Source-Sink Relations in Kiwifruit: Carbohydrate and hormone effects on fruit growth at the cell, organ and whole plant level.

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Abstract

Fruit weight of *Actinidia deliciosa*, *A. chinensis*, and *A. arguta* kiwifruit was correlated with fruit cell number and seed numbers or seed weight within and between species. Reducing seed number of *A. deliciosa* 'Hayward' by style excision reduced fruit weight and cell size, but had only minor effects on cell number. It is suggested that the impact of genotype on fruit weight was by determining the number and size of ovules available to be fertilised and form seeds.

At a leaf:fruit ratio of four, girdling of lateral shoots increased fruit weight mainly due to increased cell expansion. Fruit cell numbers were also increased when girdles were applied during post-anthesis cell division. Girdling of individual canes with a high leaf:fruit ratio also increased mean fruit weight. However when more canes were girdled on a vine, the response to girdling was decreased, and fruit weight in non-girdled canes was lower. These negative effects on fruit growth were not due to reduced root function or increased competition for photo-assimilate. Increased cane girdling resulted in a transitory increase in the concentration of cytokinins extracted from girdled canes, and this was correlated with increased bud-burst. The increased vegetative growth may have inhibited fruit growth on girdled canes, but no explanation was found for the reduced fruit weight in non-girdled canes.

An inhibitory effect of high seeded kiwifruit on the growth of low seeded kiwifruit was confirmed, and could be accounted for by increased seed abortion from inhibited fruit. Diffusible IAA from kiwifruit increased over time, but was not associated with inter-fruit competition or fruit seed number. Application of the auxin transport inhibitor N-1-naphthylphthalamic acid (NPA) to kiwifruit pedicels after fruit set, reduced fruit fresh weight and dry matter accumulation. However late NPA application had no effect on fruit weight, which suggests that IAA transport is not essential for kiwifruit growth at all times.

Application of N-(2-chloro-4-pyridyl-N'-phenylurea (CPPU) to *A. deliciosa* and *A. chinensis* kiwifruit selections increased fruit weight, but application of adenine based cytokinins in combination with CPPU increased fruit weight further. CPPU application resulted in a transitory decrease in fruit abscisic acid levels.

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List of Abbreviations

0G	no canes girdled on a vine
2iP	isopentenyl-adenine
20G	20% of canes girdled on a vine
50G	50% of canes girdled on a vine
100G	all canes girdled on a vine
2,4-D	2,4-dichlorophenoxyacetic acid
ABA	abscisic acid
AGR	average growth rate
ANOVA	analysis of variance
BSA	bovine serum albumen fractionV
cFA	Freunds complete adjuvant
Ci	internal CO_2 concentration in a leaf
CPPU	N-(2-chloro-4-pyridyl)-N'-phenylurea
DAFB	days after full bloom
D_{max}	diameter of a kiwifruit across the maximum equatorial axis
D_{min}	diameter of a kiwifruit across the minimum equatorial axis
DPM	disintegrations per minute
DZ	dihydrozeatin
DZR	dihydrozeatin-riboside
EDC	1-ethyl-3-(3-dimethyl amino propyl) carbodiimide-HCL
ELISA	enzyme linked immuno-sorbent assay
FB	full bloom
FZ	fruiting zone (tied down canes)
GA_3	Gibberellic acid A_3
GZ	girdled zone (girdled canes in fruiting zone)
HPLC	high performance liquid chromatography
IAA	indole-3-acetic acid
iFA	Freunds incomplete adjuvant
IP	inner pericarp
IPA	isopentenyl-adenosine
L	length from top to base of a kiwifruit
LSD	fishers protected least significant difference
Mab	monoclonal antibody
MUFCU	Massey University fruit crops unit
MSE	mean square error
NAA	1-naphthalene acetic acid
NGZ	non-girdled zone (non-girdled canes in fruiting zone)

NPA	naphthyl-phthalamic acid
NSB	non-specific binding
OP	outer pericarp
ODS	octadecyl silica
pAH	p-aminohippuric acid
PBS	phosphate buffered saline
P_{max}	Light saturated photosynthetic rate
Pn	net photosynthetic rate
ppm	parts per million
PVPP	polyvinylpolypyrrolidone
RCZ	replacement cane zone
RGR	relative growth rate
RIA	radio-immunoassy
rs	stomatal resistance
SAS	SAS system for statistical analysis
TBS	tris buffered saline
TEA	acetic acid pH adjusted with triethylamine
TIBA	2,3,5-triiodobenzoic acisd
WAFB	weeks after full bloom
Z	*trans*-zeatin
ZR	*trans*-zeatin riboside

Thesis Summary

The contribution of fruit cell number to sink strength of *A. deliciosa*, *A. chinensis* and *A. arguta* kiwifruit was investigated. Fruit weight of well pollinated selections from these species ranged in size from 3.4g in *A. arguta* to 176g in *A. deliciosa.* Although fruit weight was correlated with fruit cell number, fruit weight was also positively related to seed numbers and seed weight within and between all three species. Within *A. deliciosa* 'Hayward', the main effect of seed number on fruit expansion was increased cell size, and the positive effect of high seed number on fruit growth rate lasted right throughout fruit development. It is suggested that in kiwifruit the main impact of genotype on fruit size is by determining the number and size of ovules available to be fertilised and form seeds, which then determine sink strength mainly by stimulating cell expansion.

Girdling of lateral shoots and entire canes was used to alter source-sink relationships. At a leaf:fruit ratio of four, girdling of fruiting lateral shoots increased mean fruit weight by up to 57g, compared with fruit on intact shoots. Although the majority of increased fruit expansion on girdled shoots at a high leaf:fruit ratio was due to increased cell expansion, fruit cell number was also increased when girdles were applied during the post-anthesis cell division phase. When lateral shoots were girdled after the period of cell division, the response to girdling was lower, and increased fruit weight was due to cell expansion only. This suggested that fruit expansion was limited by low cell numbers when competing sinks were eliminated by girdling.

Girdling of individual canes resulted in an increase in fruit weight of up to 31g compared to intact canes on the same vine. However if a higher number of canes on a vine were girdled, the response to girdling was decreased, and fruit weight in non-girdled parts of vines was decreased compared with control vines. This negative effect on fruit growth in both girdled and non-girdled parts of the vine was not due to reduced root function, as increasing the number of canes girdled had no effect on root growth, xylem water potential, leaf photosynthesis and fruit mineral content. It is also unlikely that increased competition for photo-assimilate resulted in lower fruit weight, as leaf:fruit ratio was very high in all parts of the vine. However increased cane girdling resulted in a transitory increase in the concentration of cytokinins extracted from girdled canes, and this was

correlated with increased bud-burst of re-growth. It is suggested that the increased vegetative growth may have inhibited fruit growth on girdled canes, although no explanation was found for the reduced fruit weight in non-girdled parts of the vine.

An inhibitory effect of high seeded kiwifruit on the growth of low seeded kiwifruit was confirmed and this could be accounted for by an increase in seed abortion from the inhibited fruit. This may be due to limitation of photo-assimilate uptake, as a low leaf:fruit ratio on a shoot also increased seed abortion from low seeded fruit. Between three and seven weeks after full bloom (WAFB), diffusible IAA from kiwifruit increased from 0.136 and 0.450 $ng.hour^{-1}.fruit^{-1}$, but diffusible IAA was not associated with inter-fruit competition or fruit seed number. Application of the auxin transport inhibitor N-1-naphthylphthalamic acid (NPA) to kiwifruit pedicels up until five WAFB resulted in reduced fruit fresh weight and dry matter accumulation. However at six WAFB, NPA had no effect on fruit weight, which suggests that IAA transport is not essential for kiwifruit growth after this time.

There was an interaction between the synthetic cytokinin compound N-(2-chloro-4-pyridyl_-N'-phenylurea (CPPU) and adenine based cytokinins when these were applied to *A. deliciosa* and *A. chinensis* kiwifruit selections. Fruit weight of all selections was increased by CPPU. *A. deliciosa* 'Hayward' showed the greatest response, increasing in size from 80g in control fruit to 121g at 1ppm CPPU, and 136g at 10ppm CPPU. The response of *A. chinensis* was lower and fruit weight increased from 51g in control fruit to 56g at 1ppm CPPU and 71g at 10ppm CPPU. The lower response of *A. chinensis* to CPPU may be due to poor uptake, or lower seed numbers than 'Hayward'. There was no response to adenine based cytokinins when these were applied on their own. However when adenine cytokinins were applied in combination with CPPU, fruit weight was increased by an additional 21g in *A. deliciosa* 'Hayward' and 11g in *A. chinensis* over fruit treated with CPPU alone. This suggested that CPPU may act to protect endogenous cytokinins from metabolism, however application of CPPU to 'Hayward' kiwifruit was not found to increase endogenous cytokinin levels. In contrast, CPPU application resulted in a transitory decrease in fruit abscisic acid levels to over half the level of control fruit within seven days of application.