Cluster Analyses on Quality Attributes Identify Broccoli Cultivars Suitable for Early and Main-season Harvests on the Eastern Shore of Virginia

S.B. Sterrett¹, K.G. Haynes², and C.P. Savage, Jr.³

ADDITIONAL INDEX WORDS. *Brassica oleracea* var. *italica*

SUMMARY. Sixteen broccoli (*Brassica oleracea* var. *italica*) cultivars were evaluated for yield, head maturity, and quality attributes in the fall of 1997. 'Liberty', 'Sabre', 'Barbados', and 'XPH12211' were dropped after 1997 because of poor yield, coarse stems with severely shortened internodes, or lack of seed availability. Thus, three new cultivars, 'Nomad', 'Sussex', and 'XPH12212', were included in the 1998 trial. Head yield was generally higher in 1998 than in the cooler and drier 1997. In each year, cultivars were ranked into early and main season based on yield over sequential harvest dates. Only 'Windsor' was rated as a main-season cultivar in 1997, but an early-season cultivar in 1998. Cluster analyses were then used to group cultivars within year and season by head quality attributes. Based upon these analyses, 'Captain' is recommended for early production because of favorable head quality and moderately high yield potential. After 2 years of tests, none of the main-season cultivars could be recommended. 'Arcadia', 'Decathlon', and 'Windsor' were either too late or inconsistent in maturity. Yield

was low for 'Excelsior' and 'Arcadia'. Head quality of 'Laguna' and 'XPH12212' was poor or inconsistent. In the 1998 trial, 'Nomad' and 'Sussex' warranted additional evaluation because of improved yield, head and stem diameter and head quality.

Vegetable growers on the Eastern Shore of Virginia need to diversify into new or non-traditional crops to assure economic sustainability of agriculture in this region. Members of the Virginia Potato and Vegetable Growers Association identified broccoli as a potential new enterprise for this growing area (Sterrett et al., 1996). Broccoli consumption in the United States has increased by 177% since 1986 (U.S. Department of Agriculture, 2003). This increase in consumption has been steadily upwards, suggesting that demand for broccoli will continue to increase.

Kalo (1998) completed market window analyses (using 5 years of minimum weekly prices for four terminal markets) for several vegetables, including broccoli. The market window was considered open when the cost of production and marketing (including transportation) was lower than the weekly average minimum price in the terminal markets. The market window was open for most of the potential harvest season of 1 Oct. to 1 Dec. with broccoli yield exceeding 10.09 t·ha⁻¹ (4.5 tons/acre) but closed for all but the last 2 weeks of the harvest season when the average yield dropped to 8.07 t·ha⁻¹ (3.6 tons/acre) (Kalo, 1998). Current production budgets for VA are based upon 8.29 t·ha⁻¹ (3.7 tons/acre) (Sterrett et al., 1996). Development of heat-tolerant broccoli cultivars has facilitated production of fall broccoli in Virginia (O'Dell et al., 1993). However, local evaluations for yield and head quality to identify cultivars that meet current market standards are essential (O'Dell et al., 1993; Sterrett et al., 1996).

In previous studies in Virginia, both excessive head diameter for a bunched product and enlarged stems with shortened internodes were quality concerns (O'Dell et al., 1993; Sterrett et al., 1990, 1991). Bacterial soft rot (*Pseudomonas marginalis* pv. *marginalis*) can be a serious disease problem in the southeastern United States (Canaday, 1992). Dome-shaped

heads are less likely to collect the moisture required for the development of head rot. The U.S. No. 1 standard for bunched broccoli requires that each bunch be free of discoloration of bud clusters, decay, and damage caused by overmaturity. The bud clusters must also be fairly compact (U.S. Department of Agriculture, 1943).

In addition to marketable yield and maturity, head quality attributes including head size and uniformity, color uniformity, and head shape and tightness need to be considered in selecting a broccoli cultivar for commercial production in a given area.

The objective of this study was to evaluate broccoli cultivars for adaptation to growing conditions in eastern Virginia in terms of marketable yield and head quality. Using cluster analyses based upon head quality attributes, suitable early and main-season cultivars can be recommended for eastern Virginia.

Materials and methods

Sixteen cultivars were tested in 1997 and 15 in 1998 at the Eastern Shore Agricultural Research and Extension Center, Painter, Va., on a Bojac sandy loam soil (coarse-loamy, mixed thermic Typic Hapludult) (Table 1). A winter cover crop of cereal rye (*Secale cereale*) followed by summer fallow preceded the broccoli crop each year. Plots were seeded on 14 Aug. 1997 and 11 Aug. 1998 using a three-row Gaspardo vacuum small-seed planter (Gaspardo Seminatrici SpA, Morsano al Tagliamento, Italy) with plates drilled to plant seeds 2.5 cm (1 inch) apart (double seeded) at 22.9 cm (9 inches) within-row spacing. Plots consisted of three rows planted 45.7 cm (18 inches) apart on a 10.2-cm (4 inches) raised bed. Fertilizer [1120.9 kg·ha⁻¹ (1000 lb/acre) of 10N-4.9P-9.3K] and herbicide [trifluralin at 0.56 kg·ha⁻¹ (0.5 lb/acre) a.i.] were broadcast and incorporated within 24 h prior to seeding. After seeding, irrigation [6 mm (0.25 inch)] was applied twice daily until emergence and then in increments of 13 mm (0.5 inch) as needed for the rest of the season. Disease and insect pests were controlled as needed. Four cultivars ('Barbados', 'Liberty', 'Sabre', and 'XPH12212') from 1997 were not included in 1998 because of poor yield, poor quality, or lack of seed availability; three additional cultivars were included in the 1998 trial.

This research was supported in part by Southern SARE Project No. LS96-80. The authors thank T.J. Custis and the farm crew for their technical support.

¹To whom reprint requests should be addressed. Eastern Shore Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Painter, VA 23420.

²U.S. Department of Agriculture, Agricultural Research Service, Vegetable Laboratory, Plant Science Institute, Beltsville, MD 20705.

³Eastern Shore Agricultural Research and Extension Center, Virginia Polytechnic Institute and State University, Painter, VA 23420.

Table 1. Broccoli cultivars grown on the Eastern Shore of Virginia in 1997 and 1998 evaluated for head weight, head diameter, stem diameter, leaf scars, and percentage of marketable heads.

Cultivar	Seed source ^z	Days to first harvest	Harvest interval (d)	Head wt (g) ^y	Head diam (cm) ^y	Stem diam (mm) ^y	Leaf scar (no.)	Proportion of marketable heads (%)
<i>1997</i>								
Everest	Syngenta, Rogers	74	31	236	14.2	32.1	5.3	96
Major	PetoSeed	82	30	163	10.9	29.5	6.4	88
Regal	Harris Moran	72	40	254	15.4	42.4	6.2	78
Signal	Syngenta, Rogers	67	27	182	11.3	25.4	4.7	87
Captain	PetoSeed	85	24	163	11.1	28.6	6.0	96
Claudia	Harris Moran	74	37	282	14.9	38.3	6.9	80
Laguna	Syngenta, Rogers	93	26	282	11.1	36.4	5.2	82
Majestic	Seminis-Asgrow	101	25	259	12.2	36.5	7.3	65
Decathlon	Sakata	106	25	209	11.2	29.1	6.4	51
Excelsior	Harris Moran	99	22	200	11.6	32.1	6.4	79
Liberty	PetoSeed	113	10	272	10.7	39.8	8.1	24
Sabre	Seminis-Asgrow	110	4	150	9.6	27.8	5.8	29
Windsor	Syngenta, Rogers	88	24	227	13.6	33.3	5.9	96
XPH12211	Seminis-Asgrow	96	24	259	13.3	32.9	6.4	69
Arcadia	Sakata	106	16	209	12.0	28.9	4.9	50
Barbados	Harris Moran	98	14	182	11.1	31.5	5.2	75
Waller/Duncan K=100 (<i>P</i> =0.05)		2	11	54	3.2	6.0	1.0	19
<i>1998</i>								
Captain		76	10	223	13.0	37.4	8.9	75
Claudia		76	14	300	11.7	32.7	6.8	80
Windsor		76	18	204	10.2	29.4	6.7	82
Everest		76	14	191	8.7	21.4	4.5	90
Major		76	11	204	9.9	28.5	6.4	78
Regal		76	9	209	10.4	28.9	5.8	76
Signal		69	11	150	12.6	25.9	5.8	89
Decathlon		94	15	150	9.1	26.5	6.6	77
Excelsior		97	12	173	9.7	30.8	7.2	68
Laguna		97	4	145	6.3	29.3	6.7	78
Nomad	Sakata	97	12	191	9.8	23.5	5.8	84
Sussex	Syngenta, Rogers	95	16	186	9.7	28.3	6.9	90
Arcadia		97	16	141	9.1	27.2	7.1	75
Majestic		97	16	191	10.3	31.8	7.5	85
XPH12212	Seminis-Asgrow	104	9	218	12.0	32.0	7.7	71
Waller/Duncan K=100 (<i>P</i> =0.05)		2	7	27	2.7	4.7	1.3	32

^zHarris Moran Seed Co., Rochester, N.Y.; Sakata Seed America, Morgan Hill, Calif.; PetoSeed, Saticoy, Calif.; Seminis Vegetable Seeds, Oxnard, Calif.; Syngenta Seeds/Rogers Brand, Modesto, Calif.

^y1 g = 0.035 oz; 1 cm = 0.39 inch; 1 mm = 0.039 inch.

Harvesting began on 28 Oct. and 19 Oct. in 1997 and 1998, respectively. Early yield was based upon the first 3 weeks of harvest each year. The harvest interval was calculated as the days from first harvest to last harvest. Heads were trimmed to 20.3 cm (8 inches) in total length. Stem and head diameter, and the number of leaf scars per stem were counted for a maximum of 20 heads per plot at each harvest. Head size, head uniformity, color uniformity within the head, head shape, and head tightness were rated subjectively using a 9–1 scale (9 = ideal) at the main harvest for each cultivar. Percentage of marketable heads was calculated as

100 times the number of marketable heads/stand count.

Accumulated heat units (base 10 °C) were calculated to compare temperature differences between the two growing seasons. Trials were planted in a randomized complete-block design with four replications. Data were analyzed by the general linear models procedure with mean separation within cultivars by Waller-Duncan (*k* = 100) (SAS Institute, Cary, N.C.). Quality variables were subjected to cluster analyses using the unweighted pair group method by arithmetic averages (Romesburg, 1990). Cluster analysis facilitates the grouping of similar

individuals based on multiple traits (Romesburg, 1990).

Results and discussion

Both early and marketable yields differed between year and cultivar (Fig. 1). Marketable yield was generally lower in 1997 than 1998. Yields of ‘Arcadia’, ‘Barbados’, ‘Decathlon’, ‘Excelsior’, ‘Liberty’, and ‘Sabre’ were less than 10.09 t·ha⁻¹ in 1997, while only ‘Arcadia’ and Excelsior yielded less than 10.09 t·ha⁻¹ in 1998. The 1997 growing season was cooler than the 1998 (Fig. 2). Rainfall was below the 59-year average for this location from Aug. through Oct. of 1997 and

1998 [102 mm and 51 mm (4.0 and 2.0 inches), respectively]. While rainfall exceeded the long-term average by 74 mm (2.9 inches) in Nov. 1997, it was 51 mm below average in 1998. Frequent irrigation early in the 1997 growing season may have adversely impacted nitrogen fertility. Weather conditions also affected cultivar maturity. Of the six early-maturing cultivars, yield within the first 3 weeks of harvest exceeded 50% only for 'Signal' in 1997 and 'Windsor' had no early yield (Fig. 1). In contrast, most of the total yield was harvested during the first 3 weeks for the early-maturing cultivars in 1998. Days to first harvest and harvest interval were fewer in 1998 than 1997 for several cultivars, including 'Captain', 'Windsor', 'Major', 'Decathlon', and 'Arcadia' (Table 1). Hastening of head maturity in warmer growing seasons could complicate growing and harvest schedules.

Head quality parameters, including average head weight, head diameter, and stem diameter, directly affect marketability of broccoli as a bunched product. For a three-head bunch, average individual head diameter of 10.2 cm or less is needed to meet the maximum bunched head diameter of 20.3 cm previously described in the quality standards for Virginia (Sterrett et al., 1990, 1991). Only 'Sabre' met these criteria in 1997, although head diameter was less than 10.2 cm for several cultivars in 1998. The average individual head weight must exceed 272 g (0.6 lb) for a three-head bunched product since bunched broccoli is sold in 10.0-kg (22 lb) cartons containing 14 bunches. This criterion of head weight was met by 'Claudia', 'Laguna', and 'Liberty' in 1997, but only by 'Claudia' in 1998. Coarse stems with shortened internodes (increased number of leaf scars) continue to be a quality concern. Thickened stems with excessive leaf scars were noted for 'Liberty' and 'Majestic' in 1997; 'Captain', 'Claudia', 'Arcadia', 'Majestic', 'XPH12212', and 'Excelsior' in 1998. The stem diameter and number of leaf scars were lower for 'Everest' and 'Nomad' in 1998 (Table 1). Baggett et al. (1995) reported that broccoli with exerted heads (heads extended above canopy) tend to develop darker green color with less fiber present in a 15- to 16-cm (5.9–6.3 inches) cut head than a head of similar length from a short, compact cultivar. Sev-

Fig. 1. Yield of broccoli cultivars by season (early = first three harvests) in 1997 (top) and 1998 (bottom). The influence of environmental factors on head maturity is evident in the greater portion of yield harvested within the first three harvest dates in 1998. Harvest season of 'Windsor' is less predictable than other cultivars in this trial as yield shifted from only main-season in 1997 to mostly early yield in 1998. (1 t·ha⁻¹ = 0.446 ton/acre.)

Fig. 2. The 1997 fall growing season on the Eastern Shore of Virginia was cooler than that of 1998 as calculated as accumulated heat units: Sum of $\{[(\text{maximum daily air temperature} + \text{minimum temperature})/2] - 10^\circ\text{C}\}$. Date of planting was set as day 0.

Table 2. Broccoli cultivars grown on the Eastern Shore of Virginia in 1997 and 1998 separated into clusters by head quality parameters, including bead size, bead uniformity, color uniformity, head shape, and head tightness within season of head maturity.

Cultivar	Season ^z	Clusters within season ^y	Head quality				
			Bead size ^x	Bead uniformity ^x	Color uniformity ^x	Head shape ^x	Head tightness ^x
1997							
Everest	E	1	5.8	6.5	6.5	5.8	6.8
Major	E	1	5.0	5.8	5.3	4.8	4.0
Regal	E	1	4.0	5.8	6.5	5.8	6.8
Signal	E	1	5.0	6.3	5.8	6.8	5.3
Claudia	E	2	5.0	3.0	4.5	6.0	6.5
Captain	E	3	7.5	8.0	6.0	6.5	7.0
Laguna	M	2	6.5	5.3	6.0	8.0	8.3
Majestic	M	2	7.8	6.3	6.5	8.0	9.0
Decathlon	M	3	7.5	7.5	6.5	7.5	8.3
Excelsior	M	3	6.8	7.5	7.3	6.8	7.8
Liberty	M	---	8.5	7.8	6.5	7.5	9.0
Sabre	M	---	7.0	7.5	6.8	7.5	7.5
Windsor	M	3	7.8	7.5	6.8	7.5	7.8
XPH11211	M	---	9.0	8.0	6.5	7.3	8.0
Arcadia	M	1	5.5	6.0	6.8	6.0	7.8
Barbados	M	---	6.8	6.5	6.8	4.5	6.3
Waller/Duncan K=100 (<i>P</i> =0.05)	---	---	0.6	0.8	0.8	0.8	0.5
1998							
Captain	E	1	5.3	6.5	7.0	7.5	8.0
Claudia	E	1	6.8	7.0	7.0	5.5	8.0
Windsor	E	1	5.0	5.3	7.3	7.0	6.3
Everest	E	2	3.8	7.0	5.5	5.0	4.0
Major	E	2	4.8	4.0	4.0	5.3	6.5
Regal	E	2	2.5	6.5	6.5	5.0	6.5
Signal	E	3	3.0	3.3	6.0	3.5	3.0
Decathlon	M	1	7.5	7.3	7.0	7.3	6.5
Excelsior	M	1	7.5	7.0	6.8	7.3	7.3
Laguna	M	1	7.8	7.3	6.3	8.0	6.5
Nomad	M	2	7.5	7.8	6.8	8.3	7.8
Sussex	M	2	8.0	7.5	6.3	9.0	8.3
Arcadia	M	3	6.8	6.3	7.3	8.8	8.0
Majestic	M	3	7.0	6.3	6.5	8.3	8.0
XPH12212	M	3	7.3	6.5	5.8	8.0	7.8
Waller/Duncan K=100 (<i>P</i> =0.05)	---	---	0.7	0.8	0.6	0.7	0.6

^zMarketable maturity: E = early; M = main-season.

^yCluster analyses were run within year and maturity group on cultivars not discarded for poor yield or other factors.

^xRating scale: 9 = ideal; 1 = not acceptable.

eral cultivars in these trials produced attractive heads, but the lack of adequate head exertion may preclude sales of a bunched product from this growing area. Broccoli production in eastern Virginia may be more suited to crown-cut broccoli. Jett et al. (1995) have suggested that production of high quality single-head or crown-cut broccoli is more feasible than bunched broccoli for other regions of Virginia. The percentage of marketable heads for 'Liberty' and 'Sabre' was less than 30% in 1997 because of their late maturity (Table 1). Numerous plants of these two cultivars were blind (produced

no visible heads). Head maturity of 'Decathlon' and 'Arcadia' may also be too late for this growing area as nearly 50% of the plants failed to produce marketable heads under the cooler growing conditions of 1997.

Prior to performing cluster analyses of the quality attributes, cultivars were separated into early and main-season maturity groups within years (Table 2). Those with low yields or poor quality in 1997 were excluded from the cluster analyses since they were deemed not adapted for this growing area. While the decision regarding the number of defined clusters is subjective,

we chose to use the squared multiple correlation coefficient (R^2) to determine when to ignore further clustering. Three clusters were chosen for each maturity group within each year. Yield was not included in the cluster analyses as the variation in yield overwhelmed the magnitude of variation of all other attributes.

As seen in Table 2, within the 1997 early-maturing cultivars, 'Captain' did not cluster with any other cultivars, reflecting high ratings for bead size, bead uniformity, head shape, and head tightness. Similarly, 'Claudia' did not cluster with any other cultivars because

of lower ratings of bead uniformity and color uniformity. 'Everest', 'Major', 'Regal', and 'Signal' all clustered together in 1997. Therefore, based on head quality, 'Captain' was the best and 'Claudia' the poorest among early-maturing cultivars in 1997.

'Signal' did not cluster with any other early-maturing cultivars in 1998 because of low ratings for bead uniformity, head shape and head tightness. 'Everest', 'Major', and 'Regal' clustered together and were rated lower than 'Captain', 'Claudia', and 'Windsor' in three or four of the five quality attributes. From these analyses we conclude that among the early-season cultivars, 'Captain' is more likely to consistently produce quality marketable heads than 'Everest', 'Major', 'Regal', or 'Signal'. Head quality of 'Claudia' was inconsistent between years and head maturity of 'Windsor' may be appreciably delayed in cooler years. Additional research on the influence of multiple planting dates on yield and quality of 'Captain' is warranted.

Of the 1997 main-season cultivars, 'Laguna' and 'Majestic' clustered together and were characterized by poor bead uniformity but good head shape and tightness. 'Arcadia' did not cluster with any other cultivars and was characterized by poor bead size and uniformity and less desirable head shape and tightness than 'Laguna' and 'Majestic'. 'Decathlon', 'Excelsior', and 'Windsor' had good head quality characteristics in 1997. Within the 1998 main-season crop, 'Arcadia', 'Majestic', and 'XPH12212' clustered together and were characterized by poorer bead size and uniformity but better head shape and tightness than 'Decathlon', 'Excelsior', and 'Laguna'. 'Nomad' and 'Sussex' had good head quality characteristics in 1998. Quality attributes of 'Excelsior' and 'Decathlon' were consistent from 1997 to 1998. Unfortunately, the yield poten-

tials of 'Decathlon' and 'Excelsior' are not exceptional. Both 'Arcadia' and 'Majestic' varied within specific quality attributes from 1997 to 1998, but not necessarily in the same direction. These cultivars appear to be too sensitive to environmental conditions during the growing season to warrant inclusion in recommendations for commercial production. Additional evaluation of 'Nomad' and 'Sussex' would be needed prior to recommendations for more than small-scale or "trial" commercial plantings.

Conclusions

After the first year of testing, 'Liberty', 'Sabre', 'Barbados', and 'XPH11211' were discarded from further evaluation because of low yields, poor head quality, or lack of available seed. Among the early-maturing cultivars, quality characteristics of 'Captain' were moderately high in both years with reasonable marketable yield. After 2 years of testing, no one main-season cultivar emerged as superior for all characteristics on the Eastern Shore of Virginia. However, several cultivars could be identified that should not be planted. 'Claudia' and 'Majestic' had large stem diameter and inconsistent performance. 'Windsor' was inconsistent in maturity. 'Arcadia' among the main-season cultivars was late, with consistently lower scores for bead size and uniformity than other main-season cultivars.

Literature cited

Baggett, J.R., D. Kean, and K. Kasimor. 1995. Inheritance of internode length and its relation to head exertion and head size in broccoli. *J. Amer. Soc. Hort. Sci.* 120:292-296.

Canaday, C.H. 1992. Effects of nitrogen fertilization on bacterial soft rot in two broccoli cultivars, one resistant and one susceptible to the disease. *Plant Dis.* 76:989-991.

Jett, L.W., R.D. Morse, and C.R. O'Dell. 1995. Plant density effects on single-head broccoli production. *HortScience* 30:50-52.

Kalo, A.A. 1998. Analyzing the economic and environmental impacts of agricultural alternatives—The case of Virginia's Eastern Shore. MS Thesis, Virginia Tech, Blacksburg.

O'Dell, C.R., R. Morse, and P. Ramsey. 1993. Field seeded fall bunching broccoli production; a guide for Virginia farmers. Virginia Coop. Ext. Serv. Publ. 438-011.

Romesburg, H.C. 1990. Cluster analysis for researchers. Robert E. Krieger Publ. Co., Malabar, Fla.

SAS/STAT. 1999. Ver. 8. SAS Inst., Cary, N.C.

Sterrett, S.B., J.W. Mapp, Jr., and C.W. Coale. 1990. Feasibility of broccoli as a new enterprise—A systems approach. *HortScience* 25:638-641. [Corrigenda 25:1202.]

Sterrett, S.B., C.W. Coale, Jr., and C.P. Savage, Jr. 1991. Comparison of management techniques for broccoli production using a systems approach. *HortScience* 26:599-602.

Sterrett, S.B., S.D. Thornsby, C.W. Coale, Jr., D.B. Taylor, S.G. Sturt, and J.W. Mapp. 1996. The process for evaluating agricultural alternatives: An Eastern Shore Virginia example. Virginia Coop. Ext. Publ. 448-220/REAP R022.

U.S. Department of Agriculture 2003. Vegetables 2002 summary—Vegetables and melons outlook. VGS-296. U.S. Dept. Agr., Econ. Res. Serv., Washington, D.C. 17 Apr. 2003. <<http://www.ers.usda.gov/publications/vgs/tables/precap.pdf>>.

U.S. Department of Agriculture. 1943. United States standards for grades of bunched italian sprouting broccoli. U.S. Dept. Agr. Mktg. Serv., Washington, D.C.