Production and Postharvest Quality Maintenance of Single Unit and Bunching Broccoli in Virginia

by

Lewis W. Jett

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APPROVED:

Ronald D. Morse, Chairman

Charles R. O'Dell

Mosbah M. Kushad

Charles W. Coale

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(ABSTRACT)

Broccoli (*Brassica oleracea* L. var. italica) has become an increasingly popular vegetable with American consumers. Much of the attractiveness of fresh broccoli is derived from this vegetable's high nutrition and excellent organoleptic properties. In a consumer response survey, Virginia Master Gardeners indicated a preference for broccoli that has less stalk and more florets by weight.

The objectives of this research were to produce single unit broccoli, and to examine vacuum and shrink-film wrapping of single unit and bunching broccoli as alternatives to the standard postharvest practice of top icing in order to preserve postharvest quality attributes: vitamin C, color, odor, and turgidity.

Broccoli cv. 'Symphony' was direct seeded and transplanted at two sites in Virginia (within row spacing 20 cm , .9 m centered, 3 row bed). Single unit broccoli was classified as broccoli with head diameters greater than or equal to 20 cm (i.e. equivalent to one bunch of broccoli). Single unit and bunching broccoli for postharvest experimentation was vacuum or shrink-film wrapped with plastic film wraps of varying gauges. The broccoli was held in cold stor-

age from 12 to 22 days with no supplemental ice. Single unit broccoli was produced successfully at one site only. The yields, however, were a fraction of total bunching broccoli yields. There was no significant difference in marketable yields with either planting method (direct seeded vs transplanting) at site 2. Transplants, however, outyielded the direct seeded broccoli at site 1. Vacuum and shrink-film wrapping proved to be very effective in preserving organoleptic attributes of single unit and bunching broccoli even when never receiving ice. Vitamin C and chlorophyll retention were not influenced by wrapping.

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Introduction

Per capita consumption of broccoli has increased 330% since 1975 (Hamm, 1988). Broccoli has become particularly popular because of good organoleptic properties, vitamin C, and dietary fiber content (Nichols, 1990). As a result of this enhanced demand, fresh market broccoli acreage has increased by approximately 10% annually since the early 1970's (Amer. Veg. Grower, 1988). This increase has occured in states other than California, which produces approximately 82% of the total fresh market broccoli (ERS, 1989).

Virginia is one of several eastern states that has promoted fresh market broccoli production as an alternative cash crop. Virginia seems to have a distinct comparative advantage over California in marketing fresh produce. Virginia and other eastern states are ideally located near population centers, and, therefore, have lower transportation costs for providing high quality, fresh broccoli to consumers (Borchers, 1979).

Initially, most of the cultural practices employed by broccoli producers in California were duplicated in Virginia. However, because many of these practices were not suited to Virginia growing conditions, experiments were conducted to determine the best production practices for growing broccoli under Virginia climatic and edaphic conditions.

Despite the successful implementation of cultural practices conducive to bunching broccoli production in Virginia, many of the postharvest handling and marketing practices currently in use duplicate procedures employed by

California broccoli growers serving distant markets. Like California, Virginia broccoli is harvested as bunches with two or three stalks per bunch. Typically, 14 or 18 bunches are packed per box in the field and subsequently transported to a marketing cooperative. At the cooperative, the broccoli boxes are top or package iced with approximately 9 kg of a slurry/ice mixture. The ice serves as a cooling medium which is used to maintain or preserve quality attributes through the marketing chain.

In 1988, horticulturists at Virginia Polytechnic Institute and State University were interested in ascertaining consumer attitudes and preferences toward Virginia-grown broccoli. Approximately 1,240 Virginia Master Gardeners, a distinct target group of consumers who are high users of horticultural commodities, were surveyed (Relf et al., 1990). The response rate was greater than 40%, which indicated significant interest in the subject matter. The Master Gardener respondents indicated a preference for broccoli with more florets or buds and less stalk (i.e single unit broccoli). Also, the respondents indicated a preference for broccoli that is shrink-film wrapped.

The objectives of this thesis were to produce single unit broccoli, and to examine vacuum-wrapping and shrink-film wrapping as potentially viable alternatives to top icing in order to retain postharvest quality of both single unit and bunching broccoli.

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Literature Review

Broccoli (*Brassica oleracea*, L. var. italica) is a very perishable horticultural commodity. Because of its respiration and transpiration rate, broccoli is marketed within 1 to 14 days after harvest (Brennan and Shewfelt, 1989). Kader et al., (1985) suggested that the shelf-life of vegetables closely parallels their respiration rate. Slurry icing, at approximately 9 kg per 8 kg box of broccoli, is the recommended method for precooling and holding broccoli (Risse, 1988). The ice slurry also effectively reduces wilting and retains color of the broccoli after harvest (Rij and Ross, 1987).

Fresh market broccoli consumption in the United States has increased by approximately 330% since 1971 (Hamm, 1988). The majority of the broccoli sold in the United States is grown in California (David Stidolph, Personal communication). Virginia growers, however, seemingly have an advantage of lower transportation costs (Borchers, 1980). Although broccoli production is feasible in Virginia, its "production window", and hence, "market window" is quite short. Virginia broccoli is harvested from October through November. Thus, prolonging storage life would be advantageous for broccoli growers in Virginia as well as other southeastern states (Shewfelt, 1983).

Methods to extend the postharvest life of broccoli have been examined. Senescence inhibitors such as natural and synthetic cytokinins have been proven to effectively retain green color and extend the marketable life of broccoli (Batal et al., 1982; Fuller et al., 1977; and Shewfelt et al., 1983). Many

of the senescence inhibitors, however, are not currently approved for use as food additives (Fuller et al., 1977). Controlled atmosphere storage has also been used to successfully extend the shelf life of broccoli by varying the gas compostition surrounding the commodity and reducing the respiration rate (Leberman et al., 1968; Lipton and Harris, 1974; Wang, 1979). Controlled atmosphere storage extends the storage life of produce more than refrigeration alone, but requires precooling and refrigeration to be effective. Atmospheric composition of greater than 10% carbon dioxide can induce off-odors and flavors of broccoli (Ryall and Lipton, 1972). Also, controlled atmosphere storage requires large outlays for installation, maintenance, and energy (Ben-Yehoshua, 1985).

Wrapping of produce to extend the storage life is not a new postharvest handling practice. During the 1970's, researchers began using a heat shrinkable, high density, polyethylene plastic film to individually wrap fresh produce. This method was refered to as "seal packaging" because the film is shrink-wrapped tightly around each produce item without ventilation holes (Risse, 1988).

Shrink-film wrapping of fresh produce has several advantages: a) reduced water loss; b) greater turgidity or firmness; c) possible creation of a modified atmosphere; and d) low cost (as little as cents per unit) (Risse, 1988). Fresh broccoli overwrapped with a polyvinyl chloride wrap of a defined carbon dioxide transmission rate effectively reduced fresh weight loss, and retained green color (Rij and Ross, 1987).

Consumer attitudes toward fresh market broccoli have changed (Am. Veg. Grower, 1988). A Virginia Master Gardener survey indicated a preference for broccoli that has less stalk and more florets or bud structure (Relf et al., 1990). To successfully produce broccoli with a a higher percentage of florets and buds, growers can use the following guidelines: a) wide spacing (possibly three times wider than normal bunching broccoli spacing); b) mid to late maturing cultivar with less fiber; c) specific cultivars that inherently produce large heads such as 'Sultan', 'Ninja', 'Emerald City', 'Greenbelt', and 'Arcadia' (Howard Adams, Personal communication, 1989).

Virginia Master Gardeners also indicated that shrink-film wrapped broccoli would enhance their demand for Virginia-grown broccoli, if it effectively preserved postharvest quality attributes (Relf et al., 1990). Quality attributes of broccoli that must be preserved after harvest include ascorbic acid (vitamin C) (Ezell and Wilcox, 1959), chlorophyll or greeness (Leberman et al., 1968), and fresh weight (Risse, 1988). At the retail level, bottom icing of broccoli in concert with refrigeration was discovered to be the most effective in maintaining broccoli quality. Top icing, could be detrimental to the quality of retail broccoli if damage is done to the florets (Perrin and Gaye, 1986). Top icing costs per box are estimated to be approximately 65 to 70 cents (O'Dell, Personal communication, 1989).

Vitamin C is considered the most labile of all vitamins in the food supply. Reduced ascorbic acid, which is the predominant form found in foods of plant origin, can be reversibly oxidized to dehydroascorbic acid. Ascorbic acid

losses start with harvesting, and continue through handling, industrial or home preparation, cooking, and storage of plant foods (Erdman and Klein, 1982).

Vacuum packaging of fresh broccoli in polyethylene bags inhibited loss of chlorophyll and ascorbic acid (Wu and Salunkhe, 1976). However, frozen uncooked and cooked broccoli stored for two or four days at 3 °C prior to blanching, was significantly higher in reduced and total ascorbic acid than that blanched and frozen immediately (Eheart, 1969). Because ascorbic acid is an intermediate in carbohydrate metabolism, its synthesis in storage is probable (Payne, 1964). Ascorbic acid increases in broccoli can vary among cultivars. 'Grande' and 'Coastal' broccoli neither gained nor lost ascorbic acid between 0 and 7 days of storage at 2 °C. 'Waltham-29' gained approximately 36% ascorbic acid (Eheart, 1971). Increases in ascorbic acid have been reported to occur in frozen corn during storage (Payne, 1964). Vitamins, however, are not retained any better in produce packaged in film than in nonwrapped produce (Schomer, 1953). Refrigeration much more effectively maintains ascorbic acid content than film packaging (Hardenburg 1987).

Broccoli sealed in polyethylene bags was rated very good after 28 days in storage at 0 °C; the color was good, but there was some loss of turgor (Wang, 1979). Color is an extremely important quality attribute of fresh broccoli (Shewfelt et al.,1983). Changes of color in storage are closely correlated with changes in chlorophyll concentration. Visual color evaluation, however, is the most sensitive method used to detect changes in color (Shewfelt et al., 1983).

Chlorophyll retention of broccoli stalks decreased after 16 days storage, and losses were much greater at 7 °C than at 1 °C. Total chlorophyll retention was 78% at 1 °C, but 22% at 7 °C. Color changes in the stalk were minimal during the 16 days storage in air at either 1 °C or 7 °C (Leberman et al., 1968).

Packaging of produce also maintains quality by reducing transpiration from the commodity. The fresh appearance is maintained longer (Hardenburg, 1971). Water loss occurs because of a water vapor pressure gradient between the product and the surrounding atmosphere. The package may provide a partial barrier against movement of water vapor from the product, and thus extend the postharvest storage life (Kader et al., 1985).

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Chapter 1:

Production of Single Unit And Bunching Broccoli by Direct Seeding and Transplanting

Abstract

Single unit broccoli, with less stem and more florets by weight is seemingly preferred by Virginia Master Gardeners (Relf et al., 1990). In 1989, single unit and bunching broccoli (cv. 'Sprinter') were produced using two planting methods (direct seeding and transplants), and two sites (Carroll County and the Virginia Tech Horticultural Research farm) at a spacing comparable to commercial production of cabbage in Carroll County (20 cm within row spacing; .9 m centered beds). Bunching broccoli appreciably outyielded single unit broccoli at both locations. At the Horticultural Research Farm, there was no significant difference in marketable yields (MT/ha) with either planting method. However in Carroll County, transplants outyielded direct seeded broccoli. Single unit broccoli was harvested only in Carroll County. Based on these data, single unit broccoli can be produced in cool, mountainous regions such as Carroll County, Virginia. However, it is not realistic to assume that a large percentage of the marketable yield will be harvested as single unit broccoli given the spacing, date of planting, and cultivar used in the study.

Additional index words: single unit broccoli, direct seeded, transplanted

Introduction

Commercially produced broccoli is typically marketed as bunches weighing approximately 600 grams (1.25 lbs.). If given a choice, however, consumers may prefer broccoli with more florets or bud structure, and less stalk. To support this premise, a recent survey of 1,240 Virginia Master Gardeners revealed that slightly more than half of the respondents used only the broccoli head, and discarded the rest as waste. In addition, an overwhelming 90% of the respondents indicated that they would purchase a single large head of broccoli if it were available (Relf et al., 1990). Thus, there seems to be a demand for broccoli approaching maximum edible product (i. e. single unit broccoli).

United States grade standards for bunching broccoli define a bunch of broccoli as stalks bound together to form a unit. A single stalk may be considered "equivalent" to a bunch if it is approximately as large as other bunches (USDA., 1943). Single unit broccoli is approximately equal to or greater than 85% by weight florets. Standard bunching broccoli, however, is only 65% by weight florets.

Small-stem broccoli with large heads offers a simplified production system using transplants or direct seeding. A lower plant population/acre ratio would be used, since greater spacing would be needed to allow for the development of large heads, thus reducing costs while presumably increasing yields (Relf et.al., 1990).

Carroll County, located in mountainous southwest Virginia is a major cole crop production area in the state of Virginia. Climatic and edaphic factors related to an average elevation of 3500 feet are conducive to successful cole crop production. Carroll County produces 770 hectares of summer and fall cabbage having an annual market value of $5,000,000 (Vavrina, 1988). Single unit broccoli would be an attractive alternative crop for Carroll County growers primarily because single unit broccoli can be harvested as a unit per plant similar to cabbage and can be harvested without the use of expensive mobile packing units or bunching machines.

Crucifers such as broccoli are typically field-established by two methods: direct seeding, and by transplants from a nursery seedbed. A satisfactory plant stand with direct seeding, can be attained if the seedbed is uniform and nonundulated. Transplants require less field preparation, and can be grown in a fumigated plant bed, thus enabling control of disease (Nichols, 1990).

The objective of this research was to develop a production scheme for early fall, single unit broccoli by transplanting and direct seeding in Carroll County, Virginia, and the Virginia Tech Horticultural Research Farm.

Materials and Methods

Field experiments were conducted at the Virginia Tech Horticultural Research Farm, Blacksburg, and at Carroll County, Virginia, on a Groseclose silt loam and a Chester-Glenelg cobbly loam, respectively. 'Symphony', a mid-season broccoli cultivar (62 days), was used for all treatments.

Broccoli transplants were seeded in Carroll County during mid-May and June in a fumigated transplant bed. Standard cultural practices consistent with Virginia Cooperative Extension Service (VCES) recommendations for producing transplants were followed. The plot chosen in Carroll County for planting was determined to be a representative field for cole crop production.

Prior to planting at each location, 168 kg/ha of 15-30-15 and .72 kg a.i./ha of α trifluoro-2,6-dinitro-N, N-dipropyl-p-toluidine (trifluralin) were incorporated. Broccoli was direct seeded in Carroll County on 27 June, and the following day at the Horticultural Research Farm using a *Stanhay* S870 precision planter (Stanhay, Corp. Dixon, CA). Seeding depth was approximately 15mm. Spacing of plants was similar to that used for commercial cabbage production in Virginia. The broccoli were planted as three row beds with 91 cm centers. The plants were thinned or transplanted to achieve a within row spacing of 20 cm equalling 79,926 plants/ha. After seeding, the plots were irrigated as needed until harvest.

On 13 and 18 July, the broccoli transplants were planted in Carroll County and the Horticultural Research Farm, respectively.

Each individual plant received approximately 230 mls of 9N-45P-15K starter solution. The spacing employed was similar to the direct seeded broccoli. Four and seven weeks after seeding, the direct seeded and transplanted broccoli were side dressed with 15.5N-0P-0K at a rate of 56 kg N/ha. Tissue samples of the most recently mature leaf were taken from plants within each treatment when the broccoli initiated a head. Weeds were removed by cultivation and hand-hoeing. Insecticides and fungicides were applied as needed.

A 6 m section of the center row of each bed was harvested for data collection. Treatments were arranged as a split plot design with planting method (direct seeded vs. transplant) as the whole plot factor, and harvest method (single unit broccoli vs. bunched broccoli) as the subplot factor. Each treatment was replicated four times.

Broccoli was categorized as single unit when the head diameter reached 20 cm or greater. Heads in the range of 8 to 12 cm diameter at maturity were classified as bunching broccoli. All data were analyzed by the ANOVA procedure via the Statistical Analysis System (SAS).

Results and Discussion

Fresh green, bunching broccoli was first harvested from transplants in Carroll County on 10 August 1989. Single unit broccoli was harvested from transplants once the preset head diameter of 20 cm was attained (31 August). Assuming each single unit to be comparable to a single bunch of broccoli, marketable yields of transplanted broccoli were significantly higher on a unit basis (boxes/ha), and biomass basis (MT/ha) in Carroll County, Virginia only (Table 1).

The direct seeded broccoli in Carroll County was first harvested 8 September 1989. The transplants yielded a higher percentage of marketable bunches and single heads than the direct seeded planting method (Table 2). Much of the unmarketable direct seeded broccoli was observed to be underdeveloped at harvest.

One of the necessary "ingredients" for successful precision seeding is a firm, stable seedbed. The soils of Carroll County are steep and undulated. Hence, precision of seeding depth, and possibly emergence and subsequent growth was affected. Therefore, field establishment by transplanting is possibly a better planting method for cole crops in Carroll County.

Broccoli from both planting methods was harvested in Blacksburg on 29 August 1989 (Table 1). There was no significant difference in marketable bunching broccoli yields with either planting method. No single unit broccoli was harvested at the Blacksburg research site. The single unit broccoli was

unmarketable (at both sites) because of softening and subsequent flowering of the florets which occured at head diameters of approximately 16 cm (data not shown). High temperatures encountered in the Blacksburg location during September, drastically decreased head development and marketable longevity. High temperatures also enhanced the development of bacterial head rot (*Erwinia cartovora*), a ubiquitous pathogen of broccoli florets.

No significant difference in macro or micro nutrient tissue content was revealed by either method of planting (Appendix). At harvest, there was a significant difference in average weight of the direct seeded and transplant broccoli bunches in Carroll County. The single unit broccoli, which was allowed to mature for a longer period of time, was larger in plant height and marketable broccoli weight than the stalks used to form a bunch (Table 3).

Carroll County can possibly produce single unit broccoli. However, given that yields were approximately a small fraction of bunching broccoli yields, it is not realistic for a grower to expect a yield approaching 100 % single unit broccoli, given the methodology of this study. More research on ideal cultivars, spacing, and date of planting is needed to determine the exact production scheme for single unit broccoli production.

Table 1. Total marketable yield of single unit and bunching broccoli by two planting methods.

Treatment	Marketable yield			
	Carroll Co.		Blacksburg	
	MT/ha	Boxes/ha	MT/ha	Boxes/ha[z]
Planting method:				
Transplants	5.4	747	6.7	838
Direct seeded	3.1	350	6.9	869
Significance	*	*	NS	NS
Harvest method:				
Crown Pack	1.3	267	0	0
Bunching	7.2	830	6.8	854
Significance	*	*	*	*
S E	.9	116	.81	100
Planting method x Harvest method	NS	NS	NS	NS.

[z]*Includes* only bunching broccoli yields.
Eight kilogram box (14 bunches).
NS * Non Significant, Significant at P = .05 respectively, according to F test.

Table 2. Percent marketable single unit and bunching broccoli by two planting methods.

Treatment	Percent *marketable*[z]	
	Carroll Co.	*Blacksburg*
Planting Method:		
Direct seeded bunching	*48*	*50*
Transplants bunching	*61*	*46*
Transplants single unit	*9.2*	-
Direct seeded single unit	*.2*	-
Significance	*	-
S E	*7*	*4*

[z]*Percent* of marketable broccoli within a 6 meter section of row. Analysis of variance performed on angular transformed data.
NS * Non Significant, Significant at P = .05 respectively, according to F test.

Table 3. Harvest variables of bunching and single unit broccoli.

Treatment	*Location*	*Height(cm)*[z]	*Weight (g)*
Planting Method:			
	Carroll County:		
Transplants		39	269
Direct seeded		36	205
Significance		*	*
Harvest Method:			
Single unit		42	374
Bunching		36	164
Significance		*	*
S E		.92	30
	Blacksburg:		
Transplants bunching		41	179
Direct seeded bunching		40	172
S E		.85	8.8
Significance		NS	NS

[z]*Height* measured from soil line to crown of broccoli plant
NS * Non Significant, Significant at P = .05 respectively, according to F test.

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Chapter 2:

Postharvest Quality Maintenance of Single Unit and Bunching Broccoli

Abstract

Broccoli (*Brassica oleracea* L. var. italica) has a relatively short postharvest life. This study was conducted to determine if shrink-film and vacuum wrapping is as effective as top icing in preserving postharvest quality attributes of single unit and bunching broccoli. Four cultivars of broccoli were vacuum-wrapped and shrink-film wrapped with 50 -,60- and 75-gauge shrink film wrapping. The broccoli was stored 12 to 22 days at 1 °C. After storage, the single unit and bunches were compared to top icing, which is the standard postharvest handling practice for broccoli. Quality attributes including vitamin C (ascorbic acid), chlorophyll, fresh weight, turgidity and overall quality, were evaluated. The top iced broccoli required continual icing during storage, while the wrapped bunches or single heads never received ice during storage. Wrapping did not affect ascorbic acid and chlorophyll retention. However, wrapping reduced fresh weight loss and preserved hedonic attributes as effectively as top icing.

Shrink-film wrapping and vacuum wrapping are potentially viable alternatives to top icing for maintenance of postharvest quality of both single unit and bunching broccoli.

Additional Index Words: single unit broccoli, in-package atmosphere, postharvest quality

Introduction

Broccoli (*Brassica oleracea,* L. var. italica) is one of the most perishable horticultural commodities, and thus, is usually marketed within 1 to 14 days after harvest (Brennan and Shewfelt, 1988). The high degree of perishability of broccoli parallels its high respiration rate (Kader et al., 1985). An effective yet inexpensive method of maintaining postharvest quality is a major challenge facing the broccoli industry. Factors associated with quality of broccoli include vitamin C (ascorbic acid), color, and turgidity (Perrin and Gaye, 1986).

Despite close proximity to major population centers, postharvest handling of broccoli in Virginia and other eastern states is much the same as in California, which produces the majority of fresh market bunching broccoli (David Stidolph, Personal communication). Top icing, or contact icing, is the standard postharvest practice for preserving quality attributes of broccoli in the United States.

Top icing, in which approximately 8 - 9 kg of finely-crushed, or slurry ice is applied to 8 to 10 kg of broccoli to reduce respiration, has disadvantages. These disadvantages include increased weight of the marketing unit (the box) by using ice as the cooling medium, and additional per unit costs. For example, the ice cost per package or box of broccoli in Virginia averages approximately 60 cents (O'Dell, Personal communication). This contributes to the overall production costs of growing broccoli. Also, during marketing, the broccoli has to remain refrigerated in order to retain color and reduce wilting

of the broccoli inflorescences. In addition, top icing requires the use of more expensive, water-resistant shipping containers (Kader et al., 1985). Thus, with such distinct disadvantages, it seems desirable to explore alternative postharvest handling practices for broccoli that maintain quality at a minimal cost to the producer.

Broccoli quality can also be maintained successfully by using ethylene inhibitors (Wang, 1977) and senescence inhibitors (Batal, 1982; Fuller et al., 1977). Also, controlled atmosphere storage has yielded success in broccoli postharvest storage (Lieberman et al., 1968). However, off-odors and off-taste can develop from anaerobiosis, if exposed to high carbon dioxide and low oxygen. Neither of these processes seem to offer quality maintenance at a minimal cost to the broccoli producer.

Virginia consumers have responded favorably to the idea of shrink-film wrapped produce. This response was evident from a preference and consumption survey targeted at Virginia Master Gardeners to determine attitudes toward Virginia-grown broccoli. Fifty-five percent of the respondents indicated that shrink-film wrapped broccoli would definitely increase their demand for Virginia-grown broccoli if the wrap maintained the quality of the product (Relf et al., 1990).

Individual seal packaging of broccoli has been reported to maintain quality and extend postharvest life (Wang et al., 1977; Elkashif et al.,1983; Rij and Ross, 1987). Film wrapping produce modifies the atmosphere around and within the produce generally reducing the level of oxygen and increasing the

level of carbon dioxide. Packaged produce is a dynamic system in which respiration and transpiration occur simultaneously. Selection of the appropriate film could effectively reduce water loss and favorably modify the in-package atmosphere, thereby extending the produce shelf-life. In addition to maintaining quality, the economics of film wrapping is another potential advantage. The cost of film wrapping is between 1 and 3 cents per unit depending on the size of the produce (Risse, 1988).

Therefore, given the positive Virginia Master Gardener response towards shrink-film wrapping and single unit broccoli, the objectives of this research were to examine vacuum wrapping and shrink-film wrapping as a postharvest handling practice that would preserve the quality of single unit and bunching broccoli, and to compare wrapping with the standard postharvest practice of top icing broccoli.

Materials and Methods

Broccoli was harvested from commercial broccoli farms in Southside Virginia and eastern North Carolina. Uniform, compact heads of broccoli from a single field at each location were selected. Four cultivars of broccoli were used: 'Brigadier', 'Packman', 'Sprinter', and 'XPH-5168.'

The first three experiments examined shrink-film wrapping as a postharvest practice that could preserve quality of single unit and bunching broccoli. Both individual heads and bunches of broccoli were placed in 27x44 cm *Clysar* EHC 50- and 75-gauge bags (Table 1). A portable shrink-film wrapping machine (Dillard Packaging Co., Roanoke, Va.) was used to wrap the single large heads of 'Sprinter', 'XPH-5168', (head diameters $\simeq$ 15-18 cm), and bunches of 'Packman' broccoli. After wrapping, the 'Sprinter', XPH-5168', and 'Packman' broccoli were stored 14, 21, and 22 days respectively. All shrink-film wrapped broccoli were stored at 1 °C and 85% relative humidity.

The last experiment compared vacuum wrapping of bunched broccoli to top icing of broccoli in order to preserve postharvest quality attributes. Individual stalks of 'Brigadier' were trimmed, and arranged in uniform bunches weighing approximately 600 g. Each bunch was placed in 27x39 cm *Cryovac* PD-940 polyethylene 60-gauge bags (Table 1). A Multi-vac vacuum sealer was used to remove the void volume in the bag, thus establishing a close contact between the fresh broccoli and the wrapping. The wrapped bunches were

weighed and stored at 1 °C and approximately 85% relative humidity for 12 days.

The experimental design of each experiment was a complete factorial with wrap and top icing the main effects (Lentner and Bishop, 1986). The data were analyzed by Dunnett's procedure in which all treatments were compared to a control (top ice or day 0). The vacuum-wrapped experiment consisted of 9 replications per treatment. The 'Sprinter' and 'Brigadier' shrink-film experiments consisted of 11 replications, and the 'XPH-5168' experiment had 10 replications per treatment. After storage, the broccoli was removed, weighed, and evaluated for different organoleptic factors such as color, odor, turgidity, and overall quality. The vacuum-wrapped broccoli was evaluated by a random group of five individuals. The broccoli bunches and single stalks from the additional three shrink-film experiments were coded and evaluated organoleptically by the author. Odor and compactness were rated on a scale of 1 - 5; 1 being off odor or limp, and 5 representing normal odor and turgid. Overall quality and color were rated on a scale from 1 - 8; 1 represented yellow and poor quality, and 8 excellent quality or very green.

Immediately after the broccoli was wrapped, a random sample of uniform bunches or single heads was selected to derive a baseline for total chlorophyll and ascorbic acid (vitamin C). Approximately 8.5 cm of the large stalk from each bunch or single head was removed. The remaining broccoli tissue was finely chopped, and approximately 45 g of florets and branches were collected. The 45 g of fresh broccoli tissue were frozen at -62 °C and subsequently freeze

dried. The freeze dried broccoli tissue was was evaluated for ascorbic acid using the 2, 6-dichloroindophenol titrimetric method (AOAC, 1975).

Total chlorophyll was determined by grinding approximately 7 g of fresh tissue in 80% acetone, and filtering twice through Whatman # 1 filter paper. The absorbance of the extract was read at 663 and 645 nm using a Shamadzu spectophotometer (Shamadzu Corp., Columbus, Ohio) and total chlorophyll was calculated according to Yoshida et al.

Results and Discussion

Ascorbic Acid Retention

The retention of ascorbic acid by the experimental treatments varied for each cultivar of broccoli and length of storage (Table 2). The vacuum-wrapped 'Brigadier' broccoli that was noniced had no significant loss of ascorbic acid after 12 days of storage. However, both the wrapped/iced and noniced, non-wrapped treatments had significantly less ascorbic acid after storage. The 'Sprinter' shrink-film wrapped single unit broccoli showed an increase in ascorbic acid after 14 days storage. All treatments had significantly higher reduced ascorbic acid than the fresh broccoli samples taken at the initiation of the experiment. Individual heads of 'XPH-5168'. that were shrink-film wrapped exhibited greater ascorbic acid levels in the *Clysar* EHC 75-gauge wrapped and the noniced, nonwrapped broccoli. The top iced broccoli, however, did not differ significantly from the control at day 0.

Fresh Weight Loss

The retention of freshness of all wrapped broccoli was evident after varying lengths of storage (Table 3). The 'Brigadier' broccoli, vacuum-wrapped with *Cryovac* PD-940 60-gauge wrap, was as effective in reducing weight loss as the

top iced. The noniced, nonwrapped bunches had lost 5% of their weight, and were unsalable. Both the 75-gauge and 50-gauge shrink-film wrapped 'Sprinter' broccoli lost less than .1% of their initial fresh weight, and did not lose significantly more than the top iced treatment, despite a higher surface to volume ratio. The wrapped 'XPH-5168' single unit broccoli held for one week longer than 'Brigadier' and 'Sprinter' lost only .2% of its initial fresh weight. This loss was not significantly different from the top iced treatment which had to be frequently re-iced in order to maintain or preserve postharvest quality. The bunches of 'Packman' broccoli that were shrink-film wrapped, lost only .4% compared to the top iced bunches which had lost nearly 11% of their initial weight after 21 days storage.

Total Chlorophyll Retention

Total chlorophyll, was measured in the 'Sprinter' and 'XPH-5168' shrink-film experiments. Chlorophyll retention did not differ with treatment even after 21 days storage. Thus, wrapping of broccoli is equally effective in retaining chlorophyll as top icing. Indeed, factors such as proper storage temperature may be more effective in chlorophyll retention of broccoli.

Organoleptic Attributes

Organoleptic or hedonic properties of broccoli include color odor, turgidity, and an all-encompassing overall quality evaluation.

Color of the broccoli florets was visually evaluated (Figs. 1 & 2). Vacuum-wrapped broccoli, evaluated by a five member panel did not reveal any significant difference in color after 12 days storage. The wrapped, 60-gauge bunches which had never received postharvest icing, were perceived to be as green as those bunches that were top iced. With 'Sprinter' the 50- and 75-gauge shrink-film wrapped broccoli did not seem to differ significantly from the top iced broccoli. However, because of yellow undercolor, the noniced, non-wrapped heads were perceived to be more yellowish. After 21 days storage, the 'XPH-5168' single heads did not differ significantly from the top iced broccoli. Also, the 'Packman' bunches wrapped with 75-gauge *Clysar* EHC were rated to be as green as the top iced treatment.

Odor as a postharvest quality attribute can indicate possible anaerobiosis or anaerobic fermentation of the wrapped broccoli. However, none of the four wrapped varieties of broccoli were perceived to have an off-odor and, hence, did not differ significantly from the top iced treatments (Figs. 1 & 2). The vacuum-wrapped broccoli was very effective in retaining turgidity of the broccoli stalks by reducing fresh weight loss of the florets (Figs. 3 & 4). The 'Sprinter' heads of broccoli were as turgid as those top iced. The 'XPH-5168',

and 'Packman' heads that were wrapped and stored for 21 and 22 days respectively wre perceived to be as turgid as the top-iced treatments.

Overall quality, a summation of the foregoing attributes plus additional quality perceptions was maintained effectively by both vacuum-wrapping and shrink-film wrapping (Figs. 3 & 4). Quality of wrapped broccoli was consistently at parity with top iced or continually-iced broccoli. The wrapped 'Packman' bunches held for 22 days were perceived to be of superior quality to the continually iced top iced control.

Both vacuum or shrink-film wrapping, were effective in maintaining postharvest quality attributes of a highly perishable bunching and single unit broccoli. The quality, turgidity, nutrition, color, and organoleptic factors of single unit broccoli, can be retained after harvest by shrink-film wrapping. The ability to preserve quality during storage of single unit and bunching broccoli is important to both the broccoli producer who wants an extended "market window", and the consumer who desires broccoli with little or no loss in quality from the field to the grocery shelf.

Table 1. Oxygen,and water vapor transmission rate of film wraps[z]

Wrap	*Gas transmission rate*	
Type	*Oxygen[y]*	*MVTR[x]*
EHC 50	400	1.0
PD-940	390	.9
EHC 75	325	.7

[z]*Information* applies to film before shrinking; All film supplied by the manufacturer.
[y]*Oxygen*: permeability cc/100 in^2/24hr/atm
[x]*MVTR* = Moisture vapor transmission rate, g/100 in^2/24hr

Table 2. Ascorbic acid retention of single unit and bunching broccoli after varying lengths of storage.[z]

Cultivar	*Storage*[y]	Treatment	Ascorbic *acid*[x]
Brigadier			
(*Bunching*)	12	Wrapped (60 ga./iced)	511 b
		Wrapped (60 ga.)	566 a
		Noniced,nonwrapped	520 b
		Top-iced	549 a
	0	Baseline	595 a
Sprinter			
(*Single unit*)	14	Wrapped (75 ga.)	690 b
		Wrapped (50 ga.)	674 b
		Wrapped (50 ga./iced)	801 b
		Wrapped (75 ga./iced)	690 b
		Noniced,nonwrapped	677 b
		Top-iced	769 b
	0	Baseline	580 a
XPH-5168			
(*Single unit*)	21	Wrapped (75 ga.)	753 b
		Noniced, nonwrapped	792 b
		Wrapped (75 ga./iced)	560 a
		Top-iced	698 a
	0	Baseline	630 a

[z]*Treatment* means followed by the same letters are not significantly different (Dunnett's procedure, P = .05).
[y]*Length* of storage (days).
[x]*Ascorbic* acid expressed as mg/100 g of freeze-dried weight.

Table 3. Percent fresh weight loss of single unit and bunching broccoli[z]

Cultivar	*Treatment*[y]	Fresh weight *loss*[x]
Brigadier		
(*Bunching*)	Iced/wrapped (60 ga.)	0 a
	Wrapped (60 ga.)	0 a
	Noniced, nonwrapped	5 b
	Top iced	0 a
Sprinter		
(*Single unit*)	Wrapped (75 ga.)	0 a
	Wrapped (50 ga.)	0 a
	Wrapped (50 ga./iced)	0 a
	Wrapped (75 ga./iced)	0 a
	Noniced, nonwrapped	8 b
	Top iced	0 a
XPH-5168		
(*Single unit*)	Wrapped (75 ga.)	0 a
	Noniced,nonwrapped	13b
	Wrapped/(iced-75 ga.)	0 a
	Top iced	0 a
Packman		
(*Bunching*)	Wrapped (75 ga.)	0 b
	Wrapped (75 ga./iced)	0 b
	Noniced, nonwrapped	24b
	Top iced	11a

[z]*Treatment* means followed by the same letter are not significantly different (Dunnett's procedure, P = .05) from the control.
[y]*Top* iced is the treatment control.
[x]*Fresh* weight loss expressed as percentage of initial fresh weight. Analysis of variance performed on angular transformed data.

Table 4. Total chlorophyll content of shrink-film wrapped 'Sprinter' and 'XPH-5168' single unit broccoli[z]

Cultivar	*Treatment*[y]	Total *chlorophyll*[x]
Sprinter		
(*Single unit*)	Wrapped (75 ga.)	10.8
	Wrapped (50 ga.)	11.8
	Wrapped (75 ga./iced)	11.8
	Wrapped (50 ga./iced)	10.1
	Noniced, nonwrapped	10.6
	Top iced	10.9
	Baseline	9.4
	Significance	*NS*
XPH-5168		
(*Single unit*)	Wrapped (75 ga.)	16.0
	Noniced, nonwrapped	18.2
	Wrapped/Iced	14.2
	Top iced	14.2
	Baseline	14.9
	Significance	*NS*

[z]*Treatment* means followed by the same letter are not significantly different (Dunnett's procedure, P = .05) from the control.
[y]*Baseline* (day 0) is the treatment control.
[x]*Chlorophyll* expressed as mg $100g^{-1}$ fresh weight. All tissue (except baseline) were analyzed after removal from storage.

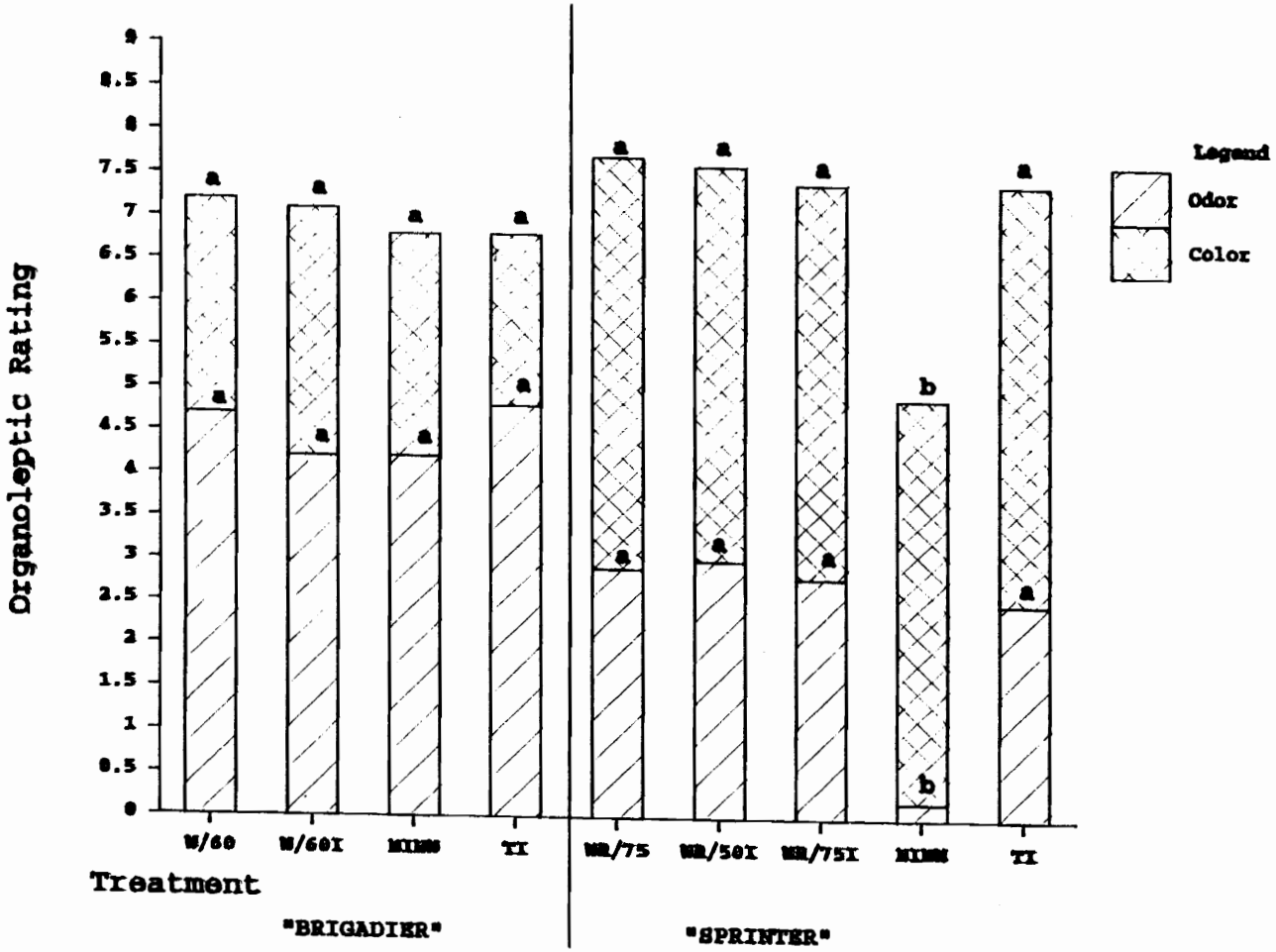

Fig 1. Organoleptic rating for color and odor as affected by cultivar and treatment.

Treatment nomenclature: Wr-wrapped; I-iced; TI-Top iced; NINW-Non-iced, non-wrapped; 60-60 gauge Clysar; 75-75 gauge Clysar;

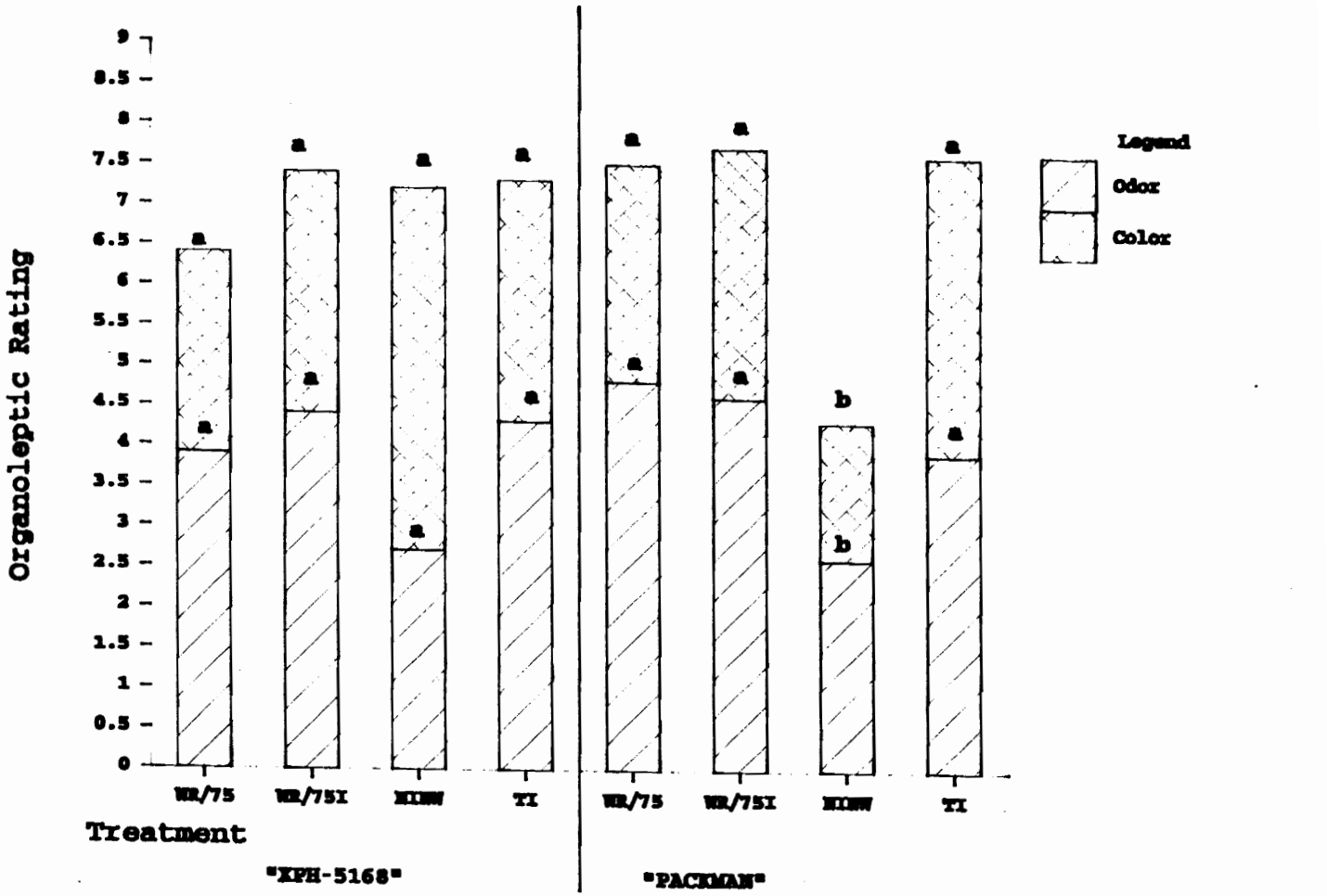

Fig 2. Organoleptic rating for color and odor as affected by cultivar and treatment.

Treatment nomenclature: WR-wrapped; I-iced; TI-Top iced; NINW-Non-iced, non-wrapped; 60-60 gauge Clysar; 75-75 gauge Clysar;

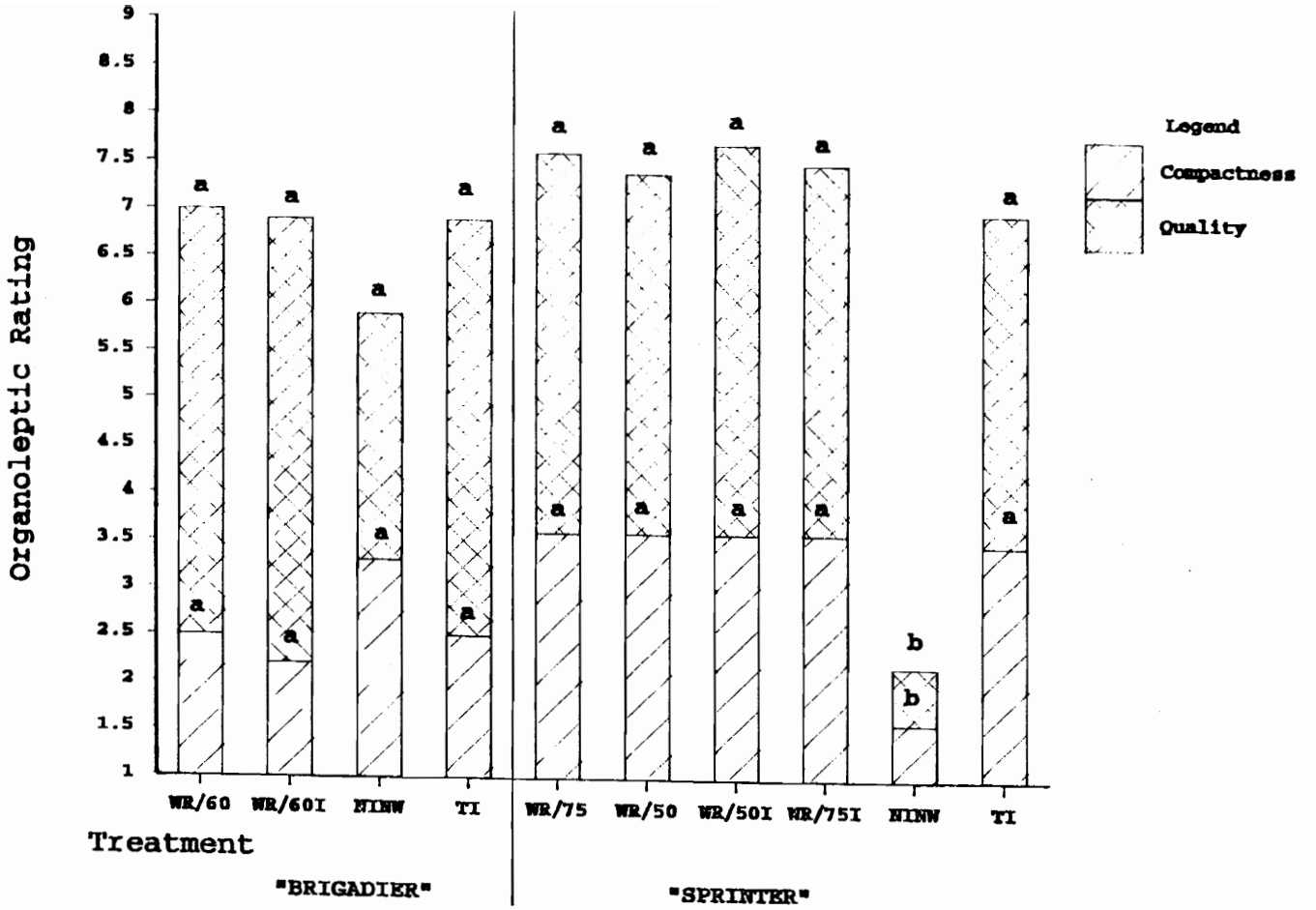

Fig 3. Organoleptic rating for compactness and quality as affected by cultivar and treatment.

Treatment nomenclature: Wr-wrapped; I-iced; TI-Top iced; NINW-Non-iced, non-wrapped; 50-50 gauge Clysar; 60-60 gauge Clysar; 75-75 gauge Clysar;

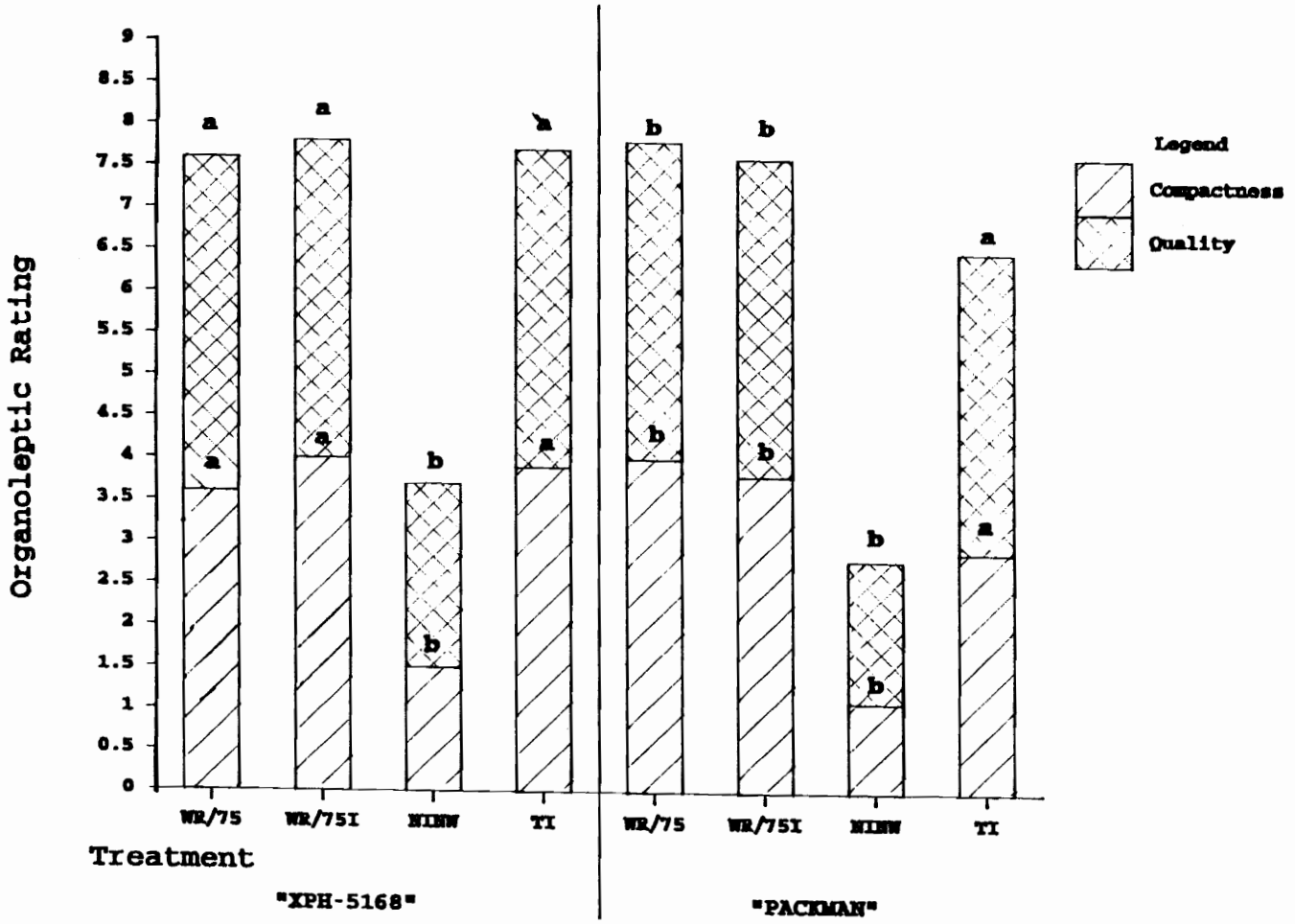

Fig 4. Organoleptic rating for compactness and quality as affected by cultivar and treatment.

Treatment nomenclature: WR-wrapped; I-iced; TI-Top iced; NINW-Non-iced, non-wrapped; 60-60 gauge Clysar; 75-75 gauge Clysar;

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Summary and Conclusions

Production of single unit broccoli is feasible in Virginia as an alternative crop. More research on ideal cultivars, time of planting, and optimal plant population for successful production is imperative. Clearly, given the spacing, cultivar, and date of planting used in this study, no grower would desire to produce single unit broccoli as an alternative crop as long as its yields are a fraction of total bunching broccoli yields. It is of paramount importance to determine what percentage of marketable broccoli yield can be potentially harvested as single unit broccoli. If indeed single unit broccoli is to be produced successfully in Virginia, all of the foregoing questions *must* be answered clearly.

Postharvest quality of both bunching and single unit broccoli can be effectively maintained by vacuum and shrink-film wrapping. Wrapping of broccoli preserves quality attributes as good as top icing at a potentially smaller cost per unit. Also, effective quality maintenance during short term storage enhances the market flexibility of the grower by potentially expanding the "market window" of Virginia broccoli.

Flexibility, by definition, is the ability to respond or conform to change. In vegetable production, it is important to satisfy changes in consumer attitudes. Single unit broccoli may offer production and market flexibility to Virginia broccoli growers. The challenge facing both vegetable research-

ers and growers is to successfully develop a production scheme for single unit broccoli.

Appendix

Consumer Acceptance of Single Unit Broccoli:

A Test Marketing Study

Introduction

Consumers in the United States have become increasingly more health conscious. As a result, per capita consumption of fresh vegetables such as broccoli has increased dramatically. Broccoli is attractive to consumers because of high nutrition and culinary versatility.

Consumer attitudes towards fresh market broccoli have changed. The results of a 1988 target survey of 1,240 Virginia Master Gardeners revealed that 90% of the respondents would purchase a single large head of broccoli if it were available (Relf et al., 1990). This response seems to be confirmed at the retail level. A supermarket chain in central Virginia has experienced a very positive consumer response towards single unit broccoli. In fact, the single unit broccoli outsells standard California bunching broccoli by a 10:1 ratio. Even though single unit broccoli is equal to or greater in weight than traditional bunching broccoli, the handling and packaging requirements do not differ from the requirements for bunching broccoli (Mike Ramkey, Personal communication, 1990). The objective of this study was to ascertain consumer demand for fresh Virginia broccoli that would be classified as a single unit.

Materials and Methods

Three test marketing studies were conducted in 1989 at the *Kroger Corporation* supermarket located in Blacksburg, Virginia. This particular store was chosen because it was observed that the clientel ranged from urban to rural consumers. Broccoli from research plots or commercial farms that had a head diameter of 20 cm or greater was used in the study. Also, Virginia bunching broccoli was used in the first test market. California bunching broccoli was used in all test markets performed.

The single unit broccoli was priced similar to the bunching broccoli. No indication of the origin of the broccoli was provided to the consumer. Each product was randomly assigned to a location on the produce shelf during each test market. Also, an approximate equal amount of space was alloted to each product. Upon initiation of the test market, all broccoli units were counted. At approximate hour intervals, the number of each product sold was recorded. The shelves were replenished as required until all available broccoli was used. The test market was concluded when any one product was sold to 50% or below of its initial level.

Results and Discussion

Consumer response towards single unit broccoli was initially low (Table 1), possibly because of the superior quality of Virginia bunching broccoli (VABB). Virginia bunching broccoli initially outsold both single unit and California bunching broccoli (CABB). However, subsequent test markets revealed a preference for single unit over standard California bunching broccoli.

The results of this limited test marketing study seem to validify the results of the consumer response survey and the strong consumer demand experienced by other retail grocery stores in Virginia. Consumers will purchase single unit broccoli. As American consumers become increasingly more health conscious fresh market broccoli consumption will undoubtedly increase in concert. The challenge facing Virginia broccoli producers is to produce broccoli that will satisfy the future demand.

Table 1. Results of test marketing single unit and bunching broccoli, Blacksburg, Virginia[z]

TestMkt	Date	Product	Percent sold	Time(hr)
1	9/16	Single unit	38	1:45
		CABB	68	
		VABB	81	
2	10/19	Single unit	50	5:00
		CABB	14	
3	12/9	Single unit	67	1:30
		CABB	62	

[z]*Treatment* nomenclature: CABB = California bunching broccoli; VABB = Virginia bunching broccoli.

Table 2. Average crown (head) diameter of bunching broccoli harvested at two locations.

Treatment	Location	Crown diameter(cm)
Trp-Bunch	Carroll Co.	12.7
DS-Bunch		12.6
DS-Bunch	Blacksburg	12.3
TRP-Bunch		12.7

Table 3. Tissue nutrient percentage of broccoli grown by two different planting methods.

Treatment	N	P	K	Ca	Mg
Blacksburg, Va					
DS	3.4	.44	2.79	2.1	.35
TRP	4.3	.63	4.23	1.81	.36
Carroll County, Va					
DS	4.46	.63	3.11	1.63	.37
TRP	4.35	.68	2.15	2.09	.46

All levels are within sufficiency range for broccoli.
DS = direct seeded; TRP = transplanted.

Vita

Lewis Jett was born in Lost Creek, West Virginia on May 1, 1965. Currently, he is an active producer and direct marketer of vegetables and strawberries in West Virginia. Lewis obtained a B.S. degree in Agriculture in 1987 with an emphasis in Agricultural economics from West Virginia University. After completing his M.S. degree in Horticulture at VPI&SU, he plans to continue his studies towards a Ph.D in Horticulture at VPI&SU.