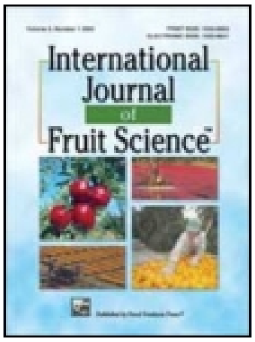

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Assimilate Partitioning Behavior in Relation to Fruit Growth in 'Shahi' Litchi

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Investigations were undertaken to develop a better understanding of assimilate partitioning behavior in litchi, with respect to the role of stored assimilates translocated from other sources in the plant during the fruiting season. The first experiment examined the fruit growth pattern in the litchi 'Shahi'. The second experiment focused on the limitation of assimilate supply to litchi fruits by leaf removal and girdling. The third experiment was aimed at fulfilling the assimilate requirement of growing litchi bunches through current photosynthesis by foliar application of a photosynthesis enhancer (triacontanol). The fruits exhibited a sigmoidal growth pattern with a phase of rapid growth 40 to 60 days after fruit set. Irrespective of method or distance of source limitation, the maximum percent of fruit drop was observed when the source limitation treatments were imposed 30 days after fruit set. Source limitation at all the distances resulted in significant increases in percent of fruit drop over those with no source limitations. With respect to different treatments, all forms of source limitation resulted in significant increase in fruit drop over the control. The results suggest that a contribution of carbohydrate from current photosynthesis for partial fulfillment of total carbon demand of growing fruits is necessary. Only no limitation of current photosynthesis contributed towards 0% loss in fruit weight while a limitation of carbohydrate translocation (girdling) contributed towards an 8.5% loss in fruit weight. However, under the

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condition of limited carbohydrate translocation, restriction on current photosynthesis caused a 19.1% loss in average fruit weight. Studies on foliar application of photosynthesis enhancers (triacontanol) on fruit drop in litchi under restricted (girdled) and unrestricted translocation of assimilate from other parts of the plant were conducted. These indicated a reduction in the rate of fruit drop with an increase in the concentration of triacontanol in case of unrestricted translocation of assimilate. However, under restricted assimilate translocation, increasing concentrations of triacontanol did not result in reducing the percent of fruit drop. Hence, the study clearly indicated the major role of translocated assimilates from other plant parts in fulfilling the assimilate demand of growing fruits in litchi where current photosynthesis contributes partially towards assimilate demand.

KEYWORDS litchi, Litchi chinensis, *carbohydrate, fruit weight, triacontanol*

INTRODUCTION

The litchi (*Litchi chinensis*) is an evergreen tree that produces delicious fruits relished for their flavor. The litchi fruits have a short postharvest life due to the appearance of browning on the peel, which reduces the marketability of the fruits. The early maturing and popular cultivar, such as 'Shahi', is highly prone to fruit cracking and any delay in harvesting of the fruits results in a heavy incidence of fruit cracking. Being a heavy bearing crop, preharvest estimation of fruit yield can be of immense help to the litchi growers in planning different postharvest management strategies for their produce. For developing a criterion for prediction of fruit yield in litchi, a thorough understanding of the source-sink interaction is essential. Different approaches have been followed by different workers to develop a proper understanding of source sink relationship in litchi. Partitioning of assimilate plays an important role in the productivity of a branch. Leaves are the main source of CO_2 assimilation in plants. Carbohydrates are important in the growth of woody plants and account for over 65% of dry matter in tree crops. The capacity of a tissue to import carbohydrates is a measure of its sink strength (Kozlowski, 1992). In litchi, a number of efforts have been made by different workers to develop an understanding of the assimilate partitioning behavior with respect to fruit growth and yield. In a crop like litchi, previous workers have indicated that litchi fruit growth depends on current CO_2 assimilation rather than on stored reserves (Roe et al., 1995). Menzel et al. (1995) reported that a proportion of the carbohydrate produced from photosynthesis is used immediately in the growth of new tissues, while another fraction accumulates as reserves during periods of excessive production. For these kind of investigations, girdling has been used as an effective method for isolating a part of the plant from the rest of the plant and, hence, for investigating source-sink relationships in perennial woody plants. Being a terminal bearing crop, girdling helps in limiting the carbohydrate source of the growing fruits within the region between the girdled portion and the panicle. However, for a better understanding of assimilate partitioning behavior in litchi, more information needs to be generated on the role of stored assimilates translocated from other sources in the plant under conditions of unrestricted assimilate translocation. Keeping this in view, an investigation was undertaken to partition the role of current photosynthate and translocated assimilate on fruit retention capacity of bunches of litchi 'Shahi'.

MATERIALS AND METHODS

The investigations were carried out at the Horticulture and Agro-Forestry Research Programme (ICAR Research Complex for Eastern Region), Plandu, Ranchi, India during the fruiting season of 2006 in three different experiments. The first experiment was aimed at description of the fruit growth pattern in litchi 'Shahi'. Twenty-five randomly selected fruits were sampled per replication during five different stages of fruit growth (30, 40, 50, 60, and 70 days after fruit set). Observations were recorded on average fresh weight and carbohydrate content of the fruit at different stages of fruit growth. The carbohydrate content was estimated using the Anthrone method (Mahadevan and Sridhar, 1986).

The second experiment consisted of studies on source limitation on litchi fruits. Treatments were imposed on healthy litchi plants of 'Shahi' (22-years-old) with uniform plant vigor. The treatments consisted of four methods of source limitation (Factor C) (girdling with no leaf removal, girdling with leaf removal, no girdling with leaf removal, and control), imposed at three different stages of fruit growth (Factor A) (30, 40, and 50 days after fruit set) at four different distances from the bunch (Factor B) (0, 30, 60, and 90 cm) applied in 48 combinations. All of the combinations in one replication were imposed on the same tree with five bunches per treatment combination. All of the treatments were replicated five times. The experiment was laid out in split-split plot design. Observations were recorded on percent of fruit drop, average fruit weight, and carbohydrate content of the shoot (10-cm region just behind the bunch). The content of carbohydrate was estimated using the Anthrone method.

The third experiment consisted of foliar application of photosynthesis enhancer (triacontanol). Plants were sprayed with triacontanol in three concentrations (1, 2, and 3 ppm) at two different stages of fruit growth (30 and 40 days after fruit set). Observations on percent of fruit drop were recorded from randomly selected bunches treated with source limitation treatments (girdling and no girdling) at the time of spraying. The experiment was laid out in split plot design with five replications and ten shoots per replication.

RESULTS AND DISCUSSION

The data on the pattern of growth of litchi fruits have been depicted in Figure 1. The litchi fruits exhibited a sigmoidal growth pattern with a phase of rapid growth during 40 to 60 days after fruit set. The carbohydrate accumulation in fruits exhibited a concave growth pattern with a rapid accumulation phase after 60 days of fruit set.

The total bunch weight in litchi is a function of percent fruit retention and average fruit weight in the bunch. The fruit retention capacity in a panicle is a function of the strength of source tissue to support the carbohydrate demand of the growing sink (fruits). Previous studies in litchi 'Bombai' indicated that the intensity of the fruit drop was positively correlated with the net CO_2 assimilation rate suggesting increasing carbon demand of growing fruits from source leaves (Debnath et al., 2006). In the present investigation, the data on effect of different source limitation treatments on percent of fruit drop are presented in Table 1. Irrespective of method or distance of source limitation, the maximum percent of fruit drop was observed when the source limitation treatments were imposed 30 days after fruit set. Source limitation after 40 or 50 days did not result in a significant increase in percent of fruit drop over that in the case of no source limitation until harvest. This indicated the criticality of the stage of fruit growth (30 days after fruit set) with respect to dependency on the source. Irrespective of date and method,

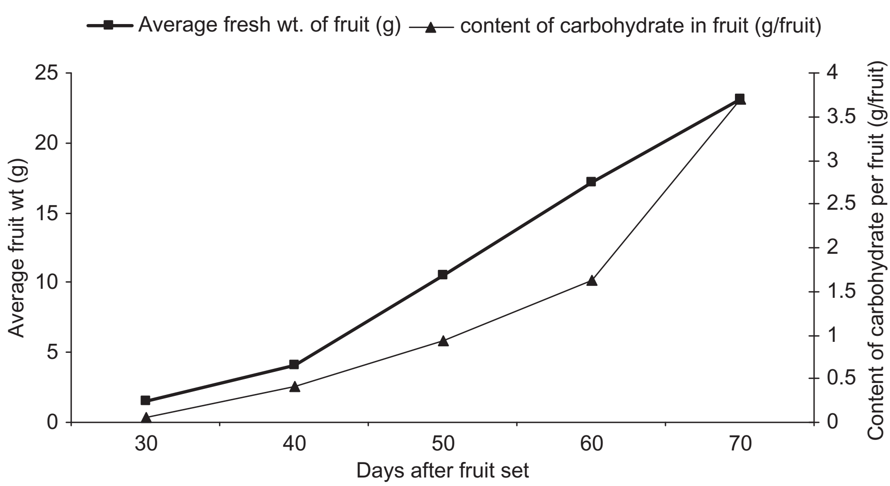

FIGURE 1 Pattern of fruit growth and accumulation of carbohydrate in fruit during fruit growth in litchi 'Shahi'.

TABLE 1 Effect of Different Source Limitation Treatments on Percent Drop of Litchi Fruits (Sink)

Days (A) ⟹	30 days after fruit set					40 days after fruit set					50 days after fruit set					Till fruit maturity					Mean of treatments (C)
Distance (B) ⟹	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	
Treatments (C)																					
Girdling with no leaf removal	53.4	69.5	78.6	74.8	69.1	51.4	49.0	51.5	42.5	48.6	51.3	39.9	57.8	58.8	52.0	53.4	51.4	50.2	51.2	51.5	55.3
Girdling with leaf removal	52.5	98.5	89.6	88.6	82.3	53.2	51.2	65.7	48.4	54.6	50.5	62.4	69.4	62.5	61.2	50.3	48.2	51.3	53.2	50.7	62.2
No girdling with leaf removal	55.6	55.1	58.2	56.2	56.3	55.2	60.6	62.5	71.9	62.6	52.2	50.7	58.5	57.3	54.7	51.2	50.5	52.2	48.7	50.6	56.0
Control	50.5	53.7	56.1	50.3	52.6	52.7	50.1	53.2	49.1	51.3	49.6	53.2	50.1	49.6	50.6	48.8	52.3	50.2	47.2	49.6	51.0
Days (A) × Distance (B)	53.0	69.2	70.6	67.5	65.1	53.1	52.7	58.2	53.0	54.3	50.9	51.5	59.0	57.1	54.6	50.9	50.6	51.0	50.1	50.6	56.1

Distance (A) × Treatment (C)	Girdling with no leaf removal				Girdling with leaf removal				No girdling with leaf removal				Control			
	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm
	52.3	52.4	59.5	56.8	51.6	65.0	69.0	63.1	53.5	54.2	57.8	58.5	50.4	52.3	52.4	49.05

Distance (B)	0 cm	30 cm	60 cm	90 cm
	52.0	56.0	59.7	56.9

SEm	Days: 2.26, Distance: 2.95, Treatment: 1.94, days × Distance: 5.90, Days × Treatment: 3.90, Distance × Treatment: 3.90, days × Distance × Treatment: 7.80
C.D. at 5%	Days: 5.97, Distance: 3.82, Treatment: 3.13, days × Distance: NS, Days × Treatment: NS, Distance × Treatment: 11.78, days × Distance × Treatment: NS

source limitation at all the distances resulted in a significant increase in percent of fruit drop over that with no source limitation in the whole plant. This indicated existence of a mechanism for fulfillment of carbon requirement of growing fruits (sink) through mobilization from other parts of the plant in absence of any source limitation in litchi. Heike et al. (2002) also reported the existence of a mechanism of assimilate support in litchi by resources from elsewhere in the tree in the case of no source limitation. With respect to different treatments, all forms of source limitation resulted in a significant increase in fruit drop over that in the control. Girdling with leaf removal resulted in the maximum fruit drop while the percent of fruit drop in the case of girdling with no leaf removal and no girdling with leaf removal were similar. The results suggested that there is a contribution of carbohydrate from current photosynthesis for partial fulfillment of total carbon demand of growing fruits. A significant effect of interaction between distance × treatment on percent of fruit drop, was observed in the present study. Source limitation by girdling at a distance of 60 cm from the panicle with complete leaf removal resulted in maximum percent of fruit drop.

The data on influence of source limitation treatments on average fruit weight are presented in Table 2. Irrespective of distance and method, source limitation at all the stages resulted in a significant reduction in average fruit weight. However, crop limitation at 40 days after fruit set resulted in a maximum reduction of average fruit weight (18.4%). There was a rapid increase in the average fruit weight after 40 days of fruit set coinciding with a sharp increase in pulp weight, which indicated an increased demand for photosynthate by the sink at that stage. Hence, source limitation at the stage of peak photosynthate demand might have contributed towards reduced fruit weight. Source limitation at different distances resulted in significant reduction in average fruit weight and the maximum reduction being observed in the case of 30 and 60 cm distances. It was interesting to note that irrespective of stage and zone of source limitation, only limitation of current photosynthesis contributed towards 0% loss in fruit weight and only limitation of carbohydrate translocation (girdling) contributed towards an 8.5% loss in fruit weight. However, under the condition of limitation of carbohydrate translocation, restriction on current photosynthesis produced a 19.1% loss in average fruit weight. The trend indicated the existence of translocation-limited-induction mechanism in litchi for enhanced contribution of current photosynthate towards fruit weight.

The data on influence of source limitation treatments on carbohydrate content in the shoot at harvest are presented in Table 3. Significant influence of source limitation was not observed with respect to stages and distance of source limitation. However, significant effects of the methods of source limitation treatments were recorded on the content of carbohydrates in shoots irrespective of stage and distance of source limitation. The minimum carbohydrate content was recorded in the case of control shoots (9.8%), which

TABLE 2 Effect of Different Source Limitation Treatments on Average Fruit Weight (g) of Litchi Fruits (Sink)

Days (A) ⟹	30 days after fruit set					40 days after fruit set					50 days after fruit set					Till maturity					Mean of treatment effects (C)
Distance (B)⟹	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	
Treatments (C)																					
Girdling with no leaf removal	17.5	17.3	16.2	17	17	17.8	11.7	12.5	14.9	14.2	17.6	14.9	16	15.7	16.0	18.2	17.5	17.1	17.9	17.6	16.2
Girdling with leaf removal	17.2	9.3	8.3	9.9	11.1	17.4	6.6	7.9	8.5	10.1	17.9	11.9	12.7	12.4	13.7	17.6	18.1	17.4	17.1	17.5	13.1
No girdling with leaf removal	17.4	17.1	16.3	16.9	16.9	17.1	17	15.7	16	16.45	18.1	20.1	20.2	21	19.8	17.1	18.4	17.3	17.8	17.6	17.7
Control	17.9	17.2	16.9	17.9	17.4	17.5	16.4	17.2	17.9	17.25	17.8	18.4	17.9	17.8	17.9	18.1	17.3	17.9	18.4	17.9	17.7
Days (A) × Distance (B)	17.5	15.2	14.4	15.4	15.6	17.4	12.9	13.3	14.3	14.5	17.8	16.3	16.7	16.7	16.9	17.7	17.8	17.4	17.8	17.7	16.1

Distance(A) × Treatment (C)	Girdling with no leaf removal				Girdling with leaf removal				No girdling with leaf removal				Control			
	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm
	17.7	15.3	15.4	16.3	17.5	11.4	11.5	11.9	17.4	18.1	17.3	17.9	17.8	17.3	17.4	18.0

Distance (B)	0 cm	30 cm	60 cm	90 cm
	17.6	15.6	15.5	16.1

SEm	Days: 0.40, Distance: 0.21, Treatment: 0.21, days × Distance: 0.50, Days × Treatment: 0.80, Distance × Treatment: 0.50, days × Distance × Treatment: 1.01
CD at 5%	Days: 0.81, Distance: 0.38, Treatment: 0.47, days × Distance: 0.99, Days × Treatment: 1.62, Distance × Treatment: 0.99, days × Distance × Treatment: NS

TABLE 3 Effect of Different Source Limitation Treatments on Carbohydrate Content (%) in the Shoots

Days (A) ⟹	30 days after fruit set					40 days after fruit set					50 days after fruit set					Till maturity					Mean of treatment (C)
Distance (B) ⟹	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	0 cm	30 cm	60 cm	90 cm	Mean	
Treatments (C)																					
Girdling with no leaf removal	9.7	10.2	8.7	9.8	9.6	9.7	16.9	14.6	14.4	13.9	10.3	10.9	11.5	12.5	11.3	10.7	12.7	9.7	12.2	11.3	11.5
Girdling with leaf removal	9.6	8.3	10.0	12.0	10.0	8.9	13.5	12.9	12.6	12.0	9.7	13.3	11.7	10.6	11.3	11.1	11.7	9.6	11.8	11.1	11.1
No girdling with leaf removal	10.1	15.0	14.7	16.4	14.1	9.1	10.5	9.7	8.6	9.5	9.1	15.1	12.9	11.9	12.3	10.0	13.5	10.7	12.3	11.6	11.9
Control	8.9	9.9	9.1	10.2	9.5	10.2	9.6	9.4	9.1	9.6	10.2	9.4	9.9	10.1	9.9	9.1	10.7	9.9	10.9	10.2	9.8
Days (A) × Distance (B)	9.6	10.9	10.6	12.1	10.8	9.5	12.6	11.7	11.2	11.2	9.8	12.2	11.5	11.3	11.2	10.2	12.2	10.0	11.8	11.0	11.0

Distance (A) × Treatment (C)	Girdling with no leaf removal				Girdling with leaf removal				No girdling with leaf removal				Control			
	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm	0 cm	30 cm	60 cm	90 cm
	10.1	12.6	11.1	12.2	9.8	11.7	11.0	11.7	9.5	13.5	12.0	12.3	9.6	9.9	9.5	10.0

Distance (B)	0 cm	30 cm	40 cm	50 cm
	9.8	12.0	10.9	11.6

SEm: Days: 0.96, Distance: 0.57, Treatment: 0.29, days × Distance: 1.14, Days × Treatment: 1.93, Distance × Treatment: 1.14, days × Distance × Treatment: 2.29

CD at 5%: Days: ns, Distance: ns, Treatment: 0.71, days × Distance: ns, Days × Treatment: ns, Distance × Treatment: ns, days × Distance × Treatment: ns was significantly lower than all the source limitation treatments. The low value of carbohydrate in the control shoots can be attributed to higher carbohydrate removal by the sink (fruits) with lower percent of fruit drop and higher fruit weight.

In order to determine any possible correlation between numbers of leaves at different distances from the bunch with the average bunch weight data were recorded from 50 shoots bearing healthy bunches. Studies on the correlation between bunch weight and number of leaves at different distances from the bunch indicated a significant positive correlation (0.775, 0.429, and 0.511 in the case of number of small leaves in 0–30 cm, number of fully grown leaves in 30–60 cm, and number of fully grown leaves in 60–90 cm, respectively). Heike et al. (2002) also reported that leaves next to the inflorescences are more important for yield than the older leaves in litchi. The relationship between bunch weight and number of leaves at different distances from the bunch could be explained through the second order linear function [Y (Bunch weight) = 841.9–35.3 (number of fully grown leaf in 0–30 cm) − 13.0 (number of small leaf in 0–30 cm) − 18.9 (number of fully grown leaf in 30–60 cm) + 6.36 (number of fully grown leaf in 60–90 cm) + 0.7 (number of fully grown leaf in 0–30 cm)^2 + 0.7 (number of small leaf in 0–30 cm)^2 + 0.3 (number of fully grown leaf in 30–60 cm)^2 − 1.25 (number of fully grown leaf in 60–90 cm)^2, $R^2 = 0.76$].

Hence, the study clearly indicated the importance of current photosynthesis for partial fulfillment of assimilate demand of growing fruits in litchi where the assimilate supply translocated from other parts of the plant plays a major role. The studies also indicated that allowing assimilate supply to the growing litchi fruits only through current photosynthesis by restriction of assimilate translocation from other parts of the plant was not sufficient in fulfilling the total assimilate requirement of the growing fruits. Therefore, keeping in view the hypothesis that by enhancing the rate of photosynthesis, the assimilate demand of the growing fruits can be fulfilled through current photosynthesis, another experiment was conducted to study the effect of foliar application of photosynthesis enhancers on fruit drop in litchi under restricted (girdled) and unrestricted translocation of assimilate from other parts of plants. Plant growth regulators, such as triacontanol, has been reported by many workers to have properties for the enhancement of the photosynthetic rate (Srivastava and Sharma, 1991; Srivastava et al., 1993; Singh et al., 1996; Ivanov and Angelov, 1997). In the present experiment, foliar application of triacontanol at 3 ppm significantly reduced the rate of fruit drop compared to treatments with lower concentrations (1 and 2 ppm) in the case of unrestricted translocation of assimilate (Fig. 2). The reduction in fruit drop was markedly higher when triacontanol was applied at 40 days after fruit set. However, under restricted assimilate conditions, increasing the concentration of triacontanol did not result in a reduction in the percent of fruit drop.

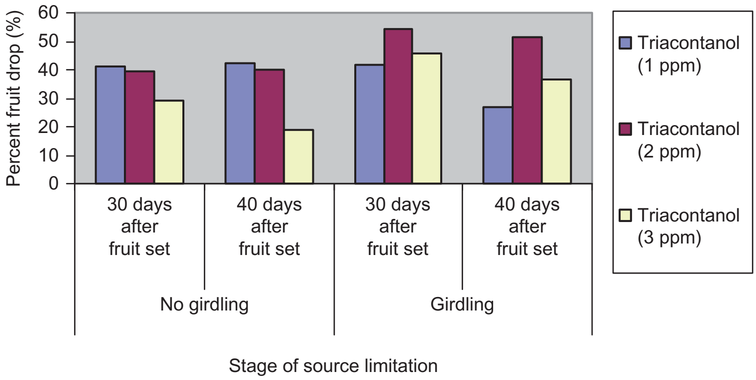

FIGURE 2 Effect of foliar application of photosynthesis enhancer (Triacontanol) on percent fruit drop in litchi shoots with source limitation treatments. (Figure is provided in color online.)

Hence, the study clearly indicated the major role of translocated assimilates from other plant parts in fulfilling the assimilate demand of growing fruits in litchi where current photosynthesis contributes partially towards assimilate demand of growing litchi. Parameters on stored carbohydrate and mechanisms of assimilate mobilization should be considered along with parameters representing current photosynthesis for developing yield forecasting criteria in litchi.

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