GROWTH ANALYSIS OF SWEET PEPPER FRUITS (CAPSICUM ANNUUM L.)

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Abstract

Growth of individual sweet pepper fruits was measured destructively as well as non-destructively throughout their development. Moreover, the relative contributions of different fruit parts to the growth of the fruit were quantified. The length, circumference and fresh and dry weight of the fruit followed sigmoid growth curves. At 20°C the fruit reached the marketable stage for green sweet pepper at 40-45 days after anthesis (DAA), while about 20 days later the fruit turned red. After 45 DAA fresh weight hardly increased while the dry weight increased by about 20%. The dry-matter percentage of the fruit decreased from 16-18% at anthesis to 6-8% at 30 DAA; thereafter it increased to 8-10%. The time course of the dry-matter percentage of pericarp and placental tissue showed a pattern similar to that of the total fruit. However, during fruit development the dry-matter percentage of the seed increased to 50%. The dry weight of the seeds as a fraction of the total fruit dry weight was rather constant during fruit development, but varied considerably among individual fruits (0-18%).

Key words: Fruit growth curve, fruit dry matter content, seed, non-destructive measurements.

1. Introduction

In fruit vegetable crops like sweet pepper, after an initial period of only vegetative growth, flowers and fruits are continuously formed and are harvested over an extended period, while growth of the vegetative parts also continues. However, the number of fruits growing simultaneously on a plant may change cyclically. Hence, fruit production rate strongly fluctuates (Kato & Tanaka, 1971; Hall, 1977). The main factors determining the number of fruits produced are the rates of abortion of flower buds, flowers and young fruits (Bakker, 1989a; Wien et al., 1989). Wien et al. (1989) concluded that the most important causes of abortion in pepper are environmental factors such as high temperature, low light, drought, diseases or insect pests. The effects of drought, diseases or insect pests are of minor importance in modern glasshouse industry in temperate zones. The effects of low light, and to some extent also those of high temperature, are probably mediated through the ratio between assimilate supply and demand (source/sink ratio), as discussed for other crops by Kinet (1977), Lieth et al. (1986) and Marcelis (1994). In addition to environmental factors, the presence of earlier formed fruits is an important factor inducing abortion in many plant species (Tamas et al., 1979; Schapendonk & Brouwer, 1984; Stephenson et al., 1988; Bangerth, 1989).

An increase in the number of fruits growing on a plant may lead to an increase in abortion of flowers and young fruits. Consequently, cyclic variations in fruit abortion and fruit production occur. As fruits are important sinks for assimilates, the effects of earlier formed fruits are probably mediated to a large extent through the assimilate availability, but also hormonal control might be involved (Ruíz & Guardiola, 1994). The fruits on a plant strongly compete with each other and with the vegetative plant parts for the available assimilates (Hall, 1977; Ali & Kelly, 1992). Hence, variations in number of fruits on a plant may result in fluctuations in size of individual fruits.

A quantitative analysis of the growth curves of individual fruits is essential for studies on the demand of fruits for assimilates and for studies on the effects of sink competition for assimilates on abortion of young fruits. Moreover, to assess effects of assimilate supply and demand on fruit size the amount of assimilates needed for growth of a fruit should be quantified throughout the development of a fruit. In the present study growth of individual sweet pepper fruits was measured destructively as well as non-destructively throughout their development. Moreover, the relative contributions of different fruit parts to the growth of the fruit were quantified.

2. Materials and methods

Sweet pepper plants (*Capsicum annuum* L. cv. Mazurka) were grown on an aerated nutrient solution. Sweet pepper shows dichotomic branching (Rylski, 1985). One (Exp. 3) or two (Exp. 1 and 2) first-order branches were retained. Subsequently, the largest of each two dichotomic branches was retained, while the smallest one was pruned just above its first leaf. This procedure is also applied in commercial practice. In this way, plants with apparently one or two main branches were formed, with side shoots pruned above their first leaf.

In Exp. 1 and 2, seeds were sown on 25 October 1993. Plants were grown in an air-conditioned glasshouse. Daily temperature was 20.1±0.1°C (day/night: 21.5/18.8°C). Plants were grown at a density of 2.1 plants per m^2. No fruit pruning was applied. In Exp. 1, the dates of anthesis of the flowers were recorded once a week. At 5 dates (8 March, 9 April, 3 and 30 May and 29 June 1994) all fruits of 6 random plants were harvested. At harvest, the length, circumference, diameter, fresh weight and dry weight (after drying for at least 2 days at 100°C) of the fruits (without peduncle) were determined. Plants were surrounded by guard plants at all sides. In Exp. 2, the two border rows of Exp. 1 were used; as these plants were not surrounded at all sides by guard plants, the plants from Exp. 2 had a higher light interception per plant than those from Exp. 1. The dates of anthesis of the flowers were recorded twice a week. At 12 July 1994 all fruits from 10 plants from one border row (east side) were harvested and at 18 July 1994 those of 10 plants from the other border row (west side). Similar measurements were made as in Exp. 1. In addition, the fresh and dry weights of the seeds were determined. At 18 July 1994 also the fresh and dry weights of the pericarp and the placental tissue were determined.

Volume was calculated from length and circumference or diameter, assuming the fruit to be cylindrical:

$$V = LC^2 / (4\pi) \qquad \text{or} \qquad V = \pi LD^2 / 4$$

Where V is volume (cm^3); L is length (cm); C is circumference (cm); D is diameter (cm).

In Exp. 3, 5 plants were grown in three subsequent periods (in total 15 plants) in a climate chamber illuminated by high pressure sodium lamps (Philips SON-T 400W) and fluorescent tubes (Metalicht 58W colour 33; ratio between number of fluorescent tubes and sodium lamps was 1:3). Photosynthetically active radiation was approximately 30 W m^{-2} at a 12h photoperiod. After the main light period, the chambers were illuminated by incandescent lamps for 15 minutes. Average temperature was 20°C (day/night: 22/18°C); relative air humidity was about 80%. All flowers were removed except 3 flowers at the 3rd, 4th and 5th node on the main branch. Plants were pruned above the 12th leaf on the main branch. Length and circumference of the fruit at the 4th node was measured twice a week; until the fruit had reached a diameter of 1cm, the circumference was estimated from the diameter ($C= D$). Fresh and dry weight were estimated non-destructively, using the regression equations derived from Exp. 1 and 2. The rates of fresh and dry weight increase were smoothed by calculating moving averages of three successive measurements.

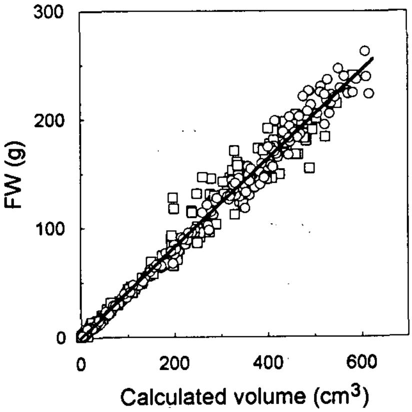

Fig. 1. Fruit fresh weight as a function of volume calculated from length and circumference of the fruit. Each symbol represents one fruit. n=496, FW=0.409X, r^2=0.987. Exp. 1 (□) and 2 (○).

3. Results

Fruit volume calculated from length and circumference correlated highly with fruit fresh weight (figure 1). The average error for prediction of the fresh weight was 10% (95% confidence). Multiple regression analysis revealed that the relationship between calculated volume and fresh weight was not significantly affected by the shape (length/circumference ratio varying between 0.2 and 0.5), the age and size of the fruits (data not shown). When the diameter instead of the circumference was used to estimate fruit volume (V) and subsequently fruit fresh weight (FW) similar results were obtained ($FW=0.402V$; $r^2=0.992$).

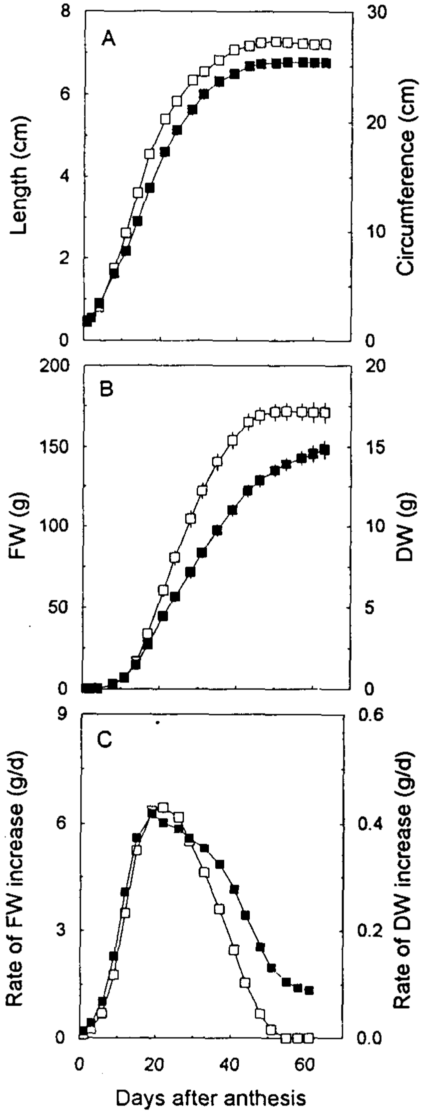

Fig. 2. Growth in length (A: □), circumference (A: ■) and estimated fresh weight (B, C: □) and estimated dry weight (B, C: ■) of a fruit as a function of time after anthesis at 20°C. Data are means of 15 fruits; vertical bars represent standard errors of means (Exp. 3).

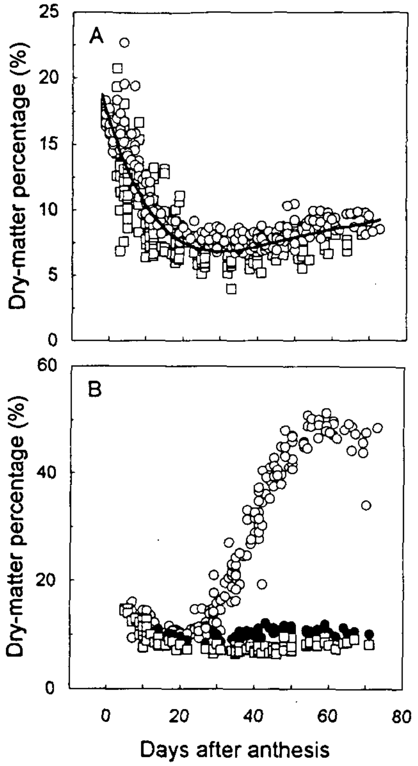

Fig. 3. Dry-matter percentage (% of fresh weight) of total fruit (A) and pericarp (B: □), placental tissue (B: ●) and seeds (B: ○) as a function of time after anthesis at 20°C. Each symbol represents one fruit. n=579, 93, 83 and 171 for total fruit, pericarp, placenta and seed, respectively. Fruit dry-matter percentage was fitted by a fourth order polynomial; r^2=0.736. Exp. 1 (A: □) and Exp. 2 (A: ○, B).

At 20°C fruits reached the stage of marketable green at 40-45 d after anthesis (DAA) and the stage of marketable red at 60-65 DAA. Length, circumference and fresh and dry weight of the fruits followed sigmoid curves (figure 2A,B). Length and circumference of the fruit increased simultaneously. The rapid increase in fresh weight started slightly later than the rapid increase in length and circumference. The fruit reached its maximum rate of fresh weight increase at 20 DAA. After the fruit had reached the stage of marketable green, fresh weight (nor volume) hardly increased while the increase in dry weight was still considerable (20%).

The dry-matter percentage of the fruits decreased from 16-18% at anthesis to 6-8% at 30 DAA; thereafter it increased to 8-10% (figure 3A). The average dry-matter percentage in Exp. 2 was slightly higher than in Exp. 1. The time course of dry-matter percentage of the pericarp and that of the placental tissue showed a pattern similar to that of the total fruit (figure 3A,B). Initially the dry-matter percentage of the seeds was close to that of the rest of the fruit, but from about 20 DAA it rapidly increased to 50% (figure 3B).

Initially the fruit dry weight consisted of equal fractions pericarp and placental tissue (figure 4). During fruit development the fraction pericarp dry weight increased to 75-85%, while that of the placental tissue decreased to 10-15%. The fresh weight of the seeds was already formed to a large extent during the first few weeks after anthesis (figure 5A). The fresh weight of the seeds as a fraction of the total fruit fresh weight decreased considerably during ontogeny of the fruit to 1-2% in red fruits (figure 5C). In contrast to the fresh weight, the dry weight of the seeds continued to increase until the fruits turned red (figure 5B). Consequently, the dry weight of the seeds as a fraction of the total fruit dry weight was rather constant during fruit ontogeny (figure 5D). However, this fraction showed a large variability among individual fruits; the ratio between seed and total dry weight varied between 0 and 18%.

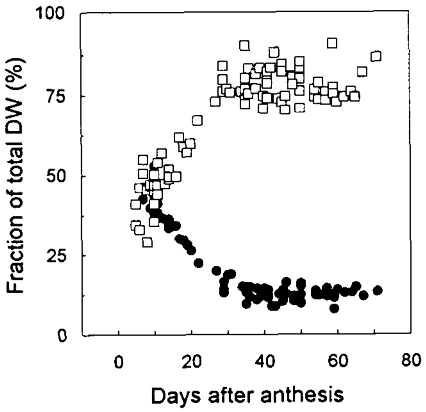

Fig. 4. Dry weight of the pericarp (□) and placental tissue (●) relative to the total fruit dry weight as a function of time after anthesis at 20°C. Each symbol represents one fruit. n=93 and 83 for pericarp and placenta, respectively (Exp. 2).

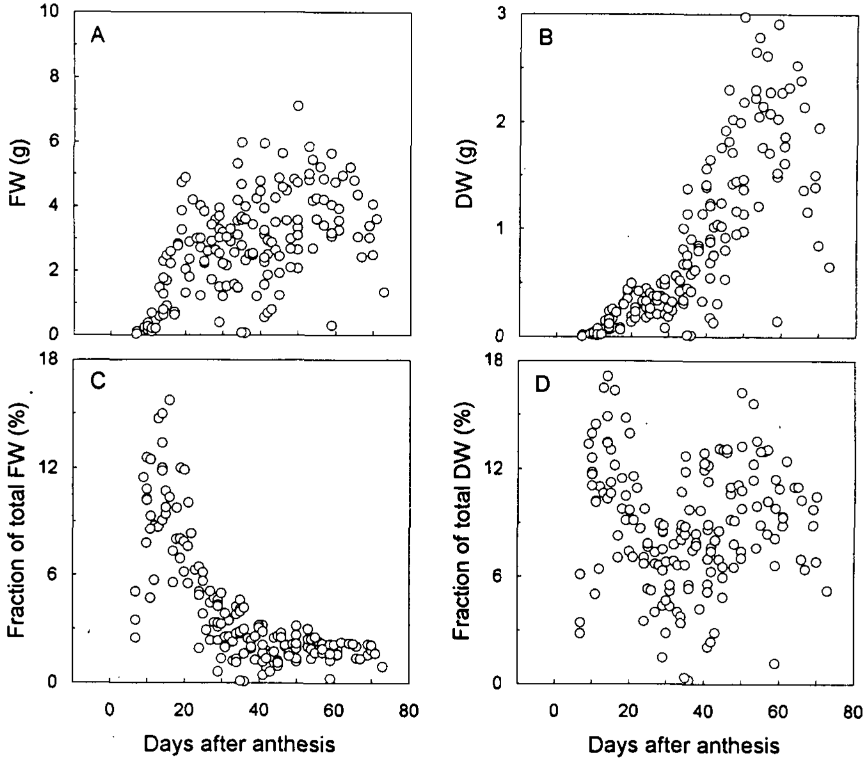

Fig. 5. Fresh (A, C) and dry weight (B, D) of the seeds as a function of time after anthesis at 20°C. Seed weight was expressed as an absolute value (A, B) or relative to the total fruit weight (C, D). Each symbol represents one fruit. n=171 (Exp. 2).

4. Discussion

Despite the hollowness and the variation in shape of the pepper fruit, the fresh weight could be estimated satisfactorily (average error of prediction was 10%) and non-destructively on basis of length and circumference or diameter of the fruit.

The sigmoid form of the growth curve is in accordance with data on sweet pepper of Rylski (1986) and many other fruit species (Bollard, 1970). The time course of fresh weight was not identical to that of dry weight. Although the increase in fresh weight stopped after the fruits had reached the green marketable stage, the dry weight of the red fruits was about 20% higher than that of the green marketable fruits. Therefore, when equal amounts of fruit dry matter are produced, the fresh weight production of fruits harvested green can be 20% higher than when harvested red. The dry-matter percentage changed considerably throughout fruit development. The pattern of the time course of dry-matter percentage was similar to that in cucumber (Marcelis, 1992) and tomato fruits (Ehret & Ho, 1986), but in tomato no increase at the end of the growing period was observed. The higher dry-matter percentage in Exp. 2 compared to Exp. 1 might be related to the higher light interception per plant, as in cucumber dry-matter percentage increases with increasing assimilate supply (Marcelis, 1992).

In this study growth curves were obtained from plants grown under one set of environmental conditions, while the number of fruits and branches were kept constant. However, factors like temperature and assimilate supply may affect these growth curves, like in other crops (De Koning, 1994; Marcelis, 1993; Marcelis & Baan Hofman-Eijer, 1993). Moreover, there may be varietal differences. More research is needed to quantify these effects. Although many factors may influence the growth rate, the type of growth curves presented here are likely to be general.

The potential capacity to accumulate assimilates is a critical determinant of fruit growth (Ho, 1988) and it may quantitatively reflect the sink strength (competitive ability to attract assimilates) of a fruit (Marcelis, 1994). This potential capacity is the fruit growth rate under conditions of non-limiting assimilate supply. However, when fruits were grown under these conditions by growing plants at high irradiance and removing competing fruits, problems like fruit deformation and blossom end rot occurred (data not shown). Therefore, the potential capacity of a sweet pepper fruit to accumulate assimilates is hard to quantify.

To calculate the total demand of a fruit for import of carbon-assimilates also the carbon concentration of the dry matter and respiration and photosynthesis of the fruit should be taken into account. According to Gijzen (1995) the carbon concentration of a sweet pepper fruit is 500 mg g^{-1}. The photosynthetic contribution of a pepper fruit to its carbon requirement was found to be 12% (Steer & Pearson, 1976). The respiratory losses of other fruit vegetables range from 13 to 15% (cumulative values) in cucumber (Marcelis & Baan Hofman-Eijer, 1995) and 5 to 26% (daily values) in tomato (Walker & Ho, 1977).

The seeds may be important in determining fruit set and fruit size (Rylski, 1986; Khah & Passam, 1992). However, clear relationships are not always observed between fruit weight and number of seeds per fruit (Baër & Smeets, 1978; Bakker, 1989b). Seeds constitute only a small fraction of the fruit fresh weight. However, they make up a significant and highly variable fraction of fruit dry weight (0-18%). The data on the seed weights were based on fruits with different dates of anthesis, but the fruits were harvested at only two dates (12 and 18 July). Although it is not likely that this has significantly affected the trends observed, seasonal interactions cannot be fully excluded. As in red fruits the dry-matter percentage of seeds was about five times that of the pericarp, with the same dry weight five times more fresh weight of pericarp than that of seeds can be produced. If the amount of seeds would be unimportant in attracting assimilates to the fruit, fruit fresh weight production would benefit from conditions reducing seed set. More research on this subject is desirable.

In conclusion, there appeared to be a pronounced difference between the time course of fresh and dry weight growth. When the growth curve of fruit dry weight is known, the consequences of retaining different numbers of fruits per plant on the demand for dry matter can be estimated. Moreover, the dynamics of dry matter demand of the main sinks of a pepper plant can be estimated when the dates of anthesis of the flowers are known.

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