How to Reduce Yield Fluctuations in Sweet Pepper?

E. Heuvelink
Wageningen University
Horticultural Production Chains Group
Marijkeweg 22
6709 PG Wageningen
The Netherlands
E-mail: Ep.Heuvelink@wur.nl

L.F.M. Marcelis
Plant Research International
P.O. Box 16
6700 AA Wageningen
The Netherlands
E-mail: Leo.Marcelis@wur.nl

O. Körner
Wageningen University
Farm Technology Group
Mansholtlaan 10-12
6708 PA Wageningen
The Netherlands
E-mail: Oliver.Koerner@wur.nl

Keywords: *Capsicum annuum*, yield flushing, fruit set, fruit abortion, parthenocarpy, planting dates, fruit pruning

Abstract

Flushing, i.e. cyclic fluctuations in fruit yield, is an important problem in sweet pepper production. These fluctuations result from cyclic variations in fruit set. Therefore, the relationship between fruit set and plant sink and source strength was investigated in several greenhouse experiments. A decrease in plant source strength by decreasing inter-plant distance or light intensity or by leaf removal led to a decrease in fruit set. For example, the percentage of fruit that set was 32, 20 and 16% at a plant density of 1.6, 3.1 and 4.6 plants m^{-2}, respectively. Plant sink strength was varied by the number and position of competing fruits on the plant. Fruit set decreased with increased plant sink strength, e.g. in plants with 0, 1, 2 or 4 early-formed fruits, fruit set of four later-formed flowers was 78, 56, 28 and 6%, respectively. Average rate of fruit set could be predicted from the ratio between plant source and sink strength. Removal of some flowers and/or young fruits in periods of abundant fruit set did reduce the cyclic fluctuations in fruit set and yield, but less than expected. When planting in late spring, as opposed to a winter planting, yield fluctuations at farm level could be substantially reduced by adopting two planting dates with four weeks in between. An increase in seed number, resulting from higher pollen load on the stigma of flowers, increased the inhibitory effect of a fruit on set and growth of later developing fruits. Variation in fruit set and yield was strongly reduced in plants with parthenocarpic fruit growth, obtained by preventing pollination through applying a lanolin-auxin paste onto the stigmas of all flowers on a plant. Hence, developing seeds in sweet pepper fruits are an important cause of the abortion of new flowers, and irregular fruit set and yield.

INTRODUCTION

Sweet pepper (1194 ha in 2001) is the most important greenhouse vegetable crop in The Netherlands. Its annual production value is equivalent to € 391 million (in 2001). Typically, sweet pepper crops are planted late November or early December, fruit set commences from the first weeks of January, first ripe fruits are harvested in March and final harvest is at the end of October. Yield levels of red sweet peppers are 25-30 kg per m^2 per year (KWIN, 2002).

An important problem in sweet pepper production is ‘flushing’: weeks with high yields are alternated by weeks with low yield (Fig. 1). This irregular harvest pattern makes it difficult for growers to meet regular weekly demands. As this cyclic production

Proc. XXVI IHC – Protected Cultivation 2002
Ed. A.P. Papadopoulos
Acta Hort. 633, ISHS 2004
Publication supported by Can. Int. Dev. Agency (CIDA)

pattern is more or less the same for all growers, it results in weeks with a high market supply and low prices alternating with weeks with a low market supply and high prices. Flushing also results in strong fluctuations in labour demand in the greenhouses. Cyclic fluctuations in yield result in variations in fruit load on the plants. In periods with low fruit load, high initial fruit growth rates may occur, resulting in blossom-end rot (BER), a physiological disorder, caused by local calcium deficiency during the initial stage of fruit development (Bangerth, 1979; Marcelis and Ho, 1999). BER causes high economic losses in sweet pepper production, as affected fruits have little value. Avoiding an irregular pattern of sweet pepper production is of great economic importance.

Sweet pepper plants show irregular fruit set, which seems to be the main reason for yield fluctuations (Fig. 1). Furthermore, abscission of flower buds, flowers and fruits is an important yield-limiting factor (Wien et al., 1989). In each leaf axil typically one flower is formed. Several fruits set at more or less the same time. A number of axils above these fruits show severe abortion, followed by axils with good fruit set. This leads to the following hypothesis: the presence of developing fruits inhibits subsequent set and growth of new fruits both by competition for limited assimilates as well as by dominance due to the production of plant growth regulators (Marcelis and Baan Hofman-Eijer, 1997). Flowers initiated on the plant in this phase will generally abort. Only when the early formed fruits are almost full-grown and their sink strength (competitive ability to attract assimilates) is low, new fruit set can occur. Hence, on a sweet pepper stem, a group of nodes with fruits is followed by a group of nodes without fruits, explaining the periods of high and low yields.

In this paper, support for the above-mentioned hypothesis, that the irregular fruit set in sweet pepper is positively correlated to fluctuations in plant source:sink ratio, is presented. Based on this hypothesis, practical solutions to overcome the problem of yield flushing are discussed, supported by experimental data. Data presented here are based on a large number of published and unpublished experiments conducted over the last 10 years. Here, a brief overview of the most important results is given.

MATERIAL AND METHODS

Unless stated otherwise, experiments were conducted with *Capsicum annuum* L. cv. Mazurka (red-fruited), grown in either aerated nutrient solution in climate chambers or on rockwool slabs in compartments of a multispan Venlo-type glasshouse in Wageningen (latitude 52°N). Plants show a dichotomic branching and were pruned to one or two main branches per plant with side shoots stopped at one leaf. Hence, for each node position on a stem there were two flowers, one on the main stem and one on the decapitated side shoot.

INFLUENCE OF SOURCE AND SINK STRENGTH ON FRUIT SET

Source Strength

The influence of a decrease in source strength (assimilate supply) on fruit set was studied in three experiments by decreasing inter-plant distance or light intensity or by leaf removal. In all cases a decrease in source strength led to a decrease in fruit set. In a greenhouse experiment (planted in January and ended in July) the average proportion of fruit that set was 32, 20 and 16% at a plant density of 1.6, 3.1 and 4.6 plants m^{-2}, respectively. In a greenhouse experiment, planted in August, plants were pruned to one main branch per plant. At anthesis of the first flower of the main branch leaf number was varied by removing 0, 20, 40, 60 or 80% of the leaves below the fourth node of the main branch while all flowers below that node were removed. Abortion of four flowers/fruit at the fourth and fifth node was studied. Above these flowers, all flowers except two at node position 6, were removed. Fruit set decreased with number of removed leaves and was 78, 69, 67, 50 and 50%, respectively. In a climate room experiment (one main branch per plant; 13 flowers retained per plant) fruit set was 25, 38, 54 and 92%, at light intensities of 1.1, 1.8, 2.8 and 4.8 MJ PAR m^{-2} d^{-1}, respectively. The lowest and the highest light integrals were similar to greenhouse conditions in the Netherlands at the end of January and mid-May, respectively.

Sink Strength

Effects of sink strength (assimilate demand) on fruit set was studied in three experiments. Firstly, a greenhouse experiment showed a negative correlation between fruit set and plant sink strength (Fig. 2). Sink strength was calculated based on actual fruit set dates and a potential fruit growth curve (Marcelis, 1994; Marcelis and Baan Hofman-Eijer, 1996). From January towards summer, a general increase in plant sink strength was observed (Fig. 2), as the average number of fruits growing on a plant increased. However, it was clearly shown that peaks in the number of young fruits on the plant coincided with periods of low sink strength and vice versa (Fig. 2).

In further experiments, sink strength was varied by changing the number and position of early-formed fruits on plants pruned to one main branch per plant. In an experiment with 0, 1, 2 or 4 early-formed fruits (nodes 1 and 2), fruit set at four higher flower positions (nodes 4 and 5) was 78, 56, 28 and 6%, respectively. In another experiment one early-formed fruit was retained at node 1, 3, 5, 7, 8 or 9. The effect of these early-formed fruits on abortion of two flowers/fruit at node position 10 was studied. From anthesis of the early-formed flowers onwards, no other flowers/fruit were allowed except the two flowers/fruit at node position 10. At anthesis of the flowers in node position 10, the age of the early-formed fruits was 42, 32, 23, 14, 9 or 5 days, respectively. A strong negative correlation between fruit set in node 10 and growth rate of the early formed fruit during one week after anthesis of the flowers in node 10 was observed.

Source:Sink Ratio

It is concluded, that in sweet pepper fruit set is positively correlated with source strength, negatively correlated with sink strength and therefore positively correlated with the source:sink ratio. Although most of the variation in abortion can be related to the sink and source strength, some effects of competing fruits can only be explained by a combination of competition and dominance (Marcelis and Baan Hofman-Eijer, 1997). Based on source:sink ratio, average rate of fruit set could be predicted for a greenhouse experiment. Source strength was calculated by an explanatory photosynthesis model and sink strength was based on fruit set and harvest dates and a constant vegetative sink strength. Also in cucumber (Marcelis, 1994) and tomato (Bertin and Gary, 1993), fruit set showed a positive correlation with the plant source:sink ratio. However, in addition to a low source:sink ratio, climatic stress, e.g. severe water stress and high irradiance (Jaafar et al., 1994) or high temperatures (Rylski and Spigelman, 1982; Aloni et al., 1991) may induce abortion in peppers.

PRACTICAL SOLUTIONS TO THE FLUSHING PROBLEM

Planting Dates

Using a delayed planting date in part of the greenhouse, may result in a more regular harvest pattern of the whole greenhouse, as the production peaks for the delayed planting might fill the production gaps of the earlier planting. In a greenhouse experiment, half of the plants were sown on March 4th and planted on April 23rd, whereas the other half was sown on April 1st and planted on May 21st. Both plantings showed the expected flushing in yield (Fig. 3). However, the overall production of the greenhouse was much more regular, as indeed peaks of the second planting were in between peaks of the first planting (Fig. 3). In another experiment, where planting dates in December and early January were used, only the first flush occurred at a different moment but later flushes synchronised (cv. Spirit; data not shown). This was also concluded by Verberne (1991), based on a comparison of groups of growers using different planting dates between November 20st and 27 December 27th. It may be that in winter, a low light level results in only a small number of fruits set in the first flush, not initiating a strong cyclic behaviour.

Furthermore, periods with low light levels in winter or early spring may result in fruit abortion anyway, whatever the phase of the plant, so independent of planting date. After such a period all plants will show fruit set, hence resulting in a synchronised fruit set and yield pattern.

Fruit Pruning

Based on the validated hypothesis, that fruit set is positively correlated with source:sink ratio, strategic flower or young fruit removal could be used as a way to influence the fruit set pattern and hence yield flushing. In a greenhouse experiment, planted in April, a regular fruit set of 1.6 ± 0.2 (mean ± standard deviation over time) fruits per plant per week could be obtained by flower or young fruit removal in an early stage. Plants were pruned twice a week such that every week 1 fruit per stem could set. This was not always achieved as all flowers of that week aborted. In the control plants (no flower or fruit removal), the first flush in fruit set showed a peak of 4.9 fruits per plant per week, whereas a few weeks later almost no fruit set was observed (only 0.6 fruits per plant per week). This resulted in an average fruit set of 2.1 ± 1.2 fruits per plant. The pruning treatment, with its regular fruit set at 1.6 fruits per plant per week, resulted in a yield pattern with a reduced first flush and extra yield between the first and second flush of the control treatment. Due to larger fruits in the pruning treatment, total yield did not differ between both treatments. Despite the regular fruit set pattern in time for the pruning treatment, harvest pattern was not completely regular. This may be the result of variation in time from fruit set to maturity among fruits.

Parthenocarpic Fruit Growth

Marcelis and Baan Hofman-Eijer (1997) studied the effect of seed number on inhibition of later-developed fruits by varying the pollen load on the stigma of sweet pepper flowers. Despite much variation, a linear increase in individual fruit weight with seed number could be observed. When seed numbers were low, the probability of fruit setting was positively related to seed number. However, a relatively low seed number (50-100 seeds/fruit: 20-30% of the maximum seed number) was sufficient for maximal fruit set. An increase in seed number increased the inhibitory effect of a fruit on set and growth of later-developing fruits. Therefore, it can be speculated that reducing pollination during peaks in fruit set and promoting pollination during periods of low rates of fruit set is an effective way of creating a regular production of fruits. Furthermore, parthenocarpic pepper cultivars, which show fruit growth without seeds, could offer a possibility of producing more regular yields. For cucumber, parthenocarpic cultivars were introduced in the 1970s. These cultivars showed a strong reduction in the inhibitory effect of growing fruits on growth of newly-formed flowers/fruit and the remainder of the plant. Parthenocarpic cucumber cultivars also showed less yield fluctuation compared to the old cultivars with seeds (De Stigter, 1969; Marcelis, 1994).

Parthenocarpic sweet pepper cultivars are not yet available; therefore chemical induction of parthenocarpy was used by Heuvelink and Körner (2001) to study the possibilities for reduction of yield fluctuations by parthenocarpic cultivars. Two treatments were conducted. In the control treatment, plants of the yellow-fruited cultivar Fiësta were grown according to commercial practice (no fruit set treatment). In the other treatment, fruits were grown parthenocarpically. To obtain parthenocarpic fruits, pollination was prevented while auxins were applied. Flowers close to anthesis (balloon stage) were slightly opened using the tip of a syringe. The stigmas were covered with a lanolin paste from the syringe, mixed with water (1:1) and enriched with 0.05% 1-naphthalene acetic acid (NAA). In these auxin-treated plants, 86% of the fruits were seedless (parthenocarpic) and 95% contained less than 30 seeds per fruit. For the control plants, 62% of the fruits were well-pollinated and contained more than 100 seeds, while none contained less than 60 seeds (Heuvelink and Körner, 2001). As expected, the fruit set pattern for the auxin-treated plants was more regular than for the control plants (Fig. 4). Weekly fruit fresh yield varied between 0.2 and 1.0 kg m^{-2} for control plants (coefficient of variation (CV) = 20%), and between 0.4 and 0.8 kg m^{-2} for auxin-treated plants (CV = 9%). Results showed that developing seeds in sweet pepper fruits are a main cause of the abortion of new flowers, and irregular fruit set and yield. Parthenocarpic fruits were flatter and 30% smaller in fresh weight, the latter because of a reduction in fruit growth rate; the duration of fruit growth was 1 week longer than for fruits from control plants (Heuvelink and Körner, 2001). Parthenocarpic fruits did hardly show BER with only 1% of the fruits being affected compared to 31% in the control. This agrees with the observation of Marcelis and Ho (1999), that the number of seeds in sweet pepper fruits was positively correlated with the incidence of BER. Their smaller size and 1 week longer growth period meant a much lower average fruit growth rate for parthenocarpic fruits, significantly reducing the chances of BER (Marcelis and Ho, 1999).

CONCLUDING REMARKS

Yield fluctuations in sweet pepper are primarily the result of an irregular fruit set pattern. Fruit set was shown to be positively correlated with plant source:sink ratio. Practical solutions for growers to obtain a more regular yield pattern at farm level are the use of several planting dates or fruit pruning. On the longer term, the development of parthenocarpic cultivars looks promising. Partenocarpic fruit growth resulted in a more regular fruit set and yield and also strongly reduced the problem of BER. However, at present no high-yielding parthenocarpic cultivars, with good fruit shape and size are available.

Literature Cited

Aloni, B., Pashkar, T. and Karni, L. 1991. Partitioning of ^{14}C sucrose and acid invertase activity in reproductive organs of pepper plants in relation to their abscission under heat stress. Ann. Bot. 67:371-377.

Bangerth, F. 1979. Calcium-related physiological disorders of plants. Ann. Rev. Phytopathol. 17:97-122.

Bertin, N. and Gary, C. 1993. Evaluation d’un modèle dynamique de croissance et de développement de la tomate (*Lycopersicum esculentum* Mill.), TOMGRO, pour different niveaux d’offre et de demande en assimilats. Agronomie 13:395-405.

De Stigter, H.C.M. 1969. Growth relations between individual fruits, and between fruits and roots in cucumber. Neth. J. Agric. Sci. 17:209-214.

KWIN 2002. Kwantitatieve informatie voor de glastuinbouw. Praktijkonderzoek Plant en Omgeving – Glastuinbouw, Aalsmeer/Naaldwijk, Netherlands.

Marcelis, L.F.M. 1994. A simulation model for dry matter partitioning in cucumber. Ann. Bot. 74:43-52.

Marcelis, L.F.M. and Baan Hofman-Eijer, L.R. 1996. Growth analysis of sweet pepper fruits (*Capsicum annuum* L.). Acta Hort. 412:470-478.

Marcelis, L.F.M. and Baan Hofman-Eijer, L.R. 1997. Effects of seed number on competition and dominance among fruits in *Capsicum annuum* L. Ann. Bot. 79:687-693.

Marcelis L.F.M. and Ho, L.C. 1999. Blossom-end rot in relation to growth rate and calcium content in fruits of sweet pepper (*Capsicum annuum* L.). J. Exp. Bot. 50:357-363.

Heuvelink, E. and Körner, O. 2001. Parthenocarpic fruit growth reduces yield fluctuation and blossom-end-rot in sweet pepper. Ann. Bot. 88:69-74.

Jafaar, H., Black, C.R. and Atherton, J.G. 1994. Water relations, dry matter distribution and reproductive development of sweet pepper (*Capsicum annuum*). Asp. Appl. Biol. 38:299-306.

Rylski, I. and Spigelman, M. 1982. Effects of different diurnal temperature combinations on fruit set of sweet pepper. Sci. Hort. 17:101-106.

Verberne, C.E.J. 1991. Plantdatum beïnvloedt productiepatroon niet. Groenten en Fruit/ Glasgroenten 1(41):18-21.

Wien, H.C., Turner, A.D. and Yang, S.F. 1989. Hormonal basis for low light intensity-induced flower bud abscission of pepper. J. Amer. Soc. Hort. Sci. 114:981-985.

Figures

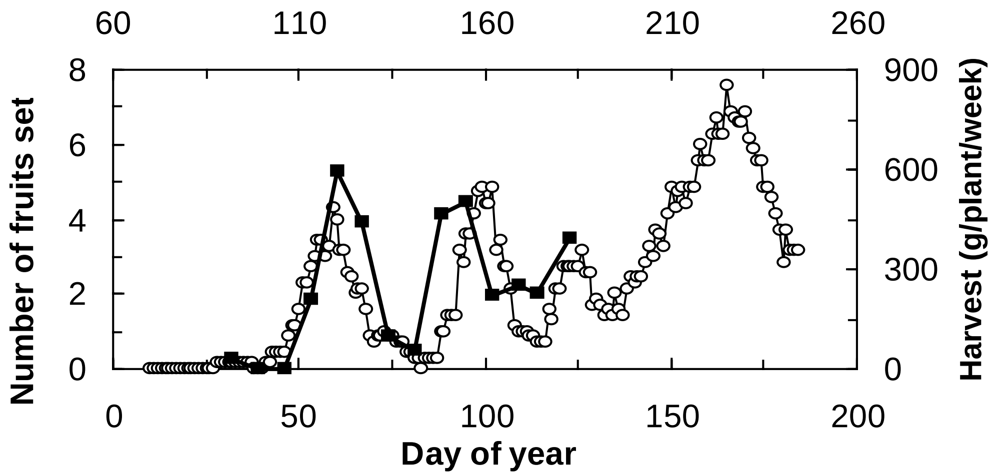

Fig. 1. Seasonal pattern of fruit set per plant (o; number of young fruits, less than 10 days from anthesis; time axis at bottom of graph) and harvest (■; fresh weight per plant; time axis at top of graph) of greenhouse-grown sweet pepper plants.

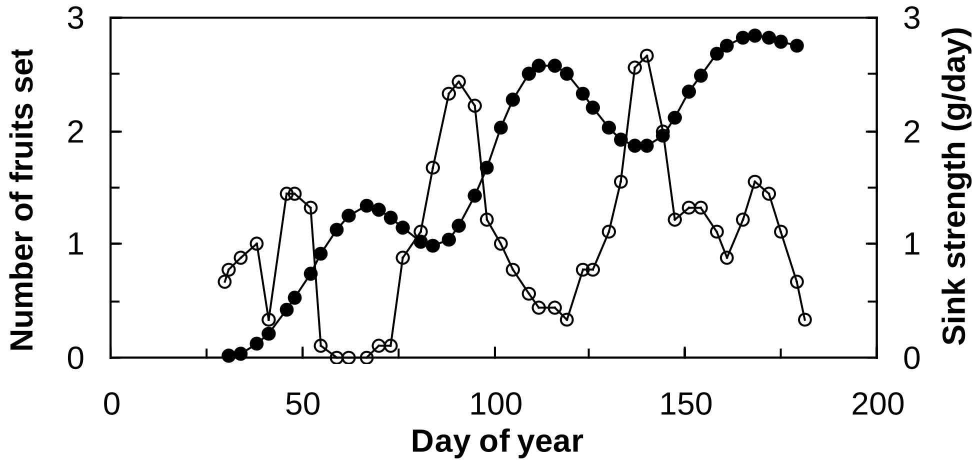

Fig. 2. Fruit set (o; number of young fruits, less than 10 days from anthesis) of sweet pepper plants and calculated plant sink strength (•) during a growing season. Calculation of sink strength is based on temperature and dates of set and harvest of fruits.

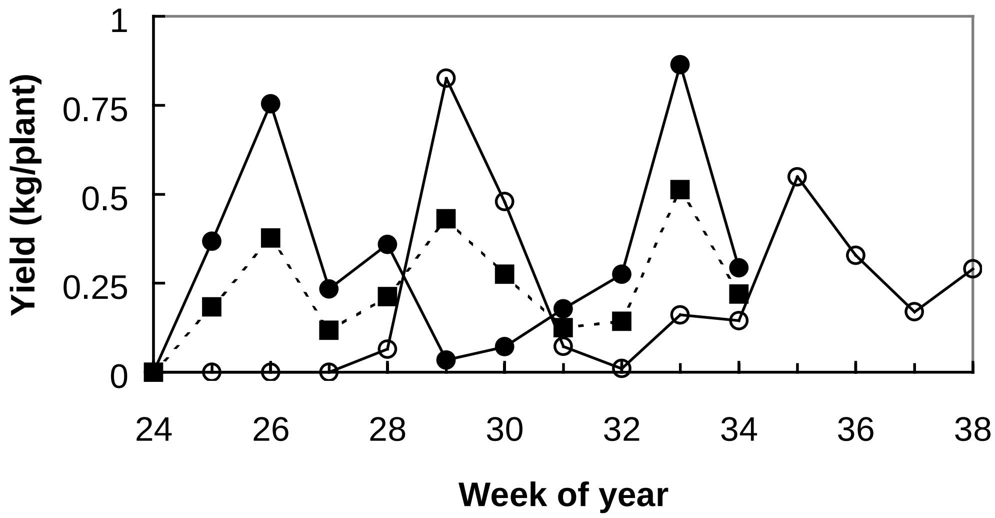

Fig. 3. Yield patterns for sweet pepper crops planted end of April (•; week 17) or end of May (o; week 21) and yield pattern averaged (■) for the two crops.

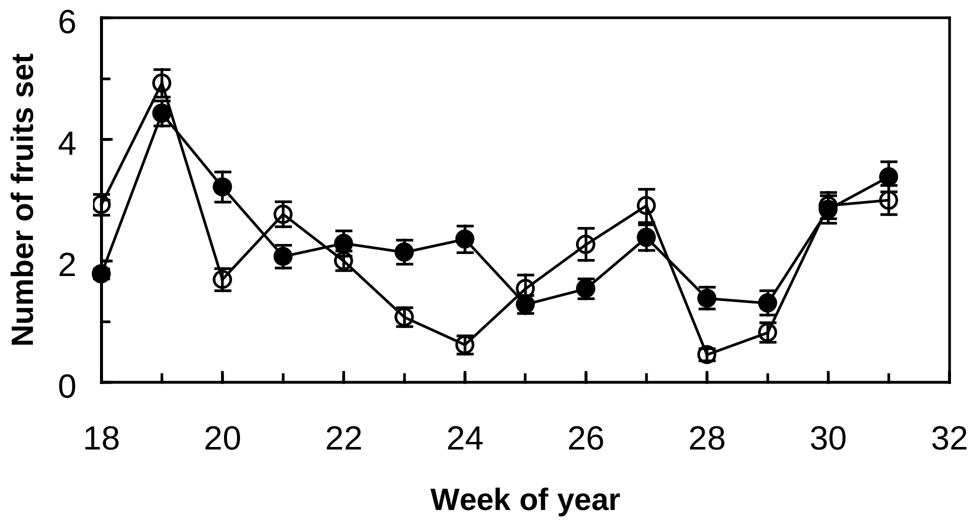

Fig. 4. Fruit set per plant (defined as number of harvested fruits that set in a certain week) as a function of time for control (o) and auxin-treated (•) plants. Vertical bars indicate standard error of mean.