Seasonal changes in starch reserves in litchi, cv. HLH Mauritius

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ABSTRACT

Like in all woody plants, carbohydrates are also important in the growth of litchi trees. There are strong seasonal influences in carbohydrate reserves which reflect the growth stages of a tree, such as vegetative shooting, flowering and fruit growth. The starch reserves of HLH Mauritius litchi trees were determined as part of an orchard management program. Wood samples from the main branches of trees of various treatments were taken up to ten times a year according to certain phenological stages of the trees. Starch content varied from year to year and within a year, reflecting alternate bearing and tree phenology. Vegetative growth, flower panicle development and rapid fruit growth resulted in reduced starch reserves, whereas rest phases, such as the period prior to flower panicle development and periods between vegetative flushing, caused starch reserves to increase again.

INTRODUCTION

The vegetative and reproductive growth of trees depends on the ability of the tree to produce and store carbohydrates. Carbohydrates account for over 65% of the dry matter in tree crops (Kozlowski and Keller, 1966). Carbohydrate assimilation mainly takes place in leaves. A proportion of the carbohydrates produced from photosynthesis is used immediately for the growth of new tissue, while another fraction is stored as mainly starch during periods of excessive production (Stephenson *et al.*, 1989; Menzel *et al.*, 1995). The utilization and storage of carbohydrate reserves have been widely studied for deciduous crops (Oliveira and Priestley, 1988; Priestley, 1970; Stassen, 1980) and some subtropical crops such as avocado (Scholefield *et al.*, 1985; Whiley & Wolstenholme, 1990), macadamia (Stephenson *et al.*, 1989) and citrus (Goldschmidt and Golomb, 1982; Goldschmidt *et al.*, 1985).

In litchi, the study of carbohydrate reserves is fairly young and only started about 10 to 15 years ago by researchers from mainly Australia, China and South Africa. Menzel *et al.* (1995) in Australia determined the carbohydrate concentrations of various plant parts during the main stages of tree phenology and discovered that the fluctuation in starch concentrations in small branches correlates very well to vegetative growth and fruiting. They were also the first researchers to draw starch curves for various plant parts. Roe *et al.* (1997) in South Africa found that litchi fruit mainly depend on CO_2 assimilation for their growth. In more recent research from Australia, Hieke *et al.* (2002a and b) thoroughly studied the relationship between yield and assimilate supply and between fruit and leaf growth in litchi and confirmed the findings by Roe *et al.* (1997). In South Africa, starch content of litchi trees was expressed as total starch content per tree (Kift, 2002). Periods of high starch depletion were related to vegetative and fruit growth, while starch was accumulated mainly during rest periods.

Certain factors that influence the accumulation and depletion of starch reserves can to some extent be controlled or moderated. These factors are tree shape and density, which influence photosynthetic capacity, vegetative growth, especially in late autumn, flowering and crop load, as well as irrigation and fertilization for recovery after harvest.

In this paper, the changes in starch concentration in relation to tree phenology, orchard management and alternate bearing were studied as part of an orchard management program (Cronje and Mostert, 2007). The aim was to investigate to what extent general orchard practices and environmental conditions influence the main starch reserves in main branches. The main branches of HLH Mauritius trees were used for this study, because starch concentrations in main branches vary less than in small branches and give a better indication as to which growth event or management practice affects the main starch reserves most.

MATERIALS AND METHODS

The field trial was conducted on 18 year-old (in 2005) HLH Mauritius trees at Nelspruit, Mpumalanga Province, between 2005 and 2009. The study on starch reserves of litchi trees during various stages of tree phenology was part of an integrated orchard management program to improve litchi yield and fruit size where various fertilizer foliar applications and plant growth regulators were applied (Cronje and Mostert, 2008). The trial was laid out in a randomized complete block design with seven replicates and three trees per replicate.

Wood core samples excluding the bark were taken from the main branches about a third of the way through the branches with a hand brace and 14 mm flat bit (**Figure 1**). The samples were oven-dried at 60°C. Starch analysis was done according to a modified AOAC (Association of Analytical Chemists) method (Davie, 1997).

The samples were taken at critical tree and fruit developmental stages and were as follow for the various years:

2005:
- November (end of rapid fruit growth),

2006:
- January (after harvest),
- May (winter rest period),
- November (end of rapid fruit growth),

2007:
- January (after harvest, start of first vegetative flush),
- May (winter rest period),
- June (flower panicle emergence),
- September (flowering and fruit set),
- November (end of rapid fruit growth),

2008:
- January (after harvest, no flush),
- March (during first vegetative post-harvest flush),
- April (first vegetative post-harvest flush hardened),
- June (small flower panicles),
- July (extending flower panicles),
- August (opening of first male flowers),
- September (full female flower),
- October (start of fruit development),
- November (rapid fruit development),

2009:
- January (after harvest, no flush).

Phenological growth patterns were recorded at weekly intervals. Temperature and humidity in the orchard were monitored on a continuous basis using data loggers (Hobo®, Davis Weather Instruments).

Figure 1: Wood sampling for starch analysis in HLH Mauritius litchi.

RESULTS AND DISCUSSION

As no statistical differences were found between the treatments and no clear treatment effects of the foliar sprays were visible (data not shown), it was decided to combine the treatment values to mean values.

Figure 2 illustrates the fluctuations in starch concentrations in main branches of HLH Mauritius litchi between November 2005 and January 2009. Tree phe-

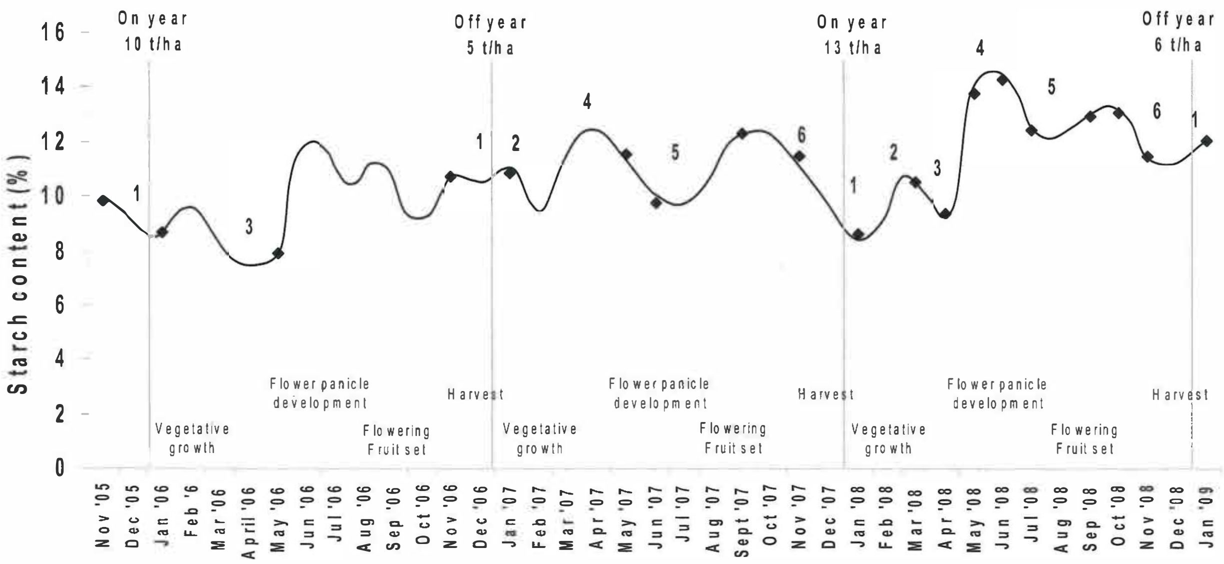

Figure 2: Starch concentration of main branches in HLH Mauritius trees in Nelspruit between November 2005 and January 2009. Data points (♦) are means of six treatments (126 trees). Numbers indicate various stages in tree phenology.

nology expressed as vegetative growth and flower and fruit development etc. is indicated at the bottom of **Figure 2**. Numbers in **Figure 2** indicate various stages in starch accumulation or depletion and will be discussed hereafter.

Apart from seasonal changes in growth pattern mostly due to climatic influences, the course of the starch curve clearly illustrates a re-occurring trend over the period of three years (**Figure 2**). After harvest (December), starch reserves in main branches were either high, after low yield (off-year), or low, after high yields (on-year). In general, vegetative growth, flower panicle development and rapid fruit growth depleted starch reserves. During rest periods between vegetative flushing and before flower panicle emergence, starch reserves were accumulated.

In the text hereafter the course of the starch curve in **Figure 2** is discussed in detail by means of numbers.

1) After harvest, first post-harvest flush

After harvest (end of December), the level of starch reserves depended on yield. If yield was high, like in the 2005/06 and 2007/08 seasons, starch reserves were depleted due to the high crop. If yields were low, like in the 2006/07 and 2008/09 seasons, starch reserves could already recover during late fruit development. During such years the first post-harvest flush appeared in January, followed by a second flush during March / April, compared to years with high yields where the first post-harvest flush only appeared in February (2007/08 season).

2) During vegetative post-harvest flushes

Between the first and second post-harvest flush, starch reserves slightly accumulated. Hieke *et al.* (2002c) found that net CO_2 assimilation was above zero only 30 days after leaf emergence, which means that only fully expanded and hardened off leaves can contribute to the carbohydrate reserves of trees.

3) Second post-harvest flush

The depletion of starch during the second post-harvest flush depended on the control of this flush during April. In 2006, the control of the flush with Ethapon in April was insufficient, probably resulting in a reduction of starch during April (no confirmed data). In 2007 and 2008, starch depletion during the second post-harvest flush was less pronounced due to efficient flush control with Ethapon. In 2007, the reduction in starch occurred earlier compared to 2006 and 2008 due to a low yield and early harvest in December 2006, which resulted in earlier flush cycles.

4) Flower initiation and early flower panicle development

Prior to flower initiation and during early flower panicle development, starch accumulated in all three years – in 2007 already during April and in 2008 from May onwards. Starch accumulation during the winter months was also found in Australia (Menzel *et al.*, 1995), South Africa (Kift, 2002) and China (Huang, personal communication).

In May / June 2008, starch levels were higher compared to 2007 and yet yield was low. However, this was not due to insufficient starch reserves, but poor fruit set due to adverse climatic conditions during the flowering and fruit set period (data not shown).

5) Flower panicle development, flowering

Starch reserves were slightly reduced during the flowering period (flower panicle development up to flowering) in 2006 (no confirmed data) and 2008, but more pronounced in 2007, probably due to heavier flowering in 2007. Anthesis does not appear to utilize significant reserves.

We suggest that the slight depletion in starch reserves during flower panicle development is not only because of the high demand for flower panicle growth, but also because of low photosynthetic activity and carbohydrate assimilation by the leaves as a result of low temperatures, shorter day length and high solar radiation, which cause the trees to experience photo inhibition.

6) Fruit set and fruit development

Fruit set and early fruit development did not impact significantly on the trees' starch reserves. However, rapid fruit growth between September and November utilized a significant amount of starch. During years with high crop load (2007), the percentage decrease in starch levels was higher (4%) than during years with low crop load (2% in 2008), indicating that fruit development requires high energy reserves. This steep decline also coincides with the second fruit drop period in October and possibly a root flush in November. During this period cell division is completed and rapid cell enlargement takes place in the developing fruit (Kift, 2002).

Where trees were in an off-year, starch reserves could already recover between fruit maturation and harvest due to a lower crop load and less reserves needed to support the growing fruit.

The effect of alternate bearing on starch reserves can also be seen in **Figure 2**. End of 2005 a yield of 10 t/ha was harvested. In April 2006, a strong vegetative flush which was not controlled efficiently caused a decrease in yield to only 5 t/ha. In April 2007, all late vegetative flush was effectively controlled with Ethapon which resulted in a high yield of 13 t/ha at the end of 2007. It appears that ineffective flush control can affect starch reserves at the time of flower panicle emergence.

The discussion of **Figure 2** revealed that not only phenological or climatic events influence starch reserves, but also orchard management. We believe that starch reserves can be managed through:

1. Control of late autumn flush with the application of Ethepon;
2. Lifting of water stress as soon as flower panicles appear to avoid stress conditions;
3. Promotion of photosynthesis through optimal fertilization, irrigation and pruning to help increase light interception and carbohydrate assimilation.

CONCLUSION

Data on starch reserves of main branches in HLH Mauritius trees in Nelspruit over the period of three years has shown a re-occurring trend of depletion of starch reserves during vegetative growth, flower panicle development and fruit growth and accumulation of starch reserves during rest periods between vegetative flushing and before flower panicle emergence.

Alternate bearing influenced the level of starch after harvest. After high yields (on-year) starch reserves in main branches were relatively lower compared to starch reserves in trees that carried a small yield (off-year).

Orchard management is also considered to influence starch reserves and the correct use of practices, like control of late autumn flush, fertilization, irrigation and pruning, can help increase starch reserves for critical periods of vegetative and reproductive growth.

Further research is required to determine whether starch levels during a certain month can indicate whether a big or small crop can be expected.

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LITERATURE CITED

CRONJE, R.B. and MOSTERT, P.G. 2007. Progress on the management program to improve yield and fruit size of litchi, cv. HLH Mauritius. *South African Litchi Growers' Association Yearbook*, 19: 6-14.

CRONJE, R.B. and MOSTERT, P.G. 2008. A management program to improve yield and fruit size of litchi, cv. HLH Mauritius - Third season's report. *South African Litchi Growers' Association Yearbook*, 20: 6-12.

DAVIE, S.J. 1997. A modification of the enzyme-chromogen method for the determination of low levels of starch in plant material. *Journal of the South African Society for Horticultural Science*, 7 (1): 35-38.

GOLDSCHMIDT, E.E. and GOLOMB, A. 1982. The carbohydrate balance of alternate-bearing citrus trees and the significance of reserves for flowering and fruiting. *Journal of the American Society for Horticultural Science*, 107 (2): 206-208.

GOLDSCHMIDT, E.E., ASCHKENAZI, N., HERZANO, Y., SCHAFFER, A.A. and MONSELISE, S.P. 1985. A role for carbohydrate levels in the control of flowering in citrus. *Scientia Horticulturae*, 26: 159-166.

HIEKE, S., MENZEL, C.M., DOOGAN, V.J. and LÜDDERS, P. 2002a. The relationship between fruit and leaf growth in lychee (*Litchi chinensis* Sonn.). *Journal of Horticultural Science and Biotechnology*, 77 (3): 320-325.

HIEKE, S., MENZEL, C.M., DOOGAN, V.J. and LÜDDERS, P. 2002b. The relationship between yield and assimilate supply in lychee (*Litchi chinensis* Sonn.). *Journal of Horticultural Science and Biotechnology*, 77 (3): 326-332.

HIEKE, S., MENZEL, C.M. and LÜDDERS, P. 2002c. Effects of leaf, shoot and fruit development on photosynthesis of lychee trees (*Litchi chinensis*). *Tree Physiology*, 22: 955-961.

KIFT, J. 2002. Physiological aspects. In: The cultivation of litchi (De Villiers, E.A., Ed.). ARC-Institute for Tropical and Subtropical Crops, South Africa, pp. 23-26.

KOZLOWSKI, T.T. and KELLER, T. 1966. Food relations of woody plants. *The Botanical Review*, 32: 293-382.

MENZEL, C.M., RASMUSSEN, T.S. and SIMPSON, D.R. 1995. Carbohydrate reserves in lychee trees (*Litchi chinensis* Sonn.). *Journal of Horticultural Science*, 70 (2): 245-255.

O'HARE, T.J. and TURNBULL, C.G.N. 2004. Root growth, cytokinin and shoot dormancy in lychee (*Litchi chinensis* Sonn.). *Scientia Horticulturae*, 102: 257-266.

OLIVEIRA, C.M. and PRIESTLEY, C.A. 1988. Carbohydrate reserves in deciduous fruit trees. *Horticultural Reviews*, 10: 403-430.

PRIESTLEY, C.A. 1970. Carbohydrate storage and utilization. In: Physiology of tree crops (Luckwill, L.C. and Cutting, C.V., Eds.). Academic Press. New York. Pp. 113-127.

ROE, D.J., MENZEL, C.M., OOSTHUIZEN, J.H. and DOOGAN, V.J. 1997. Effects of current CO_2 assimilation and stored reserves on lychee fruit growth. *Journal of Horticultural Science*, 72 (3): 397-405.

SCHOLEFIELD, P.B., SEDGLEY, M. and ALEXANDER, D. McE. 1985. Carbohydrate cycling in relation to shoot growth, floral initiation and development and yield in the avocado. *Scientia Horticulturae*, 25: 99-100.

STASSEN, P.J.C. 1980. Reserves in deciduous fruit trees and implications to the deciduous fruit grower. *The Deciduous Fruit Grower*, 30: 467-472.

STEPHENSON, R.A., GALLAGHER, E.C. and RASMUSSEN, T.S. 1989. Effects of growth manipulation on carbohydrate reserves of macadamia trees. *Scientia Horticulturae*, 40: 227-235.

WHILEY, A.W. and WOLSTENHOLME, B.N. 1990. Carbohydrate management in avocado trees for increased production. *South African Avocado Growers' Association Yearbook*, 13: 25-27.