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Source–Sink Relationships and their Effects on Fruit Growth and Quality in Casaba Melon (*Cucumis melo* L. var. *Inodorous*)

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ABSTRACT

Two field experiments were conducted in two successive spring-summer seasons at the Newe Ya'ar Research Center (northern Israel) to examine source-sink relationships in 'Noy Amid', a Casaba-type melon. The source and sink were artificially manipulated by removing leaves and fruit shortly after fruit-set. Highest fruit yield and fruit quality were obtained in control plants and any reduction in source size (by leaf removal) resulted in yield decline. In 'Noy Amid' melon, plants with 4-8 leaves could not support more than one fruit and all other young fruits aborted. The weight of mature fruits was reduced with decreasing source size (leaf number). The sink size (number of young fruits) at the beginning of treatment application had a significant effect on assimilate production and translocation to the fruits. Plants with 2 young fruits as compared to a single fruit, and with 4 young fruits as compared to 2 fruits produced larger mature fruits with the same number of leaves. These data strongly support the idea that sink size affects the photosynthetic activity of the leaves, which is increasing by increased demand of the sink organs. Decreased source size had a negative effect not only on fruit yield but also on fruit quality characters. Fruit shape, flesh perfection and total soluble solid content were all adversely affected by artificially reducing leaf number.

Keywords: first fruit, flesh dry-spots, fruit-set, fruit yield, total soluble solid

INTRODUCTION

Source-sink relationships in plants have been and still are a major issue in whole-plant physiology research. Classical plant physiology divides plant organs into resource producers, like mature leaves, and target organs for transported assimilates, like roots, fruits and young leaves. The relationships between source and sink organs has drawn the attention of many plant scientists in both basic and applied research. In agriculture, where commercial yield and quality are primary goals, an understanding of these relations is important in order to maximize yield production. Buttrose and Sedgley (1978) studied, under controlled environments, the effects of light intensity, day length and temperature on vegetative and fruit growth in watermelon. They found that the presence of developing fruit greatly reduced all vegetative parameters, and that these three environmental factors had different effects on fruit number per plant and on fruit weight. The relationship between fruit–load, temperature and irradiation with respect to assimilates supply to fruit development was intensively studied in cucumber (Marcelis 1993a, 1993b). Mineral nutrients may also affect source-sink relationships. Low levels of nitrogen and calcium in the nutrition solution significantly decreased the shoot (source) to root (sink) ratio in cucumber and pepper (Chung *et al*. 1984). Salinity is another environmental factor which affects source-sink relationships. In cucumbers, it was found that the fruits are the strongest sink (Marcelis 1992) and the last to be affected by salinity-induced assimilate limitation (Ho and Adams 1994). Hughes *et al*. (1983) and Shishido *et al*. (1992) treated different leaves of muskmelon with pulses of $^{14}CO_2$ to study the effect of leaf distance from the fruit on sink strength. The results showed that individual leaves play different roles in the support of the fruit, depending upon their position relative to the fruit with maximal movement of carbohydrate from the closest leaf. Many studies concerning source-sink relations were conducted by artificial manipulation of either source or sink organs (Mayoral *et al*. 1985a). In two summer squash cultivars and in *Cucurbita pepo* ssp. *texana*, reallocation of resources from fruit/seed production to vegetative growth and flower production in response to removal of young fruits or pistillate flowers one day after anthesis was examined (El-Keblawy and Lovett-Doust 1996a; Avila-Sakar *et al*. 2001). It was found that resources that would have gone into fruit were reallocated to vine growth and flower bud production. In melons, removal of commercial sized fruits increased the vegetative biomass but not the total biomass, and stimulated male flowering (El-Kebalawy and Lovett-Doust 1996b). The relationship between leaf number and fruit development of melons grown in protected environments revealed that more than 10 leaves are required for normal development of a fruit (Ishikawa *et al*. 1975), and high correlations were obtained between leaf area per fruit and soluble solid content or fruit weight (Montiero and Mexia 1988). Under field conditions, removal of 1/3 to 2/3 of muskmelon foliage shortly after fruit-set or shortly before fruit maturation reduced the commercial yield and the soluble solid concentration (SSC), respectively (Bartolo and Schweissing 1998). In cucumber, fruit-load at 4^{th}-7^{th} nodes inhibited the growth of fruits at higher nodes (Hikosaka and Sugiyama 2005). It appeared that fruit abortion in those higher nodes occurred if fruit growth was inhibited for longer than 10 days. However, most fruits that were inhibited for a shorter time resumed growth when fruits at the lower nodes were harvested. Source limitation by artificial defoliation in different crops, including cucumber, and fruiting plants as compared to plants deprived of flowers or fruits (Hall and Brady 1977; Pharr *et al*. 1985; Ramirez *et al.* 1988; Marcelis 1991) showed higher net photosynthesis and CO_2 assimilation rate, but this finding was not repeated consistently (Plaut and Mayoral 1984; Mayoral *et al*. 1985b; Roper *et al*. 1988). In muskmelon, photosynthesis of the whole plant was reduced by 30% if plants bore more than one fruit because of a

Received: 2 July, 2009. Accepted: 18 August, 2009.

Original Research Paper

lower leaf area, but fruit number did not affect the photosynthetic rate (Valantin *et al*. 1998).

The main purpose of the present study was to shed some light on the conflicting data published in the literature, with respect to the effects of source and sink manipulation on assimilate supply to the developing fruits in melon.

MATERIALS AND METHODS

Two field experiments were conducted at the Newe Ya'ar Research Center (Northern Israel) in the Spring-Summer season of two successive years to study the source-sink relationship and its effects on fruit development and quality in melon. The genetic material used in the study was a local cultivar 'Noy Amid' (NA) belonging to the Casaba group (*Cucumis melo* L. var. *Inodorous*) which was bred for powdery mildew resistance about 40 years ago (Karchi and Govers 1971). NA is characterized by Rugby-football-shape yellow fruits, weighing 2-3 kg with a very long shelf life (several months) and an extreme short phase between pollination and maturity (Nerson 2009).

Cultural practices

The crops were directly seeded in the field in early April and the mature fruits were harvested between the middle and end of June. The crops were grown on raised beds 2 m apart and 0.5 m between plants in row (10,000 plants/ha). The spring-summer season in the East Meditteranean region is characterized by high light intensity and high temperatures; 25-35°C during the day and 20-25°C at night. The relative humidity in this season at Newe Ya'ar is between 60 to 80%. The crops were supported by 7 weekly irrigations of 200-250 m^3/ha between flowering and fruit harvest, and 120 kg/ha of nitrogen and phosphorus divided into three applications between seedling emergence and fruit-set. Pest and diseases were controlled by weekly spraying of insecticides and fungicides as recommended in the region.

Experimental treatments

On May 14th and 16th (first and second years, respectively), about one week after pollination (fruit size 3-7 cm in diameter) artificial manipulation of plant source and sink was performed by defoliation of leaf blades and removal of fruits. Control plants were maintained intact and were allowed to produce maximal leaves and fruits. There were four treatments of leaf number per plant; 4, 8, 16 and unlimited, combined with three treatments of fruit number per plant; 1, 2 and 4, resulting in 13 treatments overall (control + 4 leaves × 3 fruits). In treatments with 2 or 4 fruits each one was grown on a separate branch, but the leaf numbers 4, 8 or 16 were total numbers per plant and not per branch. However, the unlimited leaf number treatment was employed for each fruit bearing branch, whereas extra branches (not containing fruit) were removed. Fruit development was assessed at and after treatment initiation by measuring fruit diameter at 7 days intervals and by weighing and measuring the length and the maximal width of the mature fruits. Fruit quality was evaluated by measuring flesh total soluble solids (TSS) (Yamaguchi and Hughes 1975), by evaluating fruit shape and flesh perfection, and by determining the ratio of seed cavity diameter to fruit diameter in mature fruits. The experiments were laid out in a complete randomized design with 15 replicates (plants) and 195 plants altogether (13 treatments × 15 replicates).

Statistical analysis

Preliminary analysis showed no significant differences between the data of the two experiments and therefore the data were pooled and their means are presented. Each set of data was subjected to a 2-way ANOVA and significant differences among the 13 treatments were determined by Duncan's multiple range test ($P \leq 0.05$).

RESULTS

Fruit development and fruit yield

Undisturbed NA melon plants produced on average 2.7 fruits/plant with a mean weight of 2.4 kg (**Table 1**). Plants with 4 or 8 leaves could not support in most cases more than 1 fruit, and when they started with 2 or 4 fruitlets most of them aborted. In many cases even a single fruit aborted and only 53, 73 and 80% of the plants had a mature fruit when defoliation treatments left 4, 8 and 16 leaves, respectively. Only 8, 14, 20 and 40% of plants which started with 2 fruitlets had 2 mature fruits, in plants with 4, 8, 16 and unlimited leaves, respectively. Four mature fruits per plant were obtained in only 7% of plants with unlimited number of leaves per fruited branches.

Fruit yield per plant and mean fruit weight increased with increasing leaf number/plant (**Table 1**). Mean fruit yields/plant were 0.86, 1.23, 2.00 and 3.61 kg for plants with 4, 8, 16 and unlimited leaves/plant, respectively. Independent of leaf-number, fruit yield/plant and mean fruit weight, increased with increasing young fruit number at experiment initiation (soon after fruit-set). Plants with 4 or 8 leaves produced the same number of mature fruits (1.0–1.1), regardless of the number of fruits at fruit-set. Fruit yield in plants with 4 and 8 leaves significantly increased by 86 and 42% and by 3.0- and 2.6-fold, when fruit number at fruit-set was increased from 1 to 2 or to 4, respectively.

First fruit growth, final weight and quality

The first fruit in the present study was defined as the heaviest fruit of the plant, picked at the earliest harvest date. First fruit growth was determined by measuring maximal diameter at treatment initiation (time 0) and 1, 2 and 3 weeks later. Fruit diameter increased with increasing leaf number and young fruit number at treatment application. This enhancement effect was already significant after 1 week and throughout the whole fruit growing phase (**Fig. 1**). First fruit final weight was significantly affected by leaf

Table 1 Effects of leaf number and fruit number per plant at fruit-set on mature fruit number, on plants with the initial fruit number(%), on fruit yield (kg) per plant and on mean fruit weight (kg) at maturation in 'Noy Amid' melon.

Leaves/plant	Fruits/plant at fruit-set	Fruits/plant at maturation	Plants with the initial fruit number at maturation (%)	Fruit yield/ plant (kg)	Mean fruit weight (kg)
4	1	1.0 d	53	0.44 i	0.44 g
	2	1.1 d	8	0.82 hi	0.75 f
	4	1.1 d	0	1.32 g	1.20 e
8	1	1.0 d	73	0.74 hi	0.74 f
	2	1.1 d	14	1.05 gh	0.95 f
	4	1.1 d	0	1.90 f	1.73 cd
16	1	1.0 d	80	1.22 g	1.22 e
	2	1.2 d	20	1.87 f	1.56 d
	4	1.6 c	0	2.91 d	1.82 c
Unlimited	1	1.0 d	100	2.37 e	2.37 a
	2	1.5 c	40	3.20 c	2.13 b
	4	2.4 b	7	5.25 b	2.19 b
Control	Unlimited	**2.7 a**	**100**	**6.47 a**	**2.40 a**

Table 2 Effects of leaf number and fruit number per plant at fruit-set on first fruit weight (g), percentages of off-shape and dried flesh in the first fruit, and total soluble solids (TSS) in the first fruit (%) and in fruit yield per plant (g) in 'Noy Amid' melon.

Leaves/plant	Fruits/plant at fruit-set	First fruit weight (g)	Off-shape fruits (%)	Dried flesh (%)	TSS in first fruit (%)	TSS per plant (g)
4	1	437 i	100 a	75 b	6.1 de	27 h
	2	803 gh	69 bc	100 a	5.8 e	49 gh
	4	1246 f	43 d	43 fg	6.5 c-e	87 f
8	1	739 h	73 b	64 c	7.0 c-e	54 f-h
	2	1047 fg	50 d	57 cd	6.1 de	68 fg
	4	1729 e	21 e	36 g	7.7 c	153 e
16	1	1222 f	62 c	46 ef	6.7 c-e	79 fg
	2	1784 e	20 e	53 de	7.6 cd	143 e
	4	2114 d	7 f	36 g	8.1 c	242 d
Unlimited	1	2251 cd	0 f	40 fg	9.8 b	238 d
	2	2462 bc	7 f	47 ef	10.9 ab	370 c
	4	2630 ab	0 f	47 ef	11.3 a	580 b
Control	Unlimited	2713 a	0 f	13 h	12.2 a	781 a

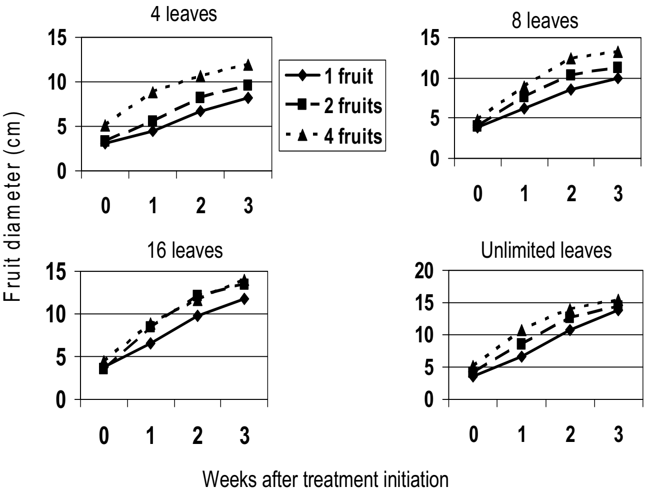

Fig. 1 Effect of leaf number and young fruit number/plant at treatments application on the development of first fruit diameter in 'Noy Amid' melon.

number, but also by the number of fruits per plant at experiment initiation (**Table 2**). The percentages of off-shape fruits increased with decreasing leaf number and their means were 71, 48, 30 and 2% for 4, 8, 16 and unlimited leaves/plant, respectively. Excluding the unlimited leaf number treatment, off-shape fruit percentages decreased when starting the experiments with 2 fruits/plant as compared to a single one, or with 4 as compared to 2. Mean percentages of fruits with dry-spots flesh were 73, 52, 45 and 45% in plants with 4, 8, 16 and unlimited number of leaves /plant, respectively. In most cases, there was no difference with respect to this quality trait, between plants started with 1 or 2 fruits, but plants which had 4 fruits at treatments beginning tended to have less dried-flesh fruits.

TSS in the first fruit increased with increasing leaf number and on average was 6.1, 6.9, 7.5 and 10.7% for 4, 8, 16 and unlimited leaves/plant, respectively. There was a general trend, but mostly non-significant, for increased TSS values with increasing number of young fruits at treatment application. Calculation of total soluble solids in the fruits/ plant (fruit weight × TSS) revealed a clear positive significant effect both for leaf and young fruit numbers at the experiment starting point.

DISCUSSION

The main objective of the present study was to clarify, through artificial manipulation of source and sink, the effects of limited leaf area and/or sink size on assimilate production by the leaves and their translocation toward fruit development. Valantin *et al.* (1998) studied the effect of fruit number/plant (sink size) on leaf (source) photosynthesis in Charentais melons, and found that artificial removing of fruits increased leaf number and total plant photosynthesis, as compared to plants with unrestricted fruit load. However, the photosynthetic rate/leaf unit was not affected. An earlier study in cucumber (Plaut and Mayoral 1984) had shown that decreasing the source to sink ratio by leaf removal reduced the photosynthetic rate 3-fold. Conflicting data in cucumber had shown that leaf (source) defoliation significantly increased the carbon exchange rate (CER) in the remaining leaves, and that fruit (sink) removal significantly decreased CER in the leaves (Ramirez *et al.* 1988). Despite the fact that no direct measurement of photosynthesis was conducted in the present study, the data strongly support the idea that increasing sink demand, by retaining more young fruits (fruitlets), increased the amount of assimilates produced by the source (leaves) and their translocation to the developing fruits. All the parameters of fruit development (**Tables 1, 2; Fig. 1**) were increased by increasing the sink size from a single fruit to 2 and from 2 to 4 independent of mature fruit number and the proportion of aborted fruits. However, it is important to mention that all the leaves are necessary for achieving maximum fruit yield and quality and all the defoliation treatments decreased these parameters significantly.

Number of fruits, mean fruit weight and fruit yield/plant were all higher in the control than in plants with 4 young fruits and unlimited leaf number at experiment initiation (**Table 1**). These differences were probably the result of disturbance of plant growth by frequent searching for, and removing of branches without fruits in the latter plants.

Defoliation resulted in limiting assimilate supply from source to sink and thus affected fruit development not only in size but also in quality traits. Regular fruit shape, flesh texture and sweetness were all adversely affected by defoliation and the intensity of damage was positively related to the amount of leaf removal. The effect of decreasing assimilate supply from leaves to fruits was already noticed 1 week after defoliation and was lasted until fruit maturation (**Fig. 1**). Assimilate limitation appears to also affect root function. An increase in fruit flesh dry-spots after defoliation suggests that roots were incapable of supplying adequate water to the developing fruits, despite the fact that soil water was readily available.

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