Taylor & Francis
Taylor & Francis Group

The Journal of Horticultural Science and Biotechnology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/thsb20

Assessing the effect of artificial shading and saccharose sprays on the yield and fruit quality of cranberry (*Vaccinium macrocarpon* Aiton)

Loreto Prat, James Robinson, Carlos Muñoz & Marco Garrido-Salinas

THE JOURNAL OF HORTICULTURAL SCIENCE AND BIOTECHNOLOGY
https://doi.org/10.1080/14620316.2024.2327373

Assessing the effect of artificial shading and saccharose sprays on the yield and fruit quality of cranberry (*Vaccinium macrocarpon* Aiton)

Loreto Prat[a], James Robinson[a], Carlos Muñoz[a] and Marco Garrido-Salinas [a,b]

[a]Departamento de Producción Agrícola, Facultad de Ciencias Agronómicas, Universidad de Chile, Santiago, Chile; [b]Centro de Estudios de Zonas Áridas, Facultad de Ciencias Agronómicas, Universidad de Chile, Coquimbo, Chile

ABSTRACT

A natural low fruit set is reported in cranberry. It is hypothesised that a carbohydrate shortage limits fruit set, and thus yield potential. We aimed to evaluate the effect of carbohydrate availability induced by shade and saccharose spraying during reproductive stages of 'Stevens' cranberry to identify critical periods for yield and juice quality (soluble solids, acidity, and colour). Two independent experiments were conducted. On five separate dates, artificial shade (90% shade nets) was imposed for two weeks. On the same dates, 417 kg ha^{-1} of saccharose was sprayed as a 10% w/v solution. Results showed that shading from full bloom to the beginning of the fruit set reduced fruit number and juice colour. In contrast, 10% saccharose spray increased yield by 22% compared to the control without compromising juice quality. Therefore, the period between the end of full bloom and the beginning of fruit growth is the most critical stage for 'Stevens' cranberry.

ARTICLE HISTORY
Received 11 September 2023
Accepted 29 February 2024

KEYWORDS
Critical period; non-structural carbohydrates; bloom period; flower development; carbohydrate availability

Introduction

The cranberry (*Vaccinium macrocarpon* Aiton) is a perennial shrub native to the Northeastern lowlands of North America. It was domesticated in the early 1900s and is currently cultivated mainly in the USA, where the state of Wisconsin is the largest producer. It is also grown in Canada, which is the second-largest world producer (Sandler & DeMoranville, 2008). The species was introduced to Southern Chile in the early 1990s (Stang, 1997), and currently, there are 780 ha planted with this species (ODEPA/CIREN, 2019), with the cultivar 'Stevens' being the most grown. The species is a vine-like woody perennial that produces horizontal shoots or runners, which grow over the soil forming a dense cover. From these runners, vertical shoots arise, called uprights, that carry the flower buds responsible for the yield of the crop (Handley, 2003; Roper & Vorsa, 1997). In Southern Chile, cranberry uprights produce 2–7 flowers per vertical shoot in spring, of which only 1–3 become fruits that reach harvest in autumn, similar to what is observed in Wisconsin, USA (Stang, 1990).

The yield components of cranberries that are important for commercial products include the number of marketable berries per cultivated area, the number of fruiting uprights per growing area, the number of marketable berries per upright, and the percent fruit set (Pelletier et al., 2015). The period in which fruit number is determined is crucial to obtaining a higher commercial yield, a period called critical period and is widely used for crops (Guglielmini et al., 2019). In this species it is reported that the fruit set is quite low, which encourages the use of many beehives in commercial orchards to maximise pollination (Brown & McNeil, 2006). Several hypotheses have been proposed to explain this low-fruit set. One of them is the competition of different organs and structures within the plant for non-structural carbohydrates, generating a carbon shortage that limits fruit set (Brown & McNeil, 2006). Another approach is hormonal regulation, with ethylene, ABA, and jasmonic acid acting as hormones that accelerate the abscission process (Estornell et al., 2013). Both approaches, carbon, and hormonal balance, seem related to the extent that sugars provide energy but also play a role as messengers regulating gene expression (Lebon et al., 2008; Sheen et al., 1999).

The cranberry plants must optimise the allocation of carbohydrates to support their reproductive and vegetative growth, maintaining a balance between reproduction, survival, and future fertility and reserves (Van den & Davenport, 2005. Studies have shown that any action that limits photosynthesis, such as leaf removal and shading, results in reduced fruit production and bud development (Roper & Klueh, 1994; Roper et al., 1995). In fact, shading for short periods has been evaluated as an alternative management for fruit load control in species such as apples (Basak, 2011). In cranberry, the concentration of non-structural carbohydrates (NSC) is particularly low

CONTACT Marco Garrido-Salinas marcogarrido@uchile.cl Departamento de Producción Agrícola, Facultad de Ciencias Agronómicas, Universidad de Chile, Santa Rosa 11315, La Pintana, Santiago 8820808, Chile

during flowering, fruit set, and fruit development, inducing a possible source limitation (Birrenkott et al., 1991; Hagidimitriou & Roper, 1994) which restricts both blooming potential and fruit set (DeVetter et al., 2016). Hagidimitriou and Roper (1995) observed that the decrease in NSC is more marked in flowering shoots than in non-fruiting ones, highlighting the significant role of cranberry fruit as a carbohydrate sink. However, the exact phenological stage at which NSC availability is critical in cranberry has not yet been determined, as Fischer (1975) first did for cereals in 1975.

While a reduction of net photosynthesis under shading can promote organ competition for sugar, inducing abscission of reproductive structures at the beginning of the reproductive growth period because of a less sink strength (Vasconcelos et al., 2009), an increase in carbohydrate availability could generate the opposite effect, particularly in low-set species such as cranberry. Spraying saccharose directly onto the plant has been proposed to overcome the source limitation observed in cranberry (Roper et al., 1993). In other fruit trees, such as pistachios (*Pistacia vera* L.), carbohydrates absorbed by leaves has been shown to improve nut quality (Arzani et al., 2001). Additionally, spraying a saccharose solution on 'Leconte' pears significantly improved fruiting, production, and other important agronomic traits (Yehia & Hassan, 2005).

Therefore, identifying the critical period for NSC availability in cranberry is crucial to designing agronomic management strategies to avoid potential stress-induced low fruit set and to optimise the use of water and other resources. We hypothesise that there is a carbohydrate shortage limiting fruit set during the reproductive stage near bloom in 'Stevens' cranberry cultivar, so higher carbon availability and photosynthesis limitation will affect the yield in a positive and negative way, respectively. Thus, the aim of this study is to identify the critical period in cranberry when carbohydrate availability is limiting for fruit set and growth. To achieve this, we evaluated the effects of artificial shade to limit photosynthesis and saccharose applications to supply carbohydrates at several flowering stages. We evaluated yield and yield components, as well as the dry weight of leaves, shoots, and roots. Additionally, we assessed the effects of these treatments on soluble solids content, acidity, and colour.

Materials and methods

Study site and experimental setup

Experiments were conducted in the 2007–2008 season on a cranberry field at the CranChile Zapaco Farm (39°23'27'S; 72°38'12'W), which was planted in 2003 with the cultivar 'Stevens', characterised by large, deep red berries, vigorous vines, and excellent productivity (Eck et al., 1990). The climate is warm temperate with a dry season, characterised by an annual rainfall of 1,208 mm and an average annual temperature of 12.2°C (Uribe et al., 2012).

Table 1. Treatment application date (TAD) for 10% saccharose spraying and 90% shading (14 days) and main and second development stage of 'Stevens' cranberry.

TAD*	Main development stage	Second development stage
October 29	Hook	Prehook
November 12	Hook	Open flower
November 16	Open flower	Hook
December 10	Open flower	Pinhead
December 24	Open flower	Pinhead

*On this date, the saccharose-spraying treatment was made and was the beginning of the shade treatment, for a period of 14 days.

To test the effect of a carbohydrate shortage on cranberry productivity, two independent experiments were conducted to affect the availability of carbohydrates positively and negatively at different times of cranberry's reproductive growth period, thus assessing the cultivar's critical period. In each experiment, we evaluated the effect of (1) 10% saccharose spraying (w/v) and (2) artificial shade over different reproductive stages. Saccharose was applied once, and shade was imposed for 14 days in five different development stages of cranberry (Table 1). In both experiments, the experimental design was a completely randomised block with four replicates, and the experimental unit was defined as a plot of 0.72 m^2 (1.2 × 0.6 m).

Saccharose application experiment

The saccharose spraying treatment was designed to increase the carbon balance at the plant level, based on the methodology of Yehia and Hassan (2005) for pear cultivation. Specifically, a 10% w/v saccharose solution was applied with the surfactant ILWET L77 at a concentration of 12 mL L^{-1} via a motor sprayer. The application rate was maintained at ~300 mL per plot, which resulted in the delivery of an equivalent of 417 kg ha^{-1} of saccharose. The spraying was carried out on five dates during the reproductive development of cranberries (Table 1) and was targeted towards the foliage until the dripping point was achieved.

Artificial shade experiment

The shading treatment was designed to reduce the plant's net photosynthesis rate, given its dependence on light under irrigated conditions. To impose shade, we used a black shade net with a nominal level of 90% (Raschel Type Net, Marienberg Company, Santiago de Chile) given the low light saturation of the species (<500 µmol m^{-2} s^{-1}; Van den & Davenport, 2005). Following the protocol established by Roper et al.

(1995) as a reference, we constructed tunnels 0.4 m high with the same dimensions as the experimental unit with a north–south orientation. The tunnels were placed over the plot for 14 days on five different dates (Table 1). The first period began at the beginning of bloom when the principal development stage was hook and prehook. The fifth shade period began when the principal development stage was open flower and pinhead.

Measurements and estimations

Reproductive phenology

At the beginning of each treatment application date, four quadrants of 0.4 m^2 were randomly selected on each plot. Flowers and fruits were observed, and the following phenological stages were determined for each structure: elongation, roughneck, prehook, hook, open flower, pinhead, pea, and mature fruit. The development stages of flowers were classified according to Workmaster et al. (1997), and fruits according to Brown and McNeil (2006).

Biomass partitioning in the plant, total fruit yield, and yield components

Once fruits reached maturity, as determined by 10% soluble solids, the colour intensity of 7 at 520 nm absorbance, and 11% titratable acidity, complete plants were removed from a randomly selected area measuring 0.4 m^2 and transported to the laboratory. The plants were subsequently separated into roots, horizontal and vertical shoots, leaves, and fruits. Each sample was oven-dried at 75°C until a constant weight was obtained to evaluate their dry weight biomass (g m^{-2}). Furthermore, the fresh and dry fruit yield (g m^{-2}), fruit number (fruits m^{-2}), and individual fresh and dry weight of fruits (g $fruit^{-1}$) were evaluated.

Fruit soluble solids, acidity and colour

To assess the chemical composition of fruit juice, a sample of approximately 50 g of fresh fruits was harvested from each plot. These fruits were heated in a microwave oven until they reached a temperature of around 90°C, ground to a paste consistency, and allowed to cool to approximately 50°C. Pectinase (Kleryzme 150 de DSM Foods) was then added to the fruit paste to increase the juice release. The soluble solids % of each juice sample was determined using a Leica ar200 Microsystems digital refractometer (Sidney, Australia), and their acidity (%) was measured using NaOH and an Extech 321,990 pH meter (Extech Instruments Corp., Massachusetts, USA). The acidity of each sample was calculated using the Equation 1 (Tyl & Sadler, 2017):

$$Acidity = \frac{V_{NaOH} \times C_{WA} \times C_B}{M_s \times 100} \quad (1)$$

Where V_{NaOH} is the Volume of NaOH, C_{WA} is the Concentration of citric acid (0.064 mEq), C_B is the Concentration of the base (NaOH; 0.1 N) and M_s is the mass of the sample to titre (g). Finally, the colour intensity of the juice was determined with a Jenway 6400 (Jenway Ltd., UK) spectrophotometer.

Statistical analyses

Each experiment (saccharose and shade) was analysed independently. Statistical analyses were conducted using the InfoStat statistical software version 2020e (DiRienzo et al., 2010) and R Statistical Software, version 4.3.0 (R Core Team, 2023). The significance level for all comparisons was set at 0.05. Yield, biomass, yield components, and quality traits were evaluated using heteroscedastic general-linear mixed models. Treatment was set as the fixed factor and blocks as the random factors, assuming a constant variance function structure (varIdent). A post hoc LSD-Fisher analysis was used when necessary.

The least-squares method was used to establish relationships between yield components. The parameters of the linear regressions of each experiment were compared through their 95% confidence intervals (Weisberg, 2014) to determine differences in the trade-off between fruit number per unit area and mean fruit weight. If the intervals did not overlap, the regression parameters were significantly different. Additionally, a correlogram was generated to investigate the associations between key parameters, including plant yield (dry matter), fruit number per unit area, mean fruit weight, biomass, and biomass components in 'Stevens' cranberry plants under saccharose and shading treatments.

Results

Flower and fruit phenology

Flower development started by the end of October and ended by the end of December, lasting for almost 60 days. The relative changes over time of the flowering phenology during this period are presented in Figure 1. In the beginning, the presence of immature flower stages (elongation, roughneck, prehook, and hook) decreased with time, while the open flower stage increased to a maximum at the beginning of the third period (November 26), which was considered the overall full bloom for this location. Once this maximum was reached, this stage began to decrease, and the fruiting period started with the appearance of the pinhead and pea stages. Therefore, the fruit set period started on December 10 and lasted till December 24.

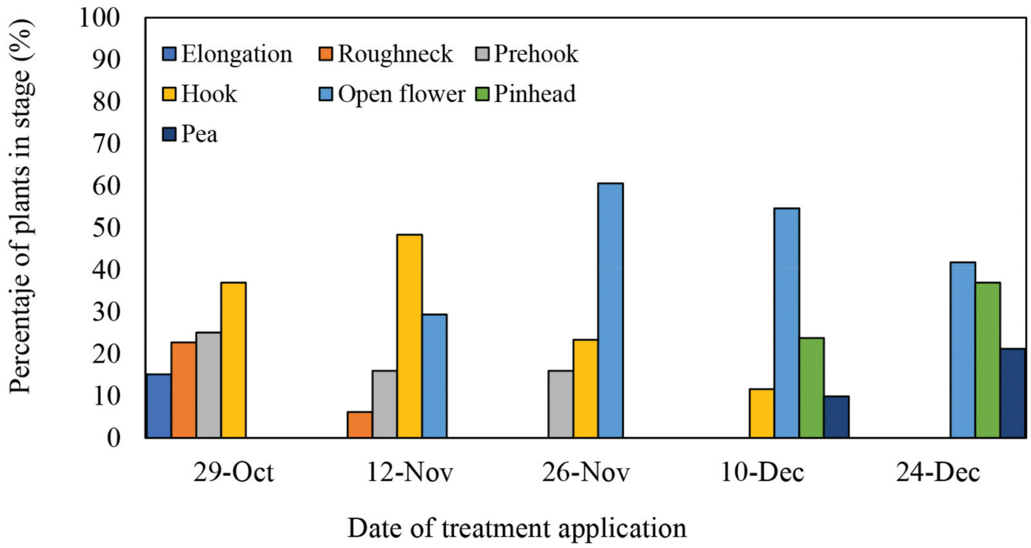

Figure 1. The percentage of 'Stevens' cranberry plants in various reproductive phenology stages. Loncoche, Araucanía Region, Chile.

Effect of artificial shade and saccharose application on fruit yield and yield components

Cranberry dry (DY) and fresh fruit yields (FY) were linearly and significantly related with no effect of the treatments. For both experiments (saccharose and shade) the relationship between the dry and fresh yield of cranberry was the same (95% confidence intervals of slope and intercept of the regression were overlapped), thus a single regression is presented for both data sets ($DY = 0.123FY + 0.24$), whose slope indicates that the percentage of the dry mass of fruits remained constant at around an average of 12.3% (Figure 2).

The sucrose spray had a significant effect on yield on the application date of December 10, and the imposition of shade had a significant effect on yield on December 10 and 24 (Figure 3). Between those dates, the predominant fruit development stages were open flower and pinhead (Figure 1). Saccharose spraying treatment has a significant effect on yield (fresh and dry matter) and fruit number (Table 2). Yield was 22% higher than the control associated with a higher fruit number on December 10 (Table 2). No significant differences were observed between the treatment application dates for the mean fruit weight (fresh or dry; Table 2). The applications of shade on December 10 and 24, significantly decreased yield (Figure 3), and fruit number per square metre (Table 2) in comparison with the control, while shading on October 29, increased yield because of an increase in the fruit number per unit area.

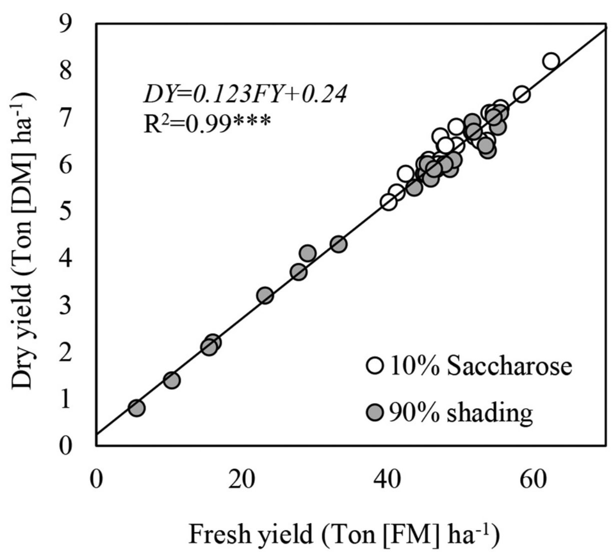

Figure 2. Regression of the dry and fresh yield of cranberry under a 10% (w/v) saccharose application and a 2-week artificial shade (90%).

Treatments affect mainly fruit number per square metre, so the yield was significantly related to this trait (Figure 4a), and not to the mean fruit weight (Figure 4b). The relationship was the same independently of treatment (95% confidence intervals of slope and intercept of the regression were overlapped).

Effects of artificial shade and saccharose application on above and underground biomass

The saccharose spraying date did not affect biomass or biomass distribution in any of the application dates (Table 3). On the other hand, the shading date had a significant effect on both total biomass and mass of uprights ($p < 0.0001$). Artificial shade imposed for 14 days from October 29, increased both traits in comparison with the control. However, artificial shade given on December 10 and 24, decreased total biomass. That was related to the decrease in fruit number. Artificial shade given on December 24, significantly decreased the uprights dry mass in comparison with the control (Table 3).

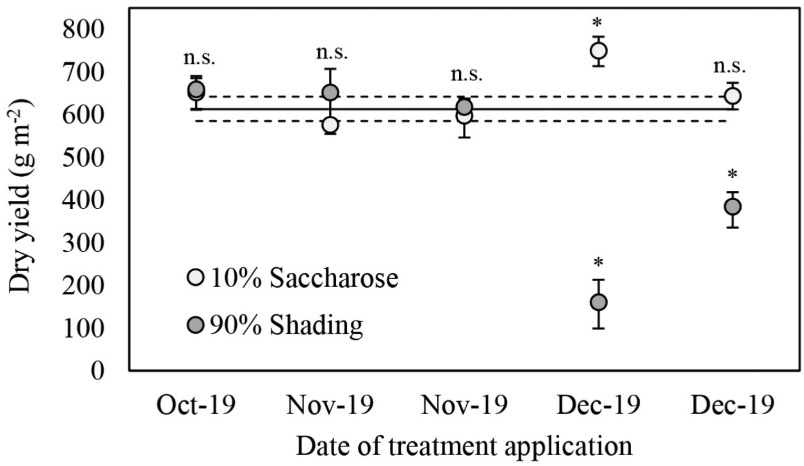

Figure 3. Effect of saccharose application or a 2-week artificial shade period on dry yield of 'Stevens' cranberry at harvest. The horizontal continuous line represents the mean yield of the control. The vertical bars and dotted lines represent the 95% confidence interval of the mean. n.S.= not statistically significant; *= statistically significant.

Table 2. Effect of 10% saccharose application and 90% shading on fruit yield, fruit number per square metre, fresh and dry mean fruit weight of 'Stevens' cranberry at harvest. Loncoche, Araucanía Region, Chile.

TAD	Yield (FM) (Ton ha^{-1})		Yield (DM) (Ton ha^{-1})		Fruit$_w$ (FM) (g fruit^{-1})		Fruit$_w$ (DM) (g fruit^{-1})		Fruit number per m^2	
10% Saccharose spray (w/v)										
Control	49.0 ± 1.8	B	6.3 ± 0.3	B	1.1 ± 0.03	A	0.15 ± 0.002	A	4,335.2 ± 74.5	B
29-oct	50.1 ± 1.8	B	6.5 ± 0.2	B	1.2 ± 0.03	A	0.15 ± 0.002	A	4,339.9 ± 141.7	B
12-nov	44.1 ± 1.3	BC	5.8 ± 0.1	BC	1.1 ± 0.01	A	0.15 ± 0.001	A	3,916.0 ± 81.3	C
26-nov	45.5 ± 1.8	BC	6.0 ± 0.3	BC	1.1 ± 0.02	A	0.15 ± 0.005	A	4,038.8 ± 97.8	BC
10-dec	57.8 ± 1.8	A	7.5 ± 0.2	A	1.2 ± 0.01	A	0.15 ± 0.001	A	5,005 ± 143.3	A
24-dec	48.8 ± 1.6	B	6.4 ± 0.2	B	1.2 ± 0.04	A	0.16 ± 0.004	A	4,111.4 ± 147.4	BC
p-value	0.0005		<0.0001		0.2527		0.0778		0.0002	
2-week Artificial Shade (90%)										
Control	46.5 ± 2.4	B	6.0 ± 0.3	B	1.1 ± 0.03	B	0.1 ± 0.002	B	4,301.6 ± 105.6	B
29-oct	51.9 ± 1.4	A	6.6 ± 0.2	A	1.1 ± 0.03	B	0.1 ± 0.005	AB	4,699.6 ± 125.2	A
12-nov	51.3 ± 2.7	AB	6.5 ± 0.3	AB	1.2 ± 0.03	A	0.2 ± 0.004	A	4,282.9 ± 147.0	B
26-nov	50.4 ± 3.4	AB	6.2 ± 0.4	AB	1.2 ± 0.04	A	0.2 ± 0.002	A	4,086.7 ± 89.2	B
10-dec	28.4 ± 1.5	C	3.8 ± 0.3	C	1.2 ± 0.05	AB	0.2 ± 0.010	A	1,019.9 ± 207.1	D
24-dec	11.9 ± 2.0	D	1.6 ± 0.3	D	1.0 ± 0.03	C	0.1 ± 0.002	B	2,765.2 ± 162.5	C
p-value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	

TAD = Treatment Application Date; FM = Fresh Matter; DM = Dry Matter; Fruit$_w$ = mean fruit weight. Different letters vertically indicate significant differences between treatments according to LSD-Fisher post hoc analysis.

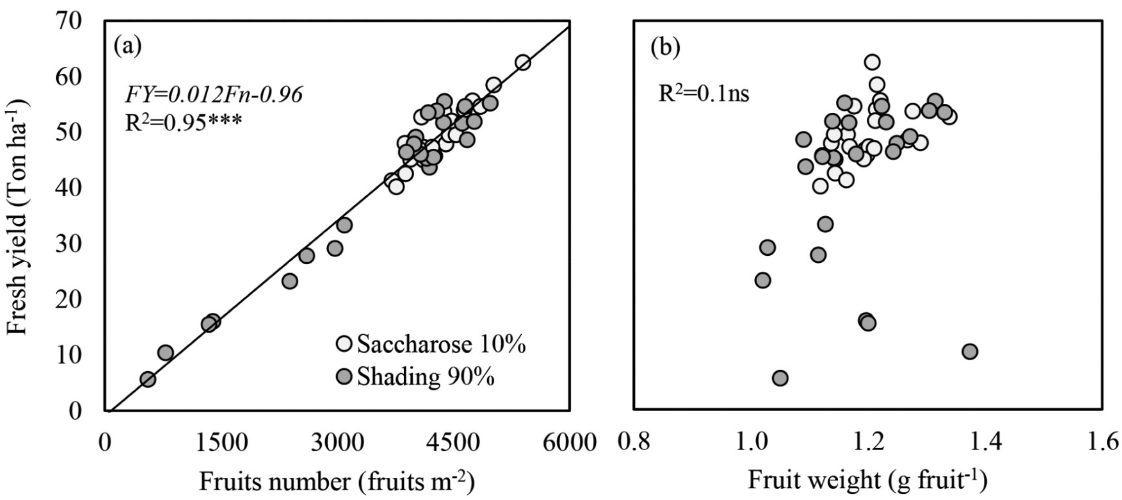

Figure 4. Relationship between fruit fresh yield and individual fruit fresh weight, and dry yield and individual fruit dry weight (insert) of 'Stevens' cranberry at harvest. Loncoche, Araucanía Region, Chile.

Table 3. Effect of a 10% (w/v) saccharose foliar spray or a 2-week artificial 10% shade on above and underground biomass of 'Stevens' cranberry at harvest. Loncoche, Chile.

DTA	Biomass (g DM *m*-2)		Leaves (g DM *m*-2)		Roots (g DM *m*-2)		Uprights (g DM *m*-2)		Runners (g DM *m*-2)	
10% saccharose spray										
Control	1,524.4 ± 43.6	A	326.8 ± 27.4	A	100.9 ± 24.4	A	267.2 ± 34.7	A	201 ± 29.3	A
29-oct	1,486.2 ± 80.5	A	339 ± 31.6	A	80.6 ± 17.3	A	246.4 ± 22.2	A	170.1 ± 17.4	A
12-nov	1,439.8 ± 62.6	A	315.2 ± 50.4	A	96.2 ± 18.9	A	261.4 ± 20.4	A	191 ± 20.8	A
26-nov	1,515.5 ± 63.8	A	339.8 ± 29.5	A	68.7 ± 19.7	A	317.4 ± 22.1	A	190.7 ± 22.9	A
10-dec	1,759 ± 111.5	A	411.8 ± 42.7	A	102.4 ± 18.5	A	307.2 ± 61.6	A	189.1 ± 17	A
24-dec	1,653 ± 93.4	A	365.2 ± 39.2	A	124.6 ± 8.2	A	306.9 ± 58.8	A	211.5 ± 33.1	A
p-value	0.1225		0.1176		0.1054		0.3095		0.8683	
2-week Artificial Shade (90%)										
Control	1565.9 ± 21.7	B	386.8 ± 25.7	A	86 ± 8.2	A	272.4 ± 15.1	BC	222.1 ± 19.4	A
29-oct	1810.5 ± 80.1	A	406.3 ± 34.5	A	124.2 ± 28	A	343.9 ± 17.3	A	277.4 ± 50	A
12-nov	1636.1 ± 73.7	AB	400.9 ± 33.3	A	96.9 ± 15.9	A	282.2 ± 42.9	ABC	207.1 ± 20.8	A
26-nov	1631.5 ± 93.6	AB	394 ± 42.8	A	100.5 ± 8.3	A	325.1 ± 43.1	AB	194.5 ± 21.1	A
10-dec	1177 ± 40.8	C	402.8 ± 23.2	A	88.8 ± 14.3	A	287.1 ± 24.6	AB	238.3 ± 16.9	A
24-dec	1315.2 ± 110.7	C	379 ± 46.3	A	92.7 ± 16.2	A	234.4 ± 19.2	C	224.4 ± 49.5	A
p-value	<0.0001		0.9922		0.5186		0.0001		0.5233	

Different letters vertically indicate significant differences between treatments according to LSD-Fisher post hoc analysis.

Relationship between yield and biomass components under shade and saccharose treatments

Figure 5 shows the association between several biomass components in cranberry under saccharose and shading treatments. Plant dry biomass was positively and significantly associated with the number of fruits per square metre and with the total plant biomass. No associations were observed between yield or yield components with other biomass components. The shoots (uprights and runners) were positively associated with the leaf dry matter.

Effect of shade and saccharose application on fruit quality traits

Table 4 shows the effect of the application of 10% saccharose spraying and 90% shade imposition on the concentration of soluble solids, titratable acidity, and colour intensity of cranberry at harvest on December 10, the date more affected by treatments. No effect of saccharose spraying was observed in any of the fruit quality traits. Shading had a significant effect on the colour intensity ($p = 0.0288$), decreasing its value in comparison with the control.

Discussion

Saccharose spraying and shade effect over cranberry yield highly depend on the time of treatment application

Our results show that saccharose spraying on December 10 increased yield (Figure 3) through an increase in fruit number (Table 2). During this period open flower was the predominant development stage. Greater availability of sugars reduces the competition for carbohydrates within reproductive uprights in early stages of development (Vasconcelos et al., 2009), allowing a bigger fruit set as we observed. This supports the hypothesis of a source limitation (Birrenkott et al., 1991; Hagidimitriou & Roper, 1994), and the critical period is similar to that reported for cranberry in other works (DeVetter et al. 2016). Alternatively, has been reported that exogenous sucrose application could attract bees and ensure complete pollination (Du et al., 2017). In our study, an application of 417 Kg ha^{-1} of saccharose produces an increase of 22% in fresh yield, representing an increase in yield of almost 8 tons/ha, reaching a total yield of 44 tons ha^{-1}. A similar effects were observed by Yehia and Hassan (2005) in 'Leconte' pears when trees that were sprayed with saccharose during full bloom increased their yield, like so in apples (Robinson & Lakso, 2004), kiwifruit (Piller et al., 1998,) and 'Searles' cranberry (Roper et al., 1995), so it could be aconserved response in multiple species.

When 14 days of shading were imposed on December 10 and 24, a reduction of yield was observed (Figure 3), that wasn't compensated by vegetative growth (Table 2; Figure 5). A reduction in photosynthesis rate results in a minor availability of assimilates increasing the competition for photoassimilates between vegetative and reproductive organs. In our experiment, the number of fruits per unit area and fruit weight were affected, which indicates stress. Petridis et al. (2018) observed that blueberry fruit development is dependent on newly assimilated carbon and that blueberry plants do not store a reserve carbohydrate buffer to support fruit development in adverse environmental conditions. It has been reported that the lower availability of assimilates can be a trigger for a hormonal imbalance that stimulates the abscission of fruits on the vine (Lebon et al., 2008).

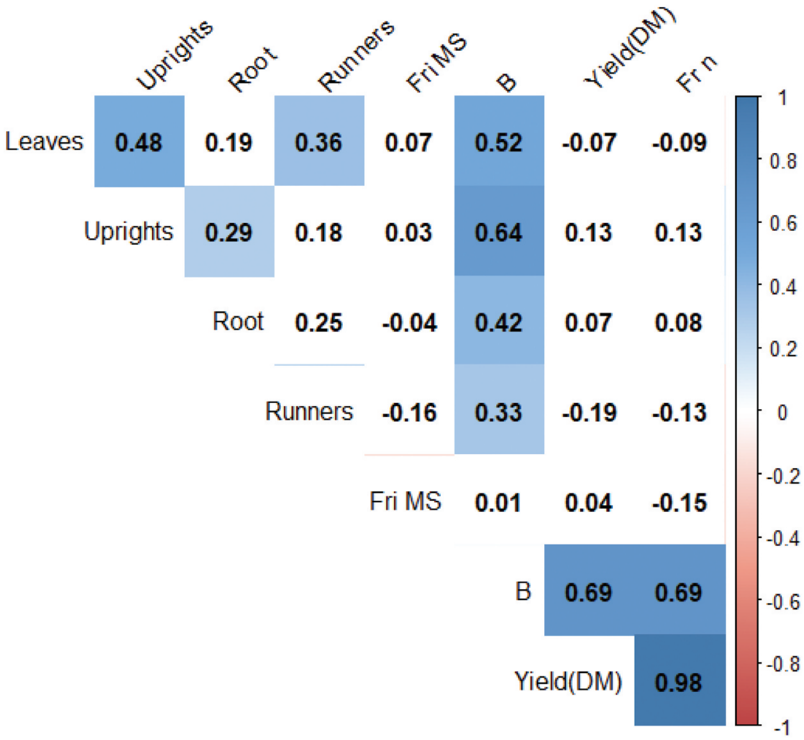

Figure 5. Correlogram for the associations between plant yield (dry matter), fruit number per unit area (fr n), mean fruit weight (FriMS), biomass (B), and biomass components in 'Stevens' cranberry treated with 10% saccharose at different dates and shaded with a 90% shading mesh. Loncoche, Chile. Numbers in the matrix represent the pearson correlation coefficient, blue colour is a positive association, and colour intensity represents a higher significance of the association.

A trade-off between fruit load and individual fruit size is well-established in several species (Kumar et al., 2019). We did not observe a reduction in fruit size despite an increase of 15% in fruit load in comparison with the control in the saccharose experiment. This could be due to the highest carbon availability and to a photosynthesis stimulus induced by greater demand for assimilates by a greater fruit load, as has been observed in apples (Blanke, 1997), citrus (Iglesias et al., 2002; Syvertsen et al., 2003), peaches (Quilot et al., 2004) and coffee (Franck et al. 2006). Nevertheless, we observed greater fruit size when shading reduces fruit number in cranberry (Table 2), expressing the trade-off at low fruit loads by suppressing the carbohydrate shortage. However, it is important to note that more observation seasons would help establish whether this trend is stable.

Shading, not saccharose spraying affects the vegetative growth of cranberry

The vegetative growth and distribution of dry matter were the same between saccharose spraying dates independently of the yield differences observed. Other studies report a negative association, as is the case in grape productivity and vegetative growth (Dami et al., 2005), based on the competition between vegetative and reproductive growth in indeterminate species (Blanke, 1997). In the shading experiment biomass was increased in comparison with the control on October 29, when hook and prehook were the main development stages, related to a higher upright dry mass (Figure 5). This could be explained by less competition between reproductive (fewer fruits number) and vegetative growth, and better water conditions by decreasing the rate of evapotranspiration, allowing the tissue to expand more effectively (Roche, 2015).

Cranberry quality traits are not affected by saccharose application or shading, except for fruit colour intensity

Because the greatest significant effects on the production variables were obtained with shading or saccharose application during the fourth period (December 10), fruit juice quality analysis was focused on this period. These analyses revealed no effect of saccharose on colour despite the findings of Li et al. (2019), where four pathways involved in anthocyanin synthesis were activated by exogenous sucrose. Only significant differences for shading date in colour intensity (Table 4). As fruit colour for cranberry is due to the presence of anthocyanins (Fuleki & Francis, 1968; Nemzer et al., 2022), the lesser fruit colour intensity under shading could be due to lesser anthocyanins, as observed in shaded grape clusters (Morrison & Noble, 1990). However, even if in the current study, shading was intense (90%), this lasted only two weeks, during an early fruit growth stage when only some of them had

Table 4. Effect of saccharose spraying and 2-week artificial shade (90%) imposition on fruit formation (10–23 Dec. 2007) over soluble solids content (%), titratable acidity (%), soluble solids/acidity ratio, and juice colour intensity in 'Stevens' cranberry at harvest.

10% Saccharose	Soluble solids (%)		Tritatable acidity (%)		Color intensity	
10-Dec	10.73	A	2.31	A	14.41	A
Control	10.83	A	2.26	A	17.73	A
p-value	0.7743		0.3074		0.4256	
90% Shading	**Soluble solids (%)**		**Tritatable acidity (%)**		**Color intensity**	
10-Dec	11	A	2.63	A	11.3	A
Control	10.68	A	2.21	A	14.85	B
p-value	0.1727		0.1969		0.0288	

Different letters vertically indicate significant differences between treatments according to LSD-Fisher post hoc analysis.

been formed and the synthesis of anthocyanins had not begun. On the other hand, the negative effect of shading on fruit colour could be due to a very small fruit load on this treatment, which may have resulted in greater vegetative development and greater fruit shading, thus affecting fruit colour development. This hypothesis was not verified, as no significant effects were found on leaf dry weight. Besides this variable related to juice colour, the shading did not affect soluble solid content or juice acidity, important economic parameters for cranberry.

Conclusions

Our investigation revealed that the period between the end of full bloom and the beginning of fruit growth when open flower and pinhead are the main development stages in the crop, is the most critical stage for 'Stevens' cranberry as it is during this period that the fruit load is established. During this period an increase in carbohydrate availability increases yield significantly, while shading (and consequently a reduction of photosynthesis rate) decreases yield, in both cases because of an increase and reduction in fruit number per unit area, respectively. So, for the experimental conditions of this study, the hypothesis of carbohydrate shortage is maintained.

While saccharose spraying had positive effects in our study, further investigation across multiple seasons, cultivars, and locations is necessary to validate its effectiveness in increasing cranberry yield by managing carbon shortage limiting fruit set. It is important to say that the observations made in this study can be influenced by other factors that influence the carbohydrate balance inside the plant, such as the cultivar, genotype x environment interaction, nutritional status, the application of growth regulators, abiotic and biotic stress, among others.

Acknowledgements

We thank and remember Dr. Nicolás Franck who was an important part of this work. Nicolás died at a young age on October 20, 2017.

Disclosure statement

No potential conflict of interest was reported by the author(s).

ORCID

Marco Garrido-Salinas http://orcid.org/0000-0002-8424-0540

Data availability statement

The datasets generated for this study are available on request to the corresponding author.

References

Arzani, K., Hokmabadi, H., & Dehghani-Shuraki, Y. (2001). Effects of foliar application of some carbohydrates on qualitative and quantitative traits of pistachio nuts cv Kalleh-Ghoochi. *Acta Horticulturae*, *594*(594), 291–296. https://doi.org/10.17660/ActaHortic.2002.594.34

Basak, A. (2011). Efficiency of fruitlet thinning in apple 'gala must' by use of metamitron and artificial shading. *Journal of Fruit and Ornamental Plant Research*, *19*(1), 51–62.

Birrenkott, B. A., Henson, C. A., & Stang, E. J. (1991). Carbohydrate levels and the development of fruit in cranberry. *Journal of the American Society for Horticultural Science*, *116*(2), 174–178. https://doi.org/10.21273/JASHS.116.2.174

Blanke, M. M. (1997). Effect of fruit load on whole tree carbon assimilation, dark respiration, and water relations in apple. *Acta Horticulturae*, *451*(451), 313–318. https://doi.org/10.17660/ActaHortic.1997.451.36

Brown, A. O., & McNeil, J. N. (2006). Fruit production in cranberry (ericaceae: Vaccinium macrocarpon): A bet-hedging strategy to optimize reproductive effort. *American Journal of Botany*, *93*(6), 910–916. https://doi.org/10.3732/AJB.93.6.910

Dami, I., Ferree, D. C., Kurtural, S. K., & Taylor, B. H. (2005). Influence of crop load on ´chambourcin´ yield, fruit quality, and winter hardiness under midwestern united states environmental conditions. *Acta Horticulturae*, *689*(689), 203–208. https://doi.org/10.17660/ActaHortic.2005.689.22

DeVetter, L. W., Beaver, E., Colquhoun, J., Zalapa, J., & Harbut, R. (2016). Comparison of nonstructural carbohydrates across cranberry cultivars. *European Journal of Horticultural Science*, *81*(6), 321–326. https://doi.org/10.17660/eJHS.2016/81.6.5

DiRienzo, J., Balzarini, M., Gonzalez, L., Casanoves, F., Tablada, M., & Walter Robledo, C. (2010). Infostat: Software para análisis estadístico. https://repositorio.catie.ac.cr/handle/11554/10346

Du, L., Qi, S., Ma, J., Xing, L., Fan, S., Zhang, S., Li, Y., Shen, Y., Zhang, D., & Han, M. (2017). Identification of TPS family members in apple (Malus x domestica Borkh) and the effect of sucrose sprays on TPS expression and floral induction plant physiol. *Biochemistry*, *120*, 10–23. https://doi.org/10.1016/j.plaphy.2017.09.015

Eck, P., Raw, V., & West, B. A. (1990). The American cranberry. Rutgers University Press, New Brunswick. Greven, M.M., raw, V., west, B.A., 2009. Effects of timing of water stress on yield andberry size. *Water Science & Technology*, *60*(5), 1249–1255. https://doi.org/10.2166/wst.2009.553

Estornell, L. H., Agustí, J., Merelo, P., Talón, M., & Tadeo, F. R. (2013). Elucidating mechanisms underlying organ abscission. *Plant Science*, *199–200*, 48–60. https://doi.org/10.1016/j.plantsci.2012.10.008

Fischer, R. A. (1975). Yield potential in a dwarf Spring wheat and the effect of shading 1. *Crop Science*, *15*(5), 607–613. https://doi.org/10.2135/cropsci1975.0011183X001500050002x

Franck, N., Vaast, P., Génard, M., & Dauzat, J. (2006). Soluble sugars mediate sink feedback down-regulation of leaf photosynthesis in field-grown Coffea arabica. *Tree Physiology*, *26*, 517–525. https://doi.org/10.1093/treephys/26.4.517

Fuleki, T., & Francis, F. J. (1968). Quantitative methods for anthocyanins. *Journal of Food Science*, *33*(1), 72–77. https://doi.org/10.1111/j.1365-2621.1968.tb00887.x

Guglielmini, A., Forcat, J., & Miralles, D. (2019). The critical period for yield determination in common buckwheat (Fagopyrum esculentum moinch). *The European Journal of Agronomy*, *110*, 125933. https://doi.org/10.1016/j.eja.2019.125933

Hagidimitriou, M., & Roper, T. R. (1994). Seasonal changes in non-structural carbohydrates in cranberry. *Journal of the American Society for Horticultural Science*, *119*(5), 1029–1033. https://doi.org/10.21273/JASHS.119.5.1029

Hagidimitriou, M., & Roper, T. R. (1995). Seasonal changes in CO2 assimilation of cranberry leaves. *Scientia Horticulturae*, *64*(4), 283–292. https://doi.org/10.1016/0304-4238(95)00835-7

Handley, D. T. (2003). *Commercial cranberry production in Maine: An introduction*. Bulletin No. 2247. University of Maine Cooperative Extension.

Iglesias, D. J., Lliso, I., Tadeo, F. R., & Talon, M. (2002). Regulation of photosynthesis through source: Sink imbalance in citrus is mediated by carbohydrate content in leaves. *Physiologia Plantarum*, *116*(4), 563–572. https://doi.org/10.1034/j.1399-3054.2002.1160416.x

Kumar, K., Singh, D., Kumar, P., Yadav, R., Prakash, S., Singh, H. L., & Kumar, R. (2019). Progress in pruning to vegetable crops: A review. *International Journal of Advances in Agricultural Science and Technology*, *19*(1), 19–32. https://doi.org/10.5958/0976-4615.2019.00018.8

Lebon, G., Wojnarowiez, G., Holzapfel, B., Fontaine, F., Vaillant-Gaveau, N., & Clément, C. (2008). Sugars and flowering in the grapevine (*vitis vinifera L.). Journal of Experimental Botany*, *59*(10), 2565–2578. https://doi.org/10.1093/jxb/ern135

Li, D., Zhang, X., Xu, Y., Li, L., Soleimani, M., & Luo, Z. (2019). Effect of exogenous sucrose on anthocyanin synthesis in postharvest strawberry fruit. *Food Chemistry*, *289*, 112–120. https://doi.org/10.1016/j.foodchem.2019.03.042

Morrison, J. C., & Noble, A. C. (1990). The effects of leaf and cluster shading on the composition of 'cabernet sauvignon' grapes and on fruit and wine sensory properties. *American Journal of Enology and Viticulture*, *41*(3), 193–200. https://doi.org/10.5344/ajev.1990.41.3.193

Nemzer, B. V., Al-Taher, F., Yashin, A., Revelsky, I., & Yashin, Y. (2022). Cranberry: Chemical composition, antioxidant activity and impact on human health: Overview. *Molecules*, *27*(5), 1503. https://doi.org/10.3390/molecules27051503

ODEPA/CIREN. (2019 Julio). Catastro fruticola, Principales Resultados, Region de Los Lagos. https://bibliotecadigital.odepa.gob.cl/bitstream/handle/20.500.12650/71147/Catastro-Fruticola-Los-Lagos-2019.pdf

Pelletier, V., Gallichand, J., Caron, J., Jutras, S., & Marchand, S. (2015). Critical irrigation threshold and cranberry yield components. *Agricultural Water Management*, *148*, 106–112. https://doi.org/10.1016/j.agwat.2014.09.025

Petridis, A., van der Kaay, J., Chrysanthou, E., McCallum, S., Graham, J., & Hancock, R. (2018). Photosynthetic limitation as a factor influencing yield in highbush blueberries (vaccinium corymbosum) grown in a northern European environment. *Journal of Experimental Botany*, *69*(12), 3069–3080. https://doi.org/10.1093/jxb/ery118

Piller, G. J., Greaves, A. J., & Meekings, J. S. (1998). Sensitivity of floral shoot growth, fruit set and early fruit size in *Actinidia deliciosa* to local carbon supply. *Annals of Botany*, *81*(6), 723–728. https://doi.org/10.1006/anbo.1998.0624

Quilot, B., Génard, M., & Kervella, J. (2004). Leaf light-saturated photosynthesis for wild and cultivated peach genotypes and their hybrids: A simple mathematical modeling analysis. *Journal of Horticultural Science and Biotechnology*, *79*(4), 546–553. https://doi.org/10.1080/14620316.2004.11511803

R Core Team. (2023). *_R: A language and environment for statistical Computing_*. R Foundation for Statistical Computing. https://www.R-project.org/

Robinson, T. L., & Lakso, A. N. (2004). Between year and within year variation in chemical fruit thinning efficacy of apple during cool springs. *Acta Horticulturae*, *636* (636), 283–294. https://doi.org/10.17660/ActaHortic.2004.636.34

Roche, D. (2015). Stomatal conductance is essential for higher yield potential of C3 crops. *Critical Reviews in Plant Sciences*, *34*(4), 429–453. https://doi.org/10.1080/07352689.2015.1023677

Roper, T. R., Hagidimitriou, M., & Klueh, J. (1993). Photosynthesis and carbohydrate partitioning in cranberry. In Cranberry School Proc., Wisconsin Cranberry Crop Library, Wisconsin, Madison.

Roper, T. R., & Klueh, J. S. (1994). Removing new growth reduces fruiting in cranberry. *Hort Science*, *29*(3), 199–201. https://doi.org/10.21273/HORTSCI.29.3.199

Roper, T. R., Klueh, J., & Hagidimitriou, M. (1995). Shading timing and intensity influences fruit set and yield in cranberry. *Horticulture Science*, *30*(3), 525–527. https://doi.org/10.21273/HORTSCI.30.3.525

Roper, T. R., & Vorsa, N. (1997). Cranberry: Botany and horticulture. *Horticultural Reviews (USA)*, *21*, 215–249. https://doi.org/10.1002/9780470650660.ch7

Sandler, H. A., & DeMoranville, C. (2008). Cranberry production: A guide for Massachusetts. In H. A. Sandler & C.

J. DeMoranville (Eds.), *Publication CP-08* (pp. 198). UMass Cranberry Station.

Sheen, J., Zhou, L., & Jang, J. C. (1999). Sugar as signaling molecules. *Current Opinion in Plant Biology*, *2*(5), 410–418. https://doi.org/10.1016/S1369-5266(99)00014-X

Stang, E. J. (1990). Cranberry fruit set: Problems and potentials. In Cranberry School Proc., Wisconsin Cranberry Crop Management Library, Wisconsin, Madison.

Stang, E. J. (1997). The emerging cranberry industry in Chile. *Acta horticulturae*, *446*(446), 159–164. https://doi.org/10.17660/ActaHortic.1997.446.23

Syvertsen, J. P., Goñi, C., & Otero, A. (2003). Fruit load and canopy shading affect leaf characteristics and net gas exchange of 'Spring' navel orange trees. *Tree Physiology*, *23*(13), 899–906. https://doi.org/10.1093/treephys/23.13.899

Tyl, C., & Sadler, G. D. (2017). pH and titratable acidity. In S. S. Nielsen (Ed.), *Food analysis. Food science text series*. Springer. https://doi.org/10.1007/978-3-319-45776-5_22

Uribe, M., Cabrera, R., de la Fuente, A., & Paneque, M. (2012). Atlas Bioclimático de Chile. *Universidad de Chile, Facultad de Ciencias Agronómicas*, 232. https://repositorio.uchile.cl/handle/2250/178567

Van den, J. E., & Davenport, J. R. (2005). Effects of light, temperature, defoliation, and fruiting on carbon assimilation and partitioning in potted cranberry. *Hort Science*, *40*(6), 1699–1704. https://doi.org/10.21273/HORTSCI.40.6.1699

Vasconcelos, M. C., Greven, M., Winefield, C. S., Trought, M. C. T., & Raw, V. (2009). The flowering process of vitis vinifera: A review. *American Journal of Enology and Viticulture*, *60*(4), 411–434. https://doi.org/10.5344/ajev.2009.60.4.411

Weisberg, S. (2014). *Applied linear regression* (4th ed.). John Wiley & Sons, Inc.

Workmaster, B. A., Palta, J. P., & Roper, T. R. (1997, February). Terminology for cranberry bud development and growth. Cranberries 11–14. Retrieved Oct 10, 2007, from www.hort.wisc.edu/cran/mgt_articles/articles_gen_info/TerminologyCranBudDev/cranbuddev.htm

Yehia, T. A., & Hassan, H. S. A. (2005). Effect of some chemical treatments on fruiting of 'Leconte' pears. *Journal of Applied Sciences Research*, *1*(1), 35–42.