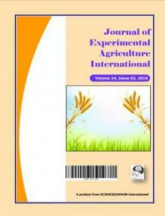

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Assessment of Passion Fruit Trees Genotypes in Terms of Fruit Quality and Yields in Rio Grande do Sul - Brazil

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Authors' contributions

This work was carried out in collaboration between all authors. Authors DW and JCN designed the study. Author DW performed the statistical analysis. Authors DW and CFB wrote the manuscript. Authors MBM, JCN and CFB managed the analyses of the study. Authors MBM, JCN, DW and CFB managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: This study aimed at evaluating genotypes of passion fruit regarding the quality and yield of their fruits in southern Brazil.
Study Design: The experimental design randomized complete block design with four genotypes and eight repetitions. The experimental unit, which was constituted by four plants, total forty plants per treatment.
Place and Duration of Study: The experiment was carried out at the Centro Agropecuário da Palma, which belongs to the Universidade Federal de Pelotas, located in Capão do Leão, Rio Grande do Sul, Brazil. The experiment was conducted during the 2013/2014 and 2014/2015 seasons.
Methodology: Experiments were carried with the following genotypes: *Passiflora edulis* Catarina, *Passiflora alata* Urussanga, *Passiflora edulis* BRS Sol do Cerrado and *Passiflora edulis* BRS Rubi

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do Cerrado. We measured in the present study productivity, yield per plant, number of fruits per plant, number of fruits per hectare, mean fruit mass, soluble solids, titratable acidity, SS/TA relation, epidermis color, pericarp thickness, mean fruit length, mean fruit diameter and pulp yield.
Results: In 2013/2014 season, the yield of the yellow passion fruit BRS Sol do Cerrado, BRS Rubi do Cerrado and Catarina stood out. In this seasons, in general, the yellow passion fruit showed more productive capacity than the selection of the sweet passion fruit Urussanga. In 2014/2015 season, the genotype BRS Sol do Cerrado (20.36 Mg ha^{-1}) had better data on yield than both genotypes Catarina (18.07 Mg ha^{-1}) and Urussanga (12.05 Mg ha^{-1}). The genotypes BRS Sol Cerrado, BRS Rubi do Cerrado and Catarina excelled in fruit mass, fruit length, fruit diameter and pulp yield. The passion fruit Urussanga had the lowest titratable acidity (2,05% citric acid in 2013/2014 and 2,07% citric acid in 2014/2015) and the highest contents of soluble solids (13,98°Brix in 2013/2014 and 14,27°Brix in 2014/201 5) in fruits.
Conclusion: However, all evaluated genotypes show potential for production in southern Brazil. The physical-chemical quality of the fruits of the genotypes, show differences between them, however all are within the acceptable parameters.

Keywords: Passiflora edulis; Passiflora alata; productivity; fruit quality.

1. INTRODUCTION

Brazil yields about 694 thousand tons of passion fruits in an area that stretches over 50 thousand hectares; from this amount, Rio Grande do Sul state (RS) yields 5,402 tons in 2016 [1]. Cultivation of passion fruit may be considered an agricultural alternative on small farms with 3-5 hectares because it adapts well to the needs for cultural practices, inputs and manpower demand, mainly in the phases of orchard planting, hand-pollination and harvest [2,3].

Cultures of passion fruit have expanded in Brazil but there is little information on their implementation in new regions. This is the case of cultures in RS, where temperatures are low and frost occurs in winter. Besides, the adaptation of cultivars to different edaphoclimatic conditions and resistance to the main diseases must also be considered [3,4].

According to Meletti [2], *Passiflorara edulis* Sims. (yellow passion fruit) and *Passiflora alata* Curtis. (sweet passion fruit) are the most widely cultivated species since both are estimated to use more than 90% of the world's cultivated area. The yellow passion fruit is mostly used for yielding juices, jams and ice cream [4,5]. The sweet passion fruit has restricted yield and commercialization; most people do not know it and has only been consumed as a fresh fruit because of its low acidity [2,4].

The definition of the productive potential of cultivars (adaptation, yield and quality of fruits) in each region is extremely important to optimize the production system and explore passion fruit s commercially. Therefore, there is much interest in studies of cultivar competition so as to identify the ones that better adapt to specific local conditions.

Since the climate may vary in different areas and influence the behavior of cultivars, recommending their cultivation in new regions cannot take into account only their behavior in the region of origin. Therefore, information on the adaptation of passion fruit s to colder areas is still insufficient. Taking into consideration that experimental reports of the adaptation of passion fruit genotypes to the edaphoclimatic conditions found in Rio Grande do Sul are scarce. This study aimed at evaluating different passion trees genotypes about yield and quality of passion fruits in southern Brazil.

2. MATERIALS AND METHODS

2.1 Location, Soil and Climatic Conditions

The experiment was carried out at the Centro Agropecuário da Palma (CAP), Universidade Federal de Pelotas (UFPel), Capão do Leão, RS, Brazil (31º52'00" S; longitude, 52º21'24"); and altitude, 13 meters.

The soil of the orchard is moderately deep with medium texture at A horizon and clay texture at B horizon; thus, it is classified as red-yellow clay soil. In 2013, the soil had 13% clay, 1.52% organic matter, 4% aluminum saturation, 61% base saturation, CTC at pH 7 of 7.9 cmolc/dm^3, 50.4 mg/dm3 of P-Mehlich, 65 mg/dm^3 of K and pH 5.0 in water. Liming was carried out in agreement with the method of the SMP index

and increased pH to 6.0, as recommended by the Manual de Adubação e Calagem para os Estados do Rio Grande do Sul e Santa Catarina [6]. Fertilizers were applied as suggested by [7], i. e., increasing doses of nitrogen were applied every 15-20 days up to blooming, and then, five doses of potassium were applied, based on the soil analysis.

The climate in the region is humid subtropical with hot summers, i. e., "Cfa" in Köppen climate classification. Its mean temperature and mean annual rainfall were 18.56ºC and 1,844.3 mm, respectively, in 2015 (EAPel, 2016). Data on the climate during experiment period are shown in Table 1.

2.2 Treatments and Experimental Design

The experiment was conducted in both 2013/2014 (1-year-old plants) and 2014/2015 (2-year-old plants) crops with the following passion fruits: *Passiflora edulis* Catarina, *Passiflora edulis* BRS Sol do Cerrado, *Passiflora edulis* BRS Rubi do Cerrado (yellow passion fruit) and *Passiflora alata* Urussanga (sweet passion fruit). The experimental design comprised randomized blocks with four genotypes and eight repetitions. The experimental unit, which was constituted by four plants, in total forty plants per treatment.

Seedlings, which were 15-cm high, were planted on November 1st, 2013. During the experiment there were no pollination and irrigation. In the 2013/2014 season, the density was 3,200 plants per hectare (2.5 x 2.5 meters) with two seedlings per hole. In the 2014/2015 season, thinning was carried out, so as to keep one seedling per hole and 1,600 plants per hectare. Plant pruning was performed at 1.80 m height and lateral pruning when the plants found the plants on the side. Fruits were harvested every week from April to August (2013/2014) and from February to August (2014/2015).

Table 1. Data on the climate at the Estação Agroclimatológica in Pelotas, Brazil, from November 2013 to December 2015

Month	Year	DMT	MMT	MmT	RH	A	SR	I	P	NDF
January	**2014**	24,8	30,5	20,6	79,4	9,9	475,6	237,6	179,6	0
	2015	24,0	29,1	20,1	80,2	9,0	490,0	252,8	234,0	0
February	**2014**	24,1	29,0	20,9	83,0	8,0	434,1	202,8	225,4	0
	2015	23,5	27,9	20,3	82,1	7,7	460,6	225,0	91,9	0
March	**2014**	21,1	26,2	17,2	83,9	9,0	386,0	232,3	148,1	0
	2015	22,1	27,6	18,0	82,5	9,6	388,5	222,3	104,1	0
April	**2014**	18,9	24,2	15,1	85,2	9,1	296,3	194,9	99,8	0
	2015	18,9	25,7	13,9	81,7	11,8	338,0	238,4	26,0	0
May	**2014**	14,8	20,4	10,8	88,5	9,6	215,4	159,9	62,3	3
	2015	16,3	22,0	12,5	87,0	9,4	214,5	166,0	144,8	2
June	**2014**	13,3	18,2	9,6	89,2	8,5	167,0	128,9	144,7	6
	2015	13,4	19,4	9,2	84,7	10,2	195,6	169,8	140,7	6
July	**2014**	13,9	18,9	10,5	88,3	8,4	193,8	163,8	203,7	4
	2015	13,5	18,3	10,0	89,5	8,4	156,9	109,3	226,9	6
August	**2014**	13,9	20,0	9,5	84,6	10,5	259,1	191,0	82,9	5
	2015	17,7	22,6	13,9	84,0	8,7	217,8	137,9	105,7	0
September	**2014**	16,7	21,1	12,9	84,6	8,2	273,3	139,0	143,7	0
	2015	15,2	19,7	11,6	82,7	8,2	259,1	125,1	252,6	2
October	**2014**	19,4	23,9	15,8	82,7	8,1	375,4	195,1	246,2	0
	2015	16,7	20,6	13,7	85,5	6,9	315,0	139,5	199,1	1
November	**2013**	20,5	24,9	16,9	80,1	8,0	473,0	237,7	136,3	0
	2014	21,2	26,4	16,8	77,4	9,5	484,3	247,3	104,0	0
	2015	19,1	23,1	15,8	81,3	7,3	401,3	179,6	158,7	0
December	**2013**	23,5	29,2	18,9	75,3	10,3	568,5	313,2	78,4	0
	2014	22,8	27,9	18,9	78,8	9,1	478,8	228,3	138,2	0
	2015	22,4	26,8	18,9	82,1	7,9	441,6	206,2	159,9	0

DMT = Daily mean temperature (℃); MMT = Mean of maximum temperatures (℃); MmT = Mean of minimum temperatures (℃); RH = Relative humidity (%); A = Amplitude (℃); SR = Solar radiation (cal cm^{-2} day^{-1}); I = Total insolation (hours and decimals); P= Precipitation (mm); NDF = Number of days with frost.
Source: Estação Agroclimatológica in Pelotas/Brazil

2.3 Traits Evaluated

Variables under evaluation in the field were: productivity (Mg ha^{-1}); yield per plant (kg $plant^{-1}$); number of fruits per plant (fruits $plant^{-1}$); and number of fruits per hectare (fruits ha^{-1}).

After the harvest, passion fruits were evaluated in terms of: mean fruit mass, by a digital scale, results expressed as grams (g); pericarp thickness, by a digital pachymeter at six spots in the median portion of the fruit, expressed as millimeters (mm); mean fruit length, expressed as millimeters (mm); mean fruit diameter, expressed as millimeters (mm); yield of pulp, aryl + seed, expressed as percentage (%); epidermis color, by a Minolta CR-300® colorimeter, with a D65 light source, which carried out readings of "L" (luminosity), "a*", "b*" and the hue or chromatic shade represented by the "hue angle", by means of ºhue = tan b*/a*-1 (+180), where values <100 = yellow and values >100 = green; soluble solids, by the Atago® digital refractometer, expressed as ºBrix; titratable acidity, quantified in 10 mL juice diluted in 90 mL distilled water and titrated with a solution of NaOH 0.1 mol L up to pH 8.1, by a Quimus® pH meter, expressed as percentages of citric acid; and the SS/TA relation, determined by the quotient of SS and TA values. Regarding the fruit physico-chemical variables, in May 2014 and 2015, 20 fruits were picked at every experimental unit, with eight repetitions of every treatment, thus, totaling 116 fruits per treatment.

2.4 Statistical Analysis

The results of the experiment were submitted to analysis of variance and when statistical significance was reached, the means of the treatments were submitted to the DUNCAN/DNMRT, significant test (p=0.05), using the statistical program WinStat [8].

3. RESULTS AND DISCUSSION

In the first season (2013/2014), the genotype BRS Sol do Cerrado had higher productivity and yield per plant than the selection Urussanga (Table 2). However, there was no statistical difference among the genotypes BRS Sol do Cerrado, BRS Rubi do Cerrado and Catarina. It shows that the genotypes which were evaluated in the first seasons, such as the ones that belong to the species *Passiflora edulis* Sims, have similar productive behavior.

In the second season (2014/2015), the genotype BRS Sol do Cerrado had higher productivity and yield per plant than both genotypes Urussanga and Catarina (Table 2). Mean productivity of all genotypes in the second seasons was 17.58 Mg ha^{-1}, similar to the general productivity value found in Santa Catarina state, which was 18.13 Mg ha^{-1} in the 2012/2013 season, according to Epagri-Cepa [9].

Regions with warm temperatures have favorable conditions for passion fruits to grow. In this case, the northeast of Brazil is the main producer of this fruit; in 2016 it yielded about 13.32 Mg ha^{-1} [1]. However, this experiment was carried out in a region with milder weather (Table 1). Even so, the genotypes of passion fruit vines under investigation showed productivity of 7.82 Mg ha^{-1} in the first year and 17.58 Mg ha-1 in the second year under study (Table 2). Thus, taking into account the climate in the south of Brazil, they showed satisfactory potential.

Passion fruit s of the species *Passiflora alata* of Urussanga had lower yield than the other genotypes of yellow passion fruit s in both crops under analysis (Table 2). According to Vasconcellos [10], the sweet passion fruit has the best performance, both in growth and in fruit yield and quality, when it is cultivated at milder temperatures. The opposite relation happens to the yellow passion fruit. Even considering that the climate in the area of this experiment is milder than the one in traditional regions that yield passion fruits, as shown in Table 1, it was not mild enough to make sweet passion fruit s yield as much as or more than the other genotypes of yellow passion fruits.

In Mato Grosso state in Brazil, evaluation of the passion fruit cultivars *Passiflora edulis*: IAC 275, IAC 277, FB 100, FB 200, BRS Sol do Cerrado, BRS Gigante Amarelo and BRS Ouro Vermelho showed that they had mean productivity of 5.92 Mg ha^{-1} in the first seasons [11]. It was lower that the general mean found by this experiment, which was 7.82 Mg ha^{-1} in the first season.

Production variables may be much below the productive potential of these materials, considering that hand-pollination was not carried out in this experiment. [11] studied the use of hand-pollination and reported that mean productivity of cultivars with hand-pollination was 16.41 Mg ha^{-1} whereas cultivars with natural pollination yielded 5.92 Mg ha^{-1}. Thus, fruit yield by hand-pollination was about three-fold the one by natural pollination.

Table 2. Productivity (P), yield per plant (YP), number of fruits per plant (NFP) and number of fruits per hectare (NFH) of passion fruit cultured in Pelotas, RS, in 2013/2014 and 2014/2015

Genotypes	P (Mg ha^{-1})	YP (Kg plant^{-1})	NFP (Fruits plant^{-1})	NFH (Fruits ha^{-1})
2013/2014				
BRS Sol do Cerrado	9.08a	2.81a	11.63a	37222a
BRS Rubi do Cerrado	8.02ab	2.50ab	10.27ab	32868ab
Catarina	7.92ab	2.47ab	9.90b	31808b
Urussanga	6.24b	1.95b	10.3ab	32960ab
Mean	7.82	2.43	10.53	33715
CV (%)	22.76	26.38	22.51	22,51
2014/2015				
BRS Sol do Cerrado	20.36a	12.72a	51.10a	81767a
BRS Rubi do Cerrado	19.81ab	12.38ab	49.90ab	79879ab
Catarina	18.07b	11.29b	45.90c	73455c
Urussanga	12.05c	7.54c	46.20bc	73920bc
Mean	17.58	10.98	48.2	77255
CV (%)	8.68	8.68	9.19	9.19

Means followed by the same letter in the column do not differ from each other by the Duncan test at (P = 0.05)

In the first seasons (2013/2014), the cultivar BRS Sol do Cerrado had the highest numbers of fruit per plant and fruit per hectare, but it did not differ much from BRS Rubi do Cerrado and Urussanga (Table 2). In the second seasons (2014/2015), the cultivar BRS Sol do Cerrado had the highest numbers of fruit per plant and fruit per hectare by comparison with both genotypes Catarina and Urussanga. In both seasons, the genotype Catarina had similar behavior, i.e., it had the lowest numbers of fruit per plant and fruit per hectare.

The genotype Urussanga was found to have the lowest yield per plant and productivity (Table 2). It may have happened due to the fact that its fruits had the lowest mean fruit mass in both seasons under evaluation (Table 3). According to Alves [12], the sweet passion fruit reaches mass of 0.165 kg. Therefore, the genotype Urussanga had good performance in this experiment, since its mean fruit mass was 0.189 kg in the 2013/2014 season and 0.163%, in the 2014/2015 season. This genotype also showed low values of mean fruit length, mean fruit diameter and puld yield.

The genotypes BRS Sol do Cerrado, BRS Rubi do Cerrado and Catarina had the highest mean fruit mass in both seasons under evaluation (Table 3). It is known that the market prefers

Table 3. Mean fruit mass (MFM), pericarp thickness (PT), mean fruit length (MFL), mean fruit diameter (MFD) and fruit yield (FY) of passion fruit cultured in Pelotas, RS, in 2013/2014 and 2014/2015

Genotypes	MFM (kg)	PT (mm)	MFL (mm)	MFD (mm)	FY (%)
2013/2014					
BRS Sol do Cerrado	0.242a	5.96b	101.81a	86.07a	52.13a
BRS Rubi do Cerrado	0.244a	5.53b	100.32a	86.03a	51.40a
Catarina	0.249a	5.72b	119.76a	84.09a	50.73a
Urussanga	0.189b	8.12a	98.25b	68.7b	32.34b
Mean	0.231	6.33	104.92	81.22	46.65
CV (%)	90.77	12.44	9.11	7.87	10.45
2014/2015					
BRS Sol do Cerrado	0.249a	6.01b	120.69a	88.78a	49.01a
BRS Rubi do Cerrado	0.248a	5.59b	118.75a	84.44a	53.22a
Catarina	0.246a	5.78b	121.31a	85.13a	51.11a
Urussanga	0.163b	8.57a	98.03b	70.27b	33.55b
Mean	0.226	6.48	114.69	82.57	46.73
CV (%)	14.64	6.77	9.15	8.30	9.90

Means followed by the same letter in the column do not differ from each other by the Duncan test at (P = 0.05)

fruits with high mass. According to [4], the mean mass of the genetically engineered yellow passion fruit is about 0.230 kg while the traditional one weighs 0.130 kg, on average.

In both seasons, the genotype Urussanga had the highest pericarp thickness, i. e., 8.12 and 8.57 mm, by comparison with the other genotypes under evaluation (Table 3). [13] evaluated five populations of sweet passion fruits in Jaboticabal, São Paulo/Brazil, with open pollination, and found fruits whose rind thickness was 11.2 mm (ranging from 7.5 to 16.1).

Regarding pulp yield, the genotypes BRS Sol do Cerrado, BRS Rubi do Cerrado and Catarina did not show any significant statistical difference among them. However, they had higher yields that the genotype Urussanga, whose pulp yields were 32.34% and 33.55% in both 2013/2014 and 2014/2015 seasons, respectively (Table 3). Even though the pulp yield of the Urussanga passion fruit s was lower than the one of the yellow genotypes, values of the pulp yield of the sweet passion fruit found by this study were higher than the ones reported by [13]. They evaluated five populations of sweet passion fruits in Jaboticabal, São Paulo/Brazil, with open pollination, and found mean pulp yield equal to 27.3%.

Concerning soluble solids, the genotype Urussanga had higher levels than the other genotypes under evaluation in both seasons (Tabela 4). Therefore, soluble solids the genotype Urussanga was better than the genotypes of yellow passion fruits (BRS Sol do Cerrado, BRS Rubi do Cerrado and Catarina). The difference was 2.60 ºBrix between the sweet genotype (13.98 ºBrix) and the mean of the yellow ones (11.28 ºBrix) in the 2013/2014 season and 1.81 ºBrix in the 2014/2015 season. [14] evaluated five populations of sweet passion fruits in Jaboticabal, São Paulo/Brazil, with open pollination, and found fruits whose content of total soluble solids was 18.1ºBrix (ranging from 15.7 to 21 ºBrix). These values were considered high, by comparison with the ones found by this study, which may have been influenced by the edaphoclimatic conditions in the region.

The genotype Urussanga had lower titratable acidity and higher RATIO than the other genotypes of passion fruit s in both 2013/2014 and 2014/2015 seasons (Table 4). Its acidity was 2.05% and its citric acid was 2.07% in the 2013/2014 and 2014/2015 seasons, respectively. These results agree with the ones found by [12], who characterized the evolution of the acidity of the sweet passion fruit according to the days after anthesis. Such values ranged from 2.3 to 1.5% of citric acid.

The genotype Catarina had the highest acidity in the 2013/2014 season while both genotypes BRS Sol do Cerrado and Catarina had the highest acidity in the 2014/2015 season (Table 4). Therefore, the genotypes BRS Sol do

Table 4. Soluble solids (SS), titratable acidity (TA), SS/AT relation (RATIO) and epidermis color (EC) of passion fruit cultured in Pelotas, RS, in 2013/2014 and 2014/2015

Genotype	SS (ºBrix)	TA (%citric acid)	RATIO	EC (ºHue)
2013/2014				
BRS Sol do Cerrado	11.33b	5.48ab	2.02b	106.09^{ns}
BRS Rubi do Cerrado	11.17b	5.11b	2.17b	108.50
Catarina	11.36b	6.22a	1.85b	108.39
Urussanga	13.98a	2.05c	6.80a	104.10
Mean	11.96	4.72	3.21	106.77
CV (%)	5.97	8.09	12.22	14.17
2014/2015				
BRS Sol do Cerrado	12.43b	6.54a	1.90b	98.02^{ns}
BRS Rubi do Cerrado	12.91b	5.56b	2.32b	100.05
Catarina	12.04b	5.69ab	2.11b	99.19
Urussanga	14.27a	2.07c	6.86a	106.12
Mean	12.89	4.96	3.29	100.85
CV (%)	6.01	6.03	8.50	16.13

Means followed by the same letter in the column do not differ from each other by the Duncan test at (P = 0.05). ns = not significant

Cerrado, BRS Rubi do Cerrado and Catarina had higher values of acidity than the sweet passion fruit Urussanga. According to Cavichioli [14], low temperatures during fruit development may be related to the accumulation of citric acid in the passion fruit. Thus, low temperatures and wide temperature amplitude during fruit ripening may lead to citric acid accumulation.

Regarding the epidermis color, no significant difference was found among the genotypes in the seasons under evaluation (Table 4), taking into account that passion fruits ripen along the days after anthesis. According to Alves [12], passion fruits were light green after 7 days (111.02 ºhue) and greener after 35 days (126.00 ºhue). At the end of ripening, the hue angle decreases considerably. Its reduction shows the yellow color that is typical of ripe passion fruits, i. e., the result of chlorophyll degradation in the pericarp and the synthesis and/or manifestation of carotenoid pigments.

4. CONCLUSION

The genotypes under evaluation have productive potential to be yielded in edaphoclimatic conditions found in Rio Grande do Sul southern Brazil.

The genotypes BRS Sol Cerrado, BRS Rubi do Cerrado and Catarina have the highest productivity, fruit mass, fruit length, fruit diameter and pulp yield in relation the genotype Urussanga.

The genotype Urussanga has the highest pericarp thickness and soluble solid content, besides the lowest acidity.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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