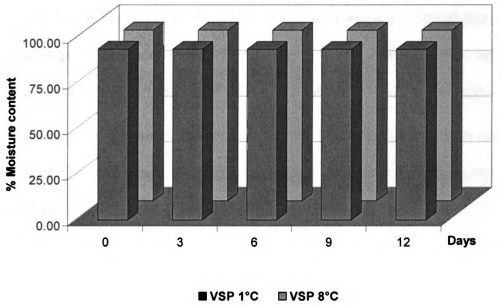


Figure 3.3: Moisture content of fresh-cut Michigan asparagus stored in VSP at 1°C and 8°C, 80% RH during storage

3.3.3 Headspace gas Analysis

Oxygen (O_2) and carbon dioxide (CO_2) concentrations inside the MAP and VSP packages at both temperatures changed during the experimental storage time because of the respiration process of the fresh asparagus, the metabolism of contaminated microorganisms and the gas exchange between the interior and exterior atmospheres through the permeable film and tray. This analysis was only able to be done on the MAP system. Samples stored in VSP system at both 1°C and 8°C could not be measured because of the product spoilage that caused liquid in the package, to accumulate and there was not enough room for sampling the gas. The gaseous atmosphere in the MAP is shown in Table 3.2, and it is represented in Figure 3.4, for O_2 and Figure 3.5, for CO_2. The initial gas concentration inside fresh-cut asparagus in the MAP system was medical air, composed of 21% O_2 and 0.03 % CO_2 while the O_2 and CO_2 concentration initially in the package headspace under VSP system was 0%. It is difficult to achieve a complete vacuum and to remove all of the air from the package (Irtwange 2006).

A change in gaseous atmosphere inside the packaging system occurred. The level of O_2 went down while CO_2 increased due to the consumption of O_2 and production of CO_2. O_2 and CO_2 levels inside the MAP at 1°C changed moderately from the initial values of 21% O_2 and 0.03% CO_2 before stabilizing at around 19% and 3%, respectively, and reached equilibrium after day 3, for O_2 and day 6, for CO_2.

At 8°C, oxygen concentration of the asparagus-packed MAP reached equilibrium after day 6, while carbon dioxide continued to increase and reached equilibrium about day 9.

Table 3.2: O_2 and CO_2 concentration in fresh-cut Michigan asparagus in MAP at 1°C and 8°C, 80% RH during storage

Days	MAP at 1°C		MAP at 8°C	
	average % O_2	average %CO_2	average %O_2	average %CO_2
0	20.90±0.00	0.03±0.00	20.90±0.00	0.03±0.00
3	19.27±0.36	2.55±0.56	19.05±0.68	3.65±0.99
6	19.32±0.18	3.12±0.12	18.60±0.54	3.77±0.84
9	19.30±0.23	3.05±0.23	18.42±0.52	4.55±0.50
12	19.23±0.23	3.03±0.36	18.30±0.54	4.47±0.79
15	19.45±0.12	3.07±0.44	18.30±0.33	4.38±0.69
18	18.88±0.17	3.38±0.71	18.33±0.36	4.35±0.58

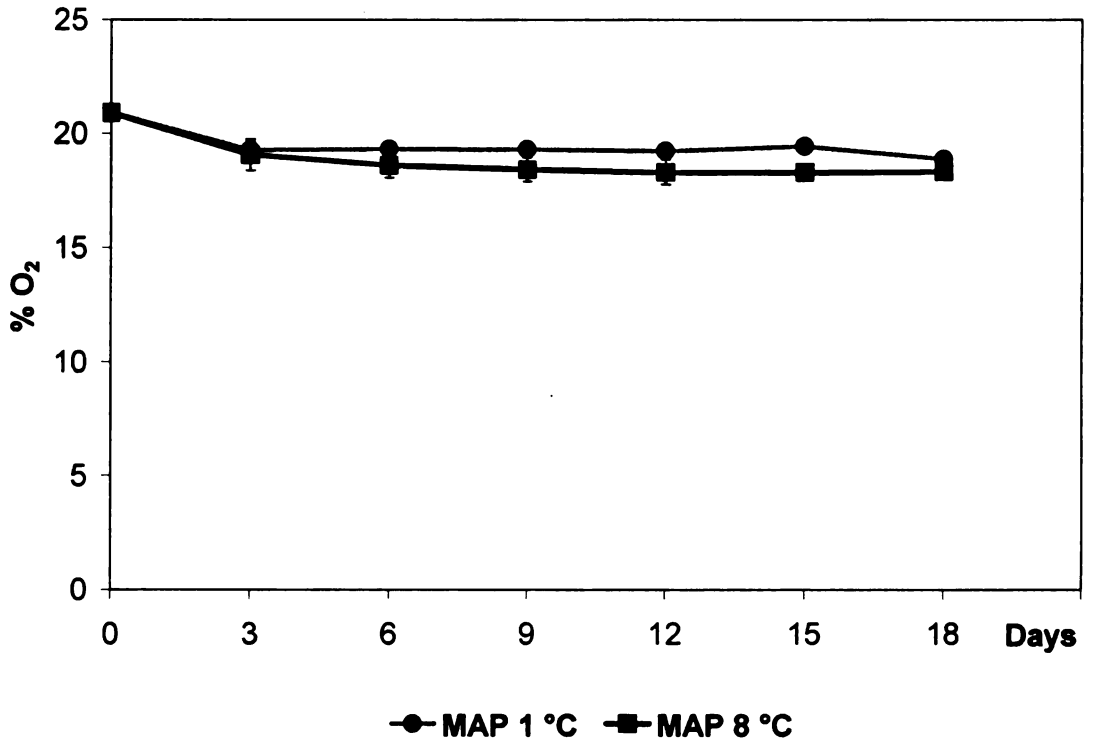


Figure 3.4: O_2 concentration in fresh-cut Michigan asparagus in MAP at 1°C and 8°C, 80% RH during storage

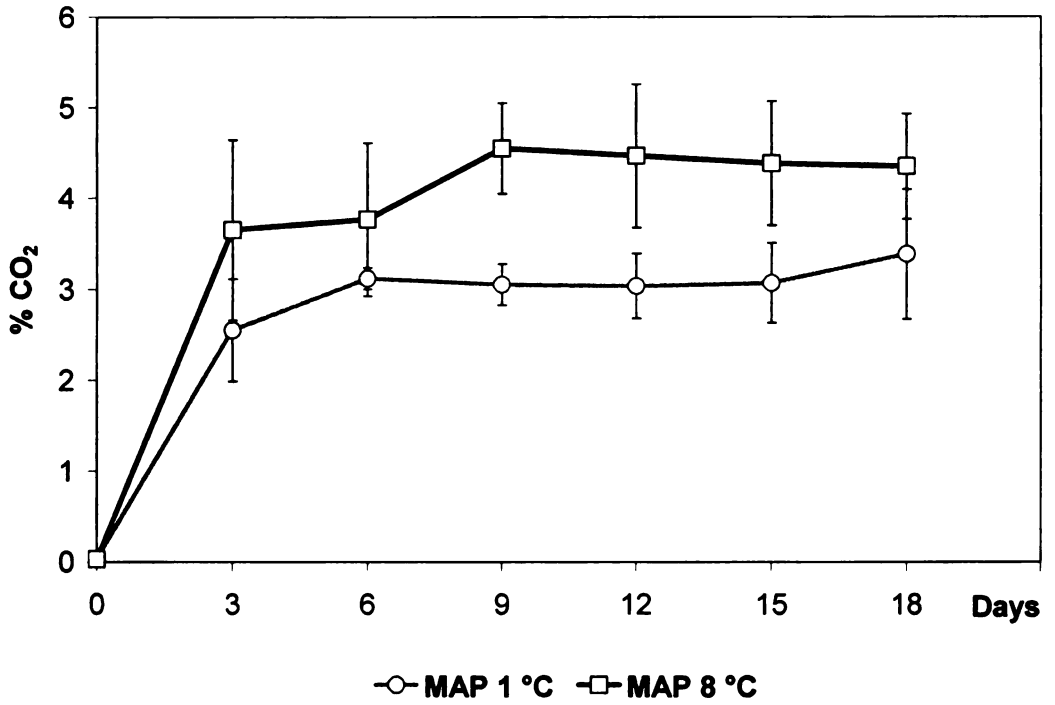


Figure 3.5: CO_2 concentration in fresh-cut Michigan asparagus in MAP at 1°C and 8°C, 80% RH during storage

3.3.4 pH Analysis

pH of fresh-cut Michigan asparagus decreased slightly over the storage time for each treatment. There was no significant difference ($p > 0.05$) in the pH of the asparagus-packed MAP at 1°C and 8°C, and between the two storage temperatures on the same evaluation day as shown in Figure 3.6. For VSP asparagus, there was no significant difference ($p > 0.05$) in pH between the two storage temperatures at the same evaluation day as illustrated in Figure 3.7. However, the pH decreased significantly over storage for product stored in VSP at 8°C and at 1°C, day 12.

The decrease in pH values of samples stored under MAP and VSP at 1°C occurred more slowly than at 8°C. The difference in the pH between the MAP

samples at the two storage temperatures was not as much as for the VSP samples.

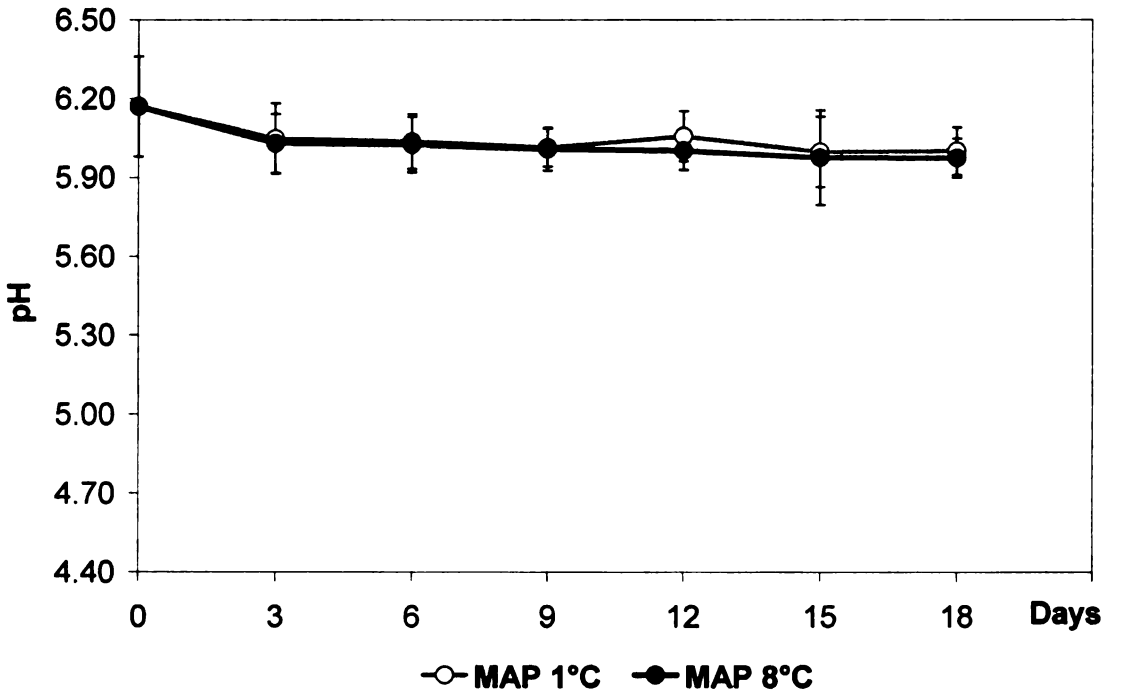


Figure 3.6: The pH of fresh-cut Michigan asparagus stored in MAP at 1°C and 8°C, 80% RH during storage

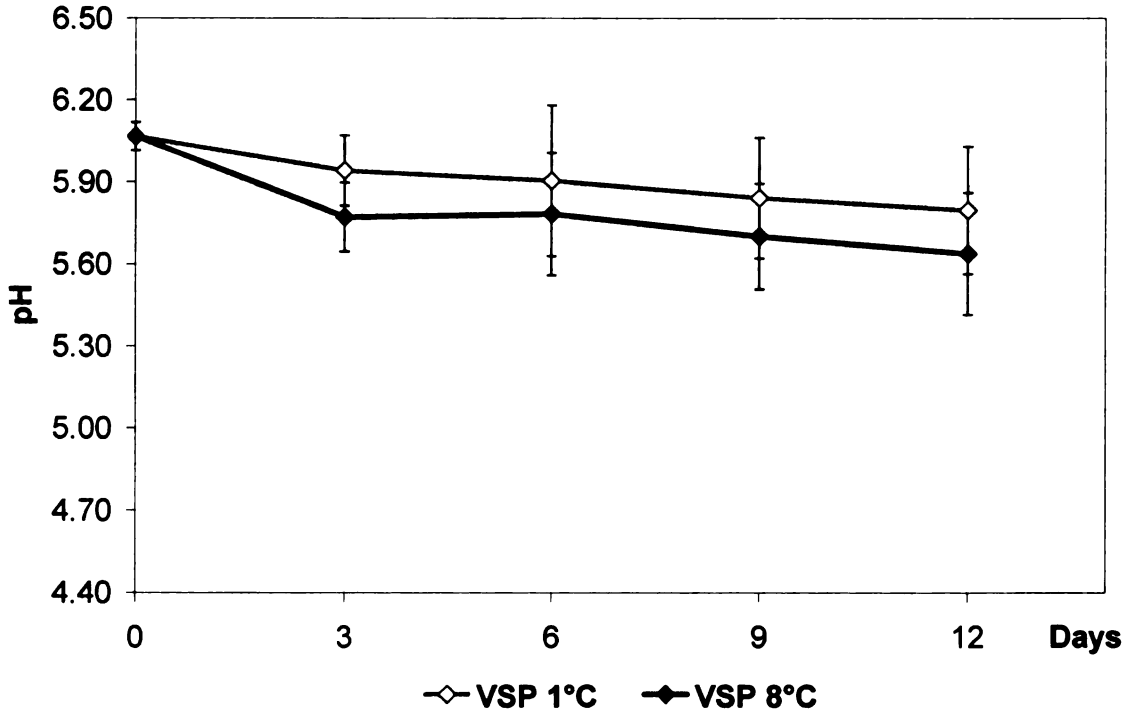


Figure 3.7: The pH of fresh-cut Michigan asparagus stored in VSP at 1°C and 8°C, 80% RH during storage

3.3.5 Microbial analysis

The microbial growth on fresh-cut Michigan asparagus stored under MAP and VSP at both 1°C and 8°C increased as indicated in Table 3.3. Microbial analysis of VSP asparagus at both 1°C and 8°C is reported for only 9 storage days due to the deterioration of the product. The initial microbial load in MAP and VSP was different since these two experiments used asparagus from different lots.

The numbers of microorganisms on fresh-cut asparagus stored under MAP at 1°C was lower than that at 8°C. The total count population of bacteria in MAP trays increased from 5.08 $\log_{10}$ CFU/g from the initial time point (day 0) to 7.57 $\log_{10}$ CFU/g at 1°C, and 7.84 $\log_{10}$ CFU/g at 8°C as shown in Figure 3.8. Yeast and mold counts increased from 4.58 $\log_{10}$ CFU/g to approximately 6.62 $\log_{10}$ CFU/g for asparagus in the MAP package at 1°C and 7.63 $\log_{10}$ CFU/g for MAP product at 8°C as illustrated in Figure 3.9. The growth of coliforms in modified atmosphere packed-asparagus stored at 1°C and 8°C was initially 3.48 $\log_{10}$ CFU/g and gradually increased to 3.90 $\log_{10}$ CFU/g at 1°C and 3.97 $\log_{10}$ CFU/g at 8°C as illustrated in Table 3.3.

The growth of bacteria on fresh-cut asparagus packed in VSP was slightly lower at 1°C than at 8°C, from 5.01 $\log_{10}$ CFU/g at the beginning, to 8.74 $\log_{10}$ CFU/g and 8.88 $\log_{10}$ CFU/g, respectively. This trend line is about the same as shown for bacterial growth in MAP packages shown in Figure 3.10. The yeast and mold loads on the VSP asparagus was initially lower than for the MAP product, but in 9 days the yeast population of the VSP product at 1°C and 8°C

grew to 7.28 $\log_{10}$ CFU/g and 7.62 $\log_{10}$ CFU/g, respectively. This was much higher than that of the MAP product at both storage conditions as shown in Figure 3.11. The coliform population in the VSP packaged asparagus stored at 1°C and 8°C on first storage day was 3.52 $\log_{10}$ CFU/g. At the end of shelf life (day 9, based on sensory evaluation), the number had risen to 3.60 $\log_{10}$ CFU/g and 4.30 $\log_{10}$ CFU/g, respectively as shown in Table 3.3.

Table 3.3: Microbial populations on fresh-cut Michigan asparagus stored in MAP and VSP at 1°C and 8°C, 80% RH during storage

Sample	Days	Microbial Quantity ($\log_{10}$ CFU/g)		
		Total Count Bacteria	Yeast and molds	Coliforms
MAP 1°C	0	5.08±0.23	4.58±0.25	3.48±0.25
	3	5.17±0.45	5.18±0.19	3.67±0.19
	6	6.12±0.34	5.51±0.16	3.80±0.16
	9	6.36±0.33	6.45±0.57	3.87±0.57
	12	6.52±0.21	6.26±0.31	3.90±0.31
	15	6.91±0.39	6.56±0.24	3.87±0.24
	18	7.57±0.05	6.62±0.39	3.90±0.39
MAP 8°C	0	5.08±0.23	4.58±0.25	3.48±0.25
	3	6.00±0.48	5.59±0.49	3.75±0.49
	6	7.59±0.17	6.12±0.93	3.82±0.93
	9	7.00±0.81	6.79±0.58	3.85±0.58
	12	7.18±0.36	7.59±0.37	3.88±0.37
	15	8.19±0.64	7.62±0.36	3.95±0.36
	18	7.84±0.52	7.63±0.80	3.97±0.80
VSP 1°C	0	5.01±0.01	3.30±0.21	3.52±0.21
	3	6.56±0.22	6.39±0.19	3.12±0.19
	6	6.28±0.07	6.82±0.08	3.67±0.08
	9	8.74±0.10	7.28±0.13	3.60±0.13
VSP 8°C	0	5.01±0.01	3.30±0.21	3.52±0.21
	3	6.83±0.08	6.93±0.08	3.60±0.08
	6	7.10±0.05	7.00±0.00	3.67±0.00
	9	8.88±0.09	7.62±0.11	4.30±0.11

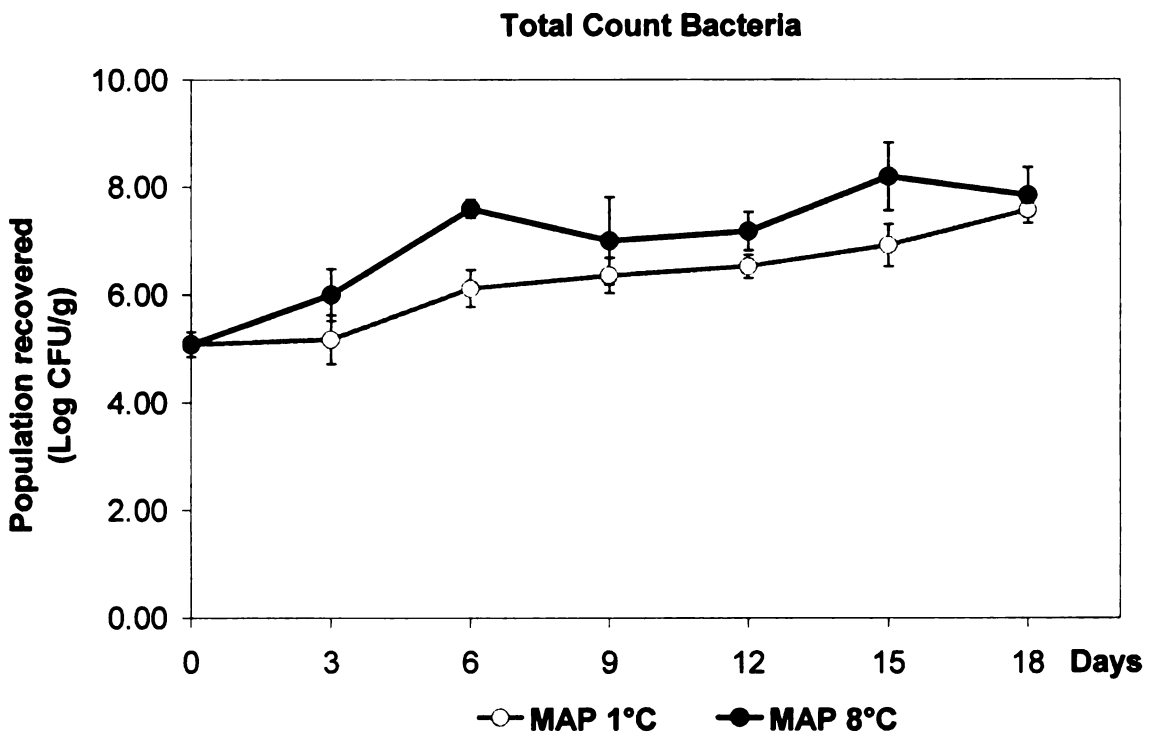


Figure 3.8: Bacterial growth on fresh-cut asparagus in MAP at 1°C and 8°C, 80% RH during storage

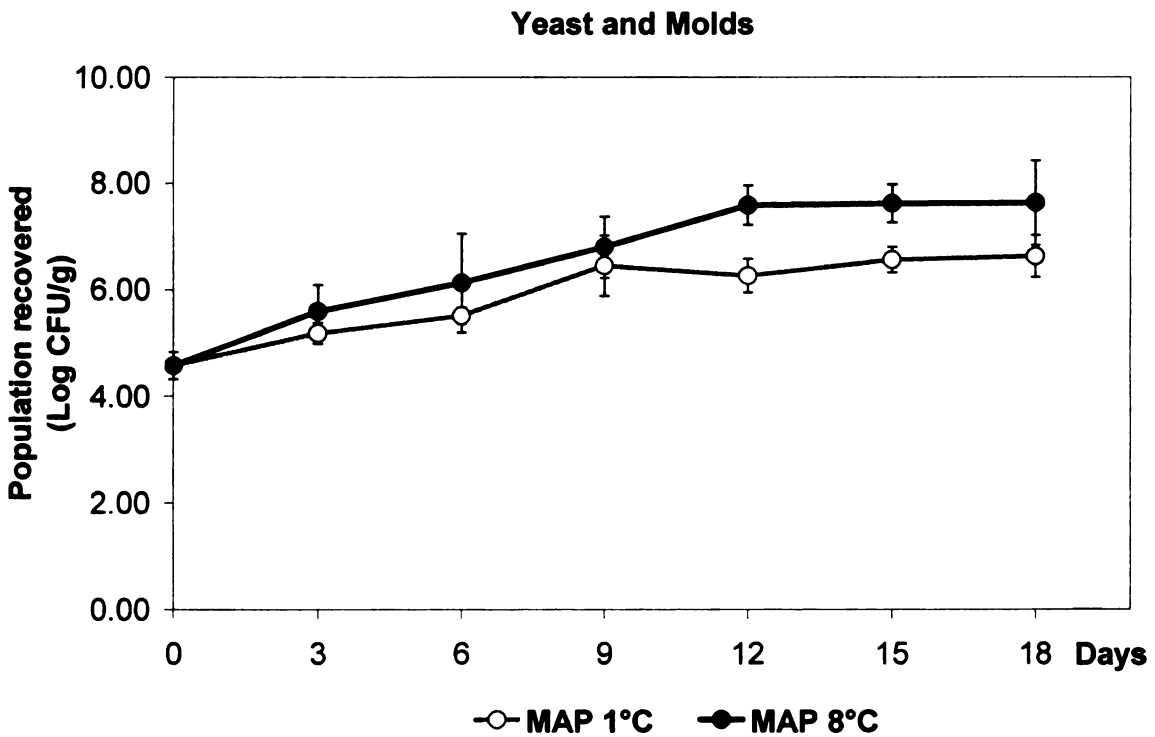


Figure 3.9: The growth of yeast and molds on fresh-cut asparagus in MAP at 1°C and 8°C, 80% RH during storage

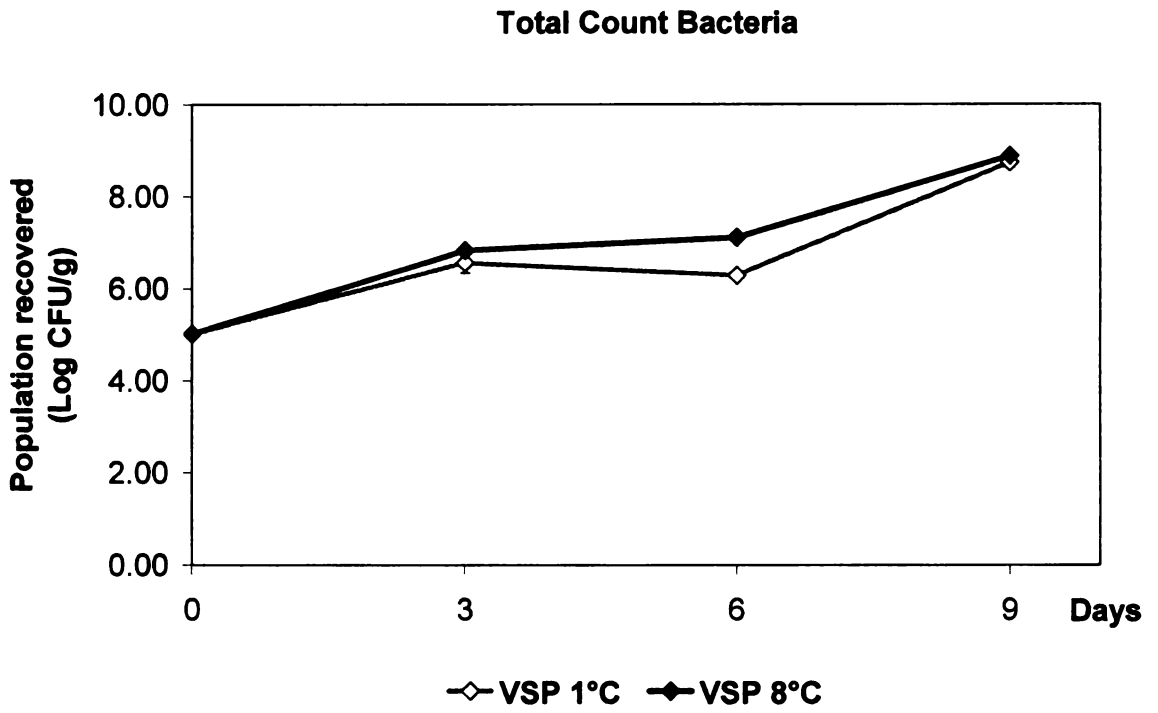


Figure 3.10: Bacterial growth on fresh-cut asparagus in VSP at 1°C and 8 °C, 80% RH during storage

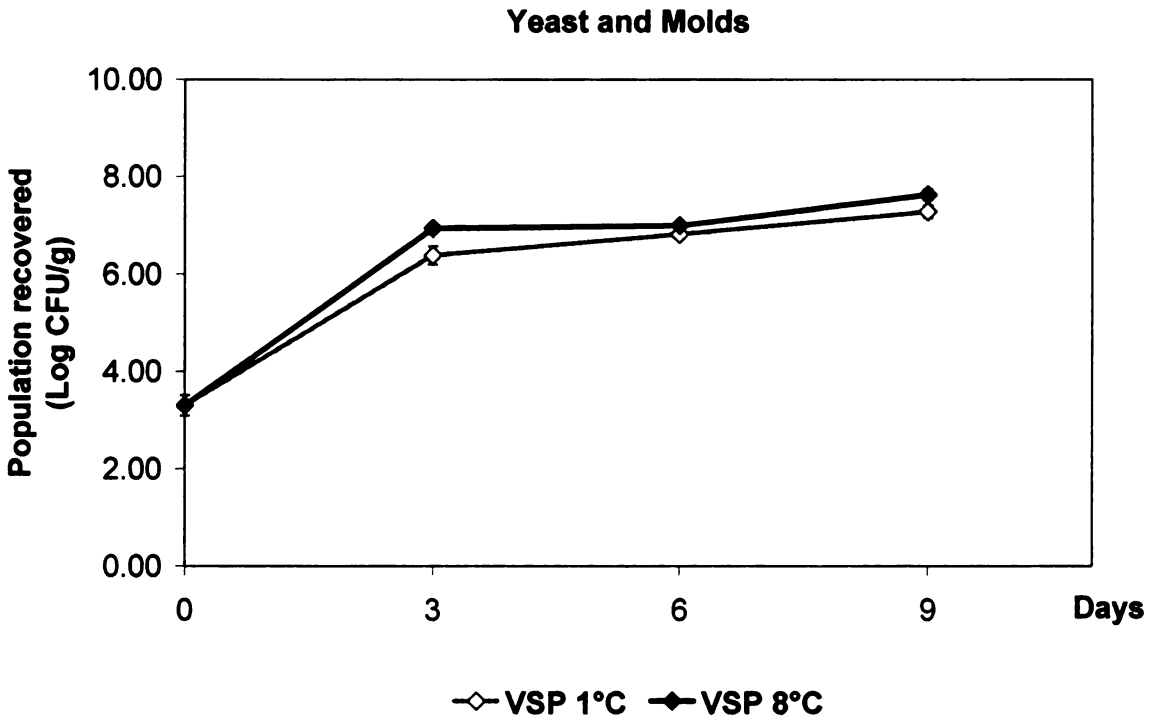


Figure 3.11: The growth of yeast and molds on fresh-cut asparagus in VSP at 1°C and 8°C, 80% RH during storage

3.3.6 Sensory evaluation

The trained panel sensory evaluation results for fresh-cut Michigan asparagus are shown in Table 3.4. The quality of MAP asparagus, stored at 1°C was acceptable for more than 18 days while the shelf life of MAP asparagus stored at 8°C was approximately 18 days due to the change in stalk color and unpleasant odor as illustrated in Table 3.5 and Figure 3.12. Quality parameters included stalk color, tip color, texture, odor and acceptability of overall appearance as evaluated by 9-12 trained panelists.

Samples stored in VSP spoiled very fast and a 9 day storage life was found at 1°C. At 8°C, the shelf life of asparagus VSP was 3 days. At the end of the experiment, the asparagus stored in the VSP had an unacceptable smell, watery, spoiled tips and dark green/purple in color.

The asparagus used in the VSP experiment was delivered near the end of the Michigan asparagus season. This affected the initial quality of the asparagus used in this treatment, which can be seen in Table 3.6 and Figure 3.13. At day 0 (initial day), sensory scores of fresh asparagus used for the VSP (overall quality score = 3, still marketable-aging, deterioration but still expectable) were lower than that of fresh asparagus used for MAP product (overall quality score = 5, very fresh/best). Moreover, due to the vacuum delivered in the VSP process, the tips of the asparagus spears were squeezed, resulting in some bruising and rot.

Table 3.4: Panelist's response (mean) for fresh-cut Michigan asparagus stored in MAP and VSP at 1°C and 8°C, 80% RH

Samples	Days	Color		Texture	Odor	Overall Quality
		Stalk	Tip			
MAP 1°C	0	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]
	3	5.0 [a]	5.0 [a]	5.0 [a]	4.8 [b]	5.0 [a]
	6	4.3 [b]	4.3 [b]	4.2 [b]	4.5 [b]	4.3 [b]
	9	4.0 [b]	4.5 [b]	4.2 [b]	4.5 [b]	4.3 [b]
	12	3.2 [b]	3.7 [b]	3.9 [b]	4.2 [b]	3.9 [b]
	15	3.8 [b]	4.3 [b]	4.1 [b]	3.8 [b]	4.3 [b]
	18	2.8 [b]	3.9 [b]	3.4 [b]	3.5 [b]	3.4 [b]
MAP 8°C	0	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]	5.0 [a]
	3	5.0 [a]	5.0 [a]	5.0 [a]	4.7 [b]	5.0 [a]
	6	4.0 [b]	4.1 [b]	4.0 [b]	4.2 [b]	4.2 [b]
	9	3.4 [b]	3.7 [b]	3.9 [b]	4.0 [b]	4.0 [b]
	12	3.2 [b]	3.5 [b]	3.3 [b]	3.3 [b]	3.1 [b]
	15	3.0 [b]	3.4 [b]	3.1 [b]	3.0 [b]	3.1 [b]
	18	2.9 [b]	3.2 [b]	3.8 [b]	2.7 [b]	2.9 [b]
VSP 1°C	0	3.1 [a]	3.6 [a]	4.1 [a]	3.4 [a]	3.3 [a]
	3	3.4 [b]	3.6 [a]	3.9 [a]	3.7 [a]	4.0 [b]
	6	3.4 [b]	2.7 [b]	3.7 [b]	3.3 [a]	3.1 [a]
	9	3.0 [a]	2.5 [b]	3.6 [b]	3.0 [b]	3.0 [b]
	12	3.3 [a]	3.0 [b]	3.8 [a]	2.5 [b]	2.1 [b]
VSP 8°C	0	3.1 [a]	3.6 [a]	4.1 [a]	3.4 [a]	3.3 [a]
	3	3.4 [b]	2.9 [b]	3.7 [b]	2.9 [b]	3.1 [a]
	6	2.8 [b]	2.7 [b]	3.7 [b]	2.0 [b]	1.8 [b]
	9	3.1 [a]	2.1 [b]	3.5 [b]	1.5 [b]	1.4 [b]
	12	2.5 [b]	1.5 [b]	2.5 [b]	1.0 [b]	1.0 [b]

[ab] Means within a column, which are not followed by a common superscript letter, are significant difference ($p<0.05$).

Table 3.5: Effect of storage temperature on sensory characteristics of fresh-cut Michigan asparagus stored in MAP

Samples	Days	Color		Texture	Odor	Overall Quality
		Stalk	Tip			
MAP 1°C	0	5.0	5.0	5.0	5.0	5.0
	3	5.0	5.0	5.0	4.8	5.0
	6	4.3 [a]	4.3	4.2 [a]	4.5 [a]	4.3
	9	4.0 [a]	4.5 [a]	4.2 [a]	4.5 [a]	4.3 [a]
	12	3.2	3.7 [a]	3.9 [a]	4.2 [a]	3.9 [a]
	15	3.8 [a]	4.3 [a]	4.1 [a]	3.8 [a]	4.3 [a]
	18	2.8	3.9 [a]	3.4 [a]	3.5 [a]	3.4 [a]
MAP 8°C	0	5.0	5.0	5.0	5.0	5.0
	3	5.0	5.0	5.0	4.7	5.0
	6	4.0 [b]	4.1	4.0 [b]	4.2 [b]	4.2
	9	3.4 [b]	3.7 [b]	3.9 [b]	4.0 [b]	4.0 [b]
	12	3.2	3.5 [b]	3.3 [b]	3.3 [b]	3.1 [b]
	15	3.0 [b]	3.4 [b]	3.1 [b]	3.0 [b]	3.1 [b]
	18	2.9	3.2 [b]	3.8 [b]	2.7 [b]	2.9 [b]

[ab] Means within a column, which are not followed by a common superscript letter, are significant difference ($p<0.05$).

Table 3.6: Effect of storage temperature on sensory characteristics of fresh-cut Michigan asparagus stored in VSP

Samples	Days	Color		Texture	Odor	Overall Quality
		Stalk	Tip			
VSP 1°C	0	3.1	3.6	4.1	3.4	3.3
	3	3.4	3.6 [a]	3.9	3.7 [a]	4.0 [a]
	6	3.4 [a]	2.7	3.7	3.3 [a]	3.1 [a]
	9	3.0	2.5 [a]	3.6	3.0 [a]	3.0 [a]
	12	3.3 [a]	3.0 [a]	3.8 [a]	2.5 [a]	2.1 [a]
VSP 8°C	0	3.1	3.6	4.1	3.4	3.3 [b]
	3	3.4	2.9 [b]	3.7	2.9 [b]	3.1 [b]
	6	2.8 [b]	2.7	3.7	2.0 [b]	1.8 [b]
	9	3.1	2.1 [b]	3.5	1.5 [b]	1.4 [b]
	12	2.5 [b]	1.5 [b]	2.5 [b]	1.0 [b]	1.0 [b]

[ab] Means within a column, which are not followed by a common superscript letter, are significant difference ($p<0.05$).

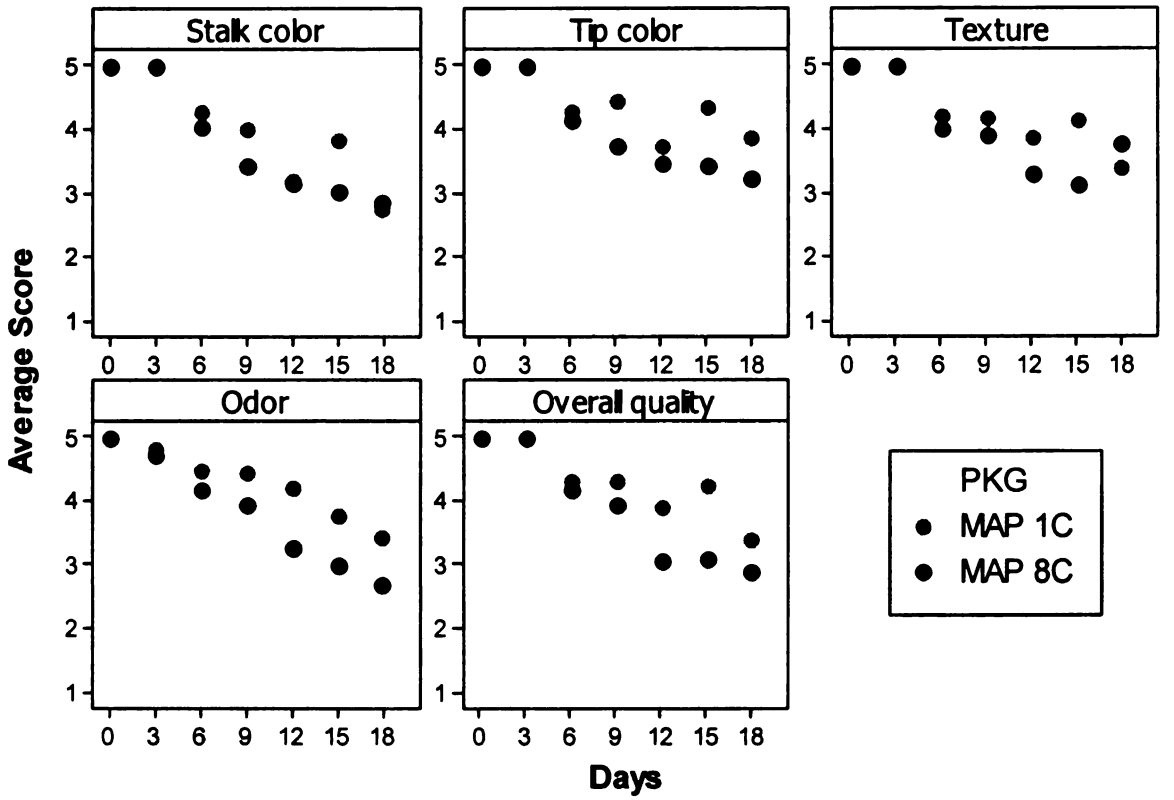


Figure 3.12: The sensory quality of fresh-cut Michigan asparagus packed in MAP tray at 1°C and 8°C, 80% RH during 18 days of storage

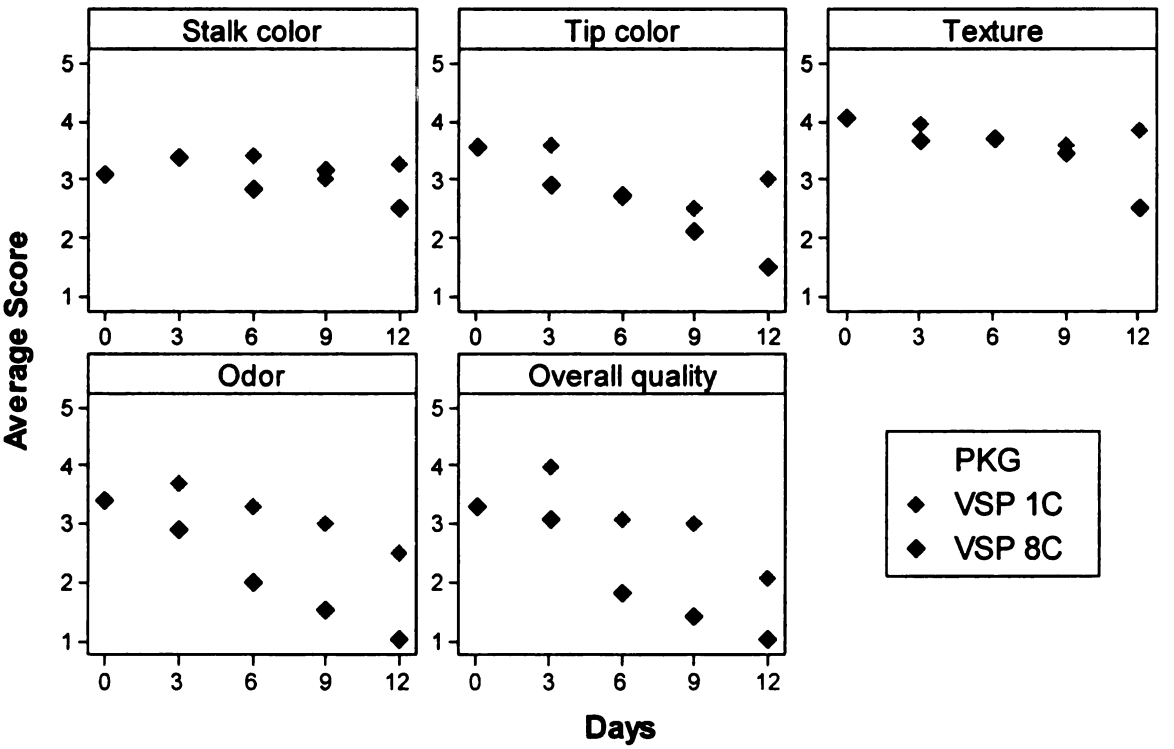


Figure 3.13: The sensory quality of fresh-cut Michigan asparagus packed in VSP tray at 1°C and 8°C, 80% RH during 18 days of storage

3.4 Conclusion

Modified atmosphere packaging (MAP), vacuum skin packaging (VSP) and temperature affect the quality and shelf life of fresh-cut Michigan asparagus. Based on sensory evaluation, the shelf life of fresh asparagus stored in MAP at 1°C was slightly more than 18 days and at 8°C, it was 18 days, which was longer than that stored under VSP at 1°C, (9 days) and at 8°C (only 3 days). As mentioned, the quality of asparagus used for VSP was not as good as that used for MAP. This might affect the shelf life of asparagus stored in VSP.

The initial quality of a fresh product is very important in overall quality maintenance and shelf life of product. Proper sanitization is also necessary to reduce the microbial load that causes the deterioration, and to preserve the quality of fresh-cut asparagus longer. 100 ppm sodium hypochlorite solution (with out controlling the pH) might not be able to provide the necessary sanitation level for fresh-cut asparagus.

The VSP technique that was used with the fresh-cut asparagus needs to be improved to avoid damage due to pressure decrease, which probably resulted in accelerated deterioration. A suitable vacuum pressure must be employed when packing fragile products such as fresh asparagus.

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4 SHELF LIFE OF FRESH-CUT GREEN ASPARAGUS IN MAP AND VSP MICROWAVABLE TRAY SYSTEMS

Abstract

Sales of fresh-cut produce have increased rapidly and have become the fastest growing part of the fresh produce industry. Asparagus (*Asparagus officinalis* L.) is one of the most popular culinary vegetables since it contains a wealth of fiber and several essential nutrients. It is a very perishable commodity due to its very high respiration rate (>60 mg CO_2/Kg-hr). To maintain product quality and to satisfy consumer demand as a convenient food, modified atmosphere packaging (MAP), vacuum skin packaging (VSP) and microwaveable containers were used to extend the shelf life of fresh-cut asparagus as a ready-to-eat food product. Asparagus has a short shelf life, approximately 14 days under refrigerated temperature (2°C). The objective of this study was to determine the shelf life of fresh-cut asparagus packed in MAP and VSP microwaveable tray systems at commercial storage conditions, 4°C, 80% RH. Weight loss, moisture content, O_2/CO_2 concentration in the package headspace, product pH, microbial growth, and sensory evaluation were used to determine the product quality and shelf life. During storage for 21 days, there was no significant difference ($p>0.05$) in weight loss, moisture content, pH, the level of O_2/CO_2 concentration in the package headspace and growth of microorganisms between the two packaging systems. MAP maintained the freshness and shelf life of the fresh-cut asparagus more than 21 days while the VSP system maintained the product shelf life through 18 days. Both MAP and

VSP products can be cooked in the package using a microwave oven to create a ready-to-eat fresh product.

4.1 Introduction

The consumer demand for ready-to-eat fresh produce is rapidly increasing due to an interest in healthy food, a well-balanced diet and convenience. This has helped fresh-cut produce become one of the most popular products in today's marketplace (IFPA 2003). Asparagus has become one of the most consumed vegetables in the world.

Asparagus (*Asparagus officinalis* L.) is a unique perennial vegetable and is a member of the lily family (Liliaceae) (Hexamer 1901; Peirce 1987; Rubatzky 1997). Green asparagus is the most popular consumed variety in the United States, Japan, New Zealand, Australia and Chilean markets, and is gradually becoming more popular in the European market (Esteve 1995; Luo 2006). Like other fresh fruits and vegetables, fresh asparagus is alive and respiring after harvesting. Asparagus has a very high respiration rate (>60 mg CO_2/Kg-hr), resulting in a perishable vegetable which has a short shelf life, normally 14 days (Kader 1986; Kader 1992 ; Fallik 2004).

Freshness is a major quality requirement, which is true of all other fresh produce. To maintain product quality and to support the growing economics of the fresh-cut asparagus market, packaging is an essential function in the fresh-cut produce business. Modified atmosphere packaging (MAP) is a technology which is used to protect the quality and maintain the shelf life of fresh fruits and vegetables for longer periods (Moleyar 1994). MAP can help to extend the

storage life of fresh-cut produce by manipulating the oxygen (O_2) and carbon dioxide (CO_2) mass balances, coordination of the storage temperature and the permeability of the polymeric film to allow O_2 to enter and CO_2 to leave.

Before designing the package, it is very important to understand the product requirements to avoid undesirable physiological damage since each fruit and vegetable has its own respiration rate and its safe O_2 and CO_2 headspace levels. Fresh asparagus has a very high metabolic activity and its tolerance levels are less than 10% at 3-6°C and less than 15 % at 0-3°C for CO_2 concentration, and less than 10% O_2 leads to discoloration (Kader 1989a; Saltveit 1989; Ooraikul 1991; Kader 1993). The recommended modified atmosphere O_2 and CO_2 levels for maintaining the quality attributes of fresh asparagus are 21% O_2 (Air) and 5-10% CO_2 (Kader 1985).

Vacuum packaging has been used as a method to preserve food since the 1960s, mostly dried foods and meat products (Blakistone 1998). Vacuum packaging helps to retard aerobic microbial growth, which is a cause of spoilage. Vacuum skin packaging (VSP) uses the same technique as vacuum packaging, and in addition uses a themoformable film to seal over the product against a rigid backboard (Tewari 2002). This process has been used to maintain meat product quality. The use of this technique with fresh asparagus and other fresh produce is not widely accepted.

In recent years, a permeable polymeric film/pouch has been used as a package for MAP and vacuum packaging to extend the shelf life of whole/cut fresh produce. To bring more added values to the fresh asparagus market as

well as to meet consumer demand for ready-to-eat products, microwaveable tray systems are being investigated for ready-to-eat products.

This study has investigated the storage shelf life of fresh-cut green asparagus packed in MAP and VSP microwaveable tray systems at the commercial storage condition of 4°C, 80% RH.

4.2 Materials and Methods

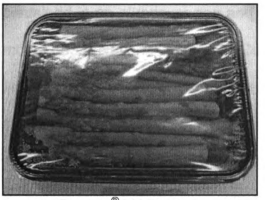
4.2.1 Sanitization, packaging and storage

Fresh, green Peru asparagus produced and packed by Danper Trujillo S.A.C under the brand name CASAVERDE® was used in this research. After one day of shipment in corrugated boxes with gel-ice packs (2-5°C), the asparagus was transported to controlled storage rooms (4°C, 80% RH) in the School of Packaging and Food Science and Human Nutrition building, East Lansing, MI. Medium diameter (8/16 – 11/16 inch) asparagus spears (U.S. Department of Agriculture 1997) were sorted and trimmed to a length of 6 inches. Trimmed spears were washed with distilled water and deionized distilled water to remove soil, debris and any other contamination and then sanitized by dipping in a 200 ppm sodium hypochlorite sanitizer (Cleaner and Sanitizer, Johnson® CRS, US) for 2 minutes (Suslow 1997; Parish M.E. 2003) and left for 5 minutes on perforated trays before washing twice with distilled water. Sanitized spears were dried with sanitized paper towels before packaging in containers. The pH of the chloride solution was controlled with vinegar to approximately 5.27 prior to use in order to increase the activity of the chlorine against pathogens. Fresh-cut asparagus was packed into microwaveable containers supplied by DuPont

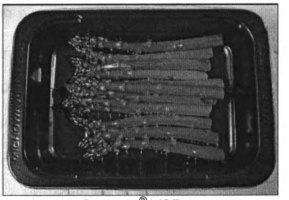
Packaging & Industrial Polymers (Wilmington, DE) and Cryovac Sealed Air Corporation (Duncan, SC). Two types of packaging techniques were used: modified atmosphere packaging (MAP) and vacuum skin packaging (VSP). Both tray systems were sealed with highly permeable lidding films as provided by the above manufacturers. A Multivac T-200 machine (Multivac, Inc., Kansas City, MO.) was used to pack the asparagus in both type systems. Products were stored at 4°C, 80% RH, a commercial storage condition, during the experimental storage time of 21 days. Asparagus in MAP and VSP trays is shown in Figure 4.1.

Modified Atmosphere Packaging (MAP): 226.5 g (0.5 lb) of pre-trimmed spears were packed in Dupont® microwaveable trays (5¼ in × 7½ in × 1½ in, Polypropylene, Dupont®, Dura Fresh™, Wilmington, DE). A passive modified atmosphere was established with medical air composed of 21% O_2, and 0.03 % CO_2, The lidding film from Dupont® (Appeel Lidding Sealant Resin 004, 2.5 mils thickness, O_2 permeability of 7.75 cc.mil/in^2.day.atm and CO_2 permeability of 8.0 cc.mil/in^2.day.atm) was heat sealed using 80 psi to the trays.

Vacuum Skin Packaging (VSP): 135.9 g (0.3 lb) of fresh-cut green asparagus spears were packed under vacuum in Cryovac® microwaveable trays (4½ in × 6¾ in × 1¼ in, CS966-B2, Cryovac®, Simple Steps™, Duncan, SC) and then vacuum-sealed with a Cryovac® lidding film (3 mils thickness, O_2 permeability of 14.3 cc.mil/in^2.day.atm and CO_2 permeability of 59.9 cc.mil/in^2.day.atm).



Dupont® MAP tray



Cryovac® VSP tray

Figure 4.1: Fresh-cut green asparagus spears packed in a Dupont® tray using MAP, and a Cryovac® tray using VSP

4.2.2 Product Evaluation

Product analysis was performed on the stored samples every 3 days by sampling three trays from each tray system for the parameters mentioned. Triplicate analyses of each parameter for each of the three trays were done on the samples. The process used for asparagus is illustrated in Appendix A.

4.2.2.1 Weight loss

The loss of weight is important since it can relate to an economic loss, as well as loss of quality. Three MAP trays and VSP trays were removed from storage and weighed to determine the water loss of product over the storage time using a precision balance scale (Arlington, VA). The weight loss from the product trays for each evaluation was calculated from the weight average of three samples of each treatment.

4.2.2.2 Moisture Content

Whole asparagus spears were randomly selected from each tray system and chopped to a length of 0.5 inch. A sample weight of approximately 11 g was

contained in an aluminum pan and dried in a vacuum oven (Precision Scientific, model 5831, National Appliance Company, Kokomo, IN) at 100°C (212°F) for 4 hours and then reweighed after cooling to determine the loss of weight (AOAC 1984). Moisture content was calculated as "wet basis", which is expressed as the loss in weight of asparagus after drying compared to the product fresh weight.

$$WetBasis = \frac{Initialweight - Finalweight}{Initialweight} \times 100$$

4.2.2.3 Headspace gas analysis

Oxygen (O_2) and carbon dioxide (CO_2) concentration in the package headspace were monitored using an O_2/CO_2 gas analyzer (Illinois 6600 Head Space Analyzer, Illinois Instruments, Inc., Johnsburg, IL). To avoid gas exchange with the surrounding atmosphere during measurement, a septum (septum PPL-193456, Illinois Instruments, Inc., Johnsburg, IL) was attached to the film surface of the packages. The MAP package was monitored for O_2/CO_2 gas using the automatic sampling mode of the machine while the O_2/CO_2 gas in the VSP package was analyzed using a syringe to gather 10 ml of gas from inside the package. It was then injected in the manual sampling mode of the machine and the gas composition inside the package was determined.

4.2.2.4 pH analysis

Whole asparagus spears were randomly selected from each package treatment. Approximately 15 g was blended with 100 ml Milli Q water in a blender. The pH of the solution was measured using a pH-meter (PHB-212 microprocessor pH meter, Omega Engineering, Inc., CT).

4.2.2.5 Microbial analysis

Asparagus spears (25 g) were randomly taken from trays of each packaging system. Samples were placed into a sterile Whirl-Pack® sampling bag (6 x 9 inch polyethylene bag, Whirl-Pack™, Nasco, Fort Atkinson, WI) and then homogenized with 100 ml of sterile 0.1% peptone water (Bacto Peptone, Difco™, Becton Dickinson and Company, USA) in a stomacher (Seward Stomacher 400 lab system, Seward Medical, London, UK) for 2 minutes at high speed. Serial dilutions (10^{-1}, 10^{-2}, 10^{-3}, 10^{-4} and 10^{-5}) were made from 1 ml of the asparagus/fluid mixture with 9 ml of sterile 0.1% peptone water in sterile tubes. Duplicate samples were plated on the following media as shown below according to the methods described in APHA (1984), and Villanueva and others (2005). Plate counts were determined as average values of each serial dilution and reported as logarithmic values of colony-forming units per gram of asparagus for each treatment (Log_{10} CFU/g). All analyses were done in duplicate.

- Total Count Bacteria was determined by spread-plating 50 µl of the diluted samples on Trypticase Soy Agar or TSAYE-C (Difco™, Becton Dickinson and Company, USA) containing 0.6% yeast extract and 100 ppm cyclohexamide (Sigma-Aldrich Co., St. Louis, MO). TSAYE-C plates were counted after 2-3 days of incubation at 35°C. The countable bacteria were 25-250 total count bacteria per plate.
- Yeasts and Molds were determined by spread-plating 50 µl of sample solution on Potato Dextrose Agar or PDA-SA (Difco™, Becton Dickinson and Company, USA) containing 20 ppm streptomycin (Sigma) and 50 ppm ampicillin (Sigma-

Aldrich Co., St. Louis, MO). PDA-SA plates were counted after 3-7 days of incubation at 23°C (room temperature). The countable range of yeast and mold was 15-150 per plate.

- *E. coli* and coliforms were determined by spread-plating 1 ml of sample solution in duplicate on 3M Petri films (3M Petrifilm™, MN). The films were incubated in chamber at 35°C and the plates examined after 24 hours.

4.2.2.6 Sensory Quality

Sensory evaluation using the human senses was applied to evaluate product quality (ASTM 1992). Visual and organoleptic characteristics of the samples were monitored to determine consumer acceptability and product shelf life during the storage time by a 9 member trained panel (Meilgaard 1991). Panelists were chosen from MSU students who were selected on the basis of their ability to detect specific product attributes. All panelists participated in the training which was conducted over a 1½ year period. The sensory testing was conducted in the Sensory Laboratory, Trout Food Science and Human Nutrition building at Michigan State University (consent form shown in Appendix B).

An evaluation of the visual and organoleptic quality of fresh green asparagus was conducted using a standard asparagus color and grading scale which was created to evaluate characteristics of the fresh green asparagus: odor, stalk color, tip color and texture. The appearance of fresh green asparagus includes characteristics such as stalk straightness, tenderness and a shiny deep green stalk, and a green-pink violet color with tightly closed and compact head tips (Lipton 1990; Michigan Asparagus Advisory Board 2005). Panel training was

based on fresh product and unacceptable product (end of the shelf life) in order to give the panelists a range of attribute intensities.

The quality attribute characteristics included color, odor, texture (crispness/freshness) and overall appearance. The samples were evaluated using a 5-point hedonic scale, where 5 represented the best (fresh) and 1 was the worst (spoiled) as indicated in Appendix C. Statistical analysis of the sensory data was performed using the statistical software program, SAS version 8.01.

4.3 Results and discussion

4.3.1 Weight Loss

No weight loss of fresh-cut green asparagus stored in MAP and VSP at 4 °C, 80% RH during storage for 21 days was detected. No loss in weight of the asparagus occurred because of the protection of the plastic lidding films and the water barrier nature of the polypropylene (PP) based tray materials. Polypropylene is a good water vapor barrier.

4.3.2 Moisture Content

The moisture content of product was calculated as wet basis (WB) and resulted from the average values of duplicate analyses from three samples of each treatment. Approximate moisture content of fresh asparagus at the first day of the experiment, prior to storage (day 0) was 93%. Moisture content of the products packed in the MAP and VSP systems over a storage time of 21 days at 4 °C, 80% RH remained satisfactory as shown in Table 4.1 and Figure 4.2. The range of moisture contents of the fresh-cut spears during storage was 93.57% to 93.78% for MAP and 93.48% to 94.03% for VSP. There was a slight increase in

moisture content, but this increase was not significant ($p>0.05$) as compared to the initial moisture content. This indicates that both polymeric material based packaging systems successfully maintained the moisture in the asparagus packages.

Table 4.1: The moisture content of fresh-cut asparagus during storage at 4°C

Days	% Moisture Content (wet basis)	
	MAP	VSP
0	93.26±0.45	93.26±0.45
3	93.75±0.33	93.63±0.22
6	93.78±0.27	94.03±0.34
9	93.57±0.25	93.92±0.29
12	93.67±0.29	93.91±0.28
15	93.73±0.47	93.48±0.29
18	93.73±0.35	93.73±0.49
21	93.72±0.25	93.97±0.21

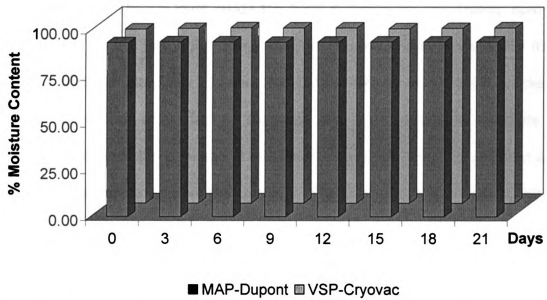


Figure 4.2: Percent moisture content of fresh green asparagus in MAP and VSP packages at 4°C, 80% RH during 21 days of storage

4.3.3 Headspace gas Analysis

The change in respiratory gases inside the headspace of fresh-cut green asparagus packed under MAP and VSP systems is illustrated in Figure 4.3 for MAP, Figure 4.4 for VSP and Figure 4.5, for comparison between the two packaging systems. Concentration of oxygen (O_2) and carbon dioxide (CO_2) inside both systems changed during storage. The level of O_2 tended to decrease whereas the CO_2 concentration increased. These changes occurred because of the respiration process of the fresh asparagus and the metabolism of microorganisms which consume O_2 and produce CO_2. Gas exchange between the external and internal atmospheres as mediated by the permeable polymeric film also affected the headspace gas concentration.

The initial gaseous atmosphere inside the MAP package was air (21% O_2 and 0.03% CO_2). The O_2 level inside the MAP package fell moderately from its initial value of 20.9% to roughly 17%, and the CO_2 level rose substantially from 0.03% to approximately 5%. O_2 and CO_2 concentrations in the MAP package reached equilibrium after day 6. Although the VSP technique attempts to eliminate all air from the package, it is difficult to achieve complete vacuum and thus remove all of the air from the package. The concentration of O_2 and CO_2 in VSP at the beginning was assumed as ideal 0%. The O_2 and CO_2 concentrations inside the VSP packages during storage changed opposite to those in MAP. Both gases rose substantially and equilibrium concentrations of O_2 and CO_2 were met after 6 days and 3 days, respectively. The final concentrations of both gases in MAP and VSP packages were within the threshold of the tolerance limits for fresh

asparagus, which are not lower than 10% for O_2 to prevent injury and not greater than 15% for CO_2 at a 0-3°C storage temperature (Kader 1989b; 1993; Salveit 1993 ; Thompson 1998).

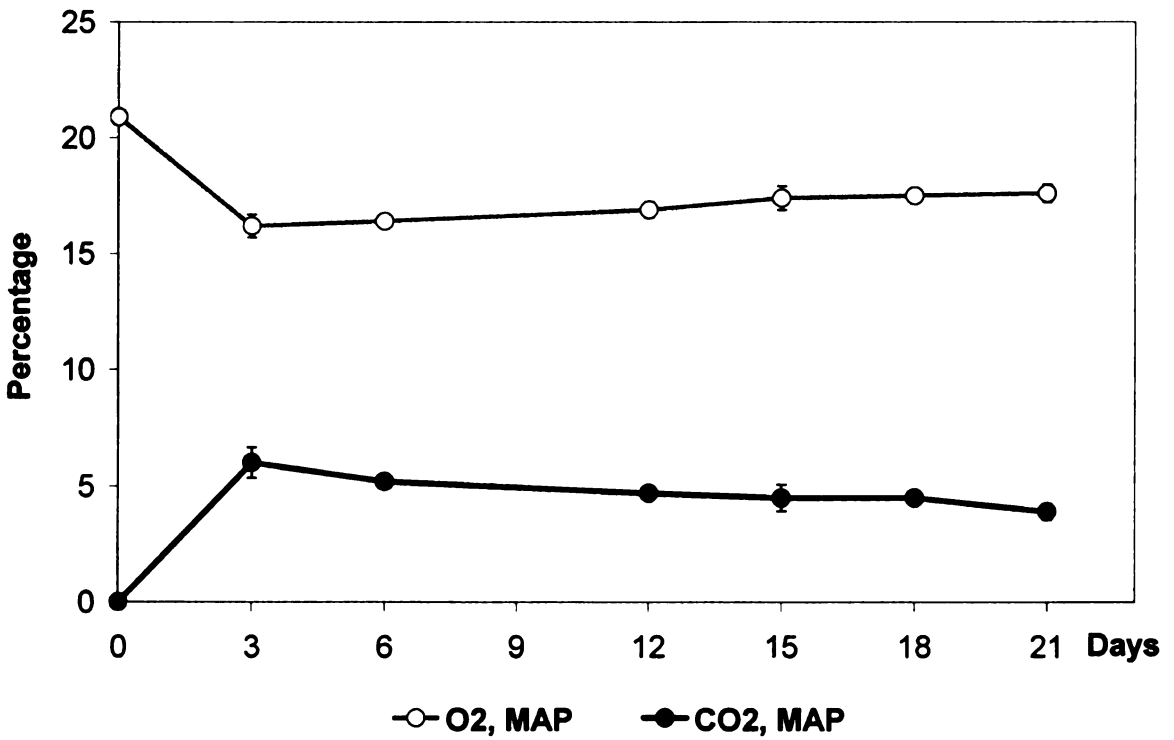


Figure 4.3: O_2 and CO_2 concentrations of fresh-cut asparagus stored in the MAP at 4°C, 80% RH during 21 days of storage

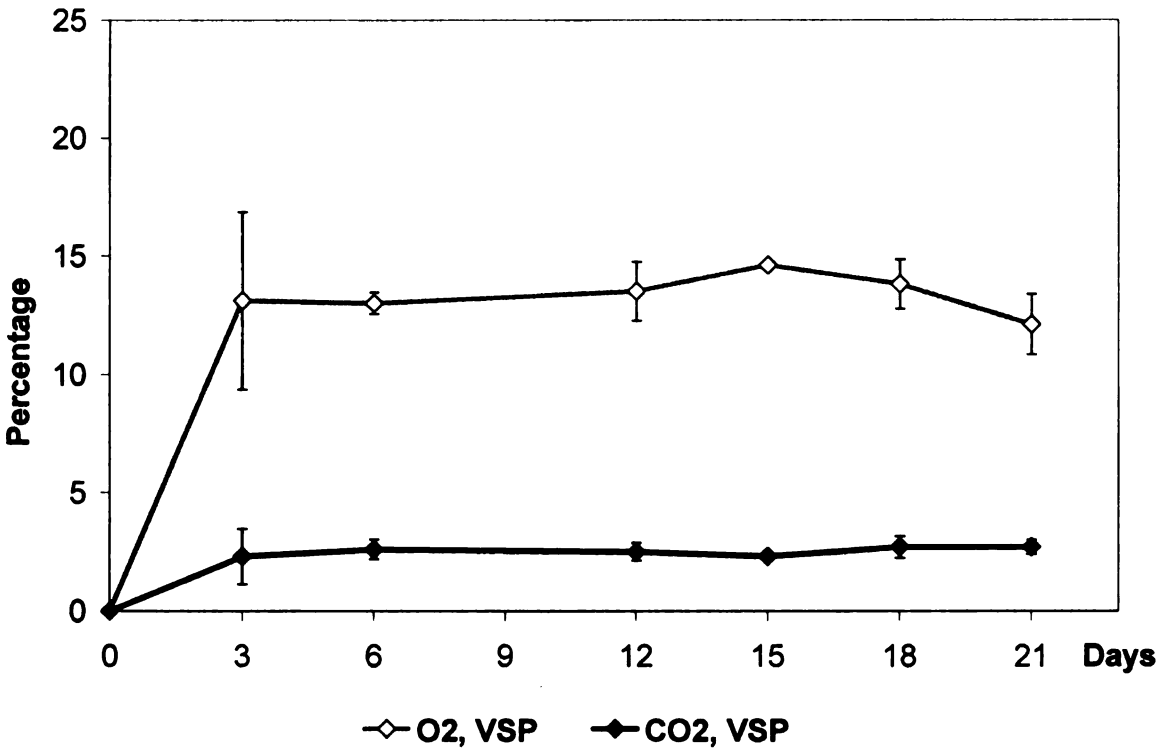


Figure 4.4: O_2 and CO_2 concentrations of fresh-cut asparagus stored in the VSP system at 4°C, 80% RH during 21 days of storage

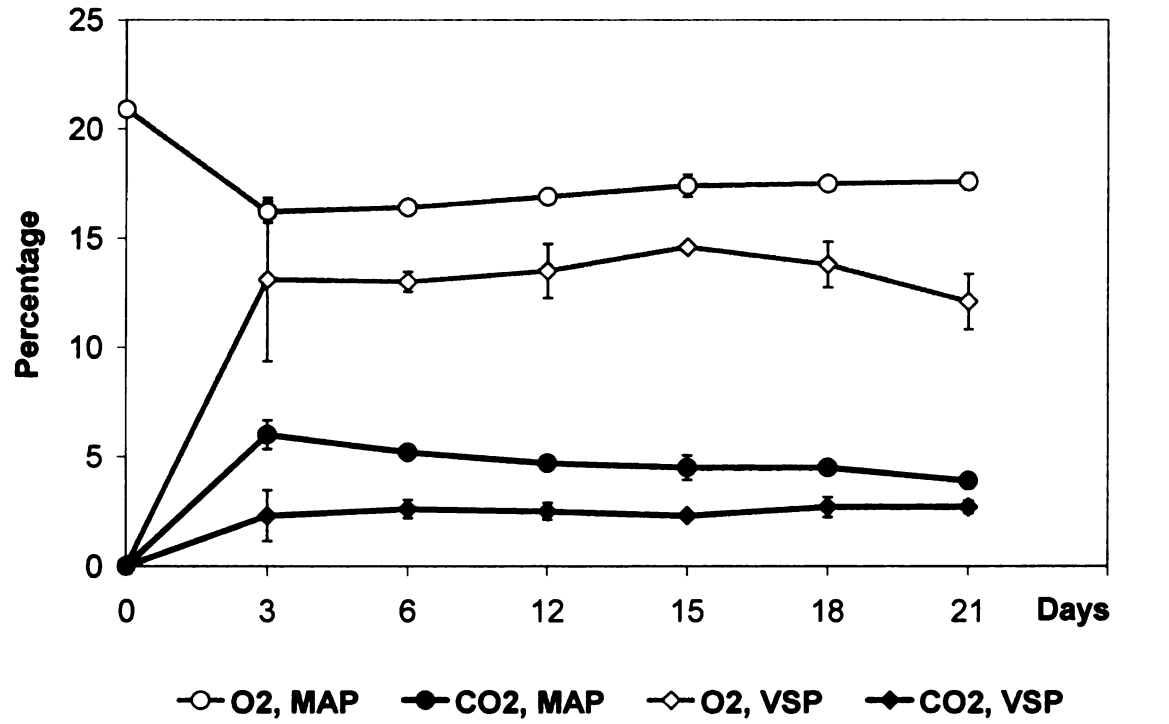


Figure 4.5: O_2 and CO_2 concentration of fresh-cut asparagus stored in the MAP and VSP system at 4°C, 80% RH during 21 days of storage

4.3.4 pH Analysis

The pH values of fresh-cut asparagus products packed in both systems decreased after 9 days of storage, and decreased to levels of 6.04 for MAP asparagus and 5.98 for VSP product after 21 days as indicated in Table 4.2 and Figure 4.6. However, there was no significant difference ($p>0.05$) between the pH of product packed under MAP and VSP during the experimental time.

Table 4.2: The pH values of fresh asparagus in MAP and VSP stored at 4°C, 80% RH for 21 days of storage

Day	Average pH	
	MAP	VSP
0	6.11±0.02	6.11±0.02
3	6.12±0.03	6.13±0.11
6	6.27±0.02	6.24±0.10
9	5.96±0.07	5.97±0.06
12	5.89±0.06	5.92±0.02
15	6.12±0.05	5.88±0.16
18	5.86±0.13	6.13±0.15
21	6.04±0.13	5.98±0.29

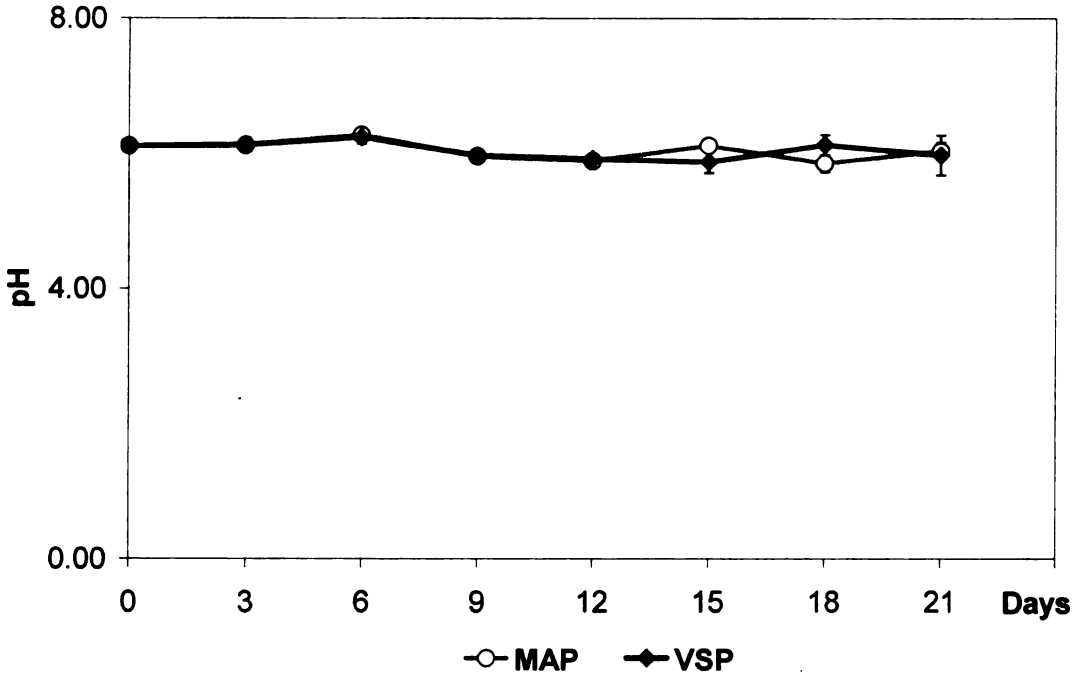


Figure 4.6: The pH measurement of fresh-cut asparagus in MAP and VSP at 4°C, 80% RH during 21 days of storage

4.3.5 Microbial Analysis

The mix of microorganisms on the asparagus included bacteria, yeasts and molds and are commonly found on many fresh fruits and vegetables. Contamination of fresh vegetables by pathogens and spoilage microorganisms originally occurs in the field during harvesting, handling, processing, packing and distribution. The original microbial population on fresh produce is generally high and depends upon the types and the physiological condition of the fresh produce (Zagory 1999). The population of bacteria initially on fresh-cut asparagus before washing with 200 ppm sodium hypochlorite was 5.65 $\log_{10}$ CFU/g and yeast was 5.44 $\log_{10}$ CFU/g. After sanitizing, the initial bacteria load and yeast on day 0 (prior to storage) were reduced to 4.75 $\log_{10}$ CFU/g and 3.08 $\log_{10}$ CFU/g, respectively. This shows that washing asparagus with sodium hypochlorite solution can help to reduce the initial microbial load about 1 to 2 log which is similar to that reported by Cherry (1999) and Parish (2003).

The microbial population of packed fresh-cut asparagus in MAP and VSP tray systems increased significantly over storage as shown in Figure 4.7 for bacteria, and Figure 4.8 for yeasts. At the end of the experiment (day 21), the microbial growth of product stored under MAP at 4°C was approximately 7.61 $\log_{10}$ CFU/g for aerobic bacteria, and 7.21 $\log_{10}$ CFU/g for yeast and molds. The population of coliforms was 2.34 $\log_{10}$ CFU/g as shown in Table 4.3. The growth of total aerobic bacteria in the VSP package at 4 °C was 7.79 $\log_{10}$ CFU/g on day 21 while the yeast and mold count was 7.33 $\log_{10}$ CFU/g. Coliforms was not detected (Table 4.3).

The microbial growth on fresh-cut asparagus in the MAP package was slightly lower than for that stored in the VSP package. The bacteria population in the modified atmosphere-packed asparagus was very similar to that reported by Berrang (1990) and Osuna (1995) at 2°C, 80% RH at the initial time point (day 0) after sanitizing and after 21 storage days. There was no significant difference in microbial growth on fresh-cut asparagus packed in MAP and VSP systems ($p>0.05$).

Table 4.3: Microbial populations on fresh-cut asparagus stored in MAP and VSP at 4°C, 80% RH during storage

Sample	Days	Microbial Quantity (Log_{10} CFU/g)		
		Total Count Bacteria	Yeast and molds	Coliforms
MAP 4°C	0 (unwashed)	5.67±0.33	5.36±0.31	0.00±0.00
	0 (washed)	4.66±0.39	2.88±0.61	0.00±0.00
	3	5.12±0.89	4.56±1.57	0.77±1.33
	6	6.35±0.48	5.97±0.45	0.00±0.00
	9	5.83±1.70	5.49±2.10	0.80±1.38
	12	7.09±0.58	6.96±0.73	1.29±1.14
	15	7.73±0.15	7.06±0.39	0.91±1.58
	18	7.95±0.38	7.11±0.69	0.85±1.47
	21	7.50±0.43	7.15±0.26	0.94±1.62
VSP 4°C	0 (unwashed)	5.59±0.29	5.36±0.31	0.00±0.00
	0 (washed)	4.66±0.39	2.88±0.61	0.00±0.00
	3	5.03±1.12	4.86±1.29	0.73±1.26
	6	5.93±0.20	5.76±0.34	0.00±0.00
	9	6.62±1.13	6.54±1.13	0.00±0.00
	12	7.19±0.21	6.94±0.33	0.57±0.98
	15	7.09±1.10	7.06±0.89	0.00±0.00
	18	7.38±0.89	7.15±0.96	1.68±1.46
	21	7.75±0.25	7.33±0.06	0.57±0.98

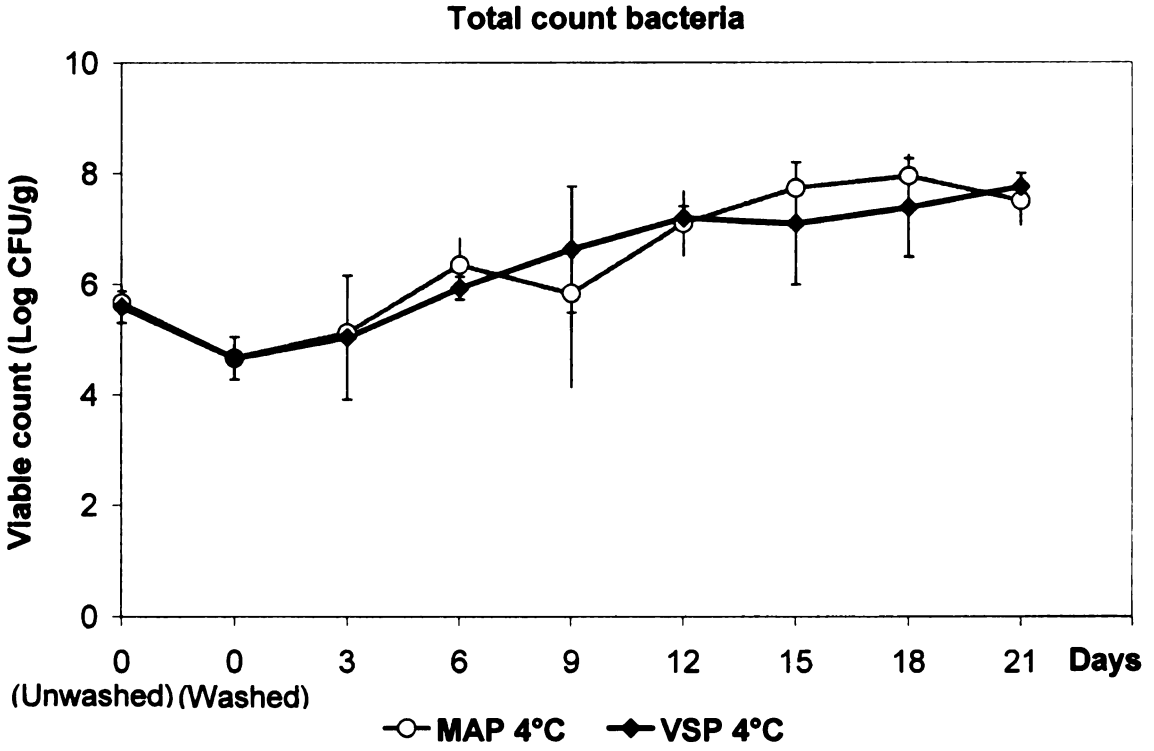


Figure 4.7: The population of total count bacteria on fresh-cut asparagus stored in MAP and VSP at 4°C, 80% RH during 21 days of storage

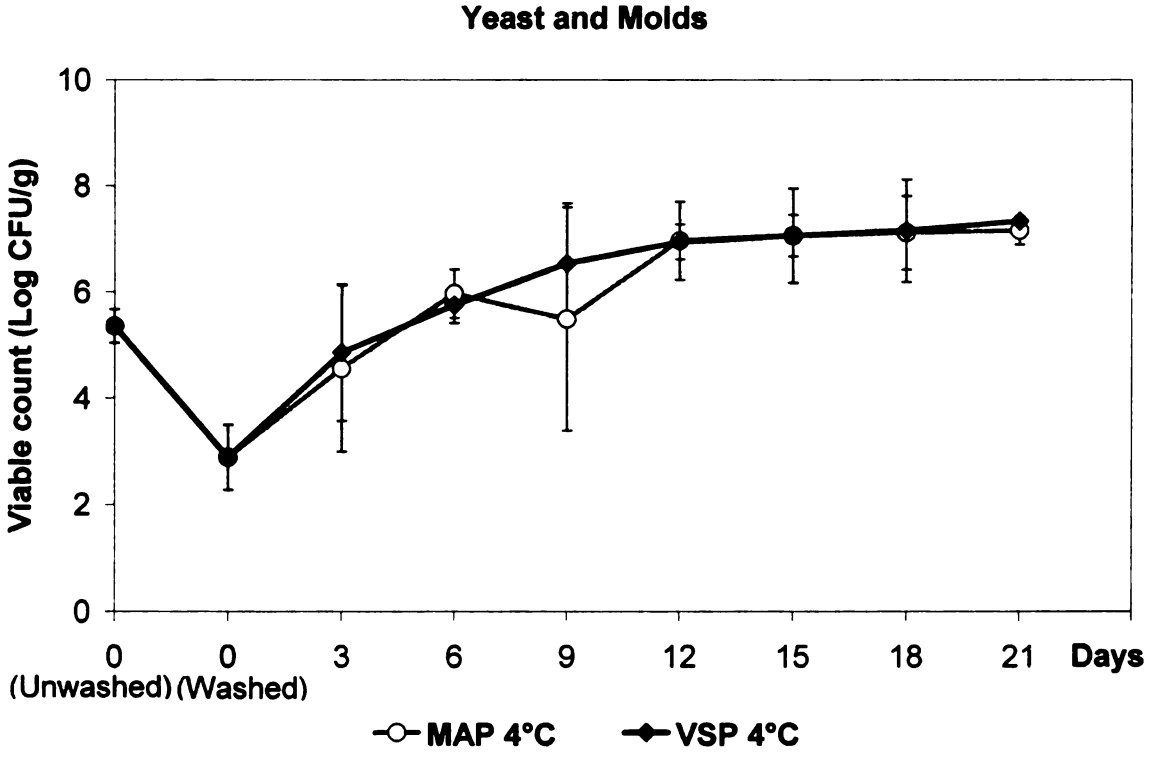


Figure 4.8: The yeast and mold population on fresh-cut asparagus stored in MAP and VSP at 4°C, 80% RH during 21 days of storage

4.3.6 Sensory Quality

The sensory analysis results are illustrated in Table 4.4 and Figure 4.9. The shelf life of the product was determined by acceptability of the overall appearance of the asparagus. Sensory quality of fresh-cut green asparagus stored under MAP at 4°C, 80% RH, including odor, tip color, stalk color, texture and overall appearance was shown to be acceptable at 21 days.

Fresh-cut asparagus in VSP packages at the same storage conditions had a product shelf life of approximately 18 days. Unpleasant odor (musty odor), tip color change and degradation of the stalk green color were observed on day 21.

Table 4.4: Panelist's response (mean) for fresh-cut asparagus stored in MAP and VSP at 4°C, 80% RH

Sample	Days	Color		Texture	Odor	Overall Quality
		Stalk	Tip			
MAP 4°C	0	5.0 [a]	4.9 [a]	4.9 [a]	5.0 [a]	5.0 [a]
	3	4.8	4.7	4.9	4.9	5.0
	6	4.8	4.9	4.9	5.0	4.9
	9	4.8	5.0	4.9	4.9	5.0
	12	4.4 [b]	4.3 [b]	4.7	4.6 [b]	4.4 [b]
	15	4.4 [b]	4.3 [b]	4.8	4.3 [b]	4.4 [b]
	18	4.0 [b]	4.0 [b]	4.0 [b]	4.0 [b]	4.0 [b]
	21	3.6 [b]	3.8 [b]	3.7 [b]	3.4 [b]	3.4 [b]
VSP 4°C	0	5.0 [a]	4.9 [a]	4.9 [a]	5.0 [a]	5.0 [a]
	3	4.9	4.8	4.9	4.9	4.9
	6	4.9	4.8	4.9	5.0	5.0
	9	4.8	4.6	4.7	5.0	4.8
	12	4.1 [b]	4.1 [b]	4.4	4.4	4.6 [b]
	15	4.1 [b]	4.3 [b]	4.3 [b]	4.7	4.3 [b]
	18	3.2 [b]	3.2 [b]	3.8 [b]	3.8 [b]	3.2 [b]
	21	2.7 [b]	3.0 [b]	3.2 [b]	3.0 [b]	2.1 [b]

[ab] Means within a column, which are not followed by a common superscript letter, are significant difference ($p<0.05$).

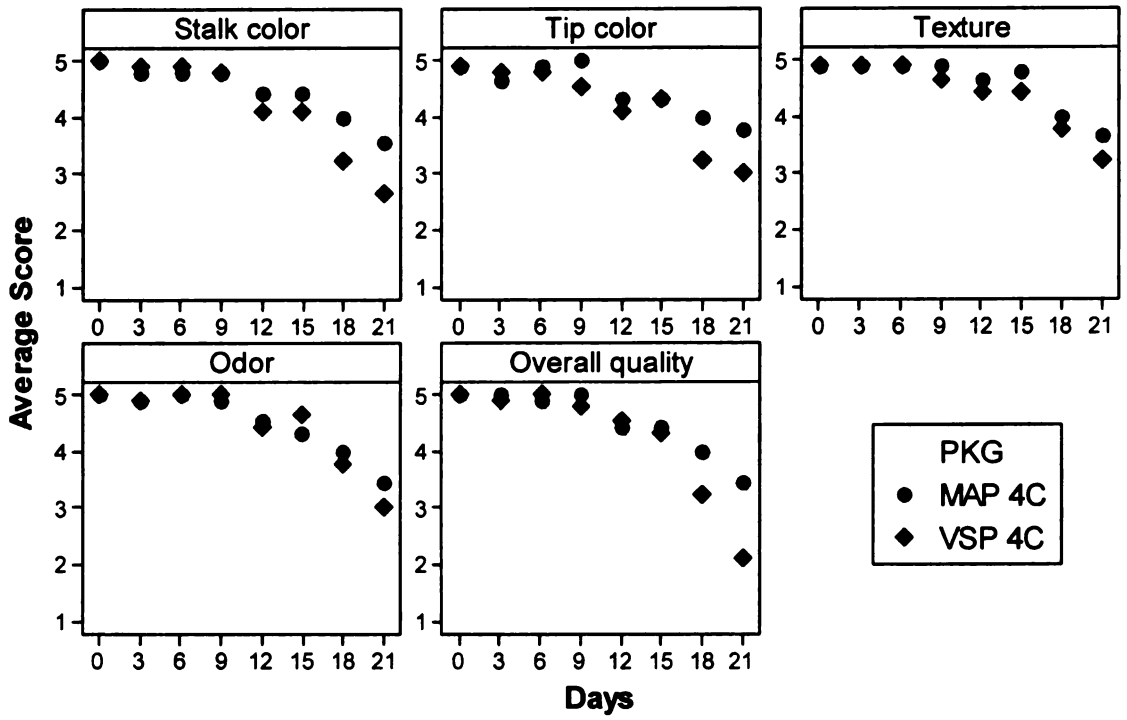


Figure 4.9: The sensory quality of fresh-cut asparagus packed in MAP and VSP trays at 4°C, 80% RH during 21 days of storage

4.4 Conclusion

The VSP system was successfully used to prolong the shelf life of fresh-cut green asparagus at 4°C, 80% RH for 18 days while a passive MAP system maintained the freshness and extended the shelf life of fresh asparagus though 21 days. There was no significant difference in weight loss, moisture content (93% same as the fresh sample at the initial day), pH and the microbial population between asparagus in either packaging system during storage for 21 days.

The initial physiological condition of fresh vegetables, proper handling and sanitation techniques and packaging system can extend product shelf life by affecting both microbial load and chemical degradation. Systems which lead to the proper proportion of gases inside the package can also maintain shelf life.

The appropriate film permeability, film thickness, and film surface area along with storage temperature can successfully preserve product quality, eliminate/control microbial growth and delay overall product deterioration.

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5 SENSORY QUALITY OF COOKED READY-TO-EAT FRESH ASPARAGUS BY MICROWAVEABLE MAP AND VSP TRAY SYSTEMS

Abstract

Fresh-cut produce, as a ready-to-eat product has become an increasingly popular product and is successful in today's market due to the consumer's desire for convenience, a nutritionally well-balanced diet and tasteful food. Unlike other food products, fresh-cut produce continues to respire even after harvesting. Asparagus (*Asparagus officinalis* L.) is one of the most consumed vegetables worldwide and has a very high metabolic rate. The shelf life of fresh asparagus as a ready-to-eat product can be prolonged by the use of modified atmosphere packaging (MAP) and/or vacuum skin packaging (VSP) in microwaveable containers. This can help to preserve the quality and enhance the shelf life of fresh-cut asparagus, as well as increase the ease of cooking.

Fresh-cut asparagus was packed in microwaveable MAP and VSP systems at a commercial storage temperature and cooked "in tray containers" using a microwave oven and several microwave time and power level combinations. Quality of the cooked asparagus in the microwaveable MAP and VSP tray systems was sensorially evaluated at several cooking times and microwave power levels. Preference of packaging type (MAP and VSP) was also determined. Cooking time and microwave power level affected the quality of the cooked asparagus, 2 - 3 minutes at full (100%) power for MAP and 2 minutes at medium (50%) power for VSP were found to produce a satisfactory product in the microwavable tray systems based on sensory evaluation. The preference for

packaging types test showed that slightly more than half of the consumer panelists preferred the MAP package to the VSP package. However, there was no significant difference ($p>0.05$) in the preference of packaging type.

5.1 Introduction

Fresh-cut produce is a rapidly growing element in the diet of many individuals, resulting in the continuous development of these products by the food industry. The fresh-cut fruit and vegetable business has been a large-scale success due to the demand trends of today's consumer, and their concerns for a healthy diet, functional nutrition and convenience (Garrett 2002).

Asparagus (*Asparagus officinalis* L.) is a perennial crop of the lily (Liliaceae) family (Hexamer 1901; Peirce 1987). It is a nutritionally well-balanced vegetable. Asparagus is composed of fibers and abundant essential nutrients such as vitamin A, vitamin B, vitamin C, folate, potassium, copper, zinc and carotenoids (California Asparagus Commission 2007). There are several asparagus varieties such as green, white and purple. Green asparagus is the most popular edible form in today's market, especially in the United States, Japan, New Zealand, Australia, Chile and the European market (Esteve and others 1995; Luo and others 2006). Asparagus is a crop that can be processed and marketed as a fresh-cut product thereby increasing its value.

Like other fresh fruits and vegetables, fresh-cut asparagus respires even after harvest. Asparagus has a high post-harvest respiration rate (>60 mg CO_2/Kg-hr) that makes it a highly perishable vegetable (Kader 1986; Kader 1992 ; Fallik and Aharoni 2004). Extending the shelf life of fresh-cut asparagus is very

important in increasing its economic viability. Packaging is very important for fresh-cut asparagus not only to serve today's consumer demand for convenience and time saving as a ready-to-cook/eat product, but also to allow the product to continue the respiration process, thus preserving its product quality through shelf life extension techniques. Modified atmosphere packaging (MAP) is an especially useful packaging technique which can reduce water loss, slow ethylene biosynthesis and microbial growth (Gorny 1997). MAP uses a gas mixture and permeable polymeric films to decelerate respiration and slow down the senescence of the product. It has been shown that MAP can help to maintain the quality and shelf life of many fresh fruits and vegetables such as broccoli and asparagus (Lange 2000). Vacuum skin packaging (VSP) is another technique which can help to preserve food quality and retard the growth of microorganisms by first pulling a vacuum on the packaged product, and then a polymeric film is vacuum-sealed over the product against a rigid backboard (Tewari 2002).

The microwave oven has become a handy kitchen appliance for cooking or heating food quickly. The use of microwaveable containers, therefore, creates the possibility for value-addition to the fresh-cut asparagus by increasing the ease of food preparation.

The main objectives of this study were to develop value added fresh-cut asparagus as a ready-to-eat product, and to determine the cooked quality of fresh asparagus using sensory evaluation.

5.2 Materials and Methods

5.2.1 Sanitation and packing

Fresh, green Peruvian asparagus was used in this experiment, and was produced and packed by Danper Trujillo S.A.C under the brand name CASAVERDE®. Medium diameter (8/16 – 11/16 inch) asparagus spears (U.S. Department of Agriculture 1997) were sorted and cut into a length of 6 inches. Cut spears were washed with distilled water and then deionized distilled water to remove any contamination. 200 ppm sodium hypochlorite sanitizer (Cleaner and Sanitizer, Johnson® CRS, US) was used with vinegar to control the pH of the chloride solution to approximately 5.27 prior to use. This was done in order to activate the chlorine against pathogens (Suslow 1997; Parish and others 2003). This solution was used to sanitize asparagus by dipping for 2 minutes and then the asparagus was left for 5 minutes before washing twice with distilled water. Sanitized spears were dried with sanitized paper toweling before packaging in microwaveable containers supplied by DuPont Packaging & Industrial Polymers (Wilmington, DE) and Cryovac Sealed Air Corporation (Duncan, SC).

226.5 g (0.5 lb) of pre-cut asparagus were packed in Dupont® microwaveable trays (5¼ in × 7½ in × 1½ in, Polypropylene, Dupont®, Dura Fresh™, Wilmington, DE). A passive modified atmosphere was established with medical air composed of 21% O_2, and 0.03 % CO_2 and heat-sealed using a lidding film from Dupont® (Appeel Lidding Sealant Resin 004, 2.5 mils thickness, O_2 permeability of 7.75 cc.mil/in^2.day.atm and CO_2 permeability of 8.0 cc.mil/in^2.day.atm). For vacuum skin packaging (VSP), 135.9 g (0.3 lb) of spears

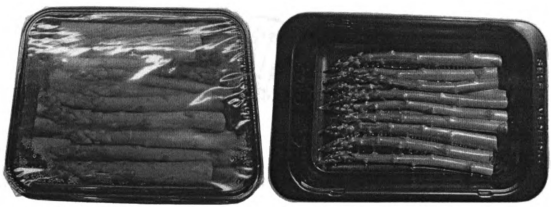
were packed in Cryovac® microwaveable trays (4½ in × 6¾ in × 1¼ in, CS966-B2, Cryovac®, Simple Steps™, Duncan, SC) and then vacuum-sealed using a Cryovac® lidding film (3 mils thickness, O_2 permeability of 14.3 cc.mil/in^2.day.atm and CO_2 permeability of 59.9 cc.mil/in^2.day.atm). Both systems were packed using a Multivac T-200 machine (Multivac, Inc., Kansas City, MO). Products were then stored for 1 day at 4°C, 80% RH, prior to use. The MAP and VSP packages are shown in Figure 5.1.

5.2.2 Cooking and Sensory Evaluation

After one day storage, asparagus packages were cooked "in package" using a 1.5 KW GE microwave (GE® Countertop Microwave Oven, General Electric Company, Louisville, KY). For MAP packages, the lidding film was removed or holes by fork were made in it before cooking for 2 and 3 minutes at full (100%) power. For the VSP package, products were cooked without peeling the film off, for 2 minutes at full (100%) power and 2 minutes at medium (50%) power. All microwave cooking conditions were selected from a preliminary test (1 minute at high power, 2 minutes at high power, 2 minutes at medium power and 3 minute at high power) based on trained panel data.

A consumer sensory panel evaluated the quality attributes of the cooked asparagus. The 80 panelists were recruited from MSU faculty and students of both sexes between the ages of 20 and 60 years old and who consumed fresh asparagus (consent form shown in Appendix D). After microwave cooking, two asparagus spears were randomly selected from each package treatment (MAP and VSP), and the different cooking conditions and served in an aluminum foil

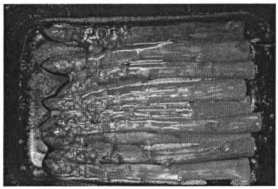
wrap with a specific 3 digit random code as shown in Figure 5.2. Panelists were asked to sample the whole spears and evaluate several quality attributes of cooked asparagus including aroma, appearance/color, flavor, texture and overall acceptability using a 9-point hedonic scale (1 = dislike extremely and 9 = like extremely) as illustrated in Appendix E. They were also asked to state their preference, based on product appearance for the asparagus packed in the two different packing systems (MAP and VSP). ANOVA was used for the statistical analysis of all sensory attributes. The statistical software was SAS version 8.01.



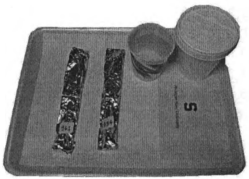
Dupont® MAP tray Cryovac® VSP tray

Figure 5.1: Fresh-cut Michigan asparagus spears packed in a Dupont® tray using a MAP technique and a Cryovac® tray using a VSP technique

Cooked asparagus in MAP tray



Cooked asparagus in VSP tray



Sample of cooked asparagus

Figure 5.2: Microwave cooking of fresh-cut asparagus in MAP and VSP trays and the cooked asparagus sample presented to the panelists

5.3 Results and Discussion

5.3.1 Modified atmosphere packaging (MAP) tray system

The sensory data for the microwave cooked asparagus shows that there was no significant difference in the quality attributes (aroma, color, flavor, texture and overall acceptability) between the cooked asparagus in microwaveable MAP trays subjected to 2 minutes and 3 minutes at full (100%) power, (Table 5.1). More panelists gave higher flavor, texture and overall quality scores for microwave cooked spears for 2 minutes at full power. More panelists liking aroma as shown in Figure 5.3 for asparagus cooked for 3 minutes at full power.

No difference was found for the color at either cooking condition. Slightly more than half of the consumer panelists (45 of 80) preferred the quality of the microwave cooked asparagus (2 minutes at full power) as indicated in Table 5.2 and Figure 5.4.

Table 5.1: Sensory quality of the cooked asparagus in the microwaveable MAP tray

Attribute	2 min/Full power	3 min/Full power	Significant Difference
Aroma	7.05 ± 1.45	7.32 ± 1.21	NS
Color	7.62 ± 1.06	7.64 ± 1.15	NS
Flavor	6.91 ± 1.44	6.80 ± 1.65	NS
Texture	7.12 ± 1.45	6.67 ± 1.82	NS
Overall Acceptability	6.96 ± 1.40	6.84 ± 1.61	NS

*means significant difference ($P \leq 0.01$), **means significant difference ($P \leq 0.05$) and NS means no significant difference

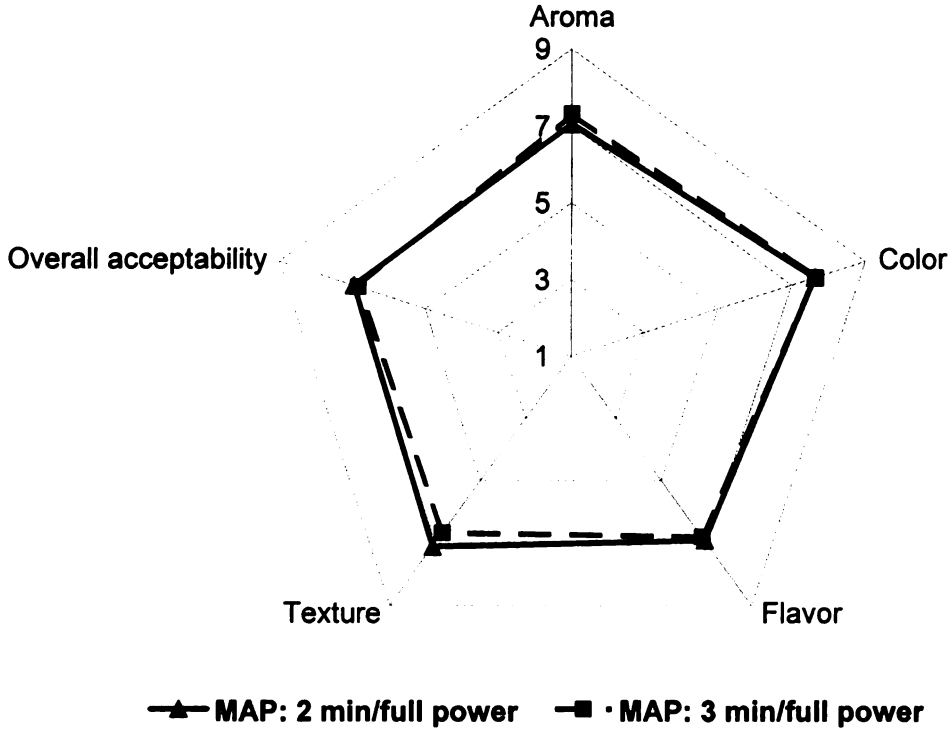


Figure 5.3: Spider plot of the sensory evaluation of microwave cooked asparagus in MAP trays under 2 different cooking conditions

Table 5.2: Consumer preference for cooked asparagus in microwaveable MAP trays at 2 different cooking conditions

Samples	Rank	Percent (%)	Frequency
2 minutes/full power	1	55.6	45
3 minutes/full power	2	44.4	35

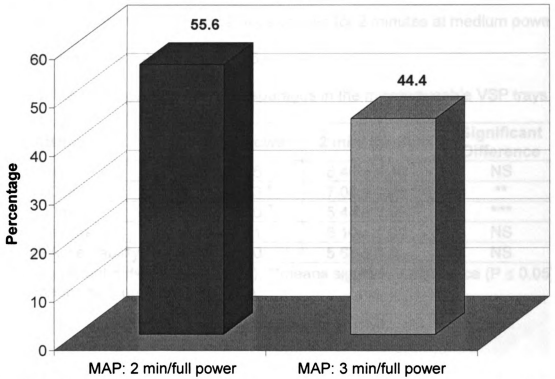


Figure 5.4: Consumer preference for cooked asparagus in microwaveable MAP trays

5.3.2 Vacuum Skin packaging (VSP) tray system

Based on consumer sensory data, it was found that there was significant difference between the color and flavor of cooked asparagus in the microwaveable VSP tray system, 2 minutes at full power versus 2 minutes at medium power as shown in Table 5.3. The spider chart in Figure 5.5 shows that the color and flavor of asparagus, cooked for 2 minutes at full power, was more acceptable to the panelists than the asparagus cooked for 2 minutes at medium power. The aroma and texture of the cooked asparagus, 2 minute at full power,

was also slightly more preferred than that for 2 minute at medium power. However, there was no significant difference in overall acceptability between cooked asparagus subjected to the 2 different conditions. Approximately 53.8% of the consumers liked the asparagus that was cooked for 2 minutes at full power while only 46.3% preferred the asparagus cooked for 2 minutes at medium power as indicated in Table 5.4 and Figure 5.6.

Table 5.3: Sensory quality of cooked asparagus in the microwaveable VSP trays

Attribute	2min/Full power	2 min/ Medium	Significant Difference
Aroma	6.61 ± 1.65	6.40 ± 1.49	NS
Color	7.45 ± 1.03 [a]	7.05 ± 1.29 [b]	**
Flavor	6.24 ± 1.76 [a]	5.44 ± 1.96 [b]	*,**
Texture	6.15 ± 1.71	6.10 ± 1.99	NS
Overall Acceptability	6.10 ± 1.60	5.68 ± 1.93	NS

*means significant difference ($P \leq 0.01$), **means significant difference ($P \leq 0.05$) and NS means no significant difference

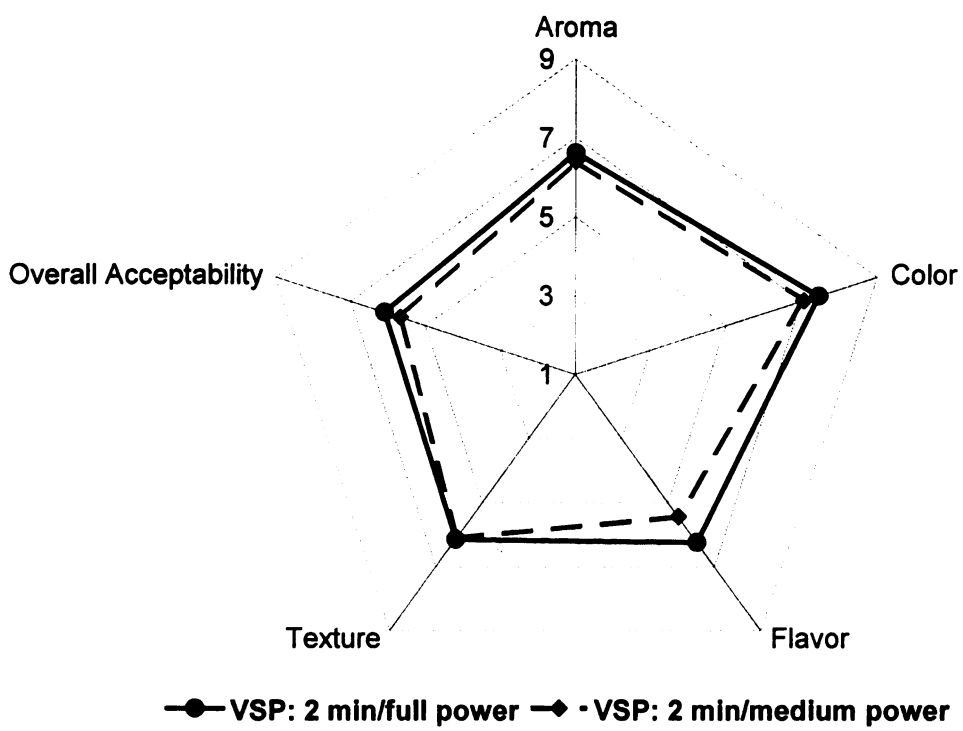


Figure 5.5: Spider plot of the sensory evaluation of microwave cooked asparagus in VSP trays under 2 different cooking conditions

Table 5.4: Consumer preference for cooked asparagus in microwaveable VSP trays at 2 different cooking conditions

Samples	Rank	Percent (%)	Frequency
2 minutes/full power	1	53.8	43
2 minutes/medium power	2	46.3	37

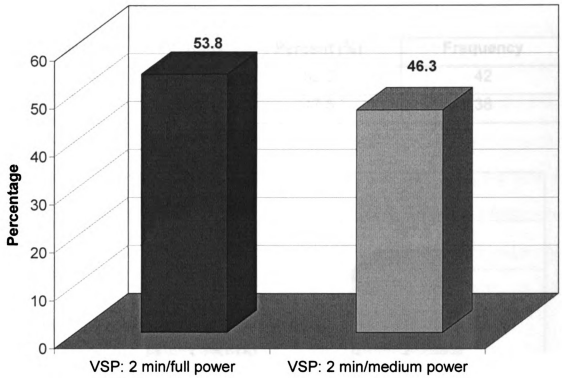


Figure 5.6: Consumer preference for cooked asparagus in microwaveable VSP trays

5.3.3 Packaging preference of fresh-cut asparagus

Slightly more than half of the consumer panelists (42 of 80) preferred the appearance of microwaveable MAP packed asparagus as shown in Table 5.5 and Figure 5.7. However, there was no statistical significance in their preference for the appearance of fresh-cut green asparagus in the two packaging systems (MAP and VSP).

From the demographic questionnaire, it was concluded that for most consumers the big purchase question is the price and quality (fresh appearance) of the product. An attractive and convenient package also influences the consumer buying decision.

Table 5.5: Consumer preference for MAP and VSP packages of fresh-cut asparagus

Samples	Rank	Percent (%)	Frequency
MAP	1	52.5	42
VSP	2	47.5	38

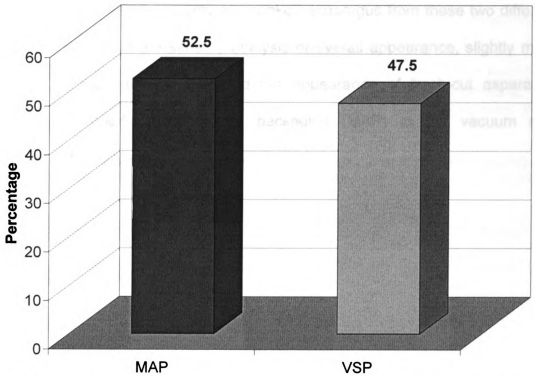


Figure 5.7: Consumer preference for overall appearance of fresh-cut asparagus packed in microwaveable MAP and microwaveable VSP trays

5.4 Conclusion

Microwave cooking time and power level affected the quality (aroma, color, flavor, texture and overall acceptability) of the cooked asparagus. Cooking of fresh-cut asparagus in a microwavable MAP tray system for 2 - 3 minutes at full (100%) power was found to produce satisfactory products. Either 2 or 3 minutes at full power were satisfactory microwave cooking processes for the MAP product. In the microwaveable VSP tray system, consumers preferred the color and flavor of cooked spears subjected to 2 minutes at full (100%) power over the 2 minutes at medium (50%) power. However, there was no significant difference in overall acceptability between the microwave cooked asparagus from these two different conditions. Based on the sensory analysis of overall appearance, slightly more than half of the panelists preferred the appearance of fresh-cut asparagus contained in modified atmosphere packaging (MAP) to the vacuum skin packaged (VSP) asparagus.

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CONCLUSION

Modified atmosphere packaging (MAP) and vacuum skin packaging (VSP) can indeed help to maintain the fresh quality of fresh-cut green asparagus. Sensory shelf life of fresh-cut asparagus sanitized with 100 ppm sodium hypochlorite solution showed that MAP can maintain the freshness of fresh-cut asparagus stored at 1°C and 8°C for 18 days, which is longer than that for VSP at 1°C and 8°C, (9 days and 3 days, respectively).

The shelf life of fresh-cut asparagus, which was sanitized with 200 ppm sodium hypochlorite solution; controlled to a pH of 5.27, and stored under MAP at 4°C was 21 days or more while that stored under VSP was 18 days. There was no significant difference ($p>0.05$) in weight loss, moisture content, pH and microbial growth between fresh-cut spears in MAP and VSP systems during the entire experimental storage time of 21 days.

The studies also found that the initial quality of fresh produce and a proper sanitation technique affected the quality and shelf life of fresh-cut asparagus as well as initial microbial load. In using VSP with fresh-cut asparagus there is concern about the pressure involved in creating the vacuum to avoid bruising and causing product damage that can lead to accelerated product deterioration.

Microwave cooking time and power level affected the cooked asparagus quality (aroma, color, flavor, texture and overall acceptability). The cooked quality of fresh-cut asparagus packed and cooked in a microwavable MAP tray system for 2 and 3 minutes at full (100%) power was found to produce a satisfactory product and these times were not significantly different ($p>0.05$). For the

microwaveable VSP package, there was no significant difference ($p>0.05$) between the overall acceptability of the quality of the microwave cooked spears, 2 minutes at full (100%) power, vs. 2 minutes at medium (50%) power. The consumers, however, preferred the color and flavor of cooked asparagus for 2 minutes at full (100%) power to that of 2 minutes at medium (50%) power.

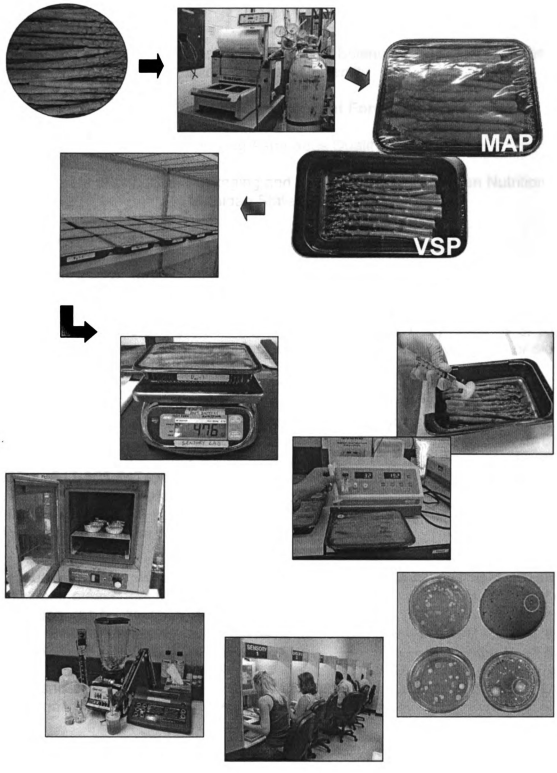
Slightly more than half of the consumer panelists preferred the appearance of fresh-cut asparagus packed in modified atmosphere packaging (MAP) to the vacuum skin packaged (VSP) asparagus. However, there was no statistically significant difference ($p>0.05$).

MAP and VSP could help the processors market the fresh-cut vegetables by extending product shelf life. Use of a microwaveable package with MAP and VSP techniques can also add value to the product as a ready-to-eat/cook menu item.

APPENDICES

APPENDIX A

FLOW CHART OF OVER ALL PROCESS



APPENDIX B

CONSENT FORM FOR SENSORY EVALUATION OF FRESH ASPARAGUS

Department of School of Packaging and Food Science and Human Nutrition, Michigan State University

Trained Panel Consent Form

Improving Asparagus Quality

Department of School of Packaging and Food Science and Human Nutrition, Michigan State University

Sample: Asparagus

Before you decide to sign this consent form and continue to participate in our study, please read carefully and thoroughly the reverse side of this form for the sample ingredients and preparation information, purpose and procedure of this study, potential risks and benefits from your participation, our assurance of your privacy, your rights as a human subject in our study, etc. You must be 18 or older to participate in this study."

If you have any question during your reading this consent form, or during or after your participation, please do not hesitate to contact the on-site sensory evaluation leader and/or the principle investigator. Feel free to contact Dr. Bruce and Janice Harte, the principle investigator of this study, via phone at 517-355-4555 or 517-355-8474, ext. 105 (114 Trout Food Science and Human Nutrition Building, Michigan State University, East Lansing, MI 48823). You also can reach us via email at harte@msu.edu or harteja@msu.edu for any inquiry you might have due to your participation in our study.

In case you have questions or concerns about your role and rights as a research participant, please feel free to contact Bruce Harte, Ph.D., Professor of School of Packaging, (517) 355-4555, e-mail harte@msu.edu, mail 130 Packaging building, Michigan State University, East Lansing, MI 48824. If you have read all the information we offer to you in this consent form and decide to participate in our study and give us your valuable response to our questionnaire, you can go ahead and sign this form now. Otherwise, you can stop here and feel free to discontinue participation in our study without any penalty.

PLEASE NOTE UPON YOUR SIGNING THIS CONSENT FORM, YOU VOLUNTARILY AGREE TO PARTICIPATE IN OUR STUDY. YOUR SIGNATURE INDICATES YOU HAVE READ THE INFORMATION PROVIDED ABOVE AND THAT YOU HAVE HAD AN ADEQUATE OPPORTUNITY TO DISCUSS THIS STUDY WITH THE PRINCIPLE INVESTIGATOR AND HAVE HAD ALL YOUR QUESTIONS ANSWERED TO YOUR SATISFACTION. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM WITH YOUR SIGNATURE FOR YOUR RECORDS UPON YOUR REQUEST.

SIGNED _____DATE_____

INVITATION TO PARTICIPATE

You are invited to participate in this study that assesses the quality attributes of asparagus.

PURPOSE OF THIS STUDY

This study is intended to study the quality consumer and acceptability of asparagus packed in microwaveable containers. Texture, color, flavor, odor and overall appearance characteristics of asparagus will be evaluated.

PROCEDURE OF THIS STUDY

Each participant will be presented with asparagus. They will be asked to evaluate after looking the appearance, score the attributes as presented on the score sheet for each sample. Samples will be presented using three digit random codes. We are asking that panelists participate in a quality study of asparagus. Evaluations should last about 30 minutes or less.

SAMPLE PREPARATION

All the ingredients used in our samples are food-grade and FDA approved for foods. The ingredients are fresh asparagus.

POTENTIAL RISKS

Because all ingredients we use in our study are food grade and FDA approved for food applications, these samples pose no adverse health risk, provided the subject has not been identified as being susceptible to an allergic reaction to the previously listed sample ingredients. If you believe there is a potential of an **allergic reaction upon sniffing**, notify the on-site sensory evaluation coordinator and/or principle investigator immediately. You will be released from participating in this study. Please note if you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for you research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of whatever are paid by your insurance, including deductibles, will be your responsibility. Financial compensation for lost wages; disability, pain or discomfort is not available. This does not mean that you are giving up any legal rights you may have. You may contact Bruce Harte with any questions (355-4555) or Patnarin Benyathiar (353-5143).

POTENTIAL BENEFITS

There are no benefits gained directly from your participation in this study. However, your participation and response will provide us valuable data, which can be used to identify optimum shelf life and packaging techniques for asparagus.

ASSURANCE OF CONFIDENTIALTY

Any information obtained in connection with this study that could be identified with you will be kept confidential by ensuring that all consent forms are securely stored. All data collected and analyzed will be reported in an aggregate format that will not permit associating subjects with specific responses or findings. **Your privacy will be protected to the maximum extent allowable by law.**

WITHDRAWAL FROM THIS STUDY

Participation in this study is voluntary. Your decision to refuse participation or discontinue participation during this study will be honored promptly and unconditionally.

APPENDIX C

QUESTIONNAIRE FOR SENSORY EVALUATION OF FRESH ASPARAGUS

SHELF LIFE STUDY

Name_____ Date _____

1. Please evaluate the ODOR of the asparagus using the following scale. How do you perceive the smell / odor in the sample?

   _____ 5 = No smell, smells like fresh asparagus
   _____ 4 = Slight asparagus smell
   _____ 3 = Neither off odor or smells like asparagus (but not rotten smell)
   _____ 2 = Off odor, slightly spoiled smell
   _____ 1 = Very intense off odor smell, as rotten

2. Please evaluate the COLOR of the asparagus using the following scale. How do you perceive the color in the sample? (Based on the color standard scale)

   Stalk

   _____ 5 = Extremely shiny and green as fresh green asparagus color
   _____ 4 = Very green
   _____ 3 = Moderately green (light green + light yellow)
   _____ 2 = Very yellow
   _____ 1 = Extremely yellow

   Tips and Braces

   _____ 5 = Very light purple (light purple + light green)
   _____ 4 = Light purple (very little green)
   _____ 3 = Moderately purple / moderately purple
   _____ 2 = Dark purple / dark purple
   _____ 1 = Very dark purple / very dark purple

3. Please evaluate the TEXTURE of the asparagus using the following scale. How do you perceive the texture (crispness or firm) in the sample?

_____ 5 = Very Firm / Crisp
_____ 4 = Firm / Crisp
_____ 3 = Moderately Soft /Firm
_____ 2 = Soft / Limp
_____ 1 = Very Soft / Limp

4. Please evaluate the OVERALL QUALITY of the asparagus using the following scale. How do you perceive the overall appearance of asparagus?

_____ 5 = Very fresh / Best
Dark green and firm with tightly closed, compact tips, braces tight to stalk, stalks are straight and glossy in appearance

_____ 4 = Some degradation of appearance
Tip not as compact, still green and healthy, possibly slight curvature in tip

_____ 3 = Still Marketable
Head less green, some loss of rigidity in stalk, braces looser, tip beginning to open, more curvature in stalk and tip

_____ 2 = Not marketable / Unacceptable
Some yellow appear and not stiff

_____ 1 = Rotten / Spoil
Completely limp, maybe mold, Very intense off odor smell, rotten

APPENDIX D

CONSENT FORM FOR SENSORY EVALUATION OF COOKED ASPARAGUS

Department of School of Packaging and Food Science and Human Nutrition
Michigan State University

Consumer Consent Form

Dear Participant:

Several Michigan State University researchers are investigating consumer acceptance of microwave cooking of fresh asparagus in alternative package systems. We would like you to take about 15 minutes (including the time you spent reading this letter) to help us evaluate 4 samples. We are asking for volunteers, 18 or older, to look at, and taste samples and to answer a few marketing questions. *If you have a known food allergy to any of the following possible FDA approved food ingredients,* asparagus, *please do not volunteer for this study.*

If you meet the above requirements, we would like you to look at, sniff and taste the samples and answer questions related to the product quality. If you agree to provide your evaluation based on the survey questionnaire, please sign the consent form below. You will be given a coupon and/or food treats that are worth less than $2 for your evaluation and completion of the survey.

If you believe there is a potential of an **allergic reaction upon sniffing and tasting**, notify the on-site sensory evaluation coordinator and/or principle investigator immediately. You will be released from participating in this study. Please note if you are injured as a result of your participation in this research project, Michigan State University will assist you in obtaining emergency care, if necessary, for you research related injuries. If you have insurance for medical care, your insurance carrier will be billed in the ordinary manner. As with any medical insurance, any costs that are not covered or in excess of whatever are paid by your insurance, including deductibles, will be your responsibility. Financial compensation for lost wages; disability, pain or discomfort is not available. This does not mean that you are giving up any legal rights you may have. Your response is confidential and we will protect your confidentiality to the full extent of the law. You are free to not answer any question you choose, but please try to answer every question. We are not able to use incomplete responses nor are we able to provide the incentive for incomplete responses.

If you have any questions about this consent form, during or after your participation, please do not hesitate to contact the on-site sensory evaluation leader and/or the principle investigator, Dr. Bruce Harte, Professor, School of Packaging, via phone at 517-355-4555. He also can be reached by email at harte@msu.edu for any inquiry you might have due to your participation in the study.

PLEASE NOTE UPON YOUR SIGNING THIS CONSENT FORM, YOU VOLUNTARILY AGREE TO PARTICIPATE IN OUR STUDY. YOUR SIGNATURE INDICATES YOU HAVE READ THE INFORMATION PROVIDED ABOVE AND THAT YOU HAVE HAD AN ADEQUATE OPPORTUNITY TO DISCUSS THIS STUDY WITH THE PRINCIPLE INVESTIGATOR AND HAVE HAD ALL YOUR QUESTIONS ANSWERED TO YOUR SATISFACTION. YOU WILL BE GIVEN A COPY OF THIS CONSENT FORM WITH YOUR SIGNATURE FOR YOUR RECORDS UPON YOUR REQUEST.

SIGNED _____DATE_____

APPENDIX E

QUESTIONNAIRE FOR SENSORY EVALUATION OF COOKED ASPARAGUS

COOKING STUDY

You will be presented with 6 samples to evaluate. 3 samples will be served for each set. When you are ready, lift the panel door and slide the READY portion of the card under the door.

Do Not Eat the sample yet.

---

1. How do you like the Aroma of sample?

_____ Like extremely
_____ Like very much
_____ Like moderately
_____ Like slightly
_____ Neither like nor dislike
_____ Dislike slightly
_____ Dislike moderately
_____ Dislike very much
_____ Dislike extremely

2. How do you like the Appearance and Color of sample?

_____ Like extremely
_____ Like very much
_____ Like moderately
_____ Like slightly
_____ Neither like nor dislike
_____ Dislike slightly
_____ Dislike moderately
_____ Dislike very much
_____ Dislike extremely

Now take a bite

---

3. How do you like the Flavor of sample?
_____ Like extremely
_____ Like very much
_____ Like moderately
_____ Like slightly
_____ Neither like nor dislike
_____ Dislike slightly
_____ Dislike moderately
_____ Dislike very much
_____ Dislike extremely

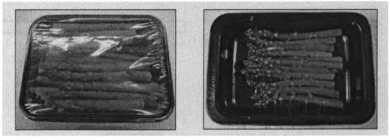
4. How do you like the Texture of sample?
_____ Like extremely
_____ Like very much
_____ Like moderately
_____ Like slightly
_____ Neither like nor dislike
_____ Dislike slightly
_____ Dislike moderately
_____ Dislike very much
_____ Dislike extremely

5. How do you like the Overall Acceptability of sample?
_____ Like extremely
_____ Like very much
_____ Like moderately
_____ Like slightly
_____ Neither like nor dislike
_____ Dislike slightly
_____ Dislike moderately
_____ Dislike very much
_____ Dislike extremely

Comments / Suggestions: _____

6. Please rank the cooked asparagus in the order of your preference. Give your most favorite cooked asparagus the ranking of 1.
(___) Sample 1 (actual blinding code will appear here during testing)
(___) Sample 2 (actual blinding code will appear here during testing)
(___) Sample 3 (actual blinding code will appear here during testing)
Rest ...Ranking Status: Incomplete

7. Please rank the asparagus products in the order of your preference. Give your most preferred product the ranking of 1.



(___) Sample 1 (actual blinding code will appear here during testing)
(___) Sample 2 (actual blinding code will appear here during testing)
(___) Sample 3 (actual blinding code will appear here during testing)
Rest ...Ranking Status: Incomplete

Demographic Questionnaire

Do you typically eat asparagus?

Yes ☐ No ☐

If Yes, how often?
Every day ☐
2 to 3 time a week ☐
Once a week ☐
2 to 3 time a month ☐
Once a month ☐

What types of asparagus products do you buy?
Fresh asparagus ☐
Canned asparagus ☐
Frozen asparagus ☐

How you cook fresh asparagus?
Steam ☐
Microwave ☐
Other, please explain _____

When choosing to buy the food product do you often choose based on
Package ☐
Price ☐
Brand ☐
Other, please explain _____

Would you buy this product?

Yes ☐ No ☐

Gender

Female ☐ Male ☐

Age range

Less than 19 ☐
20-29 ☐
30-39 ☐
40-49 ☐
50 and over ☐

Yearly household income

Less than $ 12,000 ☐
$ 12,000 - $ 19,000 ☐
$ 20,000 - $ 29,000 ☐
$ 30,000 - $ 39,000 ☐
$ 40,000 - $ 49,000 ☐
$ 50,000 - $ 59,000 ☐
$ 60,000 and over ☐

Marital Status

Single ☐
Married ☐
Divorced ☐
Widowed ☐