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The Fruiting Wall: An Alternative Training System for Peach Orchards in Southeast Brazil

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Abstract

The choice of the training system is a key step to the establishment of new orchards since it affects yield and fruit quality. In this context, the aim of this study was to evaluate the performance of the scion cv. Tropic Beauty in the Fruiting Wall training system compared with the Y-Shaped. The two training systems showed no statistical differences among the years regarding the length of phenological cycles (approximately 140 days). The Fruiting Wall showed higher values for yield per tree (from 80.2 to 112.9%), fruit weight (from 7.6 to 10.3%) and fruit pulp from 9.4 to 12.6%) than Y-Shaped. The mean values for flesh firmness and fruit chemical characteristics ranged over the years for both training systems. Despite the lack of significant differences for fruit chemical characteristics, the observed values were compatible with those expected for the cultivar. Data collected from the Fruiting Wall showed lower variance than those collected from Y-shape. This suggests that the Fruiting Wall leads to a higher uniformity of production and fruit quality than the Y-Shaped. Based on these results, we concluded that the Fruiting Wall improves the peach cv. Tropic Beauty production, particularly for yield by tree and fruit mass.

Keywords: fruit quality, yield, Y-Shaped, Tropic Beauty

1. Introduction

The worldwide agriculture has changed its cultivation systems to increase yield and quality (Lauri & Corelli-Grappadelli, 2014) of the crops. Such increasement is expected to be achieved with reduced inputs (Bussi et al., 2015) and labor requirements (Caracciolo et al., 2021; Loreti & Massai, 2002). The use of high-density orchards is adopted as an option to reach these goals and induce the plants to early production (Loreti & Massai, 2002; Pasa et al., 2017; Souza et al., 2019; Uberti et al., 2020). Although this strategy is valid for increase yield, some studies have shown that it may increase root competition and the intense pruning may reduce the total carbohydrate supply (Robinson et al., 2006). High-density orchards frequently require plant architecture modification, which can only be achieved by repetitive pruning over the years (Loreti & Massai, 2002). High positive correlation between orchard density and yield is frequently observed in cool climates (Robinson et al., 2006). However, invasive summer pruning, which are often required in warmer climates, may significantly decrease the orchards long-term profitability (Loreti & Massai, 2002). In addition, the influence of plant architecture on stone fruits yields, such as peach and nectarine, under tropical and subtropical conditions is still poorly know (Afonso et al., 2017; Lal et al., 2017; Uberti et al., 2020).

Plant architecture affects solar radiation interception and utilization, impacting fruit production and, mainly, quality (Afonso et al., 2017; Bussi et al., 2015; Corelli-Grappadelli & Marini, 2008; D'Abrosca et al., 2017; Lal et al., 2017; Loreti & Massai, 2002; Sobierajski et al., 2019). Enhancing light interception can also reduce the incidence of diseases (Bussi et al., 2015), because solar radiation is directly related to photosynthetic capacity (Corelli-Grappadelli & Marini, 2008; Lal et al., 2017), and many other physiological activities. In fact, improving light interception may effectively increase the carbon absorption rates (Lauri & Corelli-Grappadelli, 2014).

In São Paulo state, the second Brazilian peach (*Prunus persica*) and nectarine (*P. persica* var. *nuscipersica*) producer (Fernandes et al., 2022), the training system most adopted by the growers is the Y-Shaped (which has similar plant architecture, *e.g.*, to Ypsilon and Perpendicular-V), with two scaffold branches (Sobierajski et al., 2019). This training system enables high-density orchards (1,430 trees ha^{-1}). However, it also requires invasive green pruning and, prevents a complete mechanization in thinning and pruning. The Fruiting Wall (715 trees ha^{-1}; which has similar plant architecture, *e.g.*, to Central Leader and Axis), a multi-leader system with four to six scaffolds branches grown in the row direction, is an alternative training system (Sobierajski et al., 2019). Despite the lower number of trees per hectare than the Y-Shaped, the Fruiting Wall allows complete mechanization in pruning and thinning (Neri et al., 2022), and enhances light interception due to narrow canopy. Furthermore, this training system is also expected to facilitate robotic harvesting (Fu et al., 2020). With regards to environmental impacts, the Fruiting Wall may lead to Carbon footprint values lower than other training system (Vinyes et al., 2018).

Based on this background we hypothesized that the Fruiting Wall training system in mild winter regions may affect the yield and fruit quality similarly announced in cool climates. Despite all the advantages of the Fruiting Wall, there is no widespread use of this system in mild winter regions such as the State of São Paulo, because the lack of previous regional studies assessing yield and fruit quality. In this context, the purpose of this study was to evaluate the performance of the peach scion cv. Tropic Beauty trained in the Fruiting Wall and Y-Shaped training systems in four consecutive crop seasons in the State of São Paulo.

2. Method

2.1 Study Site

The trial was established in 2014 at the Irmãos Parise producers within the municipality of Jarinu, São Paulo State, Brazil (23°04′48″ S; 46°43′37″ W; 870 m a.s.l.). The climate is "Cwa" type according to Köppen's classification system (Alvares et al., 2013) and, the soil is "Cambisol" (IUSS Working Group WRB, 2015). The climate characterization was obtained from weather station of Agronomic Institute (IAC), situated in Jarinu-SP (Figure 1).

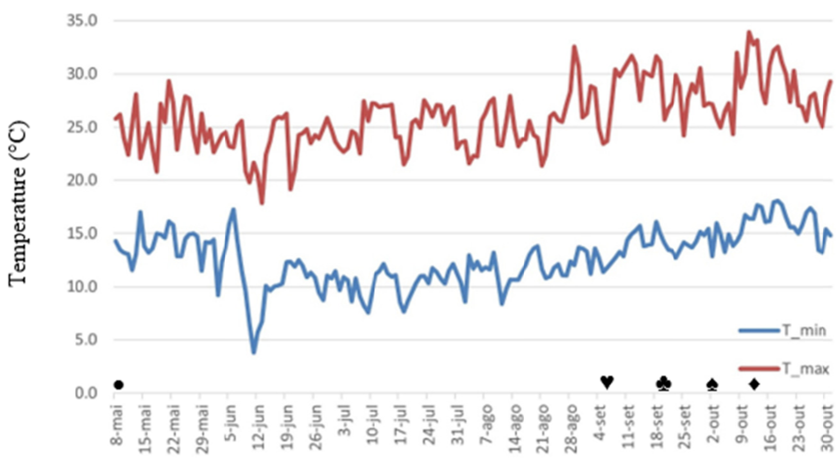

Figure 1. Means of minimum and maximum temperatures (2017-2020) at the municipality of Jarinu, São Paulo state, Brazil. ● Pruning and Hydrogen Cyanamide (0.8%) and mineral oil (1.0%) application; Harvest in ♠ 2017, ♣ 2018, ♥ 2019 and ♦ 2020

2.2 Material

Plants of Tropic Beauty scion cultivar budded on Okinawa rootstock were trained as Y-Shaped (2.0 x 3.5 m) and Fruiting Wall (4.4 x 3.5 m), displaying 1,428 and 715 trees per ha, respectively. Flowers and fruit were thinned out to standard the fruit number around 185 and 350 fruits/tree in Y-Shaped and Fruiting Wall, respectively. The pruning was conducted on the first 10 days of May, during the gem's dormancy. The Hydrogen Cyanamide (0.8%) and mineral oil (1.0%) were applicated after the pruning to overcome the lack of chilling accumulation. The phenology was measured considering the number of Julian days between the pruning and the harvest in both training systems.

2.3 Sampling and Measurements

The data were collected from 2017 to 2020 from ten trees of each training system. In each season, thirty fruits were randomly collected from each plant of both training systems. The experimental design was a randomized complete block with five replicates, consisting of six fruits each. The traits considered in this study were yield (Y_{ha}—t ha^{-1} and Y_{tree}—kg tree^{-1}), fruit weight (FW—g), fruit pulp (PY—g), flesh firmness (FF—kg cm^{-2}), soluble solids content (SSC—°Brix), titratable acidity (TA—g malic acid 100 ml^{-1}) and ratio (SS/TA). The yield was estimated by hectare and tree, considering the number of trees per ha, the number of fruits per tree and the average fruit weight of each plant, according to the Equations 1 and 2.

$$Y_{ha} = \frac{D_{tree/ha} \times N_{fruit/tree} \times \overline{FW}_g}{1000{,}000} \quad (1)$$

Where, $D_{tree/ha}$ = orchard density; $N_{fruit/tree}$ = number of fruits per tree; $\overline{FW}_g$ = average of fruit weight of each tree; divided by 1000,000 to obtain results in t ha^{-1}.

$$Y_{tree} = \frac{N_{fruit/tree} \times \overline{FW}_g}{1{,}000} \quad (2)$$

Where, $N_{fruit/tree}$ = number of fruits per tree; $\overline{FW}_g$ = average of fruit weight of each tree; divided by 1,000 to obtain results in kg tree^{-1}.

The fruit weight and fruit pulp (fruit weight—pit weight) was obtained by digital balance. The flesh firmness was measured after removing the peel on two opposite fruits sides by penetrometer (FT 327, T.R. Turoni). The soluble solids content was measured by a portable digital refractometer (Pal-1, Atago). The titratable acidity was estimated by titration with NaOH (0.1 M) to adjust the solution to pH 8.1, according to the equation 03 (Instituto Adolfo Lutz, 2008):

$$TA = \frac{V \times C_t \times F_t \times M}{Vs} \quad (3)$$

Where, V = volume of NaOH solution (mL); C_t = concentration of NaOH solution; F_t = conversion factor; M = molecular weight of malic acid; V_s = sample volume (mL).

2.4 Statistics and Data Analysis

The data of flesh firmness in 2019 were transformed to meet the normality assumption (evaluated by Shapiro-Wilk test), using the square root ($x_{transf.} = \sqrt[2]{x}$). The F test was applied to verify the significance between variances and the t test between means. The statistical tests were calculated using the R-software (R Core Team, 2019), at the 5% significance level.

3. Results

The phenology data showed no statistical differences between the training systems, across the years (Table 1). The mean phenological cycle were 140.50 days for Y-Shaped and 140.25 for Fruiting Wall. The Fruiting Wall showed the highest values for yield by tree (2017 to 2020), fruit weight (2017, 2018 and 2020) and fruit pulp (2017, 2018 and 2020; Table 2). However, this superior performance of the Fruiting Wall with regards to yield by tree was not observed for the overall yield by hectare. The yield by tree in the Fruiting Wall were between 80.20% (2019) e 112.91% (2020) more productive than the Y-Shaped.

Table 1. Julian days between the pruning and harvest dates (2017 to 2020), means and standard deviation (SD) of Julian days between the pruning and harvest dates, and t test between means of Y-Shaped and Fruiting Wall training systems. Jarinu, São Paulo, Brazil, 2017-2020

Source of variation	Y-Shaped	Fruiting Wal	t test
2017	135	148	
2018	125	134	
2019	120	120	
2020	144	159	
Mean	140.50	140.25	0.02^{ns}
SD	13.53	16.94	

Note. ns: $p > 0.05$; *: $p < 0.05$.

The fruit weight and fruit pulp were respectively 7.60 and 11.48% (2017), 8.85 and 9.42% (2018), and 10.30 and 12.63% (2020) higher for Fruiting Wall than for Y-Shaped. In this study, only in 2019 the Y-Shaped showed statistically higher values for fruit pulp (4.45%) higher than for the Fruiting Wall. The means for flesh firmness did not differ significantly in 2017 between training systems. In 2018 and 2020 the fruits from the Y-Shaped were 19.50 and 23.28%, respectively, firmer than those from the Fruiting Wall. However, in 2019 the Fruiting Wall produced fruits 31.55% firmer than the Y-Shaped.

The soluble solids content showed statistical differences only in 2020, when the fruits from the Y-Shaped was 6.08% higher than those produced by the Fruiting Wall (Table 2). The titratable acidity assessed in the fruits from the Y-Shaped was 18.57% (2018) and 6.49% (2020) higher than the fruits from the Fruiting Wall. In 2017 and 2019 the acid malic content in fruits from the Fruiting Wall were, respectively, 5.62 and 9.09% higher than the Y-Shaped. At the other hand, the fruits from the Y-Shaped showed higher values for titratable acidity in 2018 (21.25%) and 2020 (5.55%). The high titratable acidity index negatively induced the ratio, where the rates was 15.40% higher in the Fruiting Wall than in the Y-Shaped (2018); and 7.93 and 6.90% higher in the Y-Shaped than in the Fruiting Wall (2017 and 2019, respectively). In 2020, despite the statistical differences for soluble solids and titratable acidity rates, the ratio showed no statistical differences. With regards to data variance, the Fruiting Wall showed lower values than the Y-Shaped, which indicate a lower variability of the data coming from the Fruiting Wall (Table 3).

Table 2. Mean and standard deviation (SD) (yield by hectare—t ha^{-1}, yield by tree—kg tree^{-1}, fruit weight—g, fruit pulp—g, flesh firmness—kg cm^{-2}, soluble solid SS—°Brix, titratable acidity TA—g malic acid 100 ml^{-1}, and ratio—SS/TA), and t test between means of Y-Shaped and Fruiting Wall training systems. Jarinu, São Paulo, Brazil, 2017-2020

Source of variation	Y-Shaped		Fruiting Wall		t test
	Mean	SD	Mean	SD	
2017					
Yield/ha (t ha^{-1})	23.75	2.15	24.42	2.75	-0.60^{ns}
Yield/tree (kg tree^{-1})	16.63	1.51	34.15	3.84	-13.42*
Fruit weight (g)	89.65	22.85	96.46	14.53	-3.63*
Fruit pulp (g)	84.92	22.34	94.67	12.01	-5.36*
Flesh firmness (kg cm^{-2})	3.95	1.80	4.27	1.51	1.43^{ns}
Soluble solids (°Brix)	9.59	0.72	9.65	0.71	-0.37^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.84	0.13	0.89	0.03	-2.24*
Ratio	11.70	1.82	10.84	0.82	2.59*
2018					
Yield/ha (t ha^{-1})	28.30	4.76	29.67	1.27	-0.88^{ns}
Yield/tree (kg tree^{-1})	20.78	3.46	41.50	1.22	-29.51*
Fruit weight (g)	108.65	22.33	118.26	15.65	-6.05*
Fruit pulp (g)	102.55	21.83	112.21	15.29	-6.22*
Flesh firmness (kg cm^{-2})	4.78	1.51	4.00	1.27	4.52*
Soluble solids (°Brix)	9.57	0.62	9.80	0.35	-1.73^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.97	0.06	0.80	0.06	12.21*
Ratio	9.89	0.74	11.69	1.55	-7.27*
2019					
Yield/ha (t ha^{-1})	26.72	1.86	25.39	1.68	1.50^{ns}
Yield/tree (kg tree^{-1})	19.24	1.60	34.67	2.73	-15.42*
Fruit weight (g)	105.18	18.48	102.59	13.53	1.78^{ns}
Fruit pulp (g)	98.97	17.70	94.75	13.60	3.10*
Flesh firmness (kg cm^{-2})	1.68	0.17	2.21	0.32	-4.06*
Soluble solids (°Brix)	10.22	0.88	10.21	0.74	0.08^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.70	0.10	0.77	0.08	-3.99*
Ratio	13.32	1.84	12.46	1.68	2.42*
2020					
Yield/ha (t ha^{-1})	26.17	3.54	27.90	2.38	-1.28^{ns}
Yield/tree (kg tree^{-1})	17.89	2.42	38.09	3.25	-15.75*
Fruit weight (g)	97.90	18.84	107.98	18.19	-5.75*
Fruit pulp (g)	93.21	18.46	104.98	19.85	-6.28*
Flesh firmness (kg cm^{-2})	4.13	1.06	3.35	1.31	5.68*
Soluble solids (°Brix)	9.77	0.77	9.21	0.70	3.63*
Titratable acidity (g malic acid 100 ml^{-1})	0.95	0.07	0.90	0.07	3.60*
Ratio	10.47	1.10	10.26	0.92	1.05^{ns}

Note. ns: $p > 0.05$; *: $p < 0.05$.

Table 3. Variances of data (yield by hectare—t ha^{-1}, yield by tree—kg $tree^{-1}$, fruit weight—g, fruit pulp—g, flesh firmness—kg cm^{-2}, soluble solid SS—°Brix, titratable acidity TA—g malic acid 100 ml^{-1}, and ratio—SS/TA), and F test between variances of Y-Shaped and Fruiting Wall training systems. Jarinu, São Paulo, Brazil, 2017-2020

Source of variation	Y-Shaped	Fruiting Wall	F test
2017			
Yield/ha (t ha^{-1})	4.64	7.55	0.61^{ns}
Yield/tree (kg $tree^{-1}$)	2.27	14.76	0.15*
Fruit weight (g)	522.29	211.23	2.47*
Fruit pulp (g)	499.00	144.22	3.46*
Flesh firmness (kg cm^{-2})	3.24	2.27	1.43*
Soluble solids (°Brix)	0.52	0.51	1.02^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.017	0.001	2.70*
Ratio	3.31	0.68	4.87*
2018			
Yield/ha (t ha^{-1})	22.63	1.62	13.86*
Yield/tree (kg $tree^{-1}$)	1.37	3.19	0.43^{ns}
Fruit weight (g)	498.72	245.02	2.03*
Fruit pulp (g)	476.42	233.90	2.04*
Flesh firmness (kg cm^{-2})	2.29	1.62	1.41^{ns}
Soluble solids (°Brix)	0.38	0.12	3.23*
Titratable acidity (g malic acid 100 ml^{-1})	0.004	0.004	0.87^{ns}
Ratio	0.55	2.40	0.23*
2019			
Yield/ha (t ha^{-1})	3.46	2.82	1.22^{ns}
Yield/tree (kg $tree^{-1}$)	2.55	7.50	0.34^{ns}
Fruit weight (g)	341.52	183.01	1.87*
Fruit pulp (g)	313.34	184.92	1.69*
Flesh firmness (kg cm^{-2})	0.03	0.10	0.52*
Soluble solids (°Brix)	0.77	0.55	1.41^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.010	0.007	1.45^{ns}
Ratio	3.39	2.81	1.20^{ns}
2020			
Yield/ha (t ha^{-1})	12.55	5.68	2.21^{ns}
Yield/tree (kg $tree^{-1}$)	5.87	10.58	0.55^{ns}
Fruit weight (g)	354.90	330.77	1.07^{ns}
Fruit pulp (g)	340.73	394.24	0.86^{ns}
Flesh firmness (kg cm^{-2})	1.13	1.72	0.65*
Soluble solids (°Brix)	0.60	0.49	1.23^{ns}
Titratable acidity (g malic acid 100 ml^{-1})	0.005	0.005	0.94^{ns}
Ratio	1.21	0.85	1.42^{ns}

Note. ns: $p > 0.05$; *: $p < 0.05$.

4. Discussion

The lack of statistical differences between the phenological cycles in the training systems across the years is in line with Sobierajski et al. (2019), which evaluated the duration of these phenological stages in 2017. Although these authors observed a small anticipation of the "final swell" and "fruit veraison" stages in the Fruiting Wall, the commercial ripening occurred at same season for both training systems (Sobierajski et al., 2019). The harvest season ranging from September 06th to October 12th (Figure 1). Alves et al. (2018) related the Tropic Beauty's harvest period ranging from October 30th to November 05th in Araucária (25°35′15″ S; 49°24′18″ W; 897 m a.s.l.), Brazil, later than the present study. According to these authors, the average values for minimum and maximum air temperatures during the harvest season ranged from 9.2 to 11.9 °C, and from 31.5 to 34.1 °C, respectively. These values of minimum air temperature were lower than those observed in Jarinu (15.3 °C). At the other hand, the values of maximum air temperatures observed in Alves et al. (2018) were higher than those presented in this study (27.0 °C). The difference of air temperature conditions may justify the difference between the harvest seasons in these two locations.

The features yield by tree, fruit weight and fruit pulp showed the highest values in the Fruiting Wall. Nevertheless, this superior performance was not observed for the overall yield by hectare. This fact occurred because the Y-Shaped had larger number of trees per hectare than the Fruiting Wall, which compensated its lower fruit weight. Bussi et al. (2015) compared the yield from the Axis training system, which has a similar plant architecture to Fruiting Wall, with the Open Vase. These authors observed yields values equal to 22.2 t ha^{-1} (Axis) and 16.1 t ha^{-1} (Open Vase) for peach 'Conquise'. Pasa et al. (2017) concluded that the Central Leader training system, which also has similar plant architecture to Fruiting Wall, is more productive than the Ypsilon. Considering the Central Leader, this latter study obtained 7.77 t ha^{-1} and 9.57 t ha^{-1} (two-years old) and 14.41 t ha^{-1} and 11.87 t ha^{-1} (three-years old), respectively for 'Kampai' and 'Rubimel' cultivars (Pasa et al., 2017). However, considering the Ypsilon the yields were 4.39, 4.35, 3.27 and 5.22 t ha^{-1}, respectively for 'Kampai' and 'Rubimel' cultivars at two- and three-years old (Pasa et al., 2017).

Regarding yield by tree the Fruiting Wall were more productive than the Y-Shaped in2019 and 2020. These results show that despite the lower number of plants per ha, the trees from Fruiting Wall have high capability of fruit set, in addition to the highest mass per fruit. Similarly, Pasa et al. (2017) present the highest values for yield by tree for the Central Leader, with 7.77 and 14.41 kg $tree^{-1}$ (cv. 'Kampai'), and 9.57 and 11.87 kg $tree^{-1}$ (cv. 'Rubimel'), respectively in two- and three-years old orchards. The tree architecture seemed to have higher influence on yield than the orchard density due to the canopy light interception and distribution (Robinson et al., 2006). In fact, the choice of the training system and the orchard density must consider the fruit cultivar and its relationships between vegetative and reproductive growth, which are to certain degree independent phenomena (Lauri & Corelli-Grappadelli, 2014). Studies have showed a curvilinear relationship between orchard density and yield (Robinson et al., 2006).

The fruit weight and fruit pulp were greater for Fruiting Wall than for Y-Shaped, except in 2019 for fruit pulp. This result is consistent with those found in Robinson et al. (2006), which observed that the average fruit size produced by Central Leader was bigger than those of the Perpendicular-V (which has similar plant architecture to Y-Shaped) for 'Allstar', 'Blushingstar' and 'Flavortop' cultivars. Bussi et al. (2015) and Pasa et al. (2017) observed no differences among training systems for fruit weight. The values for flesh firmness varied among years, showing no conclusive behavior. Pasa et al. (2017) found no differences among training systems for fruit quality features (flesh firmness and soluble solids), regardless the cultivar.

In general, chemical characteristics did not show stability across years. The soluble solids showed statistical differences only in 2020, suggesting low influence of the training systems. Bussi et al. (2015) observed statistical differences between Axis (similar plant architecture to Fruiting Wall) and Open Vase for soluble solids (fruit grade AA: 13.3 and 12.0 °Brix; fruit grade B: 10.4 and 9.5 °Brix, respectively). Christofi et al. (2021) indicate that early ripening peach cultivars, as the 'Tropic Beauty', show lower SS content than mid and late-ripening cultivars. This latter feature occurs because there is no interruption of the growing process in mid and late-ripening cultivars (Christofi et al., 2021).

The titratable acidity showed similar behavior that flesh firmness. There is a consensus that peach acidity has polygenic control, mainly controlled by the genotype as a cultivar dependent parameter (Souza et al., 1998; C. H. Crisosto & G. M. Crisosto, 2005). However, a minor part is also controlled by environmental conditions and fruit maturity (C. H. Crisosto & G. M. Crisosto, 2005). In the present study, the acid malic content was higher in the Y-Shaped (2018 and 2020), than the Fruiting Wall. However, a opposite behavior was observed in 2017 and 2019, with the Fruiting Wall showing the highest values for acid malic content. Lima et al. (2013) found values for acid malic content ranging from 0.51 and 0.55 g 100 ml^{-1}, which are lower than those in the present study. These results indicate that, despite the low environmental control, the training system may modify the microenvironment and affect the TA contents. The ratio (SS/AT), a usual criterium of fruit quality that indicates balance between sugars and acids (C. H. Crisosto & G. M. Crisosto, 2005), was negatively induced by the high titratable acidity (in 2017 and 2019 for Fruiting Wall; and in 2018 for Y-Shaped). Despite the statistical differences for soluble solids and titratable acidity in 2020, it did not significantly affect the ratio.

The Fruiting Wall showed lower data variance than the Y-Shaped. For instance, in 2019 the Y-Shaped had 98.97 g for fruit pulp versus 94.75 g in Fruiting Wall. However, the Y-Shaped showed data variance 1.7 higher than the Fruiting Wall (σ^2: 313.34 and 184.92, respectively for Y-Shaped and Fruiting Wall). This latter difference is also significant. The same occurred with the feature Ratio in 2019. The higher homogeneity in fruit size and sweetness features observed in the Fruiting Wall, may be regarded as a desirable feature that facilitate the commercial management of the crops, provided that high-quality peaches may lead to higher prices for the producers (Costa & Botton, 2022).

5. Conclusion

The results found in this study support the hypothesis that the Fruiting Wall improves the peach cv. Tropic Beauty production. This training system increases the yield by tree for 'Tropic Beauty' peach cultivar. The peach features evaluated in this study were differently affected by the training systems. However, the yield by hectare shows no significant differences in all evaluations. The Fruiting Wall also leads to higher uniformity of production and fruit quality than the Y-Shaped.

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