Effects of Adding NaCl and Reducing Aeration to Nutrient Culture Solution on the Growth of Cucumber Fruit

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Summary

Effects of NaCl addition and reduced aeration to nutrient solution on the growth of cucumber (*Cucumis sativus* L. cv. Asomidori No. 5) fruit were studied. NaCl was added to nutrient solution when plants had about 10 expanded leaves; the aeration treatment was started 2 days later.

The relative growth rate (RGR) by fruit volume was not affected by aeration frequency at 0 mM NaCl. In the spring experiment, RGR at 60 mM NaCl decreased markedly when the solution was aerated infrequently (dissolved oxygen concentration (DO) being 1 to 2.5 mg liter⁻¹), whereas RGR at 60 mM NaCl approximated that at 0 mM NaCl when the solution was aerated continuously (DO being 5 to 7.5 mg liter⁻¹). The effect of NaCl at 60 mM in combination with reduced aeration on RGR in the autumn experiment was less marked than that in the spring experiment.

DO was suggested to be one of the environmental factors involved in the seasonal difference in the growth of cucumber as influenced by 60 mM NaCl (Tazuke, 1997).

Introduction

Cucumber is a moderately salt-sensitive crop (Maas and Hoffman, 1977), but little is known about NaCl's effects on the individual fruit growth.

Tazuke (1997) previously found that when the nutrient solution was aerated 5 min every 30 min from 6 a. m. to 6 p. m. and every 60 min from 6 p. m. to 6 a. m., the addition of 60 mM NaCl to a nutrient solution inhibited fruit growth much more in spring than it did in autumn, whereas adding 30 mM NaCl had little effect on fruit growth in any season; the addition of 100 mM NaCl killed the plants. These results indicate that 60 mM NaCl is close to the threshold for normal fruit growth, and that the effect of salt on fruit growth can be greatly altered by environmental factors, including temperature.

Guo and Tachibana (1995) reported that cucumber plants can grow normally at dissolved oxygen concentration (DO) of nutrient solution as low as 1 mg liter⁻¹. However, it is possible that DO could have influenced the effect of the NaCl treatment.

There are several reports on interactions between root aeration and susceptibility to NaCl. For example, the exclusion of Na⁺ by roots of *Zea mays* is impaired when the nutrient solution is bubbled with N₂ gas (Drew and Dikunwin, 1985; Drew and Läuchli, 1985). Thus, DO of the nutrient solution can be another factor which contributes to the seasonal difference in the susceptibility of cucumber fruit growth to NaCl in a nutrient solution.

In this experiment, the interaction between NaCl treatment and reduced aeration of nutrient solution on cucumber fruit growth was investigated in the spring and autumn. That DO is involved together with 60 mM NaCl in the seasonal difference on the fruit growth (Tazuke, 1997) was reassessed.

Materials and Methods

Growth conditions

Seeds of cucumber (*Cucumis sativus* L. Asomidori No. 5) were sown on vermiculite in a glass-house on April 18th and August 24th, 1995. Seedlings were supplied with a half-strength basal nutrient solution (BNS) when cotyledons expanded.

The composition of BNS (Yamasaki, 1982) was as follows: 6 mM KNO₃, 3.5 mM Ca (NO₃)₂, 2 mM MgSO₄, 1 mM NH₄H₂PO₄, 3 ppm Fe as Fe-EDTA, 0.5 ppm B, 0.5 ppm Mn, 0.05 ppm Zn, 0.02 ppm Cu, and 0.01 ppm Mo. Deionized water with specific resistance higher than $5 \times 10^3 \Omega\text{m}$ was used for the preparation of BNS.

When the first leaf emerged, plants were transferred to a solution culture with a half-strength BNS in containers (60 × 40 × 10 cm). The pH was adjusted to 6.0 every other day. The nutrient solution in each container was aerated continuously at a rate of about 1 liter min⁻¹.

After the second leaf expanded, plants were transferred to full-strength BNS in larger containers (100 × 100 × 10 cm) with six plants per container and two containers per treatment. The solution was continuously aerated at a rate of about 5 liter min⁻¹. The solution was not renewed during the experiment, but any loss in volume was replenished daily with BNS. Lateral shoots were pinched off just above the first node. The height of the vine tip was maintained at about 2 m by frequent attachment of shoot tips to a hanging cord.

Treatments

When the plants had about 10 expanded leaves, NaCl was added to nutrient solution so that the final concentrations were 0 and 60 mM. Aeration treatments (continuous or reduced) were started 2 days later. The frequency for the reduced aeration was 5 min every hour. The dates of treatments are shown in the figure legends. The oxygen concentration in the root medium was measured with DO meter (type UC-100M, Central Kagaku).

Analysis of fruit growth

Female flowers were hand-pollinated in the morning and the flowering date was recorded. Fruits about 9cm long (4 ± 1 days after anthesis) were chosen for fruit growth analysis. Fruit volume was estimated non-destructively from shape parameters, giving the accuracy within $\pm 3\%$ (Tazuke and Sakiyama, 1984). Measurements were taken in the morning (from 8 to 9 a. m.) and in the evening (from 6 to 7 p. m. in spring and from 5 to 6 p. m. in autumn).

Analysis of Na, K and Cl in fruit

In June and October, 1995, fruits about 20 cm

long were harvested from each treatment, weighed and sliced, were oven-dried at 70 °C for 7 days, then re-weighed. For the analyses of Na and Cl, powdered dry samples (0.2 g) were extracted by shaking with 50 ml deionized water for 1 hour at room temperature. A filtrate of the extract was made to 200 ml with deionized water. For the analysis of K, powdered dry samples (0.2g) were wet ashed and made to 100 ml with deionized water. Na and K were analysed with Polarized Zeeman Atomic Absorption Spectrometer (Z-6100, Hitachi). Cl was analysed according to the Mohr method (Johnson and Ulrich, 1959).

Results

Dissolved oxygen concentration of nutrient solution

In the spring experiment, the temperature of the nutrient solution was 25 °C. DOs of the solution were 5 to 7.5 mg liter⁻¹ and 1 to 2.5 mg liter⁻¹ for continuous and reduced aerations, respectively. In the autumn experiment, the temperature of nutrient solution was 20 °C. DOs of solution were 5.5 to 8.0 mg liter⁻¹ and 3.5 to 5.0 mg liter⁻¹ for continuous and reduced aerations, respectively.

Vegetative growth of plant

In the spring experiment, the heights of plants at 60 mM NaCl with reduced aeration was similar to those of the control (plants at 0 mM NaCl with continuous aeration) for 10 days from the start of treatment. Subsequently, plant growth was reduced, and some leaves became yellow. The heights of plants at 60 mM NaCl with continuous aeration and of those at 0 mM NaCl with reduced aeration were similar to those of the control for 3 weeks after treatment began. Damage was not visible in these plants.

In the autumn experiment, the heights of plants in 60 mM NaCl treatment with reduced aeration were similar to those of the control for the first 2 weeks; the yellowing of leaves seemed less intense than in the spring experiment. Heights of plants in the 60 mM NaCl with continuous aeration or at 0 mM NaCl with reduced aeration were similar to those of the control for 3 weeks after treatment began. Damage to plants was not observed.

Fruit growth

During the spring experiment, fine weather

favorable for fruit growth prevailed. At 0 mM NaCl, reduced aeration had little effect on fruit elongation. At 60 mM NaCl with continuous aeration, fruit length was equal to that at 0 mM NaCl for the first 6 days after flowering, but thereafter the fruit grew much slower than that at 0 mM NaCl grew. At 60 mM NaCl with reduced aeration, growth retardation occurred much earlier (Fig. 1) and most fruits became malformed: the distal half of the fruit grew slower than did the proximal half.

At 0 mM NaCl with continuous aeration, the daily change in RGR was similar to that observed at 0 mM NaCl in the spring culture of the previous experiment (Tazuke, 1997). RGR was high during the day (from 4 to $5\% \cdot \text{hr}^{-1}$) and low at night (about $3\% \cdot \text{hr}^{-1}$). At 0 mM NaCl, reduced aeration had little effect on RGR. At 60 mM NaCl with continuous aeration, RGR was as high as that at 0 mM NaCl at 4 days after flowering, thereafter it became progressively lower than that at 0 mM NaCl. At 60 mM NaCl with reduced aeration, RGR was much lower than that at 0 mM NaCl throughout the measurement (about $1\% \cdot \text{hr}^{-1}$, during the day and night) (Fig. 2).

In the autumn experiment, weather was fine on

Fig. 1. Effects of NaCl addition and reduced aeration to nutrient solution on the elongation of cucumber fruits in spring in 1995. Open symbols: 0 mM NaCl. Closed symbols: 60 mM NaCl. Circles: continuous aeration. Triangles: 5 min aeration in every hour. Each point represents a mean of 3 to 4 fruits. Vertical bars are s. e. of means. NaCl was added to solution on May 30 th. Aeration treatment started on June 1st. The date of flowering was June 3 rd.

the day measurement of fruit RGR by volume was started (Oct. 4th), but, thereafter, days became cloudy with low irradiance. At 0 mM NaCl with continuous aeration, RGR was about $4\% \cdot \text{hr}^{-1}$ during the day, but, thereafter, it declined gradually as the days remained cloudy. Reduced aeration with 0 mM NaCl or 60 mM NaCl with continuous aeration had little effect on RGR, but with reduced aeration at 60 mM NaCl, RGR gradually became lower than that at 0 mM NaCl (Fig. 3).

Percent dry matter of fruit

At 0 mM NaCl, percent dry matter of fruit was not affected by reduced aeration. In the spring and autumn trials, percent dry matter of fruit at 60 mM NaCl with continuous aeration tended to be higher than that at 0 mM NaCl. At 60 mM NaCl with reduced aeration, percent dry matter of fruit tended to be less than that at 0 mM NaCl in the spring experiment (Table 1).

Fig. 2. Effects of NaCl addition and reduced aeration to nutrient solution on the relative growth rate (RGR) in volume of cucumber fruits in spring in 1995. Open symbols: 0 mM NaCl. Closed symbols: 60 mM NaCl. Circles: continuous aeration. Triangles: 5 min aeration in every hour. Four to 6 fruits were replicated in each treatment. Vertical bars are s. e. of means. NaCl was added to solution on May 30 th. Aeration treatment started on June 1st. The date of flowering was June 5 th for 0 mM NaCl with continuous aeration, and June 6 th for other treatments.

K, Na, and Cl concentrations in fruit

In both spring and autumn, K concentration in fruit tended to be reduced by NaCl treatment, especially when aeration was reduced (Table 2).

Na and Cl concentrations in the fruit were very low at 0 mM NaCl, but were elevated by treatment with 60 mM NaCl in both spring and autumn,

especially when aeration was reduced (Table 2).

Discussion

A low oxygen concentration in the root zone, which often occurs during flooding, reduces plant growth (Drew and Lynch, 1980). Impairment of the uptake of nutrient ions during flooding has been reported (Letey et al., 1965). In this study little effect of reduced aeration on fruit RGR at 0 mM NaCl was observed. In the absence of NaCl, K concentration in fruit was not significantly affected by reduced aeration (Table 2). Guo and Tachibana (1995) reported that the growth and the absorption of mineral nutrients in cucumber seedlings were not affected by DO as low as 1 mg liter⁻¹ in the nutrient solution at 25°C. The RGR was unaffected by 60 mM NaCl when root zone was aerated continuously, but it decreased markedly when 60 mM NaCl was combined with reduced aeration in the spring experiment (Fig. 2). This suggests that the marked reduction of RGR was not caused solely by reduced aeration or by 60 mM NaCl, but by an interaction between the two factors. The extent of the reduction of RGR observed at 60 mM NaCl with reduced aeration in spring experiment was similar to that observed at 60 mM NaCl in spring cultures reported previously (Tazuke, 1997).

Reduction of RGR at 60 mM NaCl, combined with reduced aeration, was less marked in the autumn experiment (Fig. 3) than in was in the spring experiment (Fig. 2). DO at reduced aeration tended to be higher in the autumn experiment than it was in the spring experiment, although aeration frequency was the same in both experiments. The

Fig. 3. Effects of NaCl addition and reduced aeration to nutrient solution on the relative growth rate (RGR) in volume of cucumber fruits in autumn in 1995. Open symbols: 0 mM NaCl. Closed symbols: 60 mM NaCl. Circles: continuous aeration. Triangles: 5 min aeration in every hour. Four fruits were replicated in each treatment. Vertical bars are s. e. of means. NaCl was added to solution on Sept. 26 th. Aeration treatment started on Sept. 28. The date of flowering was Sept. 29 th.

Table 1. Effects of NaCl addition and aeration to nutrient solution on percent dry matter of cucumber fruit.

NaCl treatment		0 mM		60 mM	
Aeration		Continuous	Reduced	Continuous	Reduced
		Spring experiment ^z			
		4.62 (0.11) ^y ab ^x	4.81 (0.02) ab	5.22 (0.24) a	4.39 (0.26) b
		Autumn experiment ^z			
		4.21 (0.07) b	4.30 (0.14) b	4.71 (0.06) a	4.32 (0.02) b

^z Fruits were harvested on June 13th in spring experiment and on Oct. 5th in autumn experiment, respectively.

^y Standard error of means for 4 fruits from 30 to 100 g in fresh weight.

^x Different letters indicate significant difference ($P = 0.05$) within the same season by Tukey's test.

Table 2. Effects of NaCl addition and aeration to nutrient solution on Na, Cl and K concentration (me g DW⁻¹) in cucumber fruit.

NaCl treatment		0 mM		60 mM	
Aeration		Continuous	Reduced	Continuous	Reduced
Spring experiment ^z					
Na		0.14 (0.01) ^y	0.14 (0.01)	0.96 (0.04)	1.75 (0.04) ^{**x}
Cl		0.05 (0.01)	0.08 (0.01)	0.38 (0.02)	0.61 (0.04) ^{**}
K		1.17 (0.02) a ^w	1.13 (0.03) a	0.86 (0.02) b	0.71 (0.01) c
Autumn experiment ^z					
Na		0.11 (0.00)	0.11 (0.00)	0.85 (0.05)	1.30 (0.05) ^{**}
Cl		0.06 (0.02)	0.05 (0.01)	0.48 (0.03)	0.69 (0.03) ^{**}
K ^u		1.33 (0.04) a ^w	1.19 (0.07) ab	1.05 (0.01) bc	0.94 (0.02) c

^z Fruits were harvested on June 13th in spring experiment and on Oct. 5th in autumn experiment, respectively.

^y Standard error of means for 4 to 6 fruits analysed.

^x Significance of difference by t-test between high and low aeration treatments at 60 mM NaCl.

^{**}, P = 0.01.

^w Different letters indicate significant difference (P = 0.05) within the same season by Tukey's test.

higher temperature of the nutrient solution in the spring may enhance oxygen consumption by root respiration. Thus, DO may be one environmental factor which would account for the seasonal difference in cucumber growth in 60 mM NaCl as observed in the previous experiment (Tazuke, 1997).

That the influx of Na into maize shoot under NaCl salinity is enhanced when DO in nutrient solution was lowered was reported by Drew and Dikunwin (1985) and Drew and Läuchli (1985). Consistent with this finding, the Na concentration in cucumber fruit at 60 mM NaCl was increased by reduced aeration (Table 2).

The effects of salinity on dry matter accumulation by the tomato were studied extensively. Percent dry matter of tomato fruit under salinity increases with a relatively unchanged rate of dry matter accumulation and a reduced rate of water uptake by fruit (Ehret and Ho, 1986; Adams, 1991). Ho et al. (1987) suggested that the concentration of sugars in phloem sap increases under salinity. In cucumber grown at 60 mM NaCl with continuous aeration, percent dry matter of fruit increased with a relatively small change in fruit RGR (Table 1, Fig. 2). Thus, the increased percent dry matter of cucumber fruit at 60 mM NaCl with continuous aeration may be attributed to an increased sugar concentration in the phloem sap and a relatively unchanged accumulation of water in

the fruit. Percent dry matter of fruit at 60 mM NaCl tended to be lowered by reduced aeration (Table 1) which may result from a reduced sugar concentration in phloem sap.

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水耕栽培液への NaCl 添加と通気制限がキュウリ果実の生長に及ぼす影響

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摘 要

水耕栽培液への NaCl 添加と通気量がキュウリ (*Cucumis sativus* L. 'あそみどり 5 号') 果実の生長に及ぼす影響を調べた。基本培養液は山崎処方キュウリ用 1 倍液を用いた。本葉約 10 葉展開時に培養液に NaCl 60 mM を添加した。培養液への通気頻度を変える処理を NaCl 添加の 2 日後に開始した。果実長が 9 ~ 20cm の時期に果実体積の相対生長率 (RGR) を非破壊的に測定した。

NaCl 無添加区では、果実の RGR は通気制限の影響を受けなかった。春作では、NaCl 濃度 60 mM で通気

頻度が低い場合 (溶存酸素濃度 (DO) 1 ~ 2.5mg liter⁻¹) は、RGR は顕著に低下したが、NaCl 濃度 60 mM 連続通気区 (DO 5 ~ 7.5mg liter⁻¹) では、RGR は NaCl 無添加連続通気区と大きな差はなかった。秋作では、NaCl 濃度 60 mM 低通気区における RGR の低下は春作ほど顕著ではなかった。

既報 (Tazuke, 1997) において NaCl 濃度 60 mM 添加処理が果実の RGR に及ぼす影響にみられた季節間差に環境要因として DO が関与していた可能性が示唆された。