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Beretning nr. 2262

Effects of root zone warming and season on blossom-end rot and chemical composition of tomato fruit

Undervarmens og årstidens betydning for griffelråd og kemisk sammensætning af tomatfrugter

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Summary

The effects of root zone warming on yield and fruit quality were studied for tomato *(Lycopersicon esculentum* Mill. cv. Matador) grown in rockwool under glasshouse conditions from January to October. 7 different root zone temperatures were applied throughout the growing period: 0, 1, 2, 3, 4, 5 and 6°C above the actual night and day air temperature. When air temperature in the daytime exceeded 24°C no root zone warming was applied.

No differences in yield were found. The root zone warming resulted in less blossom-end rot (BER) and a small increase in the incidence of blotchy ripening during the spring. Later in the growing season no significant effects of root temperature on fruit quality were seen.

The Ca concentration in ripe fruit was reduced by root zone warming on 3 out of 9 dates of analysis. No relationship between Ca concentration and incidence of BER was found. In ripe tomato fruit no effect of raised root zone temperatures was found on firmness and concentrations of titratable acid, glucose and fructose. Significant effects on percentage dry matter and vitamin C concentration were found, but the effects could not be described by linear or quadratic regression. Seasonal variations in content of vitamin C, glucose, fructose and titratable acid were found.

Key words: Blossom-end rot, calcium, chemical composition, firmness, fruit quality, *Lycopersicon esculentum*, root temperature, root zone warming, tomato.

Resumé

Undervarmens betydning for udbytte og frugtkvalitet er undersøgt for tomat *(Lycopersicon esculentum* Mill. cv. Matador) dyrket i stenuld under væksthusforhold i perioden januar til oktober. 7 forskellige rodtemperaturer blev sammenlignet: 0, 1, 2, 3, 4, 5 og 6°C over den aktuelle lufttemperatur, både nat og dag. Der blev givet undervarme i hele kulturforløbet undtagen på de tidspunkter af dagen, hvor lufttemperaturen oversteg 24°C.

Der blev ikke fundet udbytteforskelle. Forøget rodtemperatur gav i forårsperioden anledning til lidt flere frugter med grønskjold, men færre frugter med griffelråd og sort kernemasse. Senere på vækstsæsonen havde forskellene i rodtemperatur ingen betydning for forekomsten af grønskjold, griffelråd og sorte kerner.

På 3 ud af 9 analysedage mindskede undervarme frugternes indhold af Ca. Der blev ikke fundet nogen sammenhæng mellem Ca-indhold og mængden af griffelråd. I modne tomatfrugter var der ingen virkning af øget undervarme på fastheden og koncentrationerne af titrerbar syre, glukose og fruktose. Der var derimod signifikant virkning af øget undervarme på tørstofprocenten og koncentrationen af C-vitamin, men sammenhængene kunne ikke beskrives ved lineær eller kvadratisk regression. Der blev fundet årstidsvariation med hensyn til C-vitamin, glukose, fruktose og titrerbar syre.

Nøgleord: Fasthed, frugtkvalitet, griffelråd, kalcium, kemisk sammensætning, *Lycopersicon esculentum*, rodtemperatur, tomat, undervarme.

Introduction

In 1988, an experiment at the Research Centre for Horticulture, with the tomato cultivars Elin and Matador, showed an improved taste when increasing the salinity of the nutrient solution either with extra major nutrients, with NaCl or with combinations of major nutrients, Na and Cl (31). This improvement of the taste was, however, accompanied by an increased number of unsaleable fruits with blossom-end rot (BER).

BER is a physiological disorder caused by insufficient translocation of Ca via the xylem to the distal part of the tomato fruit. The deficiency of Ca occurs mainly during the period of rapid cell expansion in the fruit 2-3 weeks after anthesis (18, 28).

BER can develop as a visible external depression of black necrotic tissues or as internal necrotic tissues inside the outer wall of the fruit including some of the seeds. The latter form is sometimes called 'black seeds' and is usually not detected during the grading procedure.

'Matador', which is the most important tomato cultivar in Denmark, is particularly susceptible to BER. It has therefore been suggested that methods should be developed to reduce the risk of BER when increasing the salinity in the root zone. One way, and probably the most effective one, would be to abandon varieties susceptible to BER. Another way would be to manipulate one or more growth factors responsible for BER.

The temperature regime in the root zone may have a considerable effect on the rate of several physiological processes determining plant productivity (9, 15).

Root zone warming increases the rate of transpiration in tomato (1, 23) and the uptake and translocation of major mineral elements such as N, P, K and Ca thereby affecting root and shoot growth as well as fruit development (1, 2, 8, 9, 23).

In the present study it was therefore chosen to investigate the possible influence of root temperature on BER and the chemical composition of the fruit.

Materials and methods

Plots and treatments

The experiment was carried out in 1989 in 3 glasshouse compartments, each with 3 double rows of plants. Each double row of 28 plants (2.2 per m^2) comprised one plot.

Polythene wrapped rockwool slabs (Grodan 90×20×7.5 cm) were used as substrate. Where root warming was applied the slabs were placed in 30 cm wide plastic-coated steel gullies insulated from the glasshouse soil by plates of expanded polystyrene. One supply and one return heating tube were placed between the gully and the underlying plates of polystyrene. The function of the steel gully was to facilitate an even dispersion of the heat. In plots without root warming the slabs were placed directly on the plates of polystyrene.

The treatments consisted of 7 root zone temperatures. One treatment was a control without root zone warming. The other treatments were root temperatures of 1, 2, 3, 4, 5 or 6°C above the actual night and day room air temperature. The treatments are referred to as 0, 1, 2, 3, 4, 5 and 6. Thermostats controlling the root temperatures were connected to a ventilated sensor measuring the actual air temperature 2 m above ground level in one of the glasshouse compartments. When the air temperature exceeded 24°C the root zone warming was switched off in all plots, i.e. the root temperature was not allowed to exceed 30°C in any of the plots. Root zone warming was applied from the first week of February and continued until the end of October.

The treatments were not replicated except for the control. Significant results are therefore expressed in terms of the best linear or quadratic regression line. All plots were completely randomized.

Cultivation procedure

Seedlings of tomato, *Lycopersicon esculentum* Mill. cv. Matador, sown early in December, were raised in rockwool cubes under glasshouse conditions with supplementary light. The seedlings were transferred to the experimental plots on 23 January, when the flowering of the first inflorescence had just begun.

Nutrient solutions were supplied by trickle irrigation. Until the first fruit had expanded to a size bigger than 2 cm a complete nutrient solution with an electrical conductivity (EC) of 4.6 mS/cm was supplied. The following EC levels were maintained in the slabs: in February 4-5 mS/cm, from March to July 3.5-4.5 mS/cm, and from August to October 2.5-3.5 mS/cm. These EC levels are from April to October somewhat higher than usual in Danish commercial tomato holdings. The intention was to provoke BER to some extent in the experiment. From May to October it is common practice in commercial holdings to keep EC in rockwool slabs between 2.0 and 2.5 mS/cm.

4 nutrient solutions with EC values between 2.4 and 3.7 mS/cm were applied. Their pH was 5.7 and their concentrations, in ppm, of major elements differed within the following limits: N 220-410, P 35-50, K 350-450, Ca 200-365, Mg 60-110 and S 116-127. NH_4-N comprised 3-6 per cent of total N.

Concentrations of Na, Cl and trace elements, in ppm, were the same in all solutions supplied: Na 15, Cl 31, Fe 3.5, Mn 0.5, B 0.35, Zn 0.4, Cu 0.15 and Mo 0.07. The ion activity ratios between K, Ca and Mg were also the same in the solutions:

$$a_{Mg}/a_{Ca} = 0.50$$

$$a_K/\sqrt{a_{Ca} + a_{Mg}} = 1.29$$

The aim was to achieve approximately the same proportional uptake of K, Ca and Mg independent of the salinity level in the root zone (25).

EC and pH in the slabs were controlled weekly. Means of all plots and measurements within each month were as follows:

Month	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
mS/cm	5.5	4.3	3.8	3.8	3.8	3.4	2.9	3.2	2.7
pH	6.2	5.8	5.9	5.6	5.6	5.7	5.4	5.7	5.8

Irrigation frequency was controlled by a time clock early in the season and from mid-February by a crop evaporimeter. 0.7-1.5 l per plant of nutrient solution was supplied per day in February increasing to 2.3-8.6 l per plant per day in June.

The duration of each watering was changed several times during the experiment to change the excess of nutrient solution supplied thereby keeping the intended EC level in the slabs. The excess of nutrient solution varied between 50 and 100% of actual evapotranspiration.

Minimum air temperatures were 16 and 18°C night and day, respectively, until the first harvest of mature fruit, and 15 and 17°C respectively thereafter, with venting at 22°C. From 17 March a hygrostat controlled the relative air humidity (RH) by venting; set point for maximum RH was 80%.

The glasshouse atmosphere was enriched with CO_2 to 700 µl/l from 1 hour before sunrise to 1 hour before sunset except during ventilation periods.

The plants were grown using the so-called layering system. Leaves below the upper truss of ripening fruits were removed weekly.

Trusses were mechanically vibrated for enhanced pollination.

Recording, sampling and analysis

Light to medium red fruits were harvested and weighed 3 times a week.

Once every fortnight fruit size, commercial grading in accordance with Danish standard (GASA Odense), incidence of hollow fruit, greenback and blotchy ripening were recorded. Incidence of external and internal BER was recorded once a week for the ripe fruit harvested and, at the end of the experiment, for all unripe fruit larger than 3 cm.

Representative samples of 20 grade 1 fruits per plot were selected for chemical analysis 9 times during the harvest season: on the dates 31/3, 8/5, 26/5, 23/6, 28/7, 18/8, 15/9, 6/10 and 27/10. The fruit were placed at room temperature for further ripening for 3 days.

The refractive index, which expresses the content of soluble solids and to some degree correlates with the concentration of reducing sugars, was determined on filtered, undiluted tomato juice. The contents of fructose and glucose were determined by HPLC (High Pressure Liquid Chromatography) using an Animex column. The column support material being a sulfonated divinyl benzene-styrene copolymer in an ionic form with lead and particle size 9 μm. The mobile phase was water. Titratable acid content was determined on 8-10 g of undiluted, blended tomato fruit, which was titrated with 0.1 N NaOH until pH 8.1 on a Mettler DL40 MemoTitrator, and calculated as g citric acid per 100 g fresh fruit. The amount of total vitamin C (ascorbic acid and dehydroascorbic acid) was determined by titration with dichlorophenol-indophenol. The method is modified from *Pongraz* (27). The dry matter content in percentage of fresh weight was determined for blended, frozen material after 16 hours at 80°C in a ventilated oven. The minerals Ca, K, Mg, Na, Fe and Zn were determined by atomic absorption spectrophotometry, where the samples were prepared from blended, frozen material after ashing and incineration in 65% HNO_3 by microwaves, in a laboratory microwave oven (CEM, Model MDS-81D, 630 W, without pressure monitor). Firmness was measured by an Instron apparatus equipped with a puncture probe 8 mm in diameter, loadcell from 50 to 500 kg. The crossheadspeed and chart speed were adjusted to 50 mm/min.

Results

Root temperature

Weekly means of the actual air and root temperatures throughout the experiment, monitored at

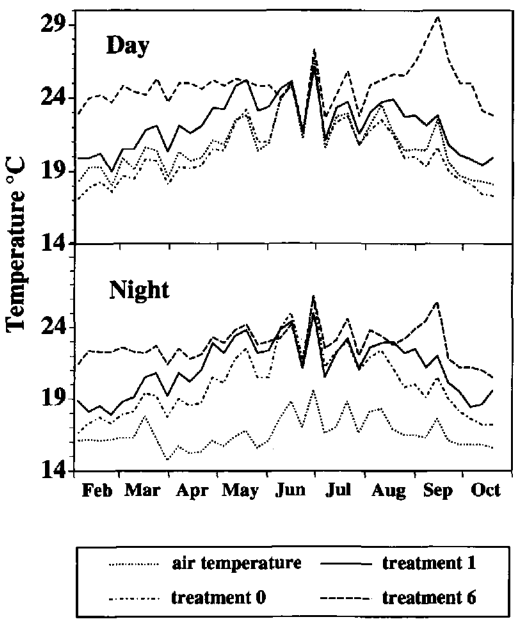

Figure 1. Day and night temperatures (week averages) in the root zone in treatments 0, 1 and 6, and in the air.
Dag- og nattemperaturen (ugegennemsnit) i rodzonen for behandling 0, 1 og 6 og i luften.

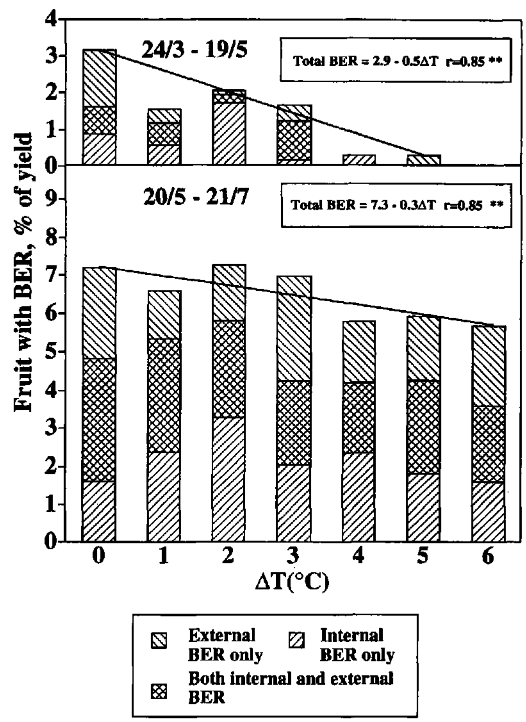

Figure 2. The influence of different root zone temperatures on incidence of external and internal blossom-end rot (BER) for 2 separate harvest periods. ΔT indicates intended increase in root temperature above that of the air.
Betydningen af forskellige rodtemperaturer for forekomsten af ydre og indre griffelråd (BER) i 2 plukkeperioder. ΔT angiver den tilstræbte forøgelse af rodtemperaturen i forhold til lufttemperaturen.

Table 1. Yield, Fruit size and percentage of grade 1 and 2, hollow fruit, fruit with blotchy ripening, external or internal blossom-end rot (BER), and total percentage of fruit with BER. Means of all root temperature treatments for 4 separate periods and for total harvest.
Udbytte, frugtstørrelse og procent 1. og 2. sortering, hule frugter, frugter med grønskjold, ydre griffelråd, sorte kerner (indre griffelråd) og samtlige frugter med griffelråd. Gns. af alle rodtemperaturbehandlinger for 4 perioder samt for hele høstperioden.

Time of year	Yield	Fruit size (grade 1)	Grade 1	Grade 2	Hollow fruit	Blotchy ripening	External BER	Internal BER	Total BER
Tid på året	*Udbytte*	*Frugtstr. (1. sort.)*	*1. sortering*	*2. sortering*	*Hule frugter*	*Grønskjold*	*Ydre grifråd*	*Sorte kerner*	*Grifråd total*
	kg/plant	g/fruit	weight%	weight%	weight%	weight%	weight%	weight%	weight%
	kg/pl.	*g/frugt*	*vægt%*	*vægt%*	*vægt%*	*vægt%*	*vægt%*	*vægt%*	*vægt%*
24/3 - 19/5	4.60	84	65	24	0.5	18.3[1]	1.0[2]	1.0[3]	1.5[4]
20/5 - 21/7	9.19	88	79	9	0	2.7	4.6	4.5	6.6[5]
22/7 - 15/9	4.80	87	67	15	0.3	3.4	12.9	11.8	17.1
16/9 - 27/10	2.48	88	71	14	2.4	1.3	14.1	20.8	26.2
24/3 - 27/10	21.07	87	72	15	0.5	7.3	6.7	7.3	10.1

1) % blotchy ripening = $15.7 + 1.0\Delta T$, $r = 0.83^*$
2) % external BER = $1.8 - 0.3\Delta T$, $r = 0.73^*$
3) % internal BER = $1.9 - 0.3\Delta T$, $r = 0.77^*$
where ΔT is intended increase in root temperature above actual air temperature.
4) and 5) Regression lines are shown in Fig. 2.

10 minutes intervals, are shown in Fig. 1 for treatments 0, 1 and 6. Similar means for treatments 2, 3, 4 and 5 are not presented; in most instances, they varied between those shown for treatments 1 and 6.

In the daytime, the root temperature without root zone warming almost coincided with the air temperature (Fig. 1). At night all root temperatures were higher than the air temperature because of the slow cooling of the rockwool slabs during the night. The largest differences in root temperature between treatments were found in February and March. In June and July no differences were found due to the relative high air temperatures outside and inside the glasshouse. In September and October marked differences in root temperature were again found.

Yield and quality

Table 1 shows means of all root temperature treatments as regards yield and fruit quality for 4 separate periods and for the whole harvest period. Results for greenback are not shown because greenback seldom appeared. No significant differences between root zone temperatures were found except for the incidence of blotchy ripening and blossom-end rot (BER).

Blotchy ripening increased and external and internal BER decreased with root temperature (ΔT) during the first 2 months of harvesting ($P<0.05$).

The percentages of yield with external and internal BER are shown in Fig. 2 for the first 4 months of harvesting. The total incidence of external and internal BER is also shown. BER was reduced by increased root zone temperatures. For the first 2 months no BER was seen at all in treatment 6.

No significant differences in BER were found between the treatments for the unripe fruit recorded at the end of the experiment; on the average 16 per cent by weight of these fruits had BER.

Generally, the external and internal BER were of the same magnitude (Table 1) and it was quite common that external and internal BER were not seen in the same fruit (Fig. 2).

Chemical composition of the fruit

No clear effect of different root zone temperatures or season was seen with regard to concentrations of soluble solids (RT), K, Na, Mg, Fe and Zn in the fruit.

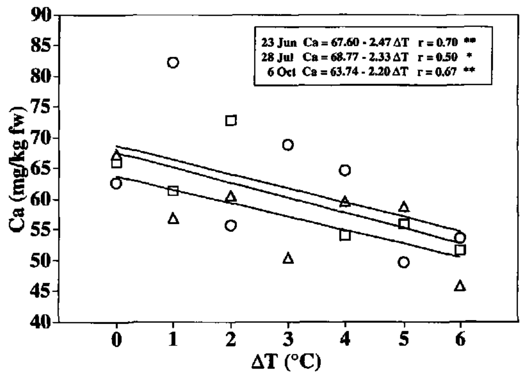

Figure 3. The influence of different root zone temperatures on the Ca content (mg/kg fresh weight) in ripe tomato fruit. Results are shown for the 3 dates of analysis where significant linear regression was found. ΔT indicates intended increase in root temperature above that of the air.
Betydningen af forskellige rodtemperaturer for Ca indholdet (mg/100 g friskvægt) i modne tomatfrugter. Resultater er vist for de 3 analysedage, hvor der blev fundet signifikant lineær regression. ΔT angiver den tilstræbte forøgelse af rodtemperaturen i forhold til lufttemperaturen.
□ 23 June, ○ 28 July, and △ 6 October.

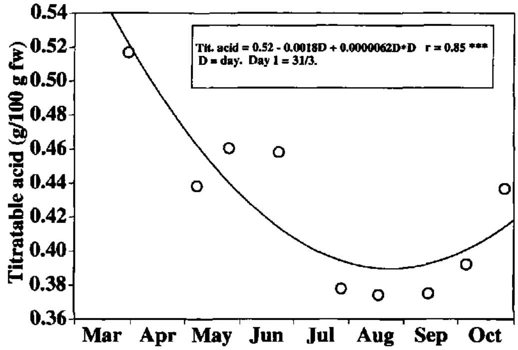

Figure 4. Effect of season on the concentration of titratable acid (g citric acid/100 g fresh weight) in ripe tomato fruit.
Høstdatoens betydning for koncentrationen af titrerbar syre (g citronsyre/100 g friskvægt) i modne tomatfrugter.

Ca concentration

Increased root zone temperatures had a negative effect on the Ca concentration (mg/kg fresh weight) in ripe fruit picked on 23 June, 28 July and 6 October (Fig. 3). No linear relations were found for the other 6 dates of analysis.

There were significant differences in fruit Ca concentration between harvest dates and interaction with root zone temperature. It was not possible to describe any of these relationships by linear orquadratic equations.

No correlation between Ca concentration and incidence of BER in the fruit was found.

Titratable acid, glucose and fructose

There were no differences in fruit content of titratable acid, glucose and fructose between different root zone temperatures, but significant seasonal differences were found. The content of titratable acid in ripe tomato fruit was highest in the spring and lowest in August-September (Fig. 4).

The seasonal variation in contents of glucose and fructose is shown in Fig. 5. The highest contents of fructose and glucose were found from the middle of June to the end of September. The lowest content was found on the 31th of March.

There was a very close correlation between the glucose and the fructose content of ripe tomato fruit (r = 0.98***). The fructose content was always higher than the glucose content (Fig. 5).

Vitamin C

There was interaction between treatments and harvest dates with regard to vitamin C.

The vitamin C concentration (mg total ascorbic

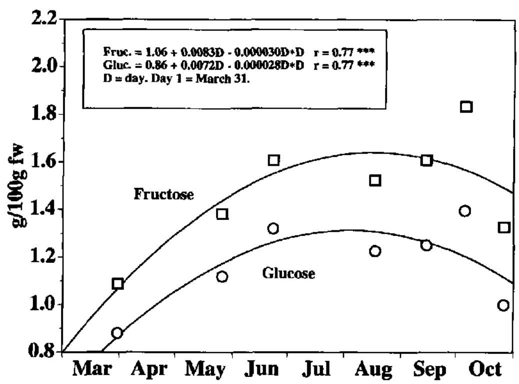

Figure 5. Effect of season on the concentrations of fructose and glucose (g/100 g fresh weight) in ripe tomato fruit.
Høstdatoens betydning for koncentrationerne af fruktose og glukose (g/100 g friskvægt) i modne tomatfrugter.
○ glucose, □ fructose.

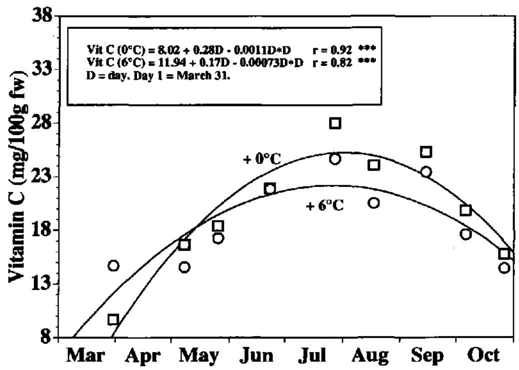

Figure 6. Effect of season on the concentration of vitamin C (mg/100 g fresh weight) in ripe tomato fruit in treatment 0 = (+0°C) and 6 = (+6°C).
Høstdatoens betydning for indholdet af C-vitamin (mg/100 g friskvægt) i modne tomatfrugter fra behandling
0 = (+0°C) og 6 = (+6°C).
○ treatment *behandling* 6, □ treatment *behandling* 0

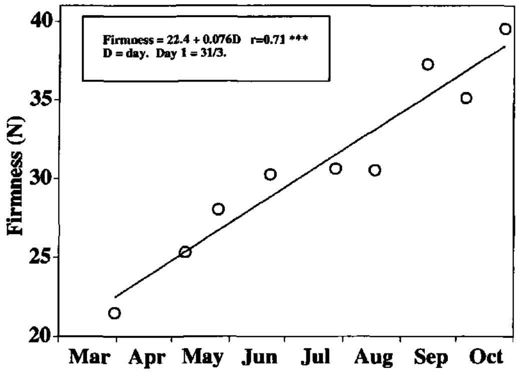

Figure 7. Effect of season on firmness (N) of ripe tomato fruit. Values are means of all root temperatures.
Høstdatoens betydning for fastheden (N) af modne tomatfrugter. Resultaterne er gennemsnit af alle rodtemperaturer.

acid/100 g fresh weight) differed significantly between different root zone temperatures, but no linear or quadratic relationship was found.

Significant effect of harvest date was also found. The vitamin C concentration in all treatments increased from 31 March to 28 July and then decreased. The relationships between harvest dates and vitamin C concentration in ripe fruit are illustrated for 2 of the treatments in Fig. 6.

Dry matter

The dry matter content of ripe tomato fruit differed significantly between root zone temperatures and harvest days. Interaction between root zone temperature and harvest day was found. The relationships could not be explained by linear or quadratic regressions.

Firmness

In the present experiment the firmness (Newton) of ripe tomato fruit increased during the season (Fig. 7).

No significant differences in firmness were found between the different root zone temperatures.

Discussion

For young non fruit-bearing tomato plants the optimal root temperature is approximately 25°C for uptake of the majority of mineral elements and for root and shoot dry weight and plant height (9, 14, 29).

In several studies 20-25°C was found to be the optimum temperature range for the quantity of yield due to a larger fruit size (8, 12, 19) or an increased number of fruits (24) while the quality in general was better at a root temperature between 15 and 20°C (8, 13, 19, 22, 26). Interactions between root temperature and air temperature (13, 22) or physiological age (19) may occur. Thus *Graves* (16) recommended that root temperature should be maintained at 15-18°C before picking starts, to ensure high fruit quality, and subsequently raised to 25°C to increase root and shoot growth and fruit yield. The higher temperature counteracts root death, the risk of which is prevalent when picking starts.

The main effect of root zone warming in the present experiment was on blossom-end rot (BER).

BER is a result of imbalance between phloem transport of sugars, N, P and K and xylem transport of Ca into the fruit causing leakage of the cell membranes in the distal part of the fruit; sufficient Ca is important for maintaining the correct permeability of cell membranes (11, 18).

The imbalance may be a result of either an increased rate of phloem transport or a decreased rate of xylem transport. An increased rate of phloem transport may occur in cases of increased photosynthesis caused by a sudden increase in solar radiation *(P. Adams & L.C. Ho;* personal communication, 1991). A decreased rate of xylem transport may occur if:

1) the environmental conditions favour an enhanced transpiration from the leaves (18),
2) the root pressure is decreased due to increased salinity in the root zone (6, 10, 11,), or
3) the resistance of the xylem tissue in the fruit and pedicel to water as well as Ca flow is increased. This is a long-term effect which can be caused by high salinity (10, 11).

Because the transpiration rate of the calyx is much higher than that of the fruit itself the calyx seems to play a role attracting xylem water and Ca towards the fruit (10, 11). At high salinities the surface area, and thereby the transpiration, of the calyx is reduced which may reduce the translocation of Ca to the fruit (10, 11).

The findings indicate that the incidence of BER depends on interactions between several growth factors. This explains why it is difficult to predict exactly in which situations BER will develop.

Only few researchers have evaluated the effect of root temperature on BER.

In the present experiment root zone warming reduced the incidence of both external and internal BER during the first 2 months of picking (Fig. 2). In this period the largest differences in root temperature were measured (Fig. 1). Almost no BER was seen where the root temperature was set at 4, 5 or 6°C above actual air temperature.

From May the incidence of BER increased (Table 1), but the differences between the treatments diminished because the root temperatures gradually became more or less the same in all treatments (Fig. 1). From July no clear differences in BER were seen, not even in September and October when root temperatures differed again from one treatment to the other.

These findings disagree with the results of *Chong & Ito* (8). They found, under summer conditions, a steady increase in BER, from 0.8 to 7.6 per cent of cumulative yield, when increasing the root temperature from 15 to 30°C; the concentration of Ca in fruit was not measured. The reason for the disagreement may be higher air temperatures in the experiment of Chong & Ito (8).

Papadopoulos and *Tiessen* (26) did not find any difference in incidence of BER in tomato between a root temperature of 24°C and an "unheated" treatment in a growth chamber experiment, and no interaction was observed between root and air temperatures. Neither under greenhouse conditions did they find any differences in BER between root temperatures of 21 and 27°C in spring and autumn crops.

Our results are, however, in accordance with English trials with sweet pepper where root warming to 24°C reduced the incidence of BER and increased yield *(M. Hardgrave & M. Harriman,* personal communication 1991).

Because BER is caused by Ca deficiency in the fruit a negative correlation between the incidence of BER and the Ca concentration in the fruit was expected, but no significant correlation was found for any period of the experiment. Determination of the Ca concentration in whole tomato fruit as done in this experiment is probably unsuitable for correlating Ca concentration to BER (1, 3, 28). A more specific analysis of the distal part of fruit is required. Furthermore, not all Ca compounds are of the same importance to BER (4, 17, 28).

The negative correlations between root temperature and Ca concentration in the fruit found in the present experiment disagree with earlier results of *Willumsen et al.* (unpublished) for tomato grown in water culture at solution temperatures maintained constantly at 20 or 25°C (experimental period: 31 January – 30 May). On the average, a significantly higher concentration of Ca was measured in mature fruit at 25 than at 20°C, 83 and 69 mg Ca per kg fresh weight respectively; no difference in yield was found.

Adams (1) found for a spring crop of tomato a higher concentration of Ca in fruit dry matter at 22°C compared to lower (14 and 18°C) and higher (26°C) root temperatures. With a possible optimum of about 22°C it may be questionable to compare the Ca concentration at 20 and 25°C, as done by *Willumsen et al.* (unpublished), and difficult to get a consistent result from the present experiment where the root temperatures were following the variations of the air temperature.

The above indicates that it is difficult to draw a clear conclusion as to the effect of root temperature on the content of Ca in tomato fruit and on the incidence of BER.

2 of the most important factors influencing the taste of tomato fruit are the contents of sugars and organic acids. High concentrations of both components form the basis of a good taste. In addition, the content of volatile compounds has a considerable influence on the aroma.

In the present experiment no effect of root zone warming was seen on the contents of titratable acid, glucose and fructose. This might be due to the relatively small differences in root zone temperature during the harvest season. The concentration of titratable acid decreased from the beginning of April until mid-September and increased thereafter. This is in agreement with *Willumsen et al.* (32) and *Benoit* and *Ceustermans* (7) who found a decreasing content of titratable acid from truss 1 to truss no. 9, whereas *Winsor* and *Adams* (33) did not find any systematically seasonal variation in 2 varieties of tomato. The concentration of titratable acid in tomato fruit is positively correlated with the K concentration in the fruit (30). The concentration of K in the fruit is dependent on the concentration of K in the nutrient solution and on the uptake rate by the roots (5, 30). *Voogt* (30) has shown that the concentration of K in per cent of dry matter in both fruit and leaf samples was higher early in the season (11/4) compared to 4/8 and 9/10, and that the rate of K uptake decreased with plant age. These results are consistent with our measurements of titratable acid.

Maximum fructose and glucose concentrations were found during midsummer in the present experiment in agreement with other results showing that the content of sugar follows the solar radiation (21, 33).

One of the most important vitamins in the tomato fruit is vitamin C. The seasonal variation suggests that vitamin C concentration, like sugars, depends on the solar radiation. *Janse* and *van Winden* (21) found a similar increase in vitamin C in both rockwool grown and soil grown tomatoes from 16 May to 20 June. In tomato grown in nutrient film the vitamin C content increased from truss 1 to truss 8 and then decreased (7).

Firmness of tomato fruit is of importance to both the distributors and the consumers. Firmness is very much dependent on the ripeness of tomatoes (20). *Benoit* and *Ceustermans* (7) found a decrease in firmness from truss no. 1 to truss no. 9. Therefore the increase in firmness during the season shown in the present experiment may reflect differences in ripeness rather than seasonal differences.

Conclusion

During the spring it appears possible to reduce the incidence of both external and internal blossom-end rot (BER) in the tomato cultivar Matador by root zone warming thereby increasing the saleable yield. In the present experiment BER was reduced when root temperature during the spring was kept 4-6°C above the actual air temperature (15-21°C). Root zone warming did not affect BER later in the season, and it did not change the chemical composition of the fruit in any notable way.

The concentrations of glucose, fructose and vitamin C reach the highest values during midsummer, in this experiment simultaneously with the lowest concentrations of titratable acid.

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Manuscript received 29 October 1992.