Table 3. Yield per plant of sweet peppers grown under 5 light treatments during the summer of 1977.

Treatment	Yield (kg)[z] Marketable[y]	Cull	Total[x]
Reflector	1.43*	.34	1.77*
Mulch	1.87**	.25	2.12**
Reflector + mulch	1.99**[w]	.34	2.33**[w]
Black screen	1.19**	.27	1.46**
Check	1.20	.28	1.48

*,**Significant at the 5%, and 1% levels, respectively, by orthogonal comparisons.
[z]Each value is the mean of 48 plants.
[y]Includes U.S. Fancy, No. 1, and No. 2 fruit grades.
[x]Includes marketable and cull fruit grades.
[w]Significance at the 1% level assigned to a mulch effect; reflector effect significant at the 5% level.

fected by any treatment.

The difference in plant response between white and black structures suggests that solar reflectors may affect growth due to an increased availability of solar energy (heat and/or light) rather than as a windbreak. We conclude that the effect of solar reflectors on plant growth and yield was negligible, but reflective mulches beneficially affected earliness and yield. We could not determine whether the effect of reflective mulches was due primarily to a solar energy enhancement (heat and/or light), to soil moisture conservation, or to other microclimatic factors. At no time did reflectors in combination with mulches significantly interact synergistically upon any variable sampled.

Literature Cited

1. Anon. 1963. United States standards for grades of sweet peppers. U.S. Dept. Agr., Washington, D.C.
2. Bensin, B.M. 1955. The prospects for various uses for solar reflectors as a means of environmental control of microclimate in agriculture. Trans. Conf. on the Use of Solar Energy, Tucson, Ariz. Sect. A 2(1):119–137.
3. Bonner, J. 1962. The upper limit of crop yield. Science 137:11–15.
4. Gerald, C.J. and G. Chambers. 1967. Effect of reflective coatings on soil temperatures, soil moisture, and the establishment of fall bell peppers. Agron. J. 59:293–296.
5. Pendleton, J.W., D.B. Egli, and D.B. Peters. 1967. Response of *Zea mays* L. to a "light-rich" field environment. Agron. J. 59:395–397.
6. Pendleton, J.W., D.B. Peters, and J.W. Peek. 1966. Role of reflected light in the corn ecosystem. Agron. J. 58:73–74.
7. Schandrel, H. and N. Weger. 1940. Studien über das Mikroklima vor verschiendenfarbigen Mauerflächen und der Einfluss auf Wachstun und Ertag der Tomaten. Biobl. B. 7:134–142.
8. Snedecor, G.W. and W.G. Cochran. 1976. Statistical methods. Iowa State Univ. Press, Ames.
9. Sondern, J.A. 1962. Soil covering with white plastic film. Meded. Dir. Tuinb. 25:175–180.

HortScience 16(1):67–68. 1981

Effect of High Temperature on Pollen Grain Germination, Pollen Tube Growth, and Seed Yield of Chinese Cabbage[1]

C.G. Kuo, J.S. Peng, and J.S. Tsay
Asian Vegetable Research and Development Center, P.O. Box 42, Shanhua 741, Taiwan

Additional index words. Brassica campestris ssp. *pekinensis,* gamete viability, seed formation, silique set

Abstract. **Seed yield of Chinese cabbage (*Brassica campestris* ssp. *pekinensis* Rupr.) was studied at 34–37/22–24°C (day/night) temperatures applied at different growth stages. High temperatures at first anthesis and immediately after pollination diminished seed yield mainly through reduction in seed number. Hand pollination with pollen grains from plants reared under normal temperature improved seed yield of the plant heated at first anthesis. Both male and female gametogeneses appeared to be affected by high temperature based on seed set, but the most drastic effect of high temperature on seed yield occurred after pollination. *In vitro* pollen viability tests indicated that the optimum temperature for pollen grain germination and pollen tube growth was 20°. Temperatures below 16° or above 28° reduced pollen grain germination and pollen tube growth mainly because of an increase in burst pollen grains.**

Heading Chinese cabbage is a cool season vegetable that is becoming popular in hot, humid Southeast Asia because of the availability of heat tolerant cultivars. However, the seed supply usually depends on importation from temperate regions. This vegetable can be induced to flower easily by artificial vernalization at the seedling stage (1). Information relating high temperature stress to Chinese cabbage seed yields is limited, and few investigations have been made of the mechanisms involved in high temperature stress. A primary objective of this study was to determine the effect of high temperature at different growth stages on seed yield and its components such as silique set, seed number per silique, and average seed weight. *In vitro* pollen grain germination and pollen tube growth under different temperature conditions were also studied.

Seeds of AVRDC Acc. No. B-32 ('Chang-puh Medium Early') were sown in seed flats. After the cotyledons fully expanded, the seedlings were chilled in a cold room at 5°C with dim light for 20 days. Five days after the completion of vernalization, the seedlings were transplanted into clay pots (ID 20 cm, height 30 cm) which contained a mixture of 70% soil, 15% compost, and 15% sand, and to which 1.8 g $(NH_4)_2SO_4$, 5.6 g $Ca(H_2PO_4)_2$, and 3.3 g KCl per pot had been added. Plants were grown in a greenhouse with average maximum and minimum temperatures of 29 and 18°, respectively. Vernalized plants were transferred into a heated compartment (temperatures maintained at 34–37/22–24°, day/night) of the greenhouse at different growth stages for 3 days at a time. Plants were exposed to high temperatures at the following stages: bolting, macroscopic appearance of flower bud, first anthesis, and immediately after pollination. Control plants were not subjected to high temperatures. When the flower buds started to open, they were immediately hand-pollinated with 2 types of pollen grains. The first pollination was carried out with bulked pollen grains of all plants in the same heat treatment, whereas the second pollination was with pollen grains from the non-heated control plants. Plants of each treatment were thinned to maintain only the main flower stalk and were decapitated when they had 12–15 flowers per stalk. Silique number, seed number per silique, 100-seed weight, and seed yield per plant were determined at 80 days after planting. There was a total of 8 treatments, each with 8 plants.

Another experiment was carried out to study the optimum temperature for *in vitro* pollen grain germination and pollen tube growth. Fresh pollen grains were taken from plants grown under normal temperature in the greenhouse and incubated in a medium consisting of 20% sucrose, 50 ppm H_3PO_3 and 100 ppm

[1]Received for publication July 19, 1980.
Journal paper no. 60 of the Asian Vegetable Research and Development Center (AVRDC).
The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

$CaCl_2 \cdot 2H_2O$ housed in the cavity of a slide glass. The slides with pollen grains were kept in a moistened petri dish to prevent the medium from drying out. Four slides per dish were incubated at 10, 16, 20, 24, 28 and 32°C for 20 hr. Pollen grain germination, pollen tube growth (μm), and number of burst pollen grains were determined under a microscope.

Results in Table 1 indicate that high temperatures at different growth stages had no effect on silique setting. However, high temperatures at different growth stages generally reduced seed number per silique and seed yield per plant. High temperatures at first anthesis and at pollination drastically reduced seed number per silique and seed yield. High temperatures at bolting and at macroscopic appearance of flower bud produced less significant effects on the seed number per silique and seed yield. When seed number per silique was reduced by high temperature at bolting, there was a tendency for seed weight to increase. However, this did not compensate for the reduction in seed number per silique. The inflorescence of Chinese cabbage is a long raceme, and it took about 3 days from the first anthesis to develop 9–12 flowers successively on the main stalk for pollination. Thus, our results suggest that flower buds 1–3 days before anthesis and flowers 1–3 days after anthesis were highly susceptible to high temperature.

Male and female organs viability can be estimated by comparing seed set and seed yield at high temperature when normal temperature pollen grains (NTP) are used. Probably the most significant measure of male and female fertility as affected by heat treatment is seed number per silique as shown in Table 1. If we compare bolting and flower bud appearance results for both high temperature pollen grains (HTP) and NTP, we observe in the case of bolting that NTP restored seed set level to that of the control, suggesting that the principal fertility reduction for HTP was due to pollen nonfunctioning. In the case of flower bud appearance, however, the seed set levels for HTP and NTP do not differ, suggesting here that upset of the carpel is principally responsible for the fertility reduction.

On the other hand, NTP increased the seed weight of plants exposed to high temperatures at flower bud appearance and first anthesis. Although NTP were able to alleviate some of the damage caused by high temperature, seed yield was still less than that of the normal temperature plants except when the plant was exposed to high temperatures at first anthesis.

The above results suggest that high temperatures affect not only the pollen grain development but also other processes such as ovule or stylar tissue development, and formation of normal stigma surfaces in Chinese cabbage. Carpel development tends to be susceptible to high temperatures 1–3 days before anthesis, whereas pollen grain development seems to be susceptible earlier than that. However, the drastic effects of high temperature on seed yield occur after pollination.

Table 1. Effect of high temperature at different growth stages on flower and silique number/plant, seed number/silique, 100-seed weight, and seed yield/plant of Chinese cabbage.

Growth stage during high temperature	Flower no./ plant	Silique no./ plant	Seed no./ silique	100-seed wt (mg)	Seed yield (mg)/ plant
Bolting	11.3	10.2	7.2 cd[y]	222 a	163 b
Flower bud appearance	11.3	10.0	8.8 b	175 b	150 b
First anthesis	14.8	11.8	4.5 d	151 c	81 c
Pollination	12.4	10.4	1.1 e	130 c	15 d
Bolting with NTP[z]	11.0	9.8	11.2 a	153 bc	159 b
Flower bud appearance with NTP	10.8	9.2	8.3 bc	208 a	155 b
First anthesis with NTP	12.8	12.0	7.1 cd	227 a	196 a
Normal temp control	12.0	11.9	11.9 a	155 bc	220 a

[z]Hand pollination with normal temperature pollen grains.
[y]Mean separation within columns by Duncan's multiple range test, 5% level.

Table 2. Effect of temperature on Chinese cabbage pollen grain germination, pollen tube growth, and pollen grain bursting.

Temperature (°C)	Pollen grain germination (%)	Pollen tube length (µm)	Pollen bursting (%)
10	12.2 d[z]	26.5 d	22.7 c
16	24.3 c	44.6 cd	0.0 d
20	41.3 a	127.0 a	0.0 d
24	31.6 b	75.7 b	0.0 d
28	28.4 bc	91.1 b	34.8 b
32	15.7 d	66.1 bc	59.6 a

[z]Mean separation within columns by Duncan multiple range test, 5% level.

The optimum temperature for pollen grain germination and pollen tube growth was 20°C (Table 2). Temperatures below 16° or above 28° reduced pollen grain germination and pollen tube growth. Beyond the optimal temperature range of 20-24°, the percentage of burst pollen grains steadily increased. The effect of high temperatures in reducing pollen grain viability has been demonstrated for bean (5), onion (2), and tomato (4). Few studies have been made of the effect of temperature on pollen viability in *Brassica*. Pearson (7) reported that the optimum temperature for pollen grain germination of *B. oleracea* was 20°, and pollen grains germinated poorly at temperatures beyond 29°. Matsuzawa (6) reported that the most appropriate temperature for pollen grain germination was about 25° in interspecific crosses between *B. campestris* and *B. oleracea*. Our results indicate that drastically reduced seed number after high temperatures at pollination (Table 1) may be due to poor pollen grain germination and pollen tube growth (Table 2). However, the possibility that high temperatures affect the process from zygote formation to embryo development cannot be ruled out. Chang and Struckmeyer (3) demonstrated in *Allium cepa* that pollination temperature had no significant effect on megasporogenesis but did affect mitosis of the zygote.

Yamada (8) found that the most suitable temperature for Chinese cabbage seed production was 13/8°C (day/night), and stress temperatures of 23/18° or 28/23° reduced seed production. Our results clearly demonstrate that extreme temperature conditions common in Southeast Asia could reduce the number of viable gametes sufficiently to account for the poor seed yield of Chinese cabbage. However, the most drastic effect of high temperatures on reducing seed yield occurs after pollination. These results also indicate that high temperature conditions are a major contributing factor limiting good seed production in the tropics.

Literature Cited

1. Asian Vegetable Research and Development Center. 1975. Annu. Rpt. for 1974. Shanhua, Taiwan.
2. Chang, W.N. and B.E. Struckmeyer. 1975. The influence of temperature and relative humidity on onion pollen germination. HortScience 10:162–163.
3. Chang, W.N. and B.E. Struckmeyer. 1976. Influence of temperature on seed development of *Allium cepa* L. J. Amer. Soc. Hort. Sci. 101:296–298.
4. El Ahmadi, A.B. and M.A. Stevens. 1979. Reproductive responses of heat-tolerant tomato to high temperatures. J. Amer. Soc. Hort. Sci. 104:686–691.
5. Halterlein, A.J., C.D. Clayberg, and I.D. Teare. 1980. Influence of high temperature on pollen grain viability and pollen tube growth in the styles of *Phaseolus vulgaris* L. J. Amer. Soc. Hort. Sci. 105:12–14.
6. Matsuzawa, Y. 1977. Pollen germination and pollen tube growth at different pollination temperatures in interspecific crosses in the genus *Brassica*. I. Cross pollination between *B. campestris* and *B. oleracea*. *Bul. Coll. Agr. Utsunomiya Univ.* 10:1–10.
7. Pearson, O.H. 1932. Breeding plants of the cabbage group. Calif. Agr. Expt. Sta. Bul. 532.
8. Yamada, E. 1977. Guidelines of seed and seedling production. p. 615-698. In: S. Shimizu (ed.) Dictionary of vegetable horticulture (in Japanese). Yokendo Press, Japan.