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Yield and quality of primocane-fruiting raspberry grown under plastic cover in southern Brazil

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ABSTRACT: Raspberry (*Rubus idaeus* L.) is an economically important crop and its cultivation has been expanded across temperate and subtropical regions of Brazil. Growing raspberries under plastic cover has becoming more common worldwide. This study investigated the effect of plastic cover on productive and morphological performance of primocane-fruiting raspberry cultivars, in southern Brazil. The experiment was arranged in a 3 × 2 × 2 factorial design, with three raspberry cultivars, 'Heritage'; 'Fallgold' and 'Alemãzinha'; two cultivation systems, presence and absence of plastic cover; and two production cycles, fall and spring. We measured days from transplanting to flowering and harvesting. Plants were evaluated for dry mass of pruning, plant height, stem diameter, plant leaf area, fruit production, number of fruits, fruit weight, fruit longitudinal and transversal diameter, and harvesting period. Plastic cover reduced incident radiation on the canopy by 17 %. Cultivar 'Heritage' is early ripening in the fall cycle. The management under plastic cover prolonged the harvesting period of raspberries in the fall productive cycle for the cultivar 'Heritage' and, in spring, for cultivars 'Alemãzinha' and 'Fallgold'. In the spring cycle, plants increased their leaf area, fruit production and number of fruits. The cultivar 'Alemãzinha' performed better in the spring cycle when managed under plastic cover and was more productive, with a longer productive cycle and larger fruits.

Keywords: *Rubus idaeus* L., production, protected crop, small fruits, berries

Introduction

The southern region of Rio Grande do Sul, Brazil, has tradition in growing peaches and temperate climate fruits (Gonçalves et al., 2017). In recent decades, other species of small fruits, such as blackberry, strawberry, and blueberry, have been introduced. Raspberry (*Rubus idaeus* L.), which is included in this group, is not yet economically important in Brazil; however, it has gained great interest among growers and expanded across temperate and subtropical regions in Brazil (Maro et al., 2013; Souza et al., 2014).

Raspberry cultivars grown in Brazil are originated from North America and Europe. Therefore, Brazilian production depends on imported cultivars, and their phenology, fruit production, and quality might not be similar to fruits from their original location. In addition, raspberries cultivation is characterized by high production per unit of area and intense labor demand. Thus, economic sustainability depends on the efficiency of agricultural practices employed in the production system.

In this context, identification of raspberry cultivars adapted to growing conditions of southern Rio Grande do Sul is essential due to the importance that the region and species represent to the Brazilian fruit chain. Alternatives are necessary to improve fruit yield and quality, since raspberries are sensitive to climatic conditions, such as precipitation, winds and hail.

An alternative to minimize problems caused by climatic adversities and improve fruit quality is the growing of plants under plastic cover. This practice may modify the conformities of climatic variables, mainly light intensity and quality, air temperature and relative humidity, wind incidence and speed, and damages caused by insect pests and diseases (Palonen et al., 2017). Furthermore, plastic cover above the canopy allows to improve fruit yield and quality through the development of a favorable microclimate, which protects the plants and provides beneficial effects of climatic variations (Bradish et al., 2015; Curi et al., 2015; Palonen et al., 2017; Yao and Rosen, 2011).

This study aimed to examine the effect of plastic cover on productive and morphological performance of primocane-fruiting raspberry cultivars under climatic conditions in southern Rio Grande do Sul, Brazil.

Materials and Methods

The trials were carried out from Nov 2013 to Dec 2014, in Pelotas-RS, Brazil (latitude 31°46′ S, longitude 52°20′ W, and altitude 60 m above sea level). The climate is characterized as "*Cfa*" subtropical with hot summer by Köppen classification (Alvares et al., 2014).

The experimental design was randomized blocks, arranged in a 3 × 2 × 2 factorial design, with three raspberry cultivars, two plastic cover systems (presence and absence of plastic cover), and two productive cycles (fall and spring/summer), with four replicates. The cultivars tested were 'Alemãzinha' and 'Heritage', which produce red fruits, and 'Fallgold', which produces yellow fruits. All cultivars are primocane-fruiting and result in two productive cycles, one during fall and the other during spring/summer.

Experimental units were composed of five plants, spaced 1.0 meter (m) between rows, and 0.5 m between plants. The six-month plants were stored in eight-liter pots filled with commercial substrate and with slow release fertilizer N-P-K, 15-09-12 formula, at concentration 5 g L^{-1}.

The experiment was installed in Nov 2013. Water was supplied by drip irrigation, with drippers spaced by 0.15 m. The irrigation system was activated every three days regardless of rainfall occurrence. The tutoring was conducted through an armed system of 1.20 m above ground level. For plants composing the plastic cover treatments, low plastic tunnels had sides partially open and the film was attached to a structure 1.80 m tall and 1.0 m wide. The plastic used for cover was a 100 μm, anti-UV, transparent low-density polyethylene (LDPE).

Slow-release fertilizer was added every 120 days, at 5 g L^{-1}, formulation 15-09-12. Insects, pests and diseases were controlled preventively with chemical treatments and removal of senescent and injured leaves.

The first pruning was performed during plants dormancy, after the fall development cycle (Aug 2014). Stems were reduced to the height of sub apical buds (10 to 20 cm). At the end of spring cycle, a second pruning was performed (Dec 2014). After each pruning, all plant material collected was used to determine the average dry mass of pruning (DMP), drying it in forced ventilation oven at 65 °C until constant mass, followed by weighing in a digital scale with results expressed in grams. For both productive cycles, the days from transplant to flowering (DF) and harvesting (DH) were observed (Surya and Rahman, 2012).

The morphological traits and yield components measured were: average plant height (PH), in centimeters (cm); average stem diameter (SD), in mm; plant leaf area (PLA), obtained after each productive cycle with a leaf area meter equipment, in cm^2 per plant; average fruit production (FP), determined by the ratio between mass of fruits harvested in each experimental unit and number of plants, measured per plant; average fruits number (FN), verified by the ratio between total number of fruits harvested and number of plants contained in the plot, measured fruit per plant; average fruit weight (FW), obtained by the ratio between production and number of fruits harvested, measured in g; fruit size measured through the longitudinal (FLD) and transversal (FTD) diameter of fruits, in mm, in which 20 fruits of each experimental unit were sampled. Harvests were standardized in three-day intervals until the end of each cycle. The harvesting period (HP) was accessed by summing the duration of both harvesting cycles, expressed in days.

The photosynthetically active radiation data (PAR radiation = $\mu mols^{-1} m^{-2}$) were obtained with a quantum sensor, in and outside plastic cover. Air temperature (°C) was verified by copper-constantan (150 T) thermocouple sensors in both environments, 60 cm above the canopy at the plant row center. The data were collected in a Datalogger and recorded every hour throughout the entire productive cycles.

All the data were analyzed by the analysis of variance at 5 % of probability. In the presence of interaction between raspberry cultivars × plastic cover systems × productive cycles, the characters were sliced into simple effects. Characters that did not present significant interaction were sliced into principal effects for each factor, separately. Statistical analyses were performed using the Genes software (Cruz, 2013).

Results and Discussion

The analysis of variance revealed interaction between cultivars × productive cycles × plastic cover systems for the harvest period (HP) (Table 1). Interaction was verified between productive cycles × cultivars for days to harvesting (DH), average dry mass of pruning (DMP), and average fruit production (FP) (Table 2). The productive cycles × cover systems presented interaction for average stem diameter (SD) and average fruit weight (FW) (Table 3). Interactions between cultivars × cover systems were observed for average fruit weight (FW) and transversal (FTD) and longitudinal fruit diameter (FLD) (Table 4). The transversal (FTD) and longitudinal fruit diameters (LFD) were influenced by productive cycles. The cultivars presented difference of average stem diameter (SD). In contrast, for average dry mass of pruning (DMP), days to harvesting (DH), and average plant production (AP), phenotypic changes were verified through cover systems (Table 5). Days to flowering (DF), average plant height (PH), fruit number per plant (FN) and plant leaf area (PLA) were sliced into principal effects (Table 6) for the significant factors separately.

The climatic data (Figure 1) showed that air temperature inside plastic cover was related to external temperature (r^2 = 0.99). However, only when external temperature was lower than 13.58 °C, the temperature inside the set with plastic cover was higher. A research by Curi et al. (2015) did not reveal discrepancy between natural and plastic cover-protected environments. The magnitude of air temperature in a protected environment was dependent on external conditions and it was

Table 1 – Harvesting period, in days, of raspberry fruits of cultivars 'Alemãzinha', 'Fallgold' and 'Heritage', cultivated under and outside plastic cover during the fall and spring cycles of 2014. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

Cultivar	Fall Cycle		Spring Cycle	
	Covered	Uncovered	Covered	Uncovered
Alemãzinha	56 bAα	57 aAα	50 aAα	44 aAβ
Fallgold	53 bAα	55 aAα	50 aAα	42 aAβ
Heritage	72 aAα	53 aBα	49 aAβ	44 aAα
C.V. (%)	11.55			

Means followed by the same lowercase letter do not differ between cultivars. Means followed by the same uppercase letters do not differ between plastic cover systems and means followed by different Greek letters do not differ for productive cycles by the Duncan test (p < 0.05). C.V. = coefficient of variation.

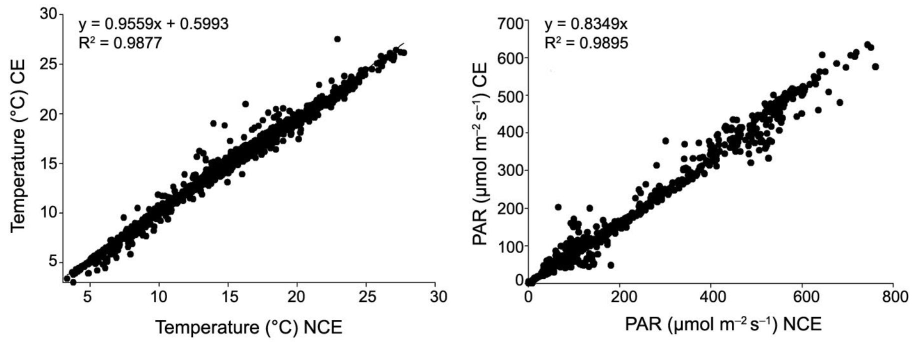

Figure 1 – Relation between air temperature in plastic covered environment (CE) and air temperature in non-covered environment (NCE). Relation between photosynthetically active radiation (PAR) in plastic covered environment (CE) and photosynthetically active radiation in non-covered environment (NCE), recorded hourly during night and daytime periods. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

Table 2 – Days to harvesting (DH), average fruit production (FP), and average dry mass of pruning (DMP) of raspberry cultivars in the fall and spring cycles of 2014. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

Cultivar	Cycle					
	DH		FP		DMP	
	days after transplant		g per plant		g per plant	
	Fall	Spring	Fall	Spring	Fall	Spring
Alemãzinha	160 aB	335 aA	10.71 aB	238.95 aA	26.6 aA	23.5 aA
Fallgold	164 aB	336 aA	10.93 aB	200.58 bA	16.5 bB	21.4 aA
Heritage	152 bB	335 aA	16.81 aB	201.64 bA	22.8 aA	24.4 aA
C.V. (%)	1.73		23.26		18.44	

Means followed by the same lowercase letter in the column do not differ. Means followed by the same uppercase letters in the row do not differ by the Duncan test ($p < 0.05$). C.V. = coefficient of variation.

Table 3 – Average stem diameter (SD) and average fruit weight (FW) of raspberry plants grown under covered and uncovered systems, during the fall and spring cycles of 2014. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

System	Cycle			
	SD		FW	
	mm		g	
	Fall	Spring	Fall	Spring
Covered	6.40 bB	7.07 aA	2.46 aA	2.27 aB
Uncovered	7.11 aA	6.66 aA	2.27 bA	2.34 aA
C.V. (%)	9.18		6.89	

Means followed by the same lowercase letter in the column do not differ. Means followed by the same uppercase letters in the row do not differ by the Duncan test ($p < 0.05$). C.V. = coefficient of variation.

related to the balance of energy inside the plastic cover, which was determined by the cover type and incidence angle of solar radiation (Cardoso et al., 2008). Studies addressing the effects of plastic cover on air temperature are essential because elevated air temperatures are harmful to raspberry mass of fruits (Remberg et al., 2010).

Plastic cover reduced the incident radiation by 17 % (Figure 1). Leitão et al. (2017) observed a reduction of 40 % in radiation incident on vineyards covered with transparent cover film of low-density polyethylene (LDPE) of 160 μm. For Cardoso et al. (2008), the material used as cover is the main factor for radiation attenuation. Its transparency may be depending on the plastic film age and inclination, as well as the lack of impurities on its surface.

Regarding the morphological and phenological characters evaluated, cultivar 'Fallgold' presented the lowest average for DMP during fall (Table 2) and longer time to flowering (DF) (Table 6). The DF was also influenced by plastic cover system, which anticipated the flowering event compared to the non-covered system (Table 6). A study on raspberries conducted in Lavras, southern Minas Gerais State, Brazil (subtropical conditions), revealed that plastic cover did not influence flowering in cultivar 'Batum' (Curi et al., 2015). The beginning of harvest was influenced by cultivar and productive cycle factors, and cultivar 'Heritage' presented earlier harvest than the others during fall cycle (Table 2).

Other morphological characters were influenced by cultivar and production cycle. Average PH presented higher value for the cultivar 'Heritage' (Table 6). In this study, there was no effect of plastic cover on plant height, in agreement with Curi et al. (2015), who did not report this effect either. Stem growth is sometimes antagonistic to production due to the lack of adaptation of introduced cultivars. The leaf area (PLA) was higher in plants cultivated during the spring cycle (Table 6), which was determinant for the increases of FP (Table 2)

Table 4 – Average fruit weight (FW), fruit longitudinal diameter (FLD) and fruit transversal diameter (FTD) of raspberry cultivars 'Alemãzinha', 'Fallgold' and 'Heritage', grown under and outside plastic cover during the fall and spring cycles of 2014. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

Cultivar	System					
	FW (g)		FLD (mm)		FTD (mm)	
	Covered	Uncovered	Covered	Uncovered	Covered	Uncovered
Alemãzinha	2.66 aA	2.41 aB	19.73 aA	19.25 aA	16.94 aA	16.42 aA
Fallgold	2.48 bA	2.43 aA	19.24 aA	18.66 aA	16.24 aA	15.31 bB
Heritage	1.99 cA	2.06 bA	18.33 bB	19.23 aA	15.06 bB	16.50 aA
C.V. (%)	7.04		3.29		4.53	

Means followed by the same lowercase letter in the column do not differ. Means followed by the same uppercase letters in the row do not differ by the Duncan test ($p < 0.05$). C.V. = coefficient of variation.

Table 5 – Fruit longitudinal diameter (FLD), fruit transversal diameter (FTD), average stem diameter (SD), average dry mass of pruning (DMP), days to harvesting (DH), and average fruit production (FP) of raspberry cultivars 'Alemãzinha', 'Fallgold' and 'Heritage', grown under and outside plastic cover during the fall and spring cycles of 2014. Embrapa Clima Temperado Pelotas-RS, Brazil, 2017.

Cycle	FLD		FTD
	mm		
Fall	17.625 b		15.120 b
Spring	20.521 a		17.033 a
C.V. (%)	3.50		4.89
Cultivar		SD	
		mm	
Alemãzinha		6.58 a	
Fallgold		6.87 a	
Heritage		6.99 a	
C.V. (%)		10.03	
System	DMP	DH	FP
	g per plant	days after transplant	g per plant
Covered	22.17 a	248 a	106.99 a
Uncovered	22.93 a	246 a	115.50 a
C.V. (%)	19.20	1.96	24.05

Means followed by the same lowercase letter in the column do not differ by the Duncan test ($p < 0.05$). C.V. = coefficient of variation.

Table 6 – Days to flowering (DF), plant height (PH), plant leaf area (PLA), and average fruit number (FN) for raspberry cultivars 'Alemãzinha', 'Fallgold' and 'Heritage', grown under and outside plastic cover during the fall and spring cycles of 2014. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2017.

Cultivar	Character			
	DF	PH	PLA	FN
	days after transplant	cm	cm^2	
Alemãzinha	218.50 b	78.25 b	4804.20 a	53.18 b
Fallgold	225.53 a	71.56 b	4348.30 a	47.30 b
Heritage	213.62 b	88.00 a	4944.30 a	66.25 a
Cycle				
Fall	131.04 b	77.14 a	2261.70 b	22.29 b
Spring	303.45 a	81.39 a	7231.40 a	90.41 a
System				
Covered	216.83 b	78.70 a	4819.70 a	53.07 a
Uncovered	221.43 a	79.83 a	4572.90 a	58.08 a
C.V. (%)	3.45	13.39	17.73	27.98

Means followed by the same lowercase letter in the column do not differ by the Duncan test ($p < 0.05$). C.V. = coefficient of variation.

and FN (Table 6). The correct establishment and reserve accumulation at low temperatures during winter allows suitable physiological conditions for plants to increase productive performance. Yao and Rosen (2011) found similar results in Minnesota, the United States, and assumed that production is increased mainly due to the correct productive cycle of primocane-fruiting raspberries.

The plastic cover system presented detrimental effects for SD by reducing it during the fall cycle (Table 3). This effect was attributed to the reduction of incident solar radiation under the plastic cover (Figure 1), and solar radiation is critical to photosynthetic rates. Moreover, radiation becomes more restrict with the proximity of winter. Radiation reduction leads plants to etiolation and SD reduction, since the growth hormone auxin induces stem elongation in response to shade (Procko et al., 2018).

The spring cycle was better regarding FP. In addition, differences in this character were observed between cultivars during this cycle (Table 2), with cultivar 'Alemãzinha' standing out and differing from the others. The production values obtained in this study were higher than in a screening of raspberry cultivars in western Paraná State, Brazil, with subtropical climate (Moura et al., 2012).

Plants submitted to plastic cover above the canopy did not show difference of FP (Table 5). A lower incident radiation in the covered system (Figure 1) may be responsible for the similar production in both covering systems, once photosynthesis is dependent on the quantity of PAR absorbed by the canopy thus determining crop yield (Kittas and Baille, 1998).

The more extreme the climatic conditions outside the plastic cover, for example, colder environments, the more pronounced are the effects of cover. In southern Minas Gerais, Brazil, with predominant high air temperatures and low rainfall, raspberry cultivar 'Batum' presented higher production in plants grown in non-covered system than in the plastic covered system (Curi et al., 2015). On the other hand, Yao and Rosen (2011) reported an increase of 380 % in plant production under plastic cover in Minnesota, The United States, with very cold winters and warm summers. Thus, there is strong evidence that primocane-fruiting raspberries production is benefited by plastic covers in environments of severe conditions with low temperatures, unlike regions with milder temperatures, such as Pelotas and southern Minas Gerais.

The interaction between productive cycles and covering systems revealed higher FW values for covered system in the fall. In contrast, for non-covered system, values were higher during the spring cycle (Table 3). Regarding the interactions between cultivars and covering systems (Table 4), only cultivar 'Alemãzinha' presented greater FW under the covered system, compared to non-covered. This cultivar also presented higher FW when cultivated under plastic cover, followed by 'Fallgold' and 'Heritage'. In the non-covered system, 'Alemãzinha' and 'Fallgold' were superior and differed only from 'Heritage'. Therefore, the highest FW values were obtained by cultivar 'Alemãzinha' in the covered system, and by cultivar 'Fallgold' in the non-covered system (Table 4).

Although cultivar 'Heritage' had the highest FN average among the cultivars evaluated (Table 6), these results prove that the highest FN obtained by cultivar 'Heritage' (Table 6) was not determinant to increase FW (Table 4) or FP (Table 2).

Our results reveal differences among cultivars, productive cycles and plastic cover management. The variables evaluated are dependent on genotypes used and climatic conditions, as well as the harvesting period, which can occur at low temperatures during fall or at elevated temperatures in spring. Thus, the cost-benefit relation must be considered before creating a plastic cover structure. In this context, FW is an indicative of higher production and an essential attribute for fruit quality (Quezada et al., 2007).

Other characters of fruit dimension are FLD and FTD. Cultivar 'Heritage' presented lower FLD than the other cultivars only in the covered system. Fruit transversal diameter (FTD) was lower for cultivar 'Heritage' in presence of plastic cover. In contrast, in the non-covered system, cultivar 'Fallgold' presented the lowest values (Table 4). Regarding the productive cycle, FLD and FTD were favored in spring (Table 5).

Raspberries harvesting period (HP) during the fall cycle was extended for cultivar 'Heritage' (Table 1) in plastic cover. Curi et al. (2015) reported a reduction in harvesting period of cultivar 'Batum' grown under plastic cover in southern Minas Gerais, showing strong effects of genotypes through environment interaction on harvesting period elongation. Regarding covering systems, cultivars 'Alemãzinha' and 'Fallgold' reduced the harvesting period without plastic cover in spring. On the other hand, cultivar 'Heritage' prolonged its harvesting period when managed under the covered system in fall (Table 1). Thus, knowing the harvesting period of plants, whether shorter or extended, could help to choose the most suitable cultivar and production system and thereby better plan the field activities.

According to Quezada et al. (2007), stems with different ages result in earlier flowering then older and more developed stems. During the spring cycle, plants go through an organ maturation period, as winter pruning and dormancy stimulate uniform sprouting and flowering.

Raspberries production in the region of Pelotas, Rio Grande do Sul, presented certain seasonality (observational data) mainly in fall harvest, which extended from Mar to June. This period is characterized by scarcity of fresh small fruits in the market, such as blackberry, which produces fruits from Nov to Jan, as well as blueberry from the group, which produces fruits from Dec to Jan. In this context, raspberry plants stand as an option to diversify farming activities, since one of the productive cycles (fall) does not coincide with that of other species, an advantage to diversity, sustainability and profitability of rural properties.

Conclusion

Cultivar 'Heritage' is early ripening in the fall cycle. The management under plastic cover prolongs raspberries harvesting period in the fall productive cycle for cultivar 'Heritage' and in spring for cultivars 'Alemãzinha' and 'Fallgold'. In the spring cycle, plants improve their leaf area, fruit production and fruit number. Cultivar 'Alemãzinha' performs better in the spring cycle when managed under plastic cover, with greater yield, longer productive cycle and larger fruits.

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Authors' Contributions

Conceptualization: Antunes, L.E.C.; Marchi, P.M.; Carvalho, I.R.C.; Pereira, I.S. Data acquisition: Marchi, P.M.; Höhn, D.; Reisser Júnior, C.; Antunes, L.E.C. Data analysis: Carvalho, I.R.; Marchi, P.M.; Szareski, V.J. Design of methodology: Pereira, I.S.; Antunes, L.E.C.; Marchi, P.M.; Reisser Júnior, C. Writing and editing: Marchi, P.M.; Carvalho, I.R.; Rosa, T.C.; Antunes, L.E.C.; Reisser Júnior, C.; Pereira, I.S.; Höhn, D.; Szareski, V.J.

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