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Capsaicin biosynthesis in water-stressed hot pepper fruits

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Abstract. "Hungariana," "Beauty Zest," and "Home Flavor" hot pepper plants (*Capsicum annuum* L. var. *annuum*) were grown with an ample or a limited water supply. The fruits of plants in the water deficit treatment were small, had a proportionally heavier placenta and had a higher concentration of capsaicin. The concentration of capsaicin in the placenta of "Beauty Zest" fruits in the water deficit treatment began to increase rapidly 10 days after flowering (DAF). It reached a maximum 30 days DAF and was 3.84-fold higher than in the placenta of control treatment plants. In the pericarp, the concentration of capsaicin reached a maximum 50 days DAF and was 4.52-fold higher than in the control treatment. In "Hungariana" fruits, the concentration of capsaicin in the placenta was not significantly different among treatments. Phenylalanine ammonia-lyase (PAL) activity was higher in the placenta of "Beauty Zest" fruits in the water deficit treatment than in the fruits of control plants 50 DAF. In 40 or 50 DAF, cinnamic acid-4-hydroxylase (C4H) activity was higher in plants subjected to the water deficit treatment than in control plants. In both treatments, C4H activity in placenta was 1.4 to 1.5-fold greater than in the pericarp 40 DAF. Capsaicinoid synthetase (CS) activity 40 DAF was 1.45 to 1.58-fold higher in fruits in the water deficit treatment than in fruits in the control treatment. Although peroxidase activity was lower in plants in the water deficit treatment than in the control treatment, the difference was not significant.

Keywords: Capsaicin; Hot pepper; Pungency; Water treatment.

Introduction

Hot pepper plants are shallow-rooted and lack a taproot, but they develop many fibrous roots that grow to 30 cm below the soil surface. Pepper plants are notorious for their sensitivity to moisture stress at flowering and fruit setting. The blossoms and immature pods of water-stressed plants often drop. On the other hand, water-stressed plants typically produce more pungent pods (Bosland and Votava, 2000).

Bucholz (1816) first discovered and extracted the pungent, oily substance from hot peppers. The active ingredient in hot pepper was isolated by Thresh (1846), and was named it capsaicin (Govindarajan, 1987). Today, more than 15 capsaicinoids are known. Capsaicin and dihydrocapsaicin account for more than 80% of the capsaicinoids that determine the pungency of peppers (Bernal et al., 1993b; Walpole at al., 1996; Kobata et al., 1998).

Two pathways are involved in the biosynthesis of capsaicinoids: fatty acid metabolism and the phenylpropanoid pathway (Ochoa-Alejo and Gomez-Peralta, 1993). The phenolic structure comes from the phenylpropanoid pathway, in which phenylalanine is the precursor. The formation of ferulic acid from phenylalanine is well understood in other higher plants. Four enzymes, phenylalanine ammonia-lyase (PAL), cinnamic acid-4-hydroxylase (C4H), ρ-coumaric acid-3-hydroxylase (C3H), and caffeic acid-*o*-methytranferase (CAOMT) are involved in the process. Capsaicinoids are formed from vanillylamine and isocapryl-CoA via capsaicinoid synthetases (CS) (Fujiwake et al., 1982; Sukrasno and Yewman, 1993; Curry et al., 1999).

During fruit ripening, capsaicin concentration reaches a maximum. Capsaicin then turns over and degrades to other secondary products (Bernal and Ros Barceló, 1996). Most peroxidase activity occurs in the placenta and the outer layer of pericarp epidermal cells. Histochemical localization was used to determine the location of peroxidase (Bernal et al., 1993a). As determined by gel permeation chromatography, the major oxidative products were 5,5'-dicapsaicin and 4'-*O*-5-dicapsaicinether (Bernal et al., 1995). Peroxidase activity increased at the time when the concentration of capsaicinoids started to decrease (Contreras-Padilla and Yahia, 1998). It is assumed that peroxidases catalyze capsaicinoid oxidation and play a central role in their metabolism.

The fruits of "Padron" pepper plants given more or less water than control contained higher capsaicin content than well-watered control fruits. Water deficit affects phenylpropanoid metabolism and the pungency of pepper fruits (Quagliotti, 1971; Estrada et al., 1999). PAL, C4H, and CS are involved in capsaicinoid biosynthesis and peroxidase isoenzyme B6 directly affects capsaicin degradation (Bernal et al., 1994a).

The goals of this research were to understand the effect water supply on the amount of capsaicin in hot pep-

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per fruits, the activity of key enzymes in capsaicin synthesis, and the mechanisms that affect pungency.

Materials and Methods

Plant Material

Hot peppers var. "Home Flavor," "Beauty Zest," and "Hungariana (Known-You Seed Co.; Evergrow Seed Co.) were grown in 6-inch diameter, plastic pots. The growing medium was comprised of peat moss, perlite, vermiculite, soil, and organic fertilizer mixed 2:1:1:2:1 by volume. Plants were grown in the Department of Horticulture greenhouse, National Chung-Hsing University, Taichung, Taiwan, and using cultural practices employed farmers.

Plants were placed in the water deficit or control treatment when the first flower and branch developed. Plants were watered until water started to flow out of the bottom of the pot. In the control treatment, plants were watered once or twice a day. The water content of the control soil was around 60%. Plants in the water deficit treatment were watered only after their leaves began to wilt, about once every three days. The soil water content of the deficit treatment was decreased from 50% to 35% during water treatment. The experiment was conducted twice; once each in March and June 2003.

"Hungariana" fruits were harvested 50 days after flowering (DAF), while "Home Flavor" and "Beauty Zest" fruits were harvested during 60 DAF. At 10-day intervals, fruit fresh weight and the proportion of the fruit fresh weight represented by the placenta were determined. Each time, three plants from each treatment and four fruits from each plant were examined. There were three replicates (nine plants total) of each treatment.

Measuring Capsaicin Concentration

Harvested fruits were dried in an oven at 50°C for 2 to 5 days until completely dehydrated. Samples were ground and mashed through a 1×1 mm screen. To extract capsaicin, 0.04 g powdered fruit was mixed with 1 mL acetone and placed on a shaker at room temperature for four h at 250 rpm. The mixture was filtered through PVDF (polyvinylidiene fluoride) millipore (0.45 μm, 13 mm diameter), and the filtered solution was collected in 2 mL tubes. Each HPLC assay was conducted with 10 μL of filtered solution (Tsou et al., 1997).

The HPLC was carried out on a Merck Lichrosorb RP-18 column (LiChroCART® 125-4 HPLC-Cartridge; LiChrospher® 100 RP-18 endcapped 5 μm, MERCK) with HITACHI autosample L-7200. For each sample, 10 μL were injected into a HITACHI L-6200 Intelligent Pump. The guard column was placed in the front. Absorbance at 229 nm was measured with a HITACHI UV-VIS Detector L-7420 UV receptor and recorded with HITACHI D-2500 Chromato-Integrator. The mobile phase was a mixture of methanol (MERCK) and water at a ratio of 35/65 (v/v), filtered through No. 41 Whatman filter paper (porosity 45 μm). The flow rate was 1 mL/min, and the flow time for each sample was 30 min.

Capsaicin (Sigma, M2028) dissolved in 100% ethanol was used as the standard sample. The wave peak of capsaicin was observed at 6.83 min. Standard solutions of 50 ppm and 100 ppm were used to calculate the capsaicin concentration in each sample (AVRDC, 1989).

Measuring Phenylalanine Ammonia-Lyase Activity

Each sample (0.5 g fresh weight) of pericarp or placenta was ground with 3 mL of 50 mM Tris-HCl buffer (pH 8.8) containing EDTA (1 mM), β-mercaptoethanol (15 mM) and ascorbic acid (50 mM) in a 4°C water bath and then centrifuged at 20,000 rpm for 30 min. The supernatant was collected and adjusted to 5 mL with extraction buffer (Ochoa-Alejo and Salgado-Garciglia, 1992). The amount of protein was calculated by comparing the sample to the calibration curve obtained with Bovine Serum Albumin (BSA). The absorbance of the sample at 595 nm was determined with a spectrophotometer (UV-1301, SHIMADZU) (Bradford, 1976).

The assay mixture contained 0.1 mL of extract, 1 mL 100 mM Tris-HCl buffer (pH 8.8), 0.5 mL of 10 mM L-phenylalanine (Sigma) and 0.4 mL deionized water. The mixture was incubated for 1 h at 37°C, and the reaction was terminated by 0.5 mL of 6 M HCl. After 7.5 mL of diethylether was added to the acidified mixture, the organic phase was dried *in vacuo* at 20°C. The residue was dissolved in 3 mL of 50 mM NaOH, and sample absorbance at 290 nm was measured. The calibration curve was constructed using cinnamic acid. The blank had the same constituents except that the extract was added after the HCl solution (Ochoa-Alejo and Gómez-Peralta, 1993).

Measuring C4H Activity

Each 0.5 g sample of fresh chili pepper fruit tissue was ground in liquid nitrogen with 6 mL 100 mM Tris-HCl buffer (pH 7.5). The extract was centrifuged at 12,850 *g* for 20 min at 4°C. The reaction mixture consisted of 1.5 mL 100 mM Tris-HCl buffer, pH 7.5, 0.05 mL each of 20 mM glucose-6-phosphate, 12 mM β-mercaptoethanol, 8 mM cinnamic acid, 8 mM NADP and G6P dehydrogenase (1000 units/12.5 mL), and 0.5 mL of extract. The absorbance of the extracted solution at 340 nm was measured for 15 min using the time-course method (Ochoa-Alejo and Gómez-Peralta, 1993).

Measuring CS Activity

Each extract was prepared by grinding 0.5 g fresh hot pepper fruit tissue in liquid nitrogen and 6 mL 100 mM Tris-HCl buffer (pH 6.8). The homogenate was centrifuged at 12,850 *g* for 20 min at 4°C. The supernatant was used as the enzyme source. The reaction mixture contained 0.1 mL 0.4 M Tris-HCl, pH 6.8, 10 μL 0.2 M vanillylamine, 5 μL each of 40 mM ATP, 40 mM $MgCl_2$, 40 mM 8-methyl-6-nonenoic acid, and 0.3 mL of extracted enzyme. The reaction was performed at 37ºC for 1 h and terminated with 0.1 mL of 1 M HCl. The assay mixture was extracted with 0.5 mL chloroform and evaporated to dryness at 50°C *in vacuo*.

Then, 1 mL acetone was added, and the mixture was placed on shaker for 1 h. The mixture was filtered with 0.45 µm PVDF (polyvinylidiene fluoride) millipore (diameter 13 mm); 10 µL filtered solution was used for each HPLC assay. (Ochoa-Alejo and Gómez-Peralta, 1993).

Measuring Peroxidase Activity

Each 1.0 g sample of fresh chili pepper fruit tissue was homogenized with a mortar and pestle in the presence of acetone at -20°C. The homogenate was filtered through one layer of filter paper (Whatman No. 40) at 4°C in a Buchner funnel. The pigments in the residue were thoroughly washed with acetone at -20°C. The precipitate was resuspended in 2.5 ml Tris buffer (1 M KCl, 50 mM Tris-HCl buffer, pH 7.5) and stirred while being incubated for 1 h at 4°C.

The assay mixture contained 0.1 ml of extract, 2 ml 0.15 M Tris-acetate buffer (pH 6.0), 0.6 ml of 5 mM capsaicin (Sigma) and 0.3 ml H_2O_2. The absorbance of the sample at 262 nm was measured. The blank had the same constituents except H_2O_2. Peroxidase activity, expressed as mmole /min/ mg protein, was calculated using the absorption coefficient of capsacin at 262 nm (Bernal et al., 1995)

Localization of Peroxidase Activity

Hot pepper fruits were frozen at -20°C. Cross sections were printed to a 0.45 µm nitrocellulose membrane (Schleicher & Schuell). Then, 0.1 M Tris-acetate buffer, pH 6.0, 1.0 mM 4-MN, 1.0 mM H_2O_2 were added and left on the cross sections for 10 min. Dark coloration indicated the location of peroxidase in the tissues (Calderón et al., 1993).

Statistics

Data were analyzed with an ANOVA (SAS Institute, Cary, NC). Treatment means were compared with Duncan's Multiple Range Test (P=0.05).

Results

Fruit Growth

During 50 days growth, the fruit of "Hungariana" grew less in the water deficit treatment than in the control (Figure 1). The fruit weight of "Home Flavor" and "Beauty Zest" fruit did not increase from 30 to 50 DAF. At 30 DAF, "Home Flavor" fruits in the control treatment were 16% heavier, and "Beauty Zest" fruits were 26% heavier than fruit in the water deficit treatment. At 50 DAF, "Hungariana" fruit in the water deficit treatment weighted 36.79 g, 22% less than control fruit. By 60 DAF, the weight of "Home Flavor" fruit in the control treatment had decreased and was the same as that of fruit in the water deficit treatment.

The placental proportion of the fresh weight of "Beauty Zest" and "Home Flavor" fruits decreased during development (Figure 2). The placental proportion of "Hungariana" was not measured at the first 10 DAF. At 30 DAF, the placenta of three cultivars fruit was a larger component of total fruit weight in the water deficit treatment than in the control treatment. From 40 to 50 DAF, the placenta represented a greater proportion of the total weight of "Home Flavor" fruits in the water deficit treatment. In "Hungariana" hot peppers, the proportion of fresh fruit weight represented by the placenta in the water deficit treatment was 1.59-fold greater than in the control treatment 40 DAF.

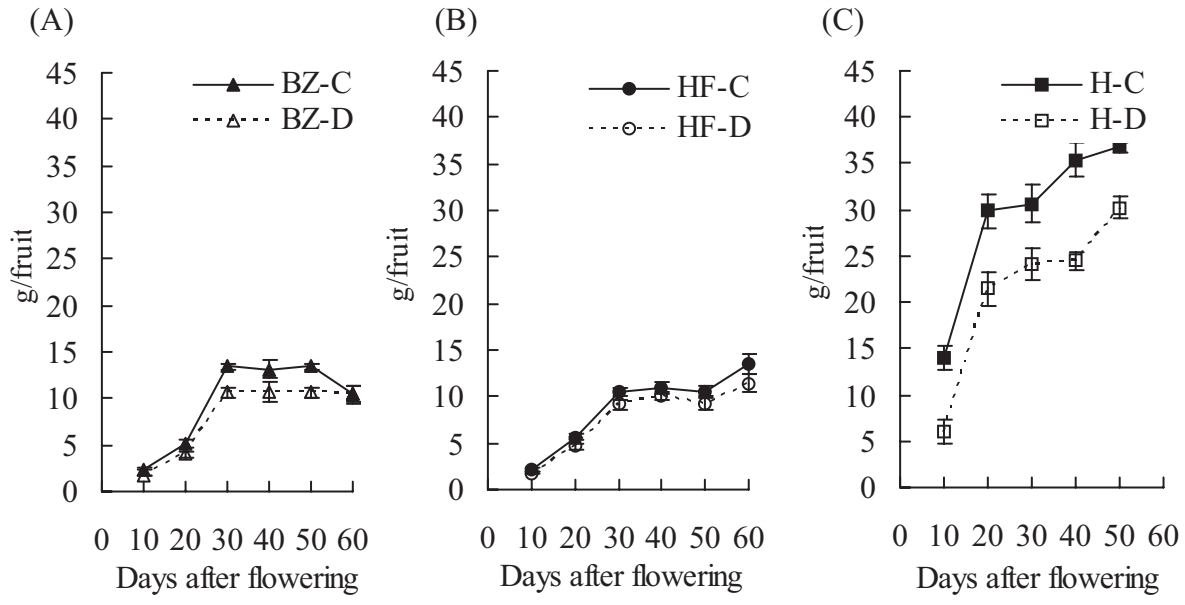

Figure 1. Fruit fresh weight of (A) "Beauty Zest" (BZ), (B) "Home Flavor" (HF) and (C) "Hungariana" (H) under water treatments. C, control; D, water deficit. Error bars show SE.

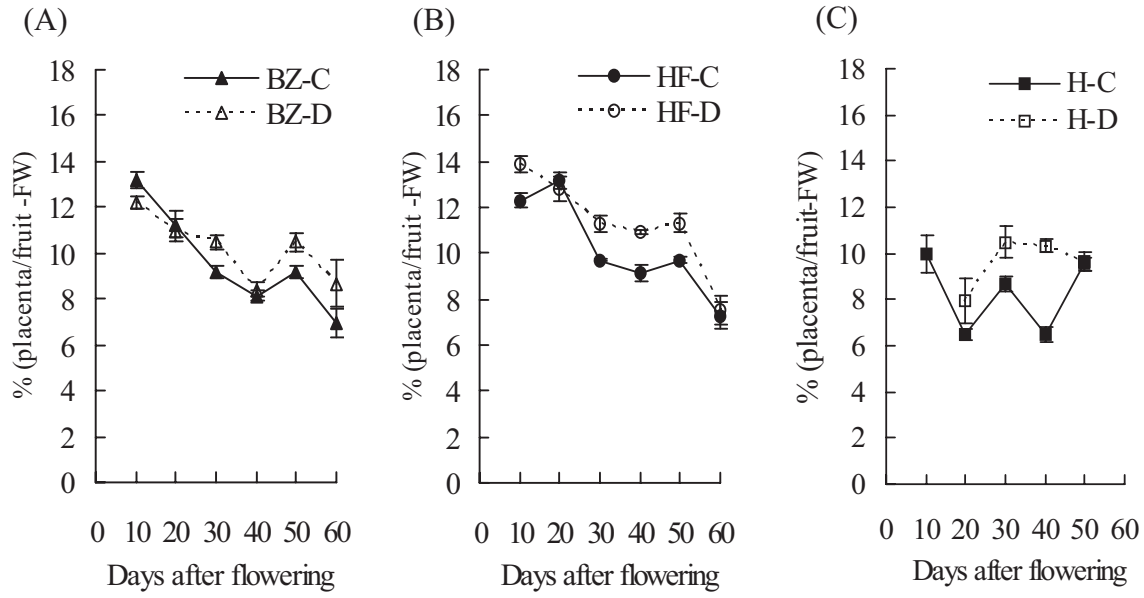

Figure 2. Proportion of placenta in fruit of (A) "Beauty Zest" (BZ), (B) "Home Flavor" (HF) and (C) "Hungariana" (H) under water treatments. C, control; D, water deficit. Error bars show SE.

Changes in Capsaicin Content

In the water deficit treatment, the highest capsaicin concentration in the pericarp of "Beauty Zest", "Home Flavor", and "Hungariana" fruits occurred 50, 30, and 20 days after flowering, respectively (Figure 3). In "Beauty Zest" fruit, the concentration of capsaicin in the pericarp was higher in the water deficit than control treatment only during 40~50 DAF. In the pericarp of "Home Flavor" fruits, the capsaicin concentration was higher in the water deficit than the control treatment at 30 DAF. Then the capsaicin concentration in the deficit treatment was decreased during 40~50 DAF. In "Hungariana" fruit, the concentration of capsaicin in the pericarp was higher in the water deficit than control treatment only during 20~30 DAF.

Ten days after flowering, the concentration of capsaicin was 0.98 mg/g DW in the placenta of "Beauty Zest" fruits from the water deficit treatment and only 0.06 mg/g DW in fruits from the control treatment (Figure 4). The ac-

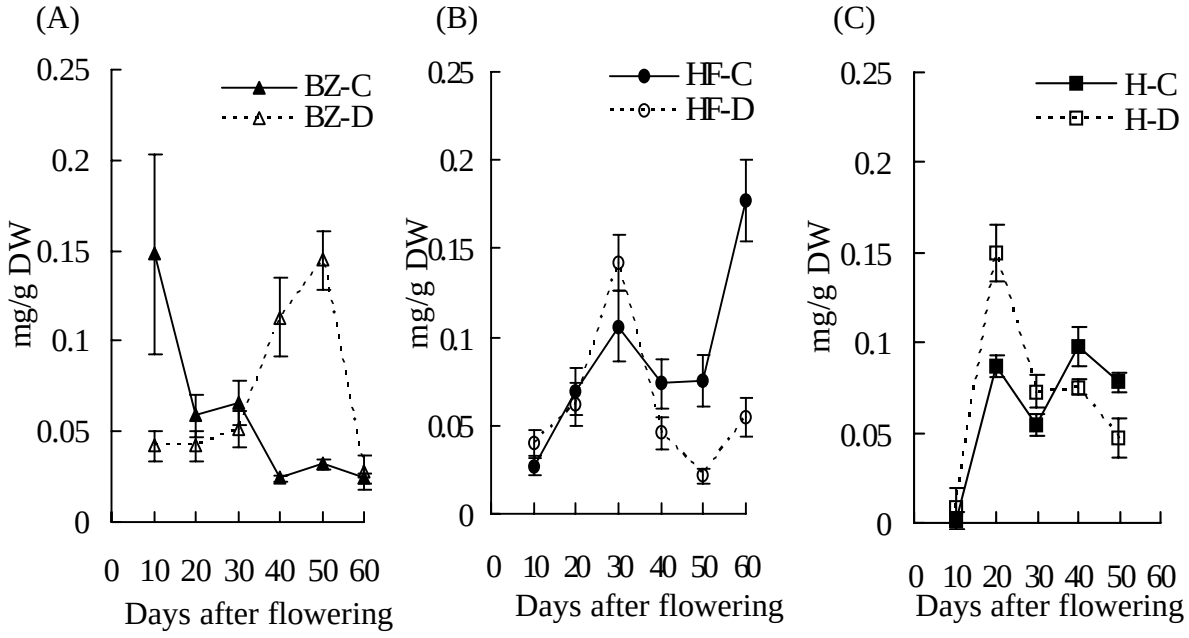

Figure 3. Capsaicin amount in pericarp of (A) "Beauty Zest" (BZ), (B) "Home Flavor" (HF) and (C) "Hungariana" (H) under water treatments. C, control; D, water deficit. Error bars show SE.

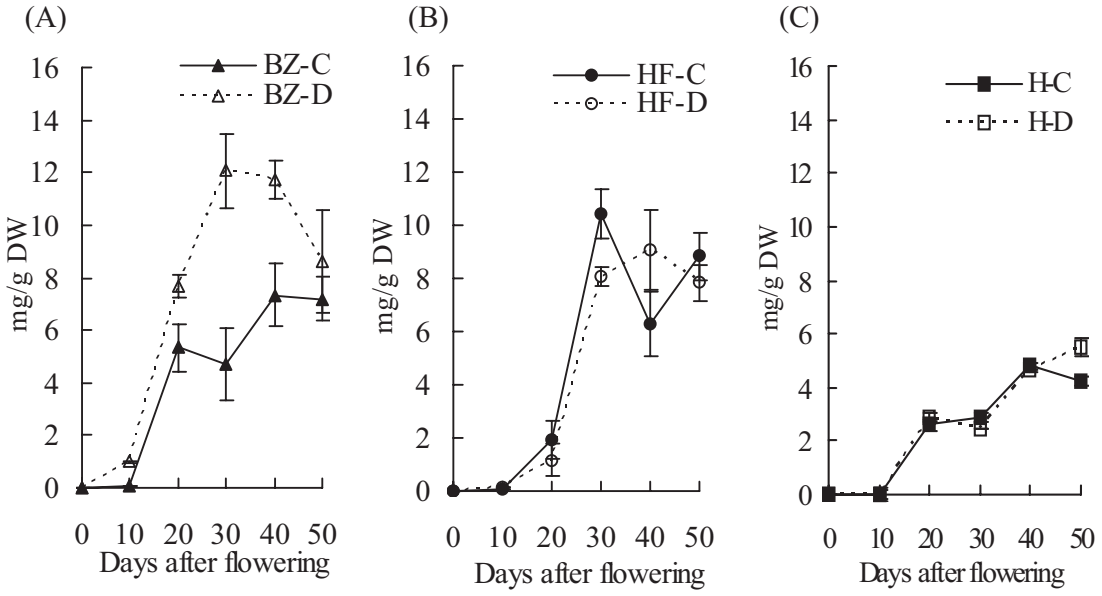

Figure 4. Capsaicin amount in placenta of (A) "Beauty Zest" (BZ), (B) "Home Flavor" (HF) and (C) "Hungariana" (H) under water treatments. C, control; D, water deficit. Error bars show SE.

cumulation of capsaicin in the placenta was rapid and correlated with the increase in fruit weight. In the water deficit treatment, the rate of capsaicin accumulation in fruit peaked at 12.05 mg/g, 30 DAF. In the control treatment, it peaked on day 40. The capsaicin concentration in fruits from the water deficit treatment was higher than in the control treatment 30 DAF, and 2.56-fold the capsaicin concentration in control treatment fruits 40 DAF. In "Home Flavor" the capsaicin concentration in the placenta of fruit from the water deficit treatment was lower than in the control treatment 30 DAF, but was higher at 40 DAF. In "Hungariana" fruit, the capsaicin concentration in the placenta was not different between treatments prior to 50 DAF. At 50 DAF, it was highest in the placenta of fruit from the water deficit treatment.

In the pericarp of "Beauty Zest" hot peppers in the water deficit treatment, PAL, C4H activity was not significantly different from the control treatment 40 DAF or 50 DAF (Table 1). CS activity was higher 40 DAF than 50 days in the water deficit treatment. In both treatments, C4H activity was higher 40 DAF than 50 DAF.

In the placenta of "Beauty Zest" peppers, CS activity was significantly higher in the water deficit treatment than the control treatment 40 DAF (Table 2). PAL activity was significantly higher in the water deficit treatment than control treatment 50 DAF. The activity of C4H and peroxidase activity in the water deficit treatment and the control treatment was not significantly different 40 DAF or 50 DAF. However, in both treatments, the activity both enzymes was greater 40 DAF than 50 DAF.

Peroxidase activity was localized in the placenta of "Beauty Zest" hot peppers (Figure 5). Greater staining in control treatment fruit indicates peroxidase activity was higher than in fruit from the water deficit treatment 40 and 50 DAF.

Table 1. PAL, C4H and CS activities in pericarp of "Beauty Zest" peppers at 40 and 50 days under water deficit treatment.

	PAL	C4H	CS
	(nmol/ min/ mg protein)		(mmole/ min/ mg protein)
Water deficit			
40 days	0.091 ab*	22.83 a	0.255 a
50 days	0.094 ab	13.31 bc	0.161 a
Control			
40 days	0.077 b	19.10 ab	0.187 a
50 days	0.104 a	6.72 c	0.254 a

*Mean separation within columns by Duncan's multiple range test, $p < 0.05$.

Table 2. PAL, C4H and CS activities in placenta of "Beauty Zest" peppers at 40 and 50 days under water deficit treatment.

	PAL	C4H	CS	Peroxidase
	(nmole/ min/ mg protein)		(mmole/ min/ mg protein)	
Water deficit				
40 days	0.073 b*	33.02 a	0.180 a	0.087 a
50 days	0.108 a	12.11 b	0.124 b	0.030 b
Control				
40 days	0.070 b	29.52 a	0.098 b	0.090 a
50 days	0.083 b	6.42 b	0.202 a	0.041 b

*Mean separation within columns by Duncan's multiple range test, $p < 0.05$.

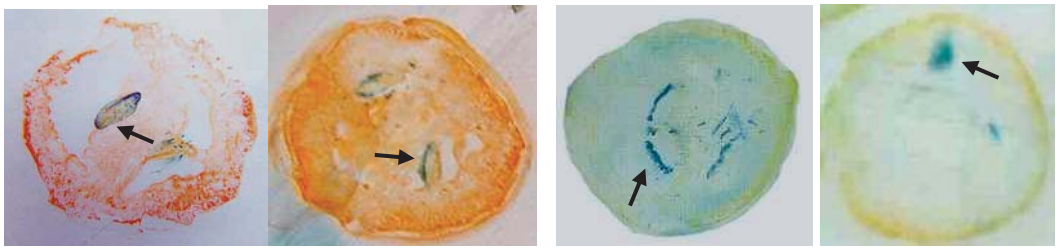

Figure 5. Peroxidase (arrow showed) in "Beauty Zest" fruits examined with tissue printing. A, CK 50days; B, water deficit 50 days; C, CK 40 days; D, water deficit 40 days.

Discussion

The Effect of Water Deficit on the Growth of Hot Pepper Fruit and Capsaicin Concentration

Pepper leaves photosynthesize more efficiently when water is abundant, resulting in a higher percentage of large, heavy, marketable fruits (Alvino et al., 1994). Under water stress, the products of photosynthesis are fewer; fruit growth and development are inhibited, and yield is decreased (Bray, 1997). For the three pepper cultivars in our study, the fruit produced by plants in the water deficit treatment weighed less than fruit from plants in the control treatment (Figure 1). However, in "Home Flavor" and "Hungariana" the proportion of total fruit weight represented by the placenta was greater in fruit from the water deficit than the control treatment (Figure 2). Similar results were obtained for other types of pepper plants subjected to a variety of stresses. For example, pepper plants exposed to low temperatures had more cells in the placenta and the receptacle (Pressman et al., 1998b). Pepper plant growth under low night temperature had short styles and large ovaries (Pressman et al., 1998a). The performance of sucrose synthase mRNA in the placenta was enhanced in tomato subjected to high temperature stress during ripening, resulting in an increased concentration of saccharides in the placenta (Demnitz-King et al., 1997).

In pepper fruits, pungency is caused by high concentrations of capsacinoids. Capsaicin and dihydrocapsaicin account for about 80% of all capsaicinoids in peppers (Bernal et al., 1993a). During the growth of "Beauty Zest" peppers (10 to 40 DAF), the capsaicin concentration in the placenta increased in direct proportion to fruit dry weight. It peaked 30 to 40 DAF and then began to drop. Similar results were obtained for the pepper cultivar "Karayatsubusa" (Iwai, 1997). In "Padron" peppers, capsaicin concentration peaked from 40 to 50 DAF (Estrada et al., 1997). The rate of capsaicin accumulation in a variety of pepper cultivars from different countries, differed among cultivars (Tsai, 1976). It was highest in "Beauty Zest" peppers 10 to 30 DAF. Pepper pungency is affected by water stress. In this experiment, capsaicin concentration was greatest in "Beauty Zest" peppers in the water deficit treatment. Water deficit has a lesser effect on the capsaicin concentration in "Home Flavor" and "Hungariana" fruits. "Padron" and "Karayatsubusa" pepper plants subjected to water deficit also have higher capsaicin and dihydrocapsaicin concentration than control plants. However, pepper cultivars differ in their ability to tolerate water stress (Iwai et al., 1979; Estrada et al., 1997).

Capsaicin Biosynthesis and the Activity of PAL, C4H, CS, Peroxidase

PAL activity was higher in the placenta of "Beauty Zest" fruits in the water deficit treatment than in control treatment fruits 50 DAF. The capsaicin concentration was higher in fruits from the water deficit treatment 50 DAF. Capsaicin concentration and PAL activity were related.

The weight of chili peppers stopped increasing 30 to 40 DAF. Capsaicinoids accumulate primarily in the placenta of pepper fruits. We found that the PAL concentration in the placenta was higher than in the pericarp 50 DAF. Higher concentrations of PAL are followed by an increase in the pungency of fruits about 10 days later. When pepper fruit stopped growth, increased PAL activity in the fruit accelerated the degradation of phenylalanine, and the concentration of cinnamic acid and capsaicinoids increased (Ochoa-Alejo and Gómez-Peralta, 1993). In chili peppers, large amounts of cinnamic acid were synthesized 7 DAF, when PAL is present, demonstrating that PAL was a key enzyme in the phenylpropanoid pathway (Ochoa-Alejo and Gómez-Peralta. 1993).

Cinnamic acid-4-hydroxylase (C4H) hydroxylates cinnamic acid to ρ-coumaric acid. Capsaicinoid synthetase (CS), the last enzyme involved in the biosynthesis of capsaicin, combines vanillylamine and isocapryl-CoA to make capsaicin (Fujiwake et al., 1982). In our study, "Beauty Zest" pepper plants in the water deficit treatment synthesized more capsaicin than plants in the control treatment 40 DAF. Capsaicin concentration began to decline 50 days after flowering. C4H activity was higher in plants in the water deficit than control treatment and peaked 40 DAF. Increases in C4H activity were directly proportional related to increases in capsaicin concentration. CS expression in plants in the water deficit treatment peaked 10 days earlier than in control treatment plants. Capsaicin biosynthesis was faster and the concentration of capsaicin was higher in fruit in the water deficit treatment because CS activity increased earlier. Other authors found that C4H and CS activity began to increase 22 DAF and peaked 30 DAF (Ochoa-Alejo and Gómez-Peralta, 1993). Enzyme activity and the quantity of synthesized product are corre-

lated with the concentration of capsaicin. Curry et al. (1999) used southern-blotting to analyze the cDNA in bell peppers and hot peppers with different levels of pungency. They found that pungency was positively correlated with the PAL and C4H activity.

Peroxidase oxidizes capsaicin in pepper fruits. The peroxidase activity and different isoenzymes in the placenta and pericarp also have been studied (Bernal et al., 1993a; Bernal et al., 1994b; Contreras-Padilla and Yahia, 1998; Estrada et al., 2000). Peroxidase activity in the placenta and pericarp of pepper fruits was negatively correlated with the concentration of capsaicin (Di et al., 2000). We obtained similar results. Peroxidase activity was lower in fruits in the water deficit treatment. Lower peroxidase and capsaicin oxidase activity means that the oxidation, or breakdown, of capsaicin will be slower when plants experience water deficit. At the same time, CS activity and capsaicin production is higher than in plants not under water stress. Thus, both higher rates of synthesis and lower rates of degradation contribute to the greater concentration of capsaicin in water-stressed plants.

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辣椒果實於缺水處理下辣椒素之生合成

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“奇雅”、“麗香”及“萬家香”等三品種辣椒之植株處於不同土壤水分環境下。缺水處理果實較小，果實內胎座比率較高，果實內辣椒素含量增加。“麗香”胎座部位之辣椒素含量於開花後 10天，即快速上升，於開花後 30 天時達最大值，為對照組的 3.84 倍，果皮內辣椒素含量於開花後 50 天達最大值，為對照組的 4.52 倍。“奇雅’胎座內辣椒素含量於處理間差異不顯著。於缺水處理下“麗香”果實內苯丙胺酸裂解酶(Phenylalanine ammonia -lyase; PAL）活性上升，於 50 天有最高的表現。於開花後 40 或 50 天，缺水使“麗香”果實內肉桂酸水解酶（cinnarmic acid-4-hydroxylase; C4H）活性較對照組者高。於開花後 40 天，兩處理胎座的 C4H 活性高於果皮 1.4～1.5 倍，缺水處理之“麗香”果實內辣椒素合成酶(caspsaicinoid syntheses; CS）活性高於對照組者 1.45～1.58 倍，過氧化酶（peroxidase）的活性比對照組低，但差異不顯著。

關鍵詞：辣椒素；辣椒；辣味；水分處理。