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Production, quality, bioactive compounds, and phenology of raspberry cultivars under an organic cropping system in a subtropical region of Brazil

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ABSTRACT: Studies on the adaptability of raspberry cultivars to subtropical regions are needed since growth, yield, and fruit quality may differ from levels observed in temperate climates. This study evaluated the phenology, yield, physical-chemical attributes, and bioactive compounds of raspberries produced in a subtropical region of Brazil under an organic cropping system. The experiment was carried out in three production cycles 2018/2019, 2019/2020, and 2020/2021 in Pinhais, Paraná State, Brazil. We evaluated ten raspberry cultivars, eight primocanes (Alemãzinha, Autumn Bliss, Bababerry, Fallgold, Golden Bliss, Heritage, Indian Summer and Polana), and two floricane cultivars (Schoenmann and Willamette). Phenological evaluations were carried out weekly at the beginning and end of flowering and harvesting. The soluble solids content, titratable acidity, the pH, and bioactive compounds were analyzed. Primocane cultivars showed two flowering and fruiting periods, the first in spring/summer and the other in summer/autumn, except for the Indian Summer cultivar, which showed a floricane-fruiting behavior, bearing fruit only on one-year-old canes, like Schoenmann and Willamette cultivars. 'Alemãzinha' shows better adaptation to the region under study with higher yield and concentration of total polyphenols, but its fruits are small and acidic. 'Heritage' is also an option for cultivation in this region, even though it is less productive, as the fruits are larger, less acidic, and have high levels of bioactive compounds. Yellow cultivars Fallgold and Golden Bliss are good options for diversifying the color offer, with yields similar to 'Heritage' and with a high total soluble solids/titratable acidity ratio.

Keywords: *Rubus idaeus*, small fruit, primocane, floricane

Introduction

Consumption of small fruits has increased worldwide, as they are excellent sources of bioactive compounds necessary for the human diet (Skrovankova et al., 2015). Species of the genus *Rubus*, which produce blackberries (*Rubus* spp.) and raspberries (*Rubus idaeus* L.), have vitamins and polyphenols that contain antioxidant, anti-inflammatory, chemopreventive, and antimicrobial activities (Schulz and Chim, 2019). A study carried out in China with 37 raspberry cultivars analyzed nine phenols, namely gallic acid, catechin, chlorogenic acid, vanillic acid, syringic acid, coumaric acid, ferulic acid, rosemary acid, and quercetin, and reported that the content of these compounds varied among cultivars and that they influence the antioxidant capacity (Wang et al., 2009).

Raspberry production has increased by 49.4 % in the last ten years, reaching 895 thousand tons in 2020. It is a temperate species; nevertheless, cultivation has expanded in tropical countries, such as Mexico, the world's second largest producer in 2020, with 146 thousand tons (FAOSTAT, 2022).

Brazil does not have breeding programs for raspberries; therefore, plantations use old cultivars from countries such as the United States, England, Poland, and Germany, which have a typically temperate climate. Thus, studies on the adaptability of exotic cultivars are necessary since the phenological, productive, and qualitative responses of the fruits may differ from those in the conditions where they were originally selected. Few studies have been conducted on raspberry cultivation in Brazilian edaphoclimatic conditions. The traditional region in Brazil for growing raspberries is Rio Grande do Sul State (Marchi et al., 2019); however, planting has also migrated to subtropical regions (Moura et al., 2012). Therefore, this study evaluated the phenology, productivity, physical-chemical attributes, and bioactive compounds of raspberries produced in a subtropical region of Brazil under an organic cropping system.

Materials and Methods

The experiment was carried out in three production cycles 2018/2019, 2019/2020, and 2020/2021 in the municipality of Pinhais, Paraná State, Brazil (25°23′15.1″ S, 49°07′58.0″ W, altitude 930 m), where the climate is Cfb (humid subtropical zone with temperate summer), according to Köppen classification (Alvares et al., 2013). Climate data for the study period were obtained at the Meteorological Station of Pinhais, Paraná State, from SIMEPAR (Paraná Meteorological System).

The soil analyses showed the following characteristics: pH $CaCl_2$ = 5.1; Al^{+3} = 0.0 $cmol_c$ dm^{-3}; $H^+ + Al^{+3}$ = 8.4 $cmol_c$ dm^{-3}; Ca^{+2} = 5.7 $cmol_c$ dm^{-3}; Mg^{+2} = 3.2 $cmol_c$ dm^{-3}; K+ = 0.90 $cmol_c$ dm^{-3}; P = 12.6 mg dm^{-3}; C = 19.0 g dm^{-3}; base saturation = 54 %. Before planting, liming was carried out by incorporating 2,900 kg ha^{-1} of limestone (Pauletti and Motta, 2017).

Ten raspberries cultivars were evaluated, eight primocane ('Alemãzinha', 'Autum Bliss', 'Bababerry', 'Fallgold', 'Golden Bliss', 'Heritage', 'Indian Summer' and 'Polana'), and two floricane cultivars ('Schöenmann' and 'Willamette'). 'Fallgold' and 'Golden Bliss' produce yellow raspberries, while the other cultivars produce red fruits. Planting was carried out in March 2017 with approximately 50 cm tall micro-propagated seedlings.

The spacing was 1.5 m between rows and 0.5 m between plants. Plants were cultivated using a trellis system with two rows of double wires 60 cm and 120 cm above the ground. A drip irrigation system was installed with a drip line on each planting row. Each drip line had 62 pressure-compensating emitters at the spacing of 0.4 m, with 1.6 L h^{-1} of flow rate. Irrigation was used during the growing season of raspberries in periods without precipitation. A polypropylene blanket was used between rows to avoid the occurrence of invasive plants. Winter pruning was carried out, reducing the height of the canes to 60 cm, and no more 15 floricanes m^{-1} were left. As the orchard is in the Environmental Protection Area of Iraí (APA), no pesticides were used to manage invasive plants, pests, and diseases. The control of invasive plants in the lines was carried out through weeding. For the disease control, applications of Bordeaux mixture and sulphur-calcium were carried out and, for the control of the fruit fly (*Anastrepha fraterculus* Wiedemann), traps with 25 % grape juice were used, while for the control of *Drosophila suzukii* Matsumura, traps with a mixture of 20 g of biological yeast + 50 g of sugar + 1 L^{-1} of water was used. Fertilization was carried out according to the soil analysis results and the technical recommendations for the blackberry crop in Paraná State (Pauletti and Motta, 2017), as there is no specific recommendation for raspberry crops.

According to the description of the developmental stages, phenological evaluations were carried out weekly following the phenological scale developed for raspberry crops (expanded BBCH) (Schmid et al., 2001), at the beginning and end of flowering and beginning and end of harvesting. In the 2019/2020 cycle, due to the onset of the COVID-19 pandemic in Brazil, phenological data on primocanes were not collected.

Fruits were harvested at the complete maturation stage (code 89 on the BBCH scale) from all plants per plot and production (g) and number of fruits per plot were evaluated and divided by 2.5 to obtain production levels and the number of fruits per meter. Yield was estimated by production per meter multiplied by 6,667, corresponding to the length of rows in 1 ha. Only healthy, defect-free fruits were harvested and frozen for later analyses. At the end of the harvest period, all fruits harvested from each plot were macerated and homogenized to analyze pH, soluble solids content, titratable acidity, and bioactive compounds.

The content of soluble solids was analyzed by means of a manual refractometer with the juice of the raspberries. The pH was measured using a digital pH meter and the acidity by titration. To analyze acidity, a 10 mL sample of juice was diluted in 90 mL of deionized water and titrated with 0.1 N sodium hydroxide (NaOH) solution until reaching pH 8.2, expressed as a percentage of citric acid.

For the analysis of total polyphenols, fruit pulp with seeds (5 g) and the extracting solution of ethanol acidified with 0.01 % HCl (20 mL) were used, according to the Folin-Ciocalteu method described by Vizzotto and Pereira (2011). The reading was performed in a spectrophotometer with a wavelength of 760 nm. The results were expressed in mg gallic acid equivalents (GAE) per 100 g of fresh weight (fw).

For the analysis of flavonoids and anthocyanins, the pulp of seedless fruits (10 g) and the extracting solution of 95 % ethanol + HCl 1.5 mol L^{-1} (85:15) (20 mL) were used, according to the method of Lees and Francis (1972). Readings were performed in a spectrophotometer at a wavelength between 374 and 535 nm. The results were expressed in mg of quercetin equivalent (QE) per 100 g of fresh weight for flavonoids and mg of pigment per 100 g for anthocyanins.

The experimental design was in randomized blocks, with ten treatments, four replications and five plants per plot. The data were subjected to the analysis of variance (ANOVA) and the means were compared using the Scott-Knott test at 5 % probability. The statistical analyses were performed using Sisvar software.

Results and Discussion

Primocane raspberry cultivars showed two flowering and fruiting periods, the first in spring/summer and the other in summer/autumn, except for the Indian Summer cultivar, which despite being mentioned as primocane-fruiting (Strik, 1989) showed a floricane-fruiting behavior, bearing fruit only on one-year-old canes, similar to Schoenmann and Willamette cultivars (Figures 1, 2, and 3). This behavior is likely associated with the lack of adaptation of this cultivar to local climatic conditions, since it is considered a cultivar with a high requirement for cold temperatures (Umar et al., 2010).

The flowering period varied among years and among cultivars. In the 2018/2019 cycle, flowering of primocanes cultivars began in the second week of Oct and ended in late Nov, ranging from 27 to 42 days (Figure 1). In the 2019/2020 cycle, the flowering period ranged from 30 to 39 days, starting in the second week of Sept, and ending in the second week of Oct (Figure 2). In the 2020/2021 cycle, flowering showed more significant variation among cultivars, starting in the second week of Oct for the Autumn Bliss, Bababerry and Polana cultivars and in mid-Nov for the Alemãzinha, Fallgold, Golden Bliss, and Heritage cultivars, with a flowering period ranging from 20 to 51 days (Figure 3). Floricane cultivars flowered later, usually in Nov, and for a shorter period, with the exception of 'Schoenmann'

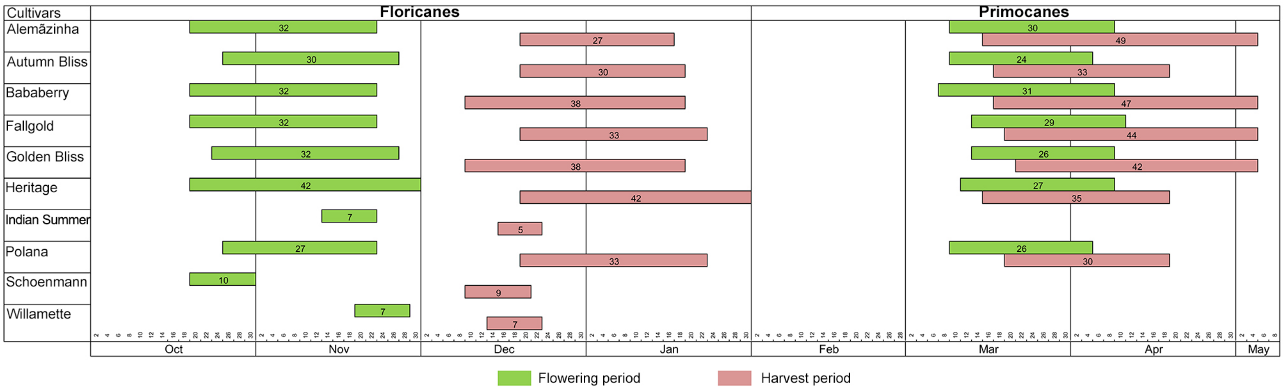

Figure 1 – Phenology of flowering and harvesting periods from floricanes and primocanes of ten raspberry cultivars in the 2018/2019 cycle in Pinhais, Paraná State – Brazil.

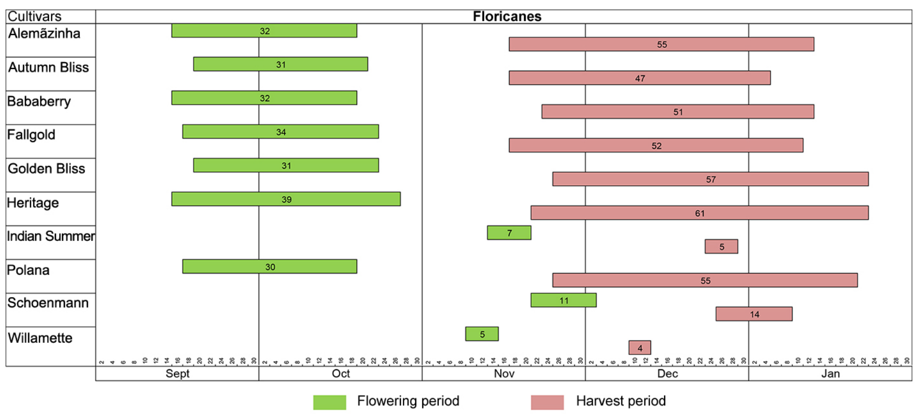

Figure 2 – Phenology of flowering and harvesting periods from floricanes of ten raspberry cultivars in the 2019/2020 cycle in Pinhais, Paraná State – Brazil.

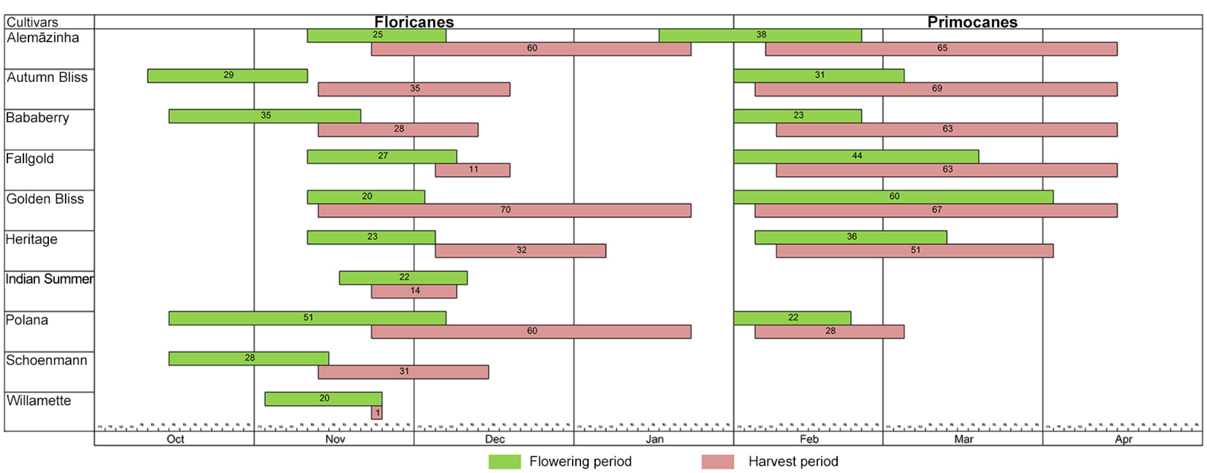

Figure 3 – Phenology of flowering and harvesting periods from floricanes and primocanes of ten raspberry cultivars in the 2020/2021 cycle in Pinhais, Paraná State – Brazil.

in 2020, which flowered from mid-Oct to mid-Nov, with 28 days of flowering, possibly because the winter was colder than in the other years, reaching 120 hours below 7.2 °C, practically twice as much as in the previous years (Figure 4).

The spring/summer harvest period of primocane cultivars also varied among cultivars and years, with concentrations from Dec to mid-Jan in the 2018/2019 cycle ranging from 27 to 42 days (Figure 1), and from mid-Nov to mid-Jan in 2019/2020 cycle ranging from

47 to 61 days (Figure 2). These periods were like those observed with Alemãzinha, Fallgold, and Heritage cultivars in Pelotas, Rio Grande do Sul State, Brazil (Marchi et al., 2019). The 2020/2021 cycle showed more significant variation among cultivars, being longer in the Alemãzinha, Golden Bliss, and Polana cultivars, with about two months (Figure 3). Floricane cultivars had shorter harvesting periods, except for 'Schoenmann' in the 2020/2021 cycle, whose harvesting occurred for 31 days.

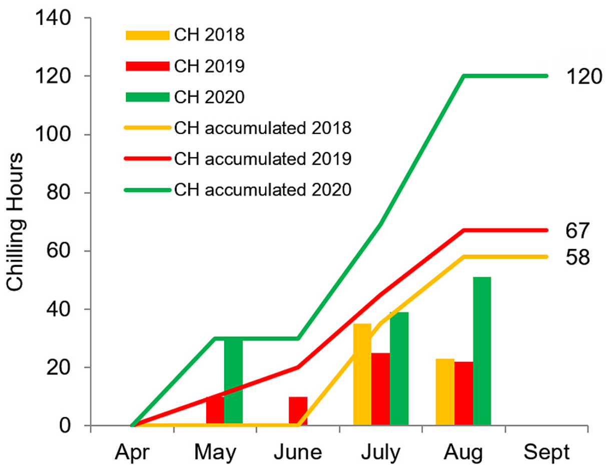

Figure 4 – Chilling hours (≤ 7.2 °C) accumulated from Apr to Sept in 2018, 2019, and 2020 in Pinhais, Paraná State – Brazil.

The summer/autumn flowering period was more uniform among cultivars and in the 2018/2019 cycle, it started from the second week of Mar and lasted until the second week of Apr, ranging from 24 to 31 days (Figure 1). In the 2020/2021 cycle, flowering ranged from 22 to 60 days, being shorter in the Bababerry and Polana cultivars and longer in the Golden Bliss cultivar. For most cultivars, flowering started in Feb, except for the cultivar Alemãzinha, which started earlier, in mid-Jan (Figure 3).

The harvest in summer/autumn differed among the cycles evaluated following the flowering periods. In the 2018/2019 cycle, the harvesting started in mid-Mar. It ended in mid-Apr for the Autumn Bliss, Heritage, and Polana cultivars. It ended in early May for the other cultivars (Figure 1), when weather conditions were already less favorable (Figure 5). In the 2020/2021 cycle, the harvesting started earlier and lasted longer, until two months for most cultivars (Figure 3). This period was longer than that observed in the autumn harvest in Pelotas, Rio Grande do Sul State, Brazil, around 55 days (Marchi et al., 2019). Harvesting started in the second week of Feb and ended in mid-Apr for most cultivars, except for 'Polana', which ended harvesting in early Mar.

Raspberry cultivars showed differences in productive characteristics in the three cycles (Table 1). Production of raspberries presents significant variation among works published worldwide due to differences

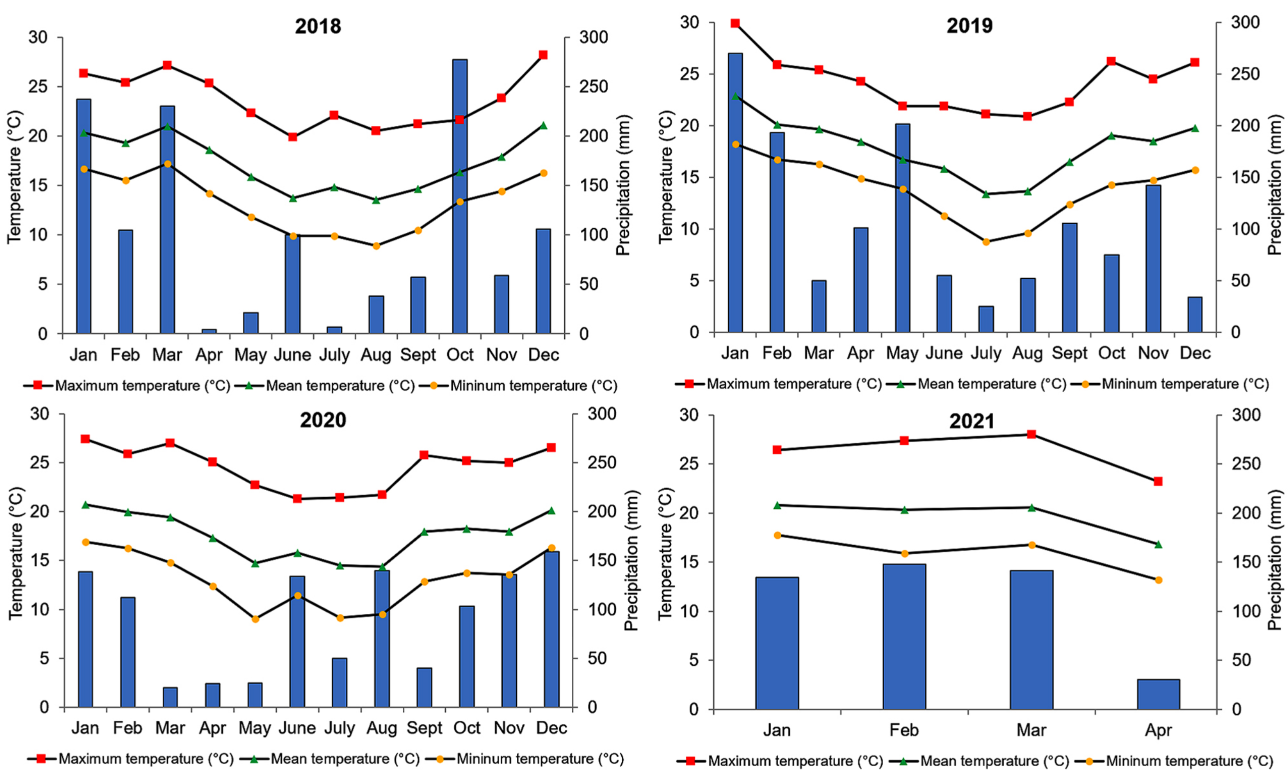

Figure 5 – Maximum, average and minimum monthly average temperature and precipitation in 2018, 2019, 2020, and 2021 in Pinhais, Paraná State – Brazil.

Table 1 – Agronomic performance of primocane and floricane raspberry cultivars in relation to the number of fruits per meter, mass produced per meter, average fruit mass, and yield (sum of both harvesting periods) in the 2018/2019, 2019/2020, and 2020/2021 cycles. Pinhais, Paraná State – Brazil.

Cultivar	Number of fruits per meter	Mass produced per meter	Average fruit mass	Yield
		------------- g	-------------	kg ha^{-1}
		2018/2019		
Alemãzinha	99.0 a	186.6 a	1.82 a	1,244.6 a
Autumn Bliss	37.8 b	54.8 b	1.49 b	365.5 b
Bababerry	64.0 b	134.2 a	2.23 a	895.1 b
Fallgold	74.8 a	143.2 a	1.91 a	955.1 a
Golden Bliss	55.6 b	117.6 a	2.13 a	784.4 b
Heritage	69.4 a	147.0 a	2.13 a	980.5 a
Indian Summer	13.0 c	18.2 c	1.38 b	121.4 c
Polana	46.2 b	85.0 a	1.95 a	566.9 b
Schoenmann	32.8 b	63.2 b	1.92 a	421.5 b
Willamette	5.8 c	9.2 c	1.56 b	61.3 c
CV (%)	24.58	24.87	7.83	15.96
		2019/2020		
Alemãzinha	101.2 a	188.8 a	1.82 b	1,255.2 a
Autumn Bliss	34.3 b	53.2 b	1.54 b	335.5 c
Bababerry	43.3 b	99.1 b	2.21 a	670.3 b
Fallgold	55.0 a	119.3 a	2.17 a	795.7 b
Golden Bliss	52.1 b	116.3 a	2.26 a	750.0 b
Heritage	64.1 a	131.0 a	2.12 a	866.6 a
Indian Summer	9.8 c	15.5 c	1.32 b	75.2 d
Polana	39.6 b	86.1 a	2.38 a	567.0 b
Schoenmann	33.8 b	77.8 b	2.03 a	518.7 b
Willamette	5.2 c	8.4 c	1.55 b	51.4 d
CV (%)	25.38	26.64	10.17	29.32
		2020/2021		
Alemãzinha	105.9 a	195.5 a	1.84 b	1,303.9 a
Autumn Bliss	27.8 b	46.5 c	1.70 b	310.5 c
Bababerry	22.4 b	37.0 c	2.21 a	247.1 c
Fallgold	29.7 b	65.2 b	2.36 a	434.9 b
Golden Bliss	47.3 b	111.0 b	2.33 a	740.6 b
Heritage	46.2 b	104.5 b	2.04 a	697.1 b
Indian Summer	2.1 c	2.5 d	1.24 b	16.6 d
Polana	35.3 b	87.7 b	2.45 a	585.1 b
Schoenmann	78.5 a	188.5 a	2.40 a	1,257.1 a
Willamette	3.8 c	6.5 d	1.53 b	43.5 d
CV (%)	27.39	30.22	10.20	30.54

Means followed by the same letter do not differ by the Scott-Knott test $p \leq 0.05$.

in the genetic potential of cultivars and cultivation and climate conditions. Autumn Bliss, Fallgold, Heritage, Golden Bliss, and Polana cultivars cultivated in Marechal Cândido Rondon, Paraná State, Brazil, presented similar production (31.2 to 87 g per plant) to those observed in this study in Pinhais, municipality of Paraná State, but much lower than those obtained in Lavras, Minas Gerais State, Brazil (312.3 to 752.6 g per plant) (Moura et al., 2012). Alemãzinha, Fallgold, and Heritage cultivars cultivated in Pelotas, Rio Grande do Sul State, Brazil, presented lower production (average of 115.5 g per plant) than that obtained in Lavras, Minas Gerais State, but higher than that of Marechal Cândido Rondon, Paraná State (Marchi et al., 2019). In conditions of intense winter cold in Finland, the Autumn Bliss cultivar produced 2.5 kg per cane only in the summer cropping season, demonstrating that the accumulation of satisfactory cold allows high productivity to floricanes (Palonen et al., 2021).

Indian Summer and Willamette cultivars were the least productive (Table 1), demonstrating a lack of adaptation to the local climate, possibly because they are more cold-demanding cultivars. In the years when this experiment was carried out, only 58 chilling hours below 7.2 °C were observed in 2018, 67 chilling hours in 2019 and 120 chilling hours in 2020 (Figure 4). These values are insufficient to adequately satisfy the requirement of the cultivars, as raspberry is a typical species of temperate climate, which requires cold temperatures for over 700 hours (Rufato and Antunes, 2016). This affected all cultivars, which showed little budbreak on the canes after dormancy, resulting in a small spring-summer production. The production evaluated represents the sum of the two harvests of each cycle, where most fruits came from the summer-autumn harvest (Table 1).

Alemãzinha, Fallgold, and Heritage cultivars were significantly superior to the others in terms of the number of fruits produced per meter in the first two cycles. In the third cycle, 'Alemãzinha' and 'Schoenmann' were superior for this variable (Table 1). As for the mass of fruits produced per meter, there was the same trend observed for the number of fruits produced, with the superiority of cultivars Alemãzinha, Fallgold, and Heritage, not differing from 'Bababerry', 'Golden Bliss', and 'Polana' in the 2018/2019 cycle and not differing from cultivars Golden Bliss and Polana in the 2019/2020 cycle. In the 2020/2021 cycle, 'Alemãzinha' and 'Schoenmann' were superior.

The estimated yield showed the superiority of Alemãzinha, Fallgold, and Heritage cultivars in the 2018/2019 cycle, which produced 1,244.6; 955.1 and 980.5 kg ha^{-1}, respectively. Alemãzinha and Heritage cultivars were superior in the 2019/2020 cycle, which produced 1,255.2 and 866.6 kg ha^{-1}, respectively, and Alemãzinha and Schoenmann cultivars were superior in the 2020/2021 cycle, which produced 1,303.9 and 1,257.1 kg ha^{-1}, respectively (Table 1). These yield values are below those obtained in Lavras, Minas Gerais State, Brazil, where the cultivars Autumn Bliss, Heritage, Golden Bliss, and Polana reached yields greater than 2,100 to 5,000 kg ha^{-1} (Moura et al., 2012).

Different yield values for the same cultivars in different locations must be attributed to regional climate differences. Low productivity and absence of formation of new canes were observed in the cultivation of raspberries in the municipality of Marechal Cândido Rondon, Paraná State, Brazil, which is linked to the lack of adaptation to the local climate, which presented high temperatures in the summer and autumn period, associated to the long period of low precipitation (Moura et al., 2012). Raspberry adapts better to places with cold winters, summers with mild temperatures, and annual precipitation of 700 to 900 mm (Rufato and Antunes, 2016). In Pinhais, Paraná State, Brazil, where this study was carried out, the climate conditions were not ideal for raspberries because, in addition to the lack of cold during the winter (Figure 4), the temperatures during the summer were high, with average maximum temperatures from 25.4 to 29.9 °C (Figure 5). Precipitation met the requirements for raspberry with an accumulated 1,241.6, 1,304.6 and 1,080.6 mm in 2018, 2019 and 2020, respectively. However, there was excessive rainfall during the summer, which harmed production due to the occurrence of diseases that caused the fruit to rot in the field. In some periods of consecutive rainy days, it was impossible to harvest healthy fruits and, as the orchard was managed organically, chemical products were not used. This fact was also observed in Lavras, Minas Gerais State, where excessive rainfall in Dec and Jan promoted a high incidence of gray mold (*Botrytis cinerea* Pers.) and rust [*Pucciniastrum americanum* (Farl.) Arthur] (Moura et al., 2012).

The outstanding yield of 'Alemãzinha' in the three cycles evaluated demonstrates better adaptation of this cultivar to the study site. 'Alemãzinha' has an unknown origin and is possibly a genotype selected by growers for the best adaptation in southern Brazil. This cultivar also stood out in Pelotas, Rio Grande do Sul State, with a higher yield, extended harvesting period, and larger fruits than 'Heritage' (Marchi et al., 2019). 'Heritage', despite being less productive than 'Alemãzinha', was also significant in this study in Pinhais, Paraná State, even though it is a cultivar whose cold requirement is 600 h (Rufato and Antunes, 2016) and presented larger fruits (2.13, 2.12 and 2.04 g) than 'Alemãzinha' (1.82, 1.82 and 1.84 g) in the three cycles, possibly due to the smaller number of fruits produced per meter (Table 1). The Schoenmann cultivar, which did not stand out in the first two cycles, was as produced as 'Alemãzinha' in the 2020/2021 cycle, possibly because it was the year with the most significant accumulation of cold during the winter (120 h) (Figure 4), promoting greater budding of stem buds after winter since it is a floricane cultivar that only produces in the summer period.

Cultivars with the lowest fruit mass were Alemãzinha, Autumn Bliss, Indian Summer, and Willamette, whose raspberries weighed less than 2 g (Table 1). Bababerry, Fallgold, Golden Bliss, and Polana cultivars formed an intermediate group in terms of yield and presented larger fruits, generally larger than 2 g (Table 1). Fallgold and Golden Bliss cultivars produce yellow fruits and are exciting options to diversify the supply of raspberries. Autumn Bliss cultivar, despite recommendations, along with 'Heritage', for planting in Vacaria, Rio Grande do Sul State, Brazil, did not show good adaptation, producing 365.5, 335.5 and 310.5 kg ha^{-1} in the three cycles evaluated as well as small-sized fruits (Table 1). 'Autumn Bliss' cultivated in Campos do Jordão, São Paulo State, Brazil, at 1.628 m of altitude, showed smaller fruits (2.3 g) than 'Golden Bliss', 'Heritage', and 'Polana', which produced fruits with more than 3.5 g (Maro et al., 2014). In Finland, 'Autumn Bliss' also produced smaller fruits compared to the cultivars Imara, Joan J, Kwanza, Kweli, and Polka, still with an average of 3 g (Palonen et al., 2021). In high latitude conditions in South America, 'Autumn Bliss' cultivated in Río Gallegos, Santa Cruz, Argentina produced 693.1 g per plant in a greenhouse and 90.7 g per plant in the field and the fruits presented 1.95 g (Birgi et al., 2019).

The values of pH, soluble solids content, and total acidity indicate the quality of the fruits and their acceptability. These parameters differed among cultivars in the three cycles evaluated (Table 2). 'Alemãzinha' and Autumn Bliss cultivars had the lowest pH values in the first two cycles evaluated, while the other cultivars had pH values generally above 3.0. In the third cycle, the pH values were lower than 3.0 for all cultivars.

The concentration of soluble solids differed significantly among cultivars in the three cycles evaluated. 'Alemãzinha' was superior to the other cultivars in the 2018/2019 cycle, with 9.4 °Brix. In the 2019/2020 cycle, this cultivar was again superior and did not differ from 'Bababerry' and 'Schoenmann'. In the 2020/2021 cycle, 'Bababerry', 'Schoenmann', and 'Autumn Bliss' were superior with values above 10.3 °Brix (Table 2). These values were higher than those observed for Autumn Bliss, Heritage, Golden Bliss, and Polana cultivars in Marechal Cândido Rondon, Paraná State, Brazil, which ranged from 5.5 to 8.8 °Brix, and the yield ranged from 200 to 600 kg ha^{-1}, also higher than the same cultivars grown in Lavras, Minas Gerais State, Brazil, which ranged from 6.7 to 7.3 °Brix and the yield ranged from 2,100 to 5,000 kg ha^{-1} (Moura et al., 2012). The difference in soluble solids content is possibly related to climate than to yield. Climate conditions less favorable to disease occurrence allow the maintenance of the photosynthetically active leaf area and greater accumulation of carbohydrates.

'Alemãzinha' showed the highest acidity in the 2018/2019 and 2019/2020 cycles (2.09 and 2.12 g citric acid 100 g^{-1}, respectively), while the other cultivars showed no difference. In the 2020/2021 cycle, cultivars Autumn Bliss, Bababerry, and Schoenmann presented the highest acidity, with values above 2.35 g citric acid 100 g^{-1} (Table 2). These values are close to those obtained for the Autumn Bliss, Heritage, and Polana cultivars in Marechal Cândido Rondon, Paraná State, Brazil (2.0 and 2.5 g citric acid 100 g^{-1}), but higher than those obtained for the same cultivars in Lavras, Minas Gerais State, Brazil (1.2 and 1.9 g citric acid 100 g^{-1}) (Moura et al., 2012) and for 'Autumn Bliss' in Finland (1.89 %) (Palonen et al., 2021) and for 'Heritage' (~1.6 %) in Yangquan,

Table 2 – Chemical attributes of fruits of primocane and floricane raspberry cultivars in the 2018/2019, 2019/2020, and 2020/2021 cycles. Pinhais, Paraná State – Brazil.

Cultivar	Solid Soluble	pH	Titratable acidity	Ratio
	°Brix		g citric acid 100 g^{-1}	Solid soluble/ Titratable acidity
			2018/2019	
Alemãzinha	9.4 a	2.4 b	2.09 a	4.5 b
Autumn Bliss	6.5 c	1.7 b	1.65 b	3.9 b
Bababerry	8.2 b	3.2 a	1.47 b	5.6 a
Fallgold	7.8 b	3.1 a	1.35 b	5.8 a
Golden Bliss	7.6 b	3.2 a	1.37 b	5.6 a
Heritage	6.0 c	2.7 a	1.44 b	4.2 b
Indian Summer	8.1 b	3.1 a	1.49 b	5.4 a
Polana	7.3 b	3.4 a	1.33 b	5.5 a
Schoenmann	6.4 c	2.7 a	1.47 b	4.3 b
Willamette	7.7 b	3.0 a	1.45 b	5.3 a
CV (%)	9.25	15.63	10.66	9.01
			2019/2020	
Alemãzinha	9.0 a	2.1 b	2.12 a	4.8 a
Autumn Bliss	7.7 b	2.4 b	1.68 b	4.2 b
Bababerry	9.2 a	3.3 a	1.52 b	5.9 a
Fallgold	8.2 b	3.1 a	1.39 b	5.8 a
Golden Bliss	8.1 b	3.5 a	1.43 b	5.9 a
Heritage	7.5 b	3.2 a	1.48 b	4.6 b
Indian Summer	7.8 b	3.4 a	1.51 b	5.5 a
Polana	7.9 b	3.4 a	1.35 b	5.7 a
Schoenmann	9.7 a	2.9 a	1.49 b	4.5 b
Willamette	7.8 b	3.5 a	1.47 b	5.5 a
CV (%)	5.11	6.93	6.91	7.31
			2020/2021	
Alemãzinha	8.0 b	2.6 b	1.79 b	4.4 b
Autumn Bliss	10.6 a	2.4 b	2.37 a	4.5 b
Bababerry	10.3 a	2.5 b	2.35 a	4.4 b
Fallgold	8.8 b	2.6 b	1.75 b	5.0 a
Golden Bliss	8.5 b	2.5 b	1.80 b	4.7 a
Heritage	8.5 b	2.9 a	1.70 b	5.0 a
Indian Summer	-	-	-	-
Polana	8.4 b	2.7 a	1.89 b	4.5 b
Schoenmann	10.3 a	2.5 b	2.35 a	4.4 b
Willamette	8.1 b	2.8 a	1.97 b	4.2 b
CV (%)	4.94	6.42	8.25	6.59

Means followed by the same letter do not differ by the Scott-Knott test $p \leq 0.05$.

Shanxi Province, China (Yang et al., 2020). These results demonstrate that the environment strongly influences the chemical characteristics of raspberries, both due to cultivation in different regions and the climate effect of each year, as observed in the present study.

The ratio (Solid soluble/Titratable acidity), which represents the balance between sugars and acidity, differed among cultivars in the three cycles evaluated, with values between 3.9 and 5.9. Significantly superior cultivars in the three cycles were 'Fallgold' and 'Golden Bliss', the yellow raspberries. The ratio values obtained in this study conducted in Pinhais, Paraná State, Brazil, for red raspberries were similar to those observed in Lavras, Minas Gerais State, Brazil, which ranged from 3.8 to 5.6, and were higher than those observed in Marechal Cândido Rondon, Paraná State, Brazil, which ranged from 2.4 to 2.8 (Moura et al., 2012). Raspberries produced in higher regions, such as Lavras, Minas Gerais State, Brazil (918 m) and Pinhais, Paraná State, Brazil (930 m) have better quality than those produced in lower regions, such as Marechal Cândido Rondon, Paraná State, Brazil (472 m). This was also observed for 'Autumn Bliss', 'Golden Bliss', 'Heritage', and 'Polana', which showed a higher ratio in cultivations in Campos do Jordão, São Paulo State, Brazil, at an altitude of 1.628 m, than in Lavras, Minas Gerais State, Brazil, at 918 m (Maro et al., 2014). This fact is possibly associated to climate conditions, as lower altitude regions have hotter summers and lower thermoperiods, resulting in more acidic fruits with lower soluble solids contents.

There was a difference among cultivars only in the 2019/2020 cycle for total polyphenols. 'Heritage' was the cultivar with the highest total polyphenol contents (863.7 mg GAE 100 g^{-1} fw) followed by 'Polana' (803.3 mg GAE 100 g^{-1} fw), 'Schoenmann' (801.2 mg GAE 100 g^{-1} fw), and 'Alemãzinha' (795 mg GAE 100 g^{-1} fw), which did not differ significantly and were superior to the other cultivars (Table 3). The highest contents of polyphenols were observed in the 2019/2020 cycle, while the lowest values occurred in the 2018/2019 cycle for all cultivars. The values found in the present study were higher than those observed in red raspberries (357.83 mg GAE 100 g^{-1} fw) harvested in the south of Minas Gerais State, Brazil (Souza et al., 2014), higher than raspberries cultivated in Mantiqueira Mountains, São Paulo State, Brazil (287.61 to 415.99 mg GAE 100 g^{-1} fw) (Maro et al., 2013), and higher than those observed in Yangquan, Shanxi Province, China for 'Heritage', which ranged from 216.22 to 251.38 mg GAE 100 g^{-1} fw between firm ripe fruit to soft over-ripe fruit (Yang et al., 2020). In the literature review by Schulz and Chim (2019), the contents of total polyphenols in raspberries showed variation from 142 to 758 mg GAE 100 g^{-1} fw. In Graminor Njøs, Leikanger in western Norway, ten cultivars of floricane fruiting red raspberry were evaluated and the total phenolic contents ranged from 183.1 to 297.7 mg GAE 100 g^{-1} fw (Mazur et al., 2014). Polyphenol contents and compositions of 12 *Rubus* species, including raspberries, blackberries, and Japanese wild *Rubus* species, cultivated in pots and kept in a plastic greenhouse in Japan, were evaluated and the highest total contents were observed in 'Blackcap' black raspberry (309.4 mg GAE 100 g^{-1} fw). 'Indian Summer' showed 70.3 mg GAE 100 g^{-1} fw, while 'Fallgold' had the lowest content (43.2 mg GAE 100 g^{-1} fw) and 0.78 mg ellagic acid 100 g^{-1} fw (Toshima et al., 2021).

A study carried out with 37 cultivars of raspberry in Qinghai-Tibetan plateau region in China found much higher levels of total polyphenols with 2,715.36 mg 100 g^{-1} for 'Heritage' and 1,977.74 mg 100 g^{-1} for

'Autumn Bliss', apparently using the same methodology, according to the Folin-Ciocalteu's procedure. The main phenolic compounds of raspberries were also analyzed for gallic acid, chlorogenic acid, coumaric acid, ferulic acid, and rosemary acid, mainly in 'Autumn Bliss' (Wang et al., 2009). These results were similar to those found in northern Greece, Spain, and Turkey. Phenolic concentrations in raspberry can be affected by many factors, namely cultivar, ripening stage, soil, and climate. The lower levels of phenolic compounds observed in the 2018/2019 cycle may have occurred due to the higher precipitation rate, which was 720.4 mm during the harvesting period from Dec 2018 to Apr 2019. In the 2019/2020 cycle, when the highest concentrations of phenols were recorded, precipitation during the harvesting period was only 328.2 mm (Figure 4).

Flavonoids showed a significant variation among cultivars in the three cycles evaluated. Fallgold and Golden Bliss yellow cultivars had the lowest flavonoid levels in the three cycles studied (Table 3). The red cultivars showed higher levels, mainly 'Heritage' with 8.4 QE mg 100 g^{-1} fw, still this value was lower than that obtained with raspberries grown in the south of Minas Gerais State (9.6 catechin CE equivalent mg 100 g^{-1}) (Souza et al., 2014).

Anthocyanins were not analyzed in the yellow cultivars ('Fallgold' and 'Golden Bliss'), since anthocyanins are pigments that range between red and blue. Cultivars were affected in the 2018/2019 cycle, with the superiority of the Autumn Bliss, Bababerry, Heritage, and Schoenmann cultivars, and in the 2020/2021 cycle, with the superiority of 'Heritage' (Table 3). The values found in this study were higher than those observed in the south of Minas Gerais State (14.69 mg 100 g^{-1} fw) (Souza et al., 2014), lower than those observed for the Heritage cultivar (79 mg 100 g^{-1} fw) in Yangquan, Shanxi Province, China (Yang et al., 2020), and similar to ten cultivars of floricane fruiting red raspberry in Graminor Njøs, Leikanger in western Norway, which ranged from 17.7 to 50.3 mg 100 g^{-1} fw (Mazur et al., 2014).

'Alemãzinha' shows better adaptation to the region of Pinhais, Paraná State, Brazil, with higher yield and higher concentration of total polyphenols. However, this cultivar produces small fruits with high acidity. 'Heritage' is also an option for cultivation in this region, even though it is less productive, as the fruits are larger, less acidic, and have high levels of bioactive compounds. Yellow cultivars Fallgold and Golden Bliss are good options for diversifying the color offer with yield levels like 'Heritage' also with a high ratio.

Table 3 – Total polyphenols, flavonoids and anthocyanins of primocane and floricane raspberry cultivars in the 2018/2019, 2019/2020, and 2020/2021 cycles. Pinhais, Paraná State – Brazil.

Cultivar	Total polyphenols	Flavonoids	Anthocyanins
	mg GAE 100 g^{-1}	mg QE 100 g^{-1}	mg 100 g^{-1}
	2018/2019		
Alemãzinha	360.0 a	5.4 b	17.5 b
Autumn Bliss	387.7 a	7.0 a	26.8 a
Bababerry	449.6 a	6.5 a	25.5 a
Fallgold	472.5 a	3.0 c	-
Golden Bliss	426.7 a	2.8 c	-
Heritage	426.7 a	6.4 a	26.5 a
Polana	537.1 a	7.5 a	18.6 b
Schoenmann	376.7 a	7.0 a	23.1 a
CV (%)	15.09	12.55	15.21
	2019/2020		
Alemãzinha	795.0 a	5.5 a	32.2 a
Autumn Bliss	670.0 b	4.5 a	26.1 a
Bababerry	742.2 b	4.6 a	28.0 a
Fallgold	707.5 b	2.3 b	-
Golden Bliss	650.5 b	2.8 b	-
Heritage	863.7 a	4.9 a	31.0 a
Polana	803.3 a	5.1 a	30.3 a
Schoenmann	801.2 a	4.8 a	29.2 a
CV (%)	10.33	24.92	19.07
	2020/2021		
Alemãzinha	688.5 a	7.1 b	25.6 b
Autumn Bliss	806.0 a	6.9 b	23.0 c
Bababerry	794.3 a	6.6 b	22.5 c
Fallgold	586.0 a	2.3 c	-
Golden Bliss	681.0 a	2.1 c	-
Heritage	661.0 a	8.4 a	30.2 a
Polana	714.3 a	7.3 b	24.7 b
Schoenmann	851.0 a	6.9 b	22.9 c
CV (%)	19.93	6.39	6.00

Means followed by the same letter do not differ by the Scott-Knott test $p \leq 0.05$.

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