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Research Paper

Cluster illumination differentially affects growth of fruits along their ontogeny in highbush blueberry (*Vaccinium corymbosum* L.)

Carlos A. Godoy*, Gloria Monterubbianesi, Enrique Sanchez[1], Jorge A. Tognetti[2]

Facultad de Ciencias Agrarias, Universidad Nacional de Mar del Plata, c.c. 276, 7620 Balcarce, prov. de Buenos Aires, Argentina

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ABSTRACT

Shading highbush blueberry plants generally leads to a delayed fruit development. Experiments have been performed to study the effects of light on fruit growth independently from the rest of the canopy. Clusters were shaded during different fruit growth periods. The equatorial diameter of the fruits as a function of days after full bloom followed a double-sigmoidal growth pattern, being fitted using a Gompertz II nonlinear mixed model, and absolute growth rates were obtained from each fitted model. Both whole-cycle shaded and second-stage shaded fruits showed a delayed peak in absolute growth curves with respect to both first-stage shaded and whole-cycle unshaded controls. Our results suggest that deficiency of light during the last stage of highbush blueberry fruits may lead to a substantial delay (of about 10–16 days) in harvest as compared with well-illuminated fruits.

In order to estimate the contribution of intrinsic fruit photosynthesis to its own growth at different stages, clusters were subjected to girdling on their peduncles at different times. Girdling just before the second-stage resulted in fruits gaining between 35 and 40% of dry weight in comparison with the controls. This suggests that fruit photosynthesis may play a relevant role in fruit growth during the second sigmoidal stage, which in turn may contribute to explain the delayed growth observed in shaded fruits.

1. Introduction

The light environment in orchards is critical for crop production and quality. Low irradiance has a negative impact on many physiological processes such as fruit set, fruit ripening and final quality (Campbell and Marini, 1992; Marini et al., 1991). While these effects of light have traditionally received most attention, evidence gathered on several species indicates that light availability also modulates fruit growth after fruit set. Shading canopies generally leads to a delayed fruit development on several species (Keller et al., 1998; Marini et al., 1991; Smart et al., 1988). This effect has also been observed in highbush blueberry – *Vaccinium corymbosum* L. (Hicklenton et al., 2004; Lobos et al., 2009) and its magnitude may be sufficient to be considered as a promising tool to delay harvest for commercial purposes (Rodríguez Beraud and Morales Ulloa, 2015).

Yáñez et al. (2009) have measured light distribution in the canopy of rabbitteye blueberry bushes (*Vaccinium ashei* Reade) and found that fruits located 60 cm below the top of the canopy received 17–37% of full sun irradiance. Besides affecting the current photosynthesis, long term exposure of leaves at low irradiances appears to negatively affect their photosynthetic performance due to an acclimatory response. Kim et al. (2011) found that highbush blueberry leaves exposed for a long term at 40–61% of full sun irradiances reached their maximum net CO_2 assimilation rate at about 700–800 μmol m^{-2} s^{-1} PPFD, while leaves that only received 17–27% of full sun irradiance exhibited their maximum at about 500 μmol m^{-2} s^{-1} PPFD.

Many agronomical practices may modify irradiance at the whole plants or individual fruits levels. Shading may be increased by practices that promote foliage production, such as irrigation and fertilization, especially with nitrogen, and lack or insufficient pruning among others. Also, covering orchards with nets for different purposes (protection against birds or hail) reduce radiation reaching crops underneath (Stamps, 2009). Lobos et al. (2013) examined the productivity and development of northern highbush blueberry under photo-selective nets. They found that red and white nets at intermediate shade levels delayed fruit harvest without detrimental effects on return bloom, yield or fruit quality.

It is not clear if the light effects on fruit growth is the result of decreased photoassimilate availability (insufficient carbon export from leaves to sustain fruit growth), or a direct effect on fruits (due to either

* Corresponding author.
E-mail address: godoy.carlos@inta.gob.ar (C.A. Godoy).
[1] Instituto Nacional de Tecnología Agropecuaria (INTA).
[2] Comisión de Investigaciones Científicas de la Provincia de Buenos Aires (CIC), Argentina.

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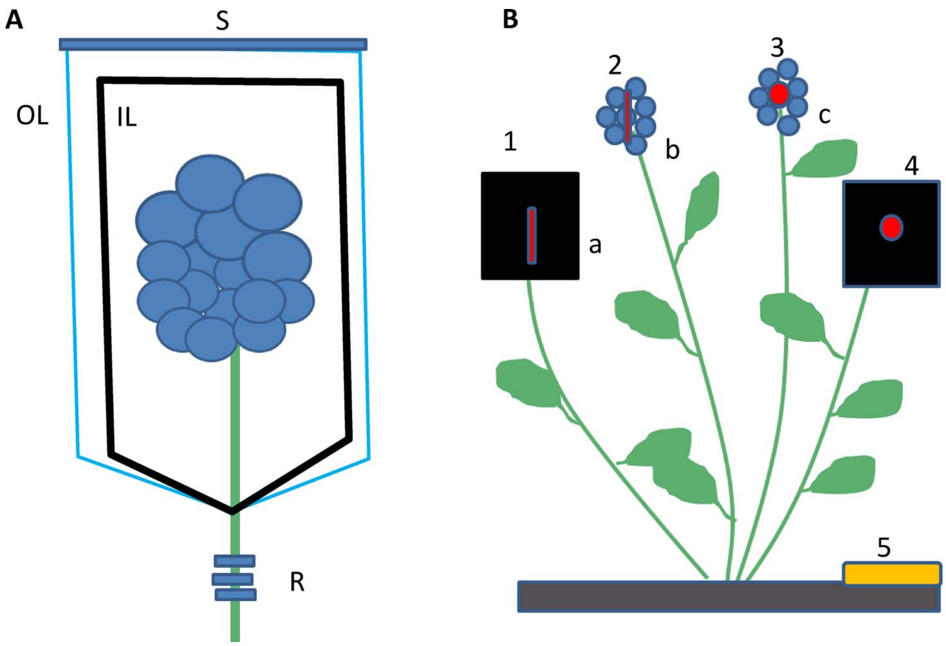

Fig. 1. A. Fruit cluster-shield: OL- outer polypropylene layer, IL-inner aluminum layer, R- twist tie ribbon, S- top seal. B- Treatments (at the first stage of sigmoidal fruit growth): a- SH, b- control, c- SH-2, d- SH-1; sensors: 1- inside thermocouple sensor, 2- outside thermocouple sensor 3- outside PAR sensor, 4- inside PAR sensor, 5- datalogger.

reduced fruit photosynthesis or some other light-mediated influence on fruit development). Attempts to separate the effects of light at the foliage level from those directly exerted on fruits, trials have been performed on grape berries – *Vitis vinifera* L. – (Morrison and Noble, 1990; Rojas-Lara and Morrison, 1989). It was found that the rates of berry growth were slower in fruits from vines with shaded leaves but no effects on berry growth were observed when only clusters were shaded. However, more recently, Chorti et al. (2010) observed a slight delay in berry development by shading clusters from fruit set to veraison.

Sour cherries – *Prunus cerasus* L.- (Flore and Layne, 1999) and rabbiteye blueberries (Birkhold et al., 1992) exhibited a positive net photosynthesis in the beginning of fruit development. Maximum net photosynthesis rate per unit of fresh weight of rabbiteye blueberry fruits is achieved immediately following petal fall (Birkhold et al., 1992). While photosynthetic rate per unit fruit area, or biomass, may be at its maximum early during fruit development, total fruit photosynthesis is also affected by its increase in size along development.

To analyze the contribution of fruit photosynthesis it is necessary to block the translocation of carbon from the rest of the plant. The removal of a bark strip around a tree's outer circumference is often used to study carbon relationships between different parts of the plant (De Schepper and Steppe, 2011). In particular, cluster peduncle girdling has been used to elucidate the effects of xylem flux during the grape berry growth (Creasy et al., 1993). However, no attempts to investigate carbon allocation to fruits by cluster girdling have been performed up to now in blueberry.

The objective of this study were 1) to determine the effect of cluster shading at different stages on the evolution of highbush blueberry fruit growth, and 2) to evaluate the relative contribution of photoassimilates from the cluster to sustain fruit growth during each stage of the double sigmoid growth curve.

2. Materials and methods

2.1. Experimental site and plant material

To evaluate the effect of shading on fruit growth, two experiments (from now on, Experiments 1 and 2) were carried out in two consecutive years in a commercial orchard of Southern highbush blueberry (*Vaccinium corymbosum*) cv OzarkBlue, located in Balcarce (37°49′S 58°12′W), South-East Pampas region, Argentina. At the time of the first experiment, plants were four years old. A further experiment (Experiment 3) was conducted in the same experimental site to evaluate the contribution of fruit photosynthesis to fruit growth. Germplasm of *Vaccinium corymbosum* cv. OzarkBlue is introgressed with *V. darrowi*; being considered as a northern (USA)-adapted blueberry (Ehlenfeldt and Martin, 2002; Manjula Carter and Clark, 2002). In the South-East Pampas region, the ocean proximity buffers summer maximum temperatures and provides an appropriate environment for this cultivar. Daily maximum and minimum temperatures, and daily radiation integral for both experiments at the experimental site are shown in the appendix (Fig. A1). Soil was a Typic Argiudoll, with pH 6.5 at the upper horizon. Previously to plantation, soil was amended with pine bark and rice hulls. Plants were set on raised beds, with a black plastic mulch and pine needles around the bushes during the first three years, later the plastic mulch was replaced with wheat straw, The orchard alley had a sod cover. Bushes were fertigated during spring with ammonium sulphate, twice a week. Soil water content at saturation was 38.5% (v/v). Drip irrigation was daily applied in the summer according to tensiometers placed at 20 and 30 cm depth. Soil moisture tension was kept within between 15–25 kPa. To correct alkalinity (pH = 7.5) of irrigation water, sulfuric acid was added to drop pH of water to 5.0–5.5. Commercial production started at the 3rd year after planting. Thereafter, plants were annually pruned during winter in order to achieve an open center. Due to commercial reasons, pruning intensity was minimum in the second winter resulting in a higher fruit load.

2.2. Effect of fruit shading during different developmental stages

A fruit cluster-shield was developed to allow full shading while minimizing its effect on temperature. The device consisted in a double layer cover, the inner one being consisting of aluminum foil (10 µ) and the outer one consisting of a 24 µ Crystal type polypropylene film, both of them with 5 mm perforations each 20 mm in order to maintain air flow and thus minimize any effect on air humidity or variation in gas concentrations within the shield respect of the open air. The shield, which had a twisted ribbon at the bottom, was also large enough to allow normal fruit growth (Fig. 1A). The outer polypropylene film was used to counteract the effect of shading on fruit temperature. Temperature measurement was performed with thermocouple sensors placed in sampled clusters, connected to a datalogger (Cavadevices, Buenos Aires, Argentina). The accuracy of this device to keep