Heat Tolerance and Holding Ability in Broccoli

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Abstract. Forty hybrid broccoli [*Brassica oleracea* L. (Italica Group)] accessions were screened for heat tolerance and holding ability over three planting dates in 1988 at the Long Island Horticultural Research Laboratory in Riverhead, N.Y. Holding periods were quantified using the number of consecutive days between the time individual heads reached 10 cm diameter and cutting, which occurred when the sepals had fully expanded and had just begun to separate. In 1989 and 1991, heat stress was applied at various weeks during maturation to determine the most sensitive stage or stages of plant development in terms of reduction in holding period and head weight. Field studies and heat stress experiments indicate that heat stress may be most critical during the time the immature inflorescence measures 5 to 10 mm in diameter. This stage corresponds to ≈ 3 weeks before harvest for summer plantings in the northeastern United States.

Broccoli production and consumption in the United States has risen dramatically over the past several decades. Land in production has tripled over the past 30 years with a remarkable 160% rise in consumption in 1983 alone (Love, 1986). While 90% to 95% of the total production remains in California, increased demand has resulted in an expansion of production into such areas as Mexico, Texas and to a lesser extent, parts of the northeastern United States. With increased interest in producing broccoli during the hot summer months, the need for cultivars with consistently good heat tolerance and holding ability is great.

The effect of low temperature on premature flowering of broccoli has been well documented (Fontes et al., 1967; Gauss and Taylor, 1969; Miller et al., 1985), but less is known about the hastening of flowering by high temperature during maturation. Fontes et al. (1967) reported that floral initiation does not occur at temperatures >24 C. This result refers, however, to a continuous temperature threshold and not to the mean of a diurnal pattern as occurs in the field. Further, the broccoli shoot tip temperature is higher than surrounding air temperatures during the day and lower than air temperatures at night (Fujime and Hirose, 1984).

The shoot apex exhibits increased sensitivity to floral induction temperatures during the postjuvenile stage of broccoli development (Fontes et al., 1967; Miller et al., 1985). Even without low temperatures during the early postjuvenile growth stage, high temperatures during the onset of heading may have a significant impact on the concentration and duration of harvest. Variety trials from Canada to Australia have consistently shown significant effects of sowing time on the harvest concentration and environmental stability of yield (Chung, 1985; Knott and Hanna, 1949; Shattuck et al., 1986; Sieczka et al., 1989). Three typical physiological symptoms of heat stress in broccoli are the

rapid swelling or puffing of sepals, irregular separation of individual florettes on the head, and the protrusion of upper leaves through the head.

Despite advances made through breeding, heat tolerant cultivars often perform quite differently when grown in diverse locations. One objective of this study was to screen 40 hybrid broccoli accessions for heat tolerance and holding ability under Long Island conditions over three planting dates in 1988. The top eight entries were again tested over the same three planting dates in 1989. Harvest concentration was assessed to provide a more useful selection criterion than simply holding period alone. Controlled environment studies were also done to better understand what stages of growth and development are most susceptible to heat stress.

Materials and Methods

Field trials. In 1988, 14 commercial and 26 experimental hybrid broccoli accessions were obtained for field evaluations at the Long Island Horticultural Research Laboratory in Riverhead. Most of the experimental entries were bred specifically for heat tolerance and holding ability. The top eight selections were advanced to 1989 experiments for further evaluation using

Fig. 1. Contrasting harvest concentration for two hybrid broccoli entries of the same maturity. The bottom of the bars indicates tagging of individual heads when they had reached 10 cm diameter; the top of the bars indicates cutting at earliest observed sepal separation. Data are the mean holding days through time of four replications in the second planting of 1988.

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the same screening criteria as in 1988. Selection was based primarily on length and uniformity of the holding period, but was also based on head weight and marketable appearance.

Three plantings were sown in a Riverhead sandy loam (coarse-loamy, mixed, mesic Typic Dystrachrepts) on 9 May, 30 May, and 13 June in 1988 and 1989. The experiments were arranged in a randomized complete block with four replications. The experimental unit consisted of one row per entry and guard rows surrounded the perimeter of each block. All plantings were direct seeded in rows 6 m long with a cone seeder in 1988 and with a precision belt seeder in 1989. Plants were hand-thinned to 30 cm apart in the row after 3 weeks. The between-row spacing was 86 cm and data were collected from the center 3 m of each row. The wide spacing between plants was done to minimize plant-to-plant interaction and to allow full expansion

of the heads, thereby providing a better assessment of true holding potential for each genotype. Plots had been limed before plowing, and fertilizer was broadcast after plowing and incorporated with a springtooth harrow. Fertilizer was applied at the rate of 112N-98P-93K kg-ha⁻¹ with an additional 56 kg of N/ha sidedressed when plants were ≈ 15 cm tall. Nitrogen was applied as Ca(NO₃)₂. The fertilizer mixture also included 3 kg B and 56 kg Mg/ha. Rainfall was supplemented with overhead irrigation to total 25 mm of water per week in both seasons. High and low temperatures and precipitation were recorded daily from first seeding to final harvest.

Individual heads were tagged when they reached 10 cm in diameter and were cut when sepals first began to separate. The holding period of each entry was calculated as days from tagging to harvest. Heads were cut at a length of 20 cm from the top of the dome to the cut stem end and head weights and diameters were recorded. Harvest concentration is a measure of both the duration of the holding period and the uniformity with which a population of plants matures. Harvest concentration was estimated (Fig. 1) by plotting the mean holding periods of individual heads as they matured through time. By running horizontal lines across the graph from each holding period day, the average number of days that a particular entry may be cut at any given percentage was calculated based on each of the 10 heads being equivalent to 10% of the total.

Shade house/greenhouse experiment. In an experiment conducted in 1989, we attempted to determine what stage or stages of plant development are most critically affected by heat stress. This was measured in terms of reduction in the holding period and head weight as calculated in previous field experiments. The hybrid XPH 5168 was selected for this experiment based on its high degree of uniformity and excellent harvest concentration as determined from previous field and greenhouse plantings (unpublished).

Seeds were sown on 9 May in 36-cell flats with individual cell volume being 118 cm³ using a 1 peat : 1 vermiculite mixture. After 3 weeks, seedlings were transplanted into eighty-four 6-liter plastic pots filled with the same mix. Once potted, all plants received weekly fertilization with a complete soluble fertilizer (15N-16P-17K plus micronutrients) at the rate of 5

Table 1. Average temperatures^a and total precipitation for broccoli sown over three planting dates^b in 1988 and 1989, Riverhead, N.Y.

Date	Air temperature (°C)						Precipitation (mm)	
	High		Low		Mean		1988	1989
	1988	1989	1988	1989	1988	1989		
9 May	19	19	8	7	13	13	3	67
16 May	20	25	12	11	16	18	40	47
23 May	26	25	12	12	19	18	19	37
30 May	25	27	12	16	18	21	13	14
6 June	24	25	14	15	19	20	1	78
13 June	31	25	18	15	24	20	8	60
20 June	29	29	17	18	23	23	18	1
27 June	26	29	13	17	19	23	0	3
4 July	31	29	17	20	24	24	0	67
11 July	33	27	21	17	27	22	0	67
18 July	34	28	21	18	27	23	87	5
25 July	34	30	21	19	27	24	14	1
25 July	34	30	22	19	27	24	0	4
8 Aug.	33	26	23	18	28	22	0	196
15 Aug.	29	28	18	20	23	24	3	1
22 Aug.	27	27	17	17	22	22	22	0
29 Aug.	26	27	16	18	21	22	17	45

^aAverage temperatures for each week beginning on the date listed.

^bPlanting dates: 9 May, 30 May, and 13 June in 1988 and 1989.

Table 2. Average head weight, head diameter, and holding period for eight hybrid broccoli entries over three planting dates in 1988 and 1989, Riverhead, N.Y.

Entry	Planting dates															
	9 May						30 May						13 June			
	Head wt		Head diam		Holding period ^a		Head wt		Head diam		Holding period		Head wt		Head diam	
	(g)		(cm)		(days)		(g)		(cm)		(days)		(g)		(cm)	
	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989	1988	1989
Symphony	498	525	17	17	5.5	4.4	384	475	15	17	3.2	3.6	292	356	13	15
XPH 5168	412	431	15	16	3.9	2.9	386	399	15	15	2.9	2.8	230	309	12	13
Excaliber	410	517	14	15	5.6	3.5	291	342	11	13	1.9	2.6	293	277	11	11
NVH 521	651	673	20	20	6.8	3.8	522	580	18	18	4.4	3.5	734	368	22	15
Green																
Valiant	420	544	15	16	4.5	3.3	307	395	14	15	2.4	2.5	288	294	14	14
Packman	453	559	16	17	4.1	4.2	422	455	16	16	3.7	3.4	269	318	13	14
Sakata #19	404	532	13	14	3.2	3.4	407	411	14	14	3.5	2.7	308	281	13	12
Sultan	489	486	15	15	5.9	3.5	419	332	14	13	5.2	3.3	337	344	13	13
Waller-Duncan																
LSD (5%)	67	82	2.6	1.7	1.3	0.5	89	61	2.3	1.9	1.2	0.4	74	70	2.7	2.1

^aHolding period measured in consecutive days from tagging heads at 10 cm diameter to harvest at earliest observed sepal separation. Holding data not recorded for planting date 13 June.

g-liter⁻¹. An additional application of calcium nitrate (19% water soluble Ca) at the rate of 5.3 g-liter⁻¹ after 9 weeks from seeding was given to prevent apical necrosis. Standard pest control practices were used.

Based on preliminary field and greenhouse observations, we determined that the heads of hybrid XPH 5168 matured during the 11th week from seeding. Fourteen treatments, including the control, were used in a completely randomized design with six replications. The treatments consisted of 1, 2, 4, and 6 week exposures to heat stress applied during the final 6 weeks of postjuvenile development. All plants were grown in a greenhouse with air at 25 to 27C/20 to 22C (day/night) cycle for the first 5 weeks to prevent premature flowering. At the onset of the 6th week, heat stress treatments were applied during various weeks until maturity by moving plants to a hot greenhouse. After each specified heat stress treatment was completed, plants were returned to the cool house. Control plants were grown continuously in the cool house.

Average air temperatures in the cooled shade house were 23 ± 1.9C day and 19 ± 2.4C night. Overhead irrigation was used when needed to maintain the temperature at ≈ 23C. The hot greenhouse was covered with translucent plastic and a 20% shade cloth was erected over the plants to equalize light levels with those in the cool house. Both houses had nearly identical amounts of natural solar radiation averaging 650 ± 32 μmol·m⁻²·s⁻¹ as read by a quantum sensor mounted on a model LI-1600 porometer (LI-COR, Lincoln, Neb.). Average temperatures in the hot greenhouse were 35 ± 1.3C day and 23 ± 0.9C night. Plants were watered frequently to avoid drying of the soil in the hot greenhouse.

Data collection for holding period was the same as for field experiments, except that individual heads were tagged when they reached 5 cm diameter to compensate for the reduction in head size due to container culture. Heads were cut to a length of 20 cm at the earliest observed sepal separation. Control plants reached this fully mature stage by the end of the 11th week from seeding. The heads were then weighed and measured. Any unusual heat stress disorders were also recorded.

Growth chamber experiment. To verify the previous results and eliminate possible confounding effects that overhead irrigation for cooling may have had on holding period due to alterations in transpirational loss and shoot apex temperature, the experiment was repeated in 1991 using only 1-week heat stress treatments and identical growth chambers for the hot and cool

environments. Seeds of XPH 5168 from the 1989 seed lot kept under optimum storage conditions were planted and grown for the first 5 weeks as described above. Nine treatments, including the control, were used in a completely randomized design with six replications. An extra treatment was added due to maturation occurring 1 week later than was reported in the previous experiment. The air temperature in the hot chamber was 35/23C (day/night), while the cool chamber was kept at 23/19C (day/night). Daylength was maintained at 14 h during the first 5 weeks from seeding and increased to 16 h during the final 6 weeks of maturation to closely follow the natural photoperiod during the first experiment. Light levels were 162 and 169 μmol·m⁻²·s⁻¹ in the cool and hot chambers, respectively. All treatments were watered daily with equal volumes of water and data were collected as described above.

Statistical analysis. Data from all experiments were subjected to a standard analysis of variance (ANOVA). Treatment means were separated with the Waller-Duncan k-ratio *t* test at the 0.05 significance level. Quadratic P values were generated using the general linear models (GLM) procedure of SAS (1982).

Results

Field trials. During the summer of 1988, field temperatures were very high from July through early August (Table 1). Although all three plantings experienced heat stress, the timing and duration of the heat varied for each planting date. Highs ran in the 20 to 30C range during vegetative and early reproductive growth of the first planting followed by temperatures > 32C during the final weeks of maturation. The second planting was exposed to highs >31C between the 6th and 10th weeks from seeding, and mean highs fell back <30C only after the 9th week from seeding in the third planting (Table 1).

In 1988, mean holding period ranged from 3.2 to 6.8 days for the top eight entries in the first planting with four of the entries having mean holding periods of 5.5 days or longer (Table 2). However, mean holding in the second planting ranged from 1.9 to 5.2 days. The hybrid NVH 521 had significantly heavier heads than the other seven entries in all three planting dates and a significantly larger head diameter in the first and third plantings. This hybrid matured late into September in the third planting, thereby escaping the bulk of the heat stress. Some of the fluctuations in average head weight can be attributed to changes in final mean head diameter (Table 2). However, lower holding

Table 3. Mean number of days allowing 70%, 80%, 90%, and 100% field harvest in a single cut and harvest duration for 1988 and 1989.”

Entry	Harvest concn potential (%)								Harvest duration [†]	
	70		80		90		100			
	Mean number of days allowing each percent harvest									
	1988	1989	1988	1989	1988	1989	1988	1989		
Symphony	3.9	2.6	2.1	1.6	1.6	0.6	0.2	0.1	8.7	11.4
XPH 5168	3.1	0.3	2.4	0.0	2.4	0.0	1.7	0.0	7.4	13.8
Excalber	2.6	1.1	1.9	0.9	1.4	0.6	1.0	0.1	9.7	11.7
NVH 521	7.4	1.2	5.3	0.6	3.3	0.2	2.6	0.0	12.7	13.5
Green Valiant	3.3	1.4	2.6	0.7	0.1	0.5	0.0	0.0	8.5	11.4
Packman	3.7	1.3	3.0	0.3	2.0	0.0	2.0	0.0	7.0	13.7
Sakata #19	2.1	0.7	2.1	0.2	0.7	0.0	0.7	0.0	7.4	15.7
Sultan	4.6	0.4	4.6	0.0	1.5	0.0	1.5	0.0	11.9	15.6
Waller-Duncan										
LSD (5%)	1.6	0.9	1.2	0.7	0.8	NS	0.7	NS	3.2	2.1

[†]Based on the first two planting dates, 9 May and 30 May, for each year.

[‡]Harvest duration is the total number of days from first to last cut.

Table 4. Mean holding, head diameter, and weight and general appearance of hybrid broccoli XPH 5168 after postjuvenile heat stress treatments in 1989.

Heat stress, duration, and weeks applied ^a	Holding ^b period (days)	Head diam (cm)	Head wt (g)	Appearance of heads
None	7.2	13.5	160	Marketable quality
1 week				
6 ^c	7.7	13.3	141	Marketable quality
7	4.3	8.5	101	Irregular/loose
8 ^c	2.0	6.8	97	Small/puffy bud
9	5.0	9.8	118	Flat/long stalks
10	5.5	11.0	125	Slight puffy bud
11 ^c	6.5	11.0	132	Marketable quality
2 weeks				
6-7	3.8	8.0	101	Irregular
8-9	1.5	6.3	96	Small/puffy bud
10-11	4.5	9.5	103	Midhead flat
4 weeks				
6-9	2.0	6.8	90	Loose/leafyhead
7-10	1.5	6.2	84	Loose/leafyhead
8-11	1.2	5.5	86	Small/irregular
6 weeks				
6-11	0.5	4.8	81	Very small/loose
Waller-Duncan LSD (5%)	0.9	1.4	18	

^aWeeks after seeding when exposed to 35C daily highs in greenhouse.

^bHolding period measured in mean consecutive days from tagging heads at 5 cm diameter to cutting at earliest observed sepal separation.

^cVegetative plant growth at 6th week from seeding. Early reproductive development at 8th week, with immature head measuring 5 to 10 mm in diameter. Final week of maturation of inflorescence during 11th week.

values were not consistently correlated with smaller head diameters.

For the 32 entries that were not advanced for testing in the second season, average head weight at harvest ranged from 183 to 415 g, average head diameter ranged from 5 to 16 cm, and mean holding periods ranged from 0.4 to 3.1 days. For these entries, there was no general trend for hybrids bred for heat tolerance to perform better than commercial cultivars. In fact, the worst entry with mean head diameter of 7 cm and mean holding of only 0.4 days in the second planting was an experimental hybrid bred for heat tolerance. Two cultivars in the top eight of 1988 not bred specifically for heat tolerance, 'Green Valiant' and 'Packman', performed similarly compared to the six experimental hybrids (Table 2). The hybrids 'Symphony', 'Excaliber', and 'Sultan' were released as cultivars during the course of this research. Experimental hybrids XPH 5168, NW-I 521, and Sakata #19 were discontinued.

In 1989, frequent heavy rains became the critical environmental stress factor rather than heat. Although stand and plant populations were constant in both years, flooding decreased plant biomass and vigor in the lowest areas of the field in 1989. Mean highs did not rise >30C during 1989 (Table 1). Mean holding ranged from 2.9 to 4.4 days in the first planting and only from 2.5 to 3.6 days in the second planting (Table 2). The hybrid NVH 521 again had significantly heavier heads than the other seven entries in the first two plantings, but was not significantly different from 'Symphony', XPH 5168, 'Packman', or 'Sultan' in the third planting. The dramatic decrease in head weight for

Fig. 2. Growth response measured in (A) mean holding period (days), (B) average head diameter at harvest (centimeters), and (C) mean head weight (grams) following exposure of hybrid broccoli XPH 5168 to 1 week of heat stress at 35C. Data from both years show a highly significant ($P \leq 0.001$) quadratic fit.

NVH 521 in the third planting was most likely attributable to extensive flooding.

Harvest concentration of NVH 521 was 3 days to cut 100% and 4 days to cut at least 80% of the heads, while that of the more erratic maturing line, Sunre 8023, was only 2 days to cut 50% (Fig. 1). Pooled data from the first two planting dates in 1988 indicate that average harvest concentration values ranging from 2 to 5 days to cut 80% of the total were possible for the top eight entries (Table 3). The high degree of heat stress during 1988 resulted in significant differences in harvest concentration between entries (Table 3). There was less harvest uniformity in 1989 than in 1988. 'Symphony' was the only exception to this general trend, maintaining moderately good harvest concentration and holding values throughout the season. No significant differences were found between the eight entries in 1989 for 90% and 100% harvest concentration potential (Table 3).

Fig. 3. Hybrid broccoli XPH 5168 heads at harvest 11 weeks from seeding. Treatments shown photographed at the same distance from the tip of the heads are: (A) continuous cool conditions; 13 cm diameter with mature, uniform buds. (B) single week of heat stress during the final week of maturation; 11 cm diameter with mature, uniform buds. (C) single week of heat stress at 3 weeks before harvest; 7 cm diameter with immature and sporadic puffy buds, and (D) continuous heat stress, 4 cm diameter with only immature buds.

Shade house/greenhouse experiment. For the 1-week treatments in the 1989 experiment, mean holding period was lowest following exposure to heat stress during the 8th week from seeding (Table 4), when the immature head measured 5 to 10 mm in diameter. Average head diameter was also lowest after the 8th week treatment, while mean head weight was not sig-

nificantly different for the 7th and 8th week treatments. Although the 6th and 11th week treatments resulted in market quality heads, the mean head weight for these treatments was significantly lower than the control grown without heat stress (Table 4). The data for 1-week treatments indicate a highly significant ($P \leq 0.001$) quadratic relationship (Fig. 2).

Table 5. Mean holding, head diameter, and weight and general appearance of hybrid broccoli XPH 5168 after postjuvenile heat stress treatments in 1991.

Weeks heat stress applied ^a	Holding ^b period (days)	Head diam (cm)	Head wt (g)	Appearance of heads
None	6.7	10.2	122	Marketable quality
6 ^c	6.5	9.8	105	Marketable quality
7	6.5	8.9	101	Slightly irregular
8	5.6	7.0	98	Irregular/loose
9 ^x	3.9	6.5	86	Small/puffy buds
10	4.2	6.9	96	Irregular/puffy
11	5.9	9.1	103	Marginal quality
12 ^x	6.1	9.8	119	Marketable quality
6-1	0.3	4.2	78	Very small/loose
Waller-Duncan LSD (5%)	0.8	1.6	19	

^aWeeks after seeding exposed to 35C daily high temperatures.

^bHolding period measured in mean consecutive days from tagging heads at 5 cm diameter to cutting at earliest observed sepal separation.

^cVegetative plant growth at 6th week from seeding. Early reproductive development at 9th week, with immature head measuring 5 to 10 mm in diameter. Final week of maturation of inflorescence during 12th week.

For the 2-week treatments, mean holding period and head diameter were lowest following exposure to heat stress during weeks eight through nine (Table 4), while mean head weights were similar for all three 2-week treatments. Mean holding period, head diameter, and weight were similar for the three 4-week treatments. These values were also similar to the eighth 1-week and weeks eight through nine for the 2-week treatment values (Table 4). Mean holding was the lowest for the final 4- and 6-week treatments. All 2-, 4-, and 6-week treatments resulted in small heads of very poor quality. Increased growth of vegetative axillary shoots was also observed in many of the prolonged heat treatments. Mature heads from four of the treatments were photographed at the same distance from each head (Fig. 3).

Growth chamber experiment. When the experiment from the greenhouse in 1989 was repeated in 1991, but in a growth chamber, significant differences were observed for holding period, head diameter, and weight (Table 5). While a quadratic fit similar to the 1989 data was noted (Fig. 2), mean holding was not significantly different for the 9th and 10th week treatments (Table 5). The 6-week treatment resulted in the lowest mean holding and head diameter values, while mean head weight for the 6-week treatment was similar to that for the 9th and 10th week treatments. Heat stress during 8th week in 1989 resulted in

aberrant heads with puffy sepals identical in appearance to those in the 9th week treatment of the 1991 experiment.

Discussion

The data collected on cultivar screening for heat tolerance and holding ability combined with the results from the experiments relating heat tolerance to specific stages of growth and development suggest that both timing and duration of heat stress are important in determining the pattern of broccoli floral development.

Cultivar screening results over both years of this study indicate that some entries performed well under a wide range of temperatures and conditions (Table 1). Most of the forty entries tested, however, performed poorly during the high temperatures experienced in 1988. High air temperatures only during maturation in the first planting did not decrease holding ability as much as earlier or cumulative heat during the reproductive growth stages that occurred in the second planting. This trend was true for seven out of eight entries (Table 2). Cultivars such as 'Symphony' had a consistently strong performance over all three planting dates for both years in Riverhead. This hybrid, however, exhibited poor heat tolerance when grown in Geneva, N.Y., during the same years (Dickson, unpublished data). Upon inspection of Geneva weather records for 1988, it was noted that while daily high temperatures were only slightly higher than values recorded in Riverhead, the duration of the high temperatures was much longer in Geneva.

Perhaps as important as good holding ability is the potential for a cultivar to provide consistently good harvest concentration. Harvest concentration was particularly poor in the second planting of 1989, effectively reducing the mean values when pooled with those of the first planting (Table 2). Early heavy rains and low temperatures resulted in nonuniform seedling growth. During the 1988 season, timely irrigation and steady higher temperatures may have provided a greater degree of control over the growth rate. Somewhat heavier heads were produced in the 1989 season, while holding periods remained similar to or even lower than in 1988 (Table 1). A marked decrease in the incidence of hollow stem coupled with greater head turgidity in 1989 may have contributed to higher head weight. Since B levels were tested as adequate in both seasons, the tendency for hollow stem to occur in 1988 was probably due to rapid growth rate. This was confirmed by both harvest date and harvest duration (Table 3).

The greatest disruption in normal growth and development of broccoli by heat stress appears to occur ≈ 3 weeks before harvest. This may vary, depending on the maturity date of the cultivar and the growth rate. The head measures ≈ 5 to 10 mm in diameter at this stage as confirmed by field observations and greenhouse data (Tables 4 and 5). Mature heads from the treatments receiving heat stress either during the 6th week or during the final week of head maturation exhibited uniform bud maturation similar to heads matured under constant cool temperatures (Fig. 3). However, mean head weights for these treatments were lower than those grown under constant cool conditions (Tables 4 and 5).

The occurrence of a small group of puffy or enlarged sepals on an otherwise immature head marked the typical growth abnormality observed when heat stress was applied during the 5

to 10 mm head diameter stage in both years tested (Fig. 3C). Disruption of time periods bracketing the 5 to 10 mm diameter stage with heat stress typically resulted in uneven florette length, causing loose or irregularly shaped heads. Both of these symptoms were observed for many of the 40 hybrids tested in the field during 1988, as well as other variations including extremely elongated sepals occurring throughout the entire head. Different hybrids may respond quite differently to heat stress. Many of the experimental hybrids bred specifically for heat tolerance performed poorly during the 1988 season in Riverhead. We emphasize that data from these heat stress experiments represent the effects on one hybrid, XPH 5168. Likewise, the results of the cultivar screening presented here are indicative of testing in only one location over 2 years.

While high ambient light levels may have contributed to larger and heavier heads in the 1989 heat stress study, the overall trend in holding period, head diameter, and weight reductions remained the same in the 1991 experiment (Fig. 2). Statistically significant differences were detected for all three categories in both years. However, a greater range of values was recorded in 1989. A major difference in the 1991 experiment was a 1-week delay in maturity, which may be attributable to the lower light levels in the growth chambers. Our data provide good evidence that heat stress during the 5 to 10 mm head diameter stage is especially likely to result in reductions in holding and head weight. Whether or not timely overhead irrigation applied during this critical growth stage at peak hours of daytime heat would alleviate some of the problems associated with heat stress in the field remains to be tested. Other potential methods to reduce the problems of heat stress include cultivar selection and planting dates that minimize the amount of heat during the critical stage of growth or simply avoidance of heat entirely.

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