https://doi.org/10.1590/1678-4499-2023-0167

PLANT BREEDING
Article

Production stability of pear cultivars for cultivation in the subtropical altitude climate

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Received: Aug. 26, 2022; | **Accepted:** Dec. 5, 2022

Section Editor: Alberto Cargnelutti Filho

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How to cite: Pio, R., Farias, D. H., Peche, P. M., Bisi, R. B., Fazenda, L. H. V. and Silva, A. D. (2023). Production stability of pear cultivars for cultivation in the subtropical altitude climate. Bragantia, 82, e20230167. https://doi.org/10.1590/1678-4499-2023-0167

ABSTRACT: The aim of this study was to select pear cultivars with production stability for the environmental conditions in the tropics. The design was in randomized blocks with 11 cultivars of pear, four replications and plots consisting of four plants. Between 2015 and 2019, the phenological were evaluated based on the beginning, full bloom, end and duration of flowering and harvest. The number and average fruit mass, yield per plant and estimated yield were also quantified. In the last year of evaluation, the quality of the fruits was quantified through the length and average diameter of the fruits, total titratable acidity, total soluble solids content and total soluble solids / total titratable acidity ratio. The data were submitted to the Scott–Knott grouping test and to quantify the divergence between cultivars was used the genetic distance. After detecting significant interaction between genotypes × environments, phenotypic stability of pear cultivars were analyzed by GGE Biplot methods for the estimated yield variable. The 'Tenra', 'Triunfo' and 'Seleta' cultivars are the most suitable for cultivation in regions with subtropical altitude climate. They are genetically similar, more adapted and stable, and have full or partial synchronized flowering for satisfactory productivity.

Key words: *Pyrus communis*, *Pyrus pyrifolia*, yield.

INTRODUCTION

Temperate tree fruit species originate from locations that have cold winters and well-defined climatic seasons and that have temperatures appropriate to growth during the spring and summer. Advances in the development of germplasm and varieties in recent centuries have made these fruit species highly productive (Pio et al. 2019).

More recently, the cultivation of fruit trees has been extended to nontraditional areas in the subtropical and tropical regions worldwide, where the climate is different from their natural habitat, with mild and dry winters and hot and rainy summers (Alcântara et al. 2018; Barbosa et al. 2010).

Despite being a temperate-climate fruit tree, some pear tree hybrid cultivars obtained from the cross *Pyrus communis* × *P. pyrifolia* are adapted in tropics, where the climate is characterized by mild winter and higher temperatures in the summer, compared to temperate regions. The cultivation of these hybrid cultivars in subtropical regions was made possible by the combination of the quality of the European pear (*P. communis*) with the low chill hours required by the Asian pear (*P. pyrifolia*) (Curi et al. 2017).

Most pear tree cultivars have gametophytic self-incompatibility, causing the plant to reject its own pollen (Bisi et al. 2019; 2021). Therefore, they depend on cross-pollination for fruit production. In general, the use of two to three pear cultivars with a coincident flowering period is recommended (Tatari et al. 2017). The existence of few adapted pear cultivars, is a limiting factor for the expansion of pear tree crops in subtropical regions (Bettiol Neto et al. 2014).

The wetlands from the tropics show hot and humid summer and cold and dry winter. Furthermore, thermal fluctuations in winter caused by conflicting air masses from tropics and polar regions result in insufficient chill accumulation. Thus, pear trees do not reach good vegetative and productive development because it does not reach the proper number of cold hours at temperatures equal to or lower than 7.2 °C. There are cultivars with chilling requirements lower than 500 h and over 700 h, and it is essential that Brazilian producers choose low-chilling cultivars (Alcântara et al. 2018).

The selection of cultivars should not be based on a single factor, since cultivars with economic potential combine multiple traits of agronomic interest, such as productive performance, and stability in production (Coutinho et al. 2019).

In order to advance the selection of cultivars, tools based on multivariate analyzes become essential in the development of studies for plant breeding programs (Coutinho et al. 2019). According to Cruz (2021), comparing results from several multivariate analysis techniques allows a more accurate interpretation of the divergence, hence providing more accurate interpretation of results with less demand for resources and work in breeding programs.

The objective of the present study was to identify pear cultivars with greater production stability for subtropical altitude climate by multivariate analysis.

MATERIAL AND METHODS

The experiment was carried out in the experimental orchard of the Federal University of Lavras, Minas Gerais, Brazil, with geographical coordinates of 21°14’ S, 45°00’ W and has an average altitude of 918 m. The climate is subtropical, with dry winters and rainy summers (Alvares et al. 2013).

The experiment was carried out in a randomized block design with 11 pear cultivars: Asian (*P. pyrifolia* - ‘Shinseiki’), European (*P. communis* – ‘William’s’ and ‘Packham’s Triumph’) and the hybrids *P. communis* × *P. pyrifolia* (‘Centenária’, ‘Cascatence’, ‘Triunfo’, ‘D’água’, ‘Tenra’, ‘Le Conte’, ‘Primorosa’ and ‘Seleta’), four repetitions and plots consisting of four plants each. Statistical analyses were made a split plots in time, with time (production cycles) constituting the main plots and the cultivars the split plots.

The pear cultivars were grafted to the *Pyrus calleryana* rootstock. They were taken to the field in November 2010, in a row spacing of 4.0 and 3.0 m between plants (population density of 834 plants per hectare). The crowns of the plants were conducted in a *central leader* system.

The defoliation, performed during the experimental period, was made with 10% urea and 12.5% sulfur lime (32° Bé density), usually at the end of April of each year, spraying with 1% copper after 30 days. Pruning was always performed in early July, complementing this activity with breaking dormancy of buds with hydrogenated cyanamide (a.i.) at 1% associated with 3% mineral oil.

In the four production cycles (2015/16, 2016/17, 2017/18 and 2018/19), a general phenological study was carried out on all plants, monitoring the start dates, full bloom every day after the dormancy period. and termination of flowering, regardless of the type of reproductive structure. During the growing season of each year, the average date for the beginning of the harvest and the phenotypic values for the duration of flowering and harvest were recorded between the pruning and the beginning of the harvest (development cycle) in days.

The yield analyzes of each cultivar were measured by the number of fruits per plant, average fresh fruit weight (g), yield ($P{\cdot}kg{\cdot}tree^{-1}$) and estimated yield ($P{\cdot}t{\cdot}ha^{-1}$) that was calculated, multiplying yield by tree density (834 plants per hectare).

In the last productive cycle (2018/19) the chemical and physical characteristics of the fruits were quantified. Twenty random fruits from each cultivar were collected for laboratory analysis. Measured variables included fruit length and fruit diameter. The soluble solids content of the fruit was analyzed from the juice extracted manually from the equatorial region on one side of each fruit using an ATAGO digital refractometer (Palette PR-101), and the values were expressed in °Brix. Titratable acidity was determined by titrating 10 g of pulp juice with an additional 50 mL of distilled water by a 0.1 N NaOH solution, and the result was expressed as the percentage of malic acid. The ratio of soluble solids to titratable acidity was then calculated.

The data were submitted to the Scott–Knott grouping of means test, with a 5% error probability. For the quantification of the genetic diversity of cultivars was evaluated through the analysis of the unweighted paired method with arithmetic mean (UPGMA) and by canonical variables analysis, based on 11 variables: number of fruits, mean fruit weight, yield, estimated yield, duration of flowering and duration of harvest, by four cycles, and average fruit length, average fruit diameter, total soluble solids, titratable total acidity and ratio (total soluble solids / total titratable acidity), the last productive cycle (2018/19). The standardized mean for Gower distance was used as a dissimilarity measure. Canonical variables were also used, which is an alternative process to evaluate the degree of genetic similarity between cultivars that takes into account both the residual covariance matrix and the phenotypic covariance matrix of the evaluated characters (Cruz et al. 2021). The relative contribution of characteristics to dissimilarity was estimated according to the criteria of Singh (1981).

To test the efficiency of the hierarchical clustering method, the cophenetic correlation coefficient was estimated according to the methodology described by Sokal and Rolf (1962). Mojena's method (1977) was used to determine the number of groups in the dendrogram. This method is based on the relative size of fusion levels (distances) in the dendrogram and consists of selecting the number of groups at stage j, which first satisfies the following inequality: $\alpha j > \theta k$, where αj is the value for distances between the dendrogram the fusion levels corresponding to stage j (j = 1, 2,…, n) and θk are the reference value expressed by $\theta k = \bar{\alpha} + k\hat{o}\alpha$, where $\bar{\alpha}$ and $k\hat{o}\alpha$ are, respectively, unbiased estimates of the values of mean and the standard deviation of α and k is a constant. The value of k = 1.25 was defined as the cutoff point to determine the number of groups, as suggested by Milligan and Cooper (1985).

The identification of superior genotypes, based on the simultaneous selection of the 11 characters evaluated, was based on the rank sum index or rank index. The rank sum index consists of classifying the cultivars in order favorable to the selection, according to the classes of each evaluated character. After this classification, the positions of the various characters of each cultivar were summed, forming the index proposed by Mulamba and Mock (1978). The index model $Ij = \Sigma nij$ is considered, where: Ij is the index for cultivar j; and nij is the classification number of character i for cultivar j.

The interaction between the years and the cultivars was presented through the GGE biplot method (genotype main effect and genotype by environment interaction), as described by Yan et al. (2000). Analysis was carried using the R program, considering the simplified model of two principal components (Eq. 1):

$$\bar{Y}_{ij} - \mu_j = \lambda_1 \gamma_{i1} \alpha_{j1} + \lambda_2 \gamma_{i2} \alpha_{j2} + \rho_{ij} + \bar{\varepsilon}_{ij} \tag{1}$$

In which $\lambda_1 \gamma_{i1} \alpha_{j1}$ is the first principal component (PCA1) of the effect of genotypes (G) + the interaction (G×E); $\lambda_2 \gamma_{i2} \alpha_{j2}$ is the second principal component (PCA2) of the effect of genotypes (G) + the interaction (G×E); λ_1 and λ_2 are the eigenvalues associated with PCA1 and with PCA2; γ_{i1} and γ_{i2} are the scores of PCA1 and of PCA2, respectively, for genotypes; α_{j1} and α_{j2} are the scores of PCA1 and of PCA2, concomitantly for environments, ρ_{ij} is the residue of the genotype × environment interaction, corresponding to the principal components not retained in the model, and $\bar{\varepsilon}_{ij}$ is the residue of the model with normal distribution, with zero mean, and variance σ^2/r (where σ^2 is the variance of the error between plots for each environment, and r is the number of replications). Statistical analyses were made a split plots in time, with time (production cycles) constituting the main plots and the cultivars the split plots.

All statistical analyses were performed using the Genes software (Cruz 2016). Analyses of stability, for estimated yield, were performed using GGE biplot methodology (Yan et al. 2000). The stability evaluation of cultivars for estimated yield was performed by their distances from the *ideal genotype*. The center of the concentric circles represents the position of an ideal genotype (Yan and Tinker 2006). The graphs were generated using R Program Software for PC.

RESULTS AND DISCUSSION

According to the phenological data (Tables 1 and 2), it was observed that the beginning of flowering of pear cultivars still begins in a varied way between the years of evaluation. Under subtropical conditions without the use of irrigation, flowering duration was very long. This amplitude reflected the extended harvest duration. It is believed that in irrigated planting there may be a decrease in flowering and harvesting duration. It is noteworthy that even in subtropical regions of altitude, the peculiarities of the microclimate or the thermal and water fluctuations between the years can influence the phenology of the pear trees.

Table 1. Phenological description of flowering and harvest, of 11 pear cultivars cultivated in the 2015/16 and 2016/17 production cycles in subtropical region of altitude.

Cultivars	Flowering				Harvest		
	Beginning	Full bloom	End	Duration (Days)*	Beginning	End	Duration (Days)*
				Production cycles 2015/16			
'Shinseiki'	12/Aug.	20/Sept.	14/Oct.	63 b	10/Dec.	08/Jan.	29 c
'Packham's Triumph'	15/July	10/Aug.	01/Oct.	70 a	11/Dec.	10/Jan.	30 c
'William's'	10/July	10/Aug.	18/Aug.	39 b	21/Dec.	10/Jan.	20 e
'Triunfo'	22/June	08/Aug.	01/Sept.	71 a	15/Dec.	03/Jan.	19 e
'Centenária'	01/July	10/Aug.	30/Aug.	60 b	20/Dec.	14/Jan.	25 d
'Seleta'	08/July	08/Aug.	01/Sept.	55 b	01/Dec.	10/Jan.	42 a
'Cascatense'	05/July	07/Aug.	01/Sept.	58 b	19/Dec.	18/Jan.	30 c
'Primorosa'	22/June	08/Aug.	04/Sept.	74 a	28/Nov	07/Jan	40 a
'D'água'	10/July	01/Aug.	30/Aug.	51 b	25/Nov.	29/Dec.	34 b
'Tenra'	26/June	20/Aug.	04/Sept.	70 a	25/Nov.	06/Jan.	42 a
CV (%)	19.59	5.08					
Cultivars				**Production cycles 2016/17**			
'Shinseiki'	17/Aug.	15/Sept.	30/Sept.	44 d	14/Dec.	05/Jan.	22 d
'Packham's Triumph'	06/Aug.	12/Sept.	26/Sept.	51 d	17/Dec.	14/Jan.	28 c
'Triunfo'	01/July	30/Sept.	12/Oct.	103 a	14/Dec.	03/Jan.	20 e
'Centenária'	14/Aug.	28/Aug.	30/Sept.	47 d	23/Dec.	14/Jan.	22 d
'Seleta'	15/July	08/Sept.	22/Sept.	69 c	03/Dec.	15/Jan.	43 a
'Cascatense'	03/Aug.	08/Sept.	12/Oct.	70 c	09/Dec.	19/Jan.	41 a
'Primorosa'	02/Aug.	12/Sept.	07/Oct.	66 c	26/Nov.	06/Jan	41 a
'D'água'	02/Aug.	30/Sept.	21/Oct.	80 b	26/Nov.	27/Dec.	31 b
'Tenra'	23/July	02/Sept.	30/Sept.	69 c	30/Nov.	06/Jan.	37 b
CV (%)	7.92	15.70					

* Averages followed by the same letter do not differ from each other to the Scott-Knott grouping of means test (P ≤ 0.05). (-) Did not bloom.

Table 2. Phenological description of flowering and harvest of 11 pear cultivars cultivated in the 2017/18 and 2018/19 production cycles in subtropical region of altitude.

Cultivars	Flowering				Harvest		
	Beginning	Full bloom	End	Duration (Days)*	Beginning	End	Duration (Days)*
				Production cycles 2017/18			
'Shinseiki'	21/Sept.	04/Oct.	04/Nov.	44 d	20/Dec.	19/Jan.	30 b
'Packham's Triumph'	16/Sept.	01/Nov.	09/Nov.	54 c	20/Dec.	03/Jan.	14 e
'William's'	21/Sept.	07/Nov.	13/Nov.	53 c	22/Dec.	09/Jan.	18 d
'Triunfo'	30/Sept.	22/Oct.	01/Nov.	32 f	15/Dec.	20/Jan.	36 a
'Centenária'	04/Oct.	01/Nov.	13/Nov.	40 d	13/Dec.	12/Jan.	30 b
'Seleta'	01/Sept.	16/Sept.	22/Oct.	51 c	20/Dec.	10/Jan.	21 d
'Cascatense'	14/Sept.	23/Nov.	03/Dec.	80 a	28/Dec.	17/Jan.	20 d
'Le Conte'	30/Sept.	07/Nov.	05/Nov.	36 e	20/Dec.	12/Jan.	23 c
'Primorosa'	28/Sept.	11/Oct.	18/Nov.	51 c	20/Dec.	19/Jan.	30 b
'D'água'	12/Sept.	11/Oct.	21/Nov.	70 b	09/Dec.	01/Jan.	23 c
'Tenra'	16/Sept.	18/Oct.	18/Nov.	63 b	15/Dec.	07/Jan.	23 c
CV (%)	12.62						7.84
Cultivars				**Production cycles 2018/19**			
'Shinseiki'	02/Aug.	15/Sept.	23/Sept.	52 c	24/Dec.	18/Jan.	25 b
'Packham's Triumph'	30/July	12/Sept.	20/Sept.	52 c	27/Dec.	10/Jan.	14 d
'William's'	20/Aug.	18/Oct.	30/Oct.	71 a	27/Dec.	14/Jan.	18 c
'Triunfo'	17/July	14/Aug.	22/Sept.	67 b	17/Dec.	15/Jan.	29 a
'Centenária'	19/Aug.	20/Sept.	14/Oct.	56 c	23/Dec.	13/Jan.	21 b
'Seleta'	13/Aug.	08/Sept.	20/Oct.	68 a	30/Dec.	20/Jan.	21 b
'Cascatense'	20/Aug.	25/Sept.	26/Oct.	67 a	22/Dec.	19/Jan.	28 a
'Le Conte'	18/Aug.	15/Sept.	01/Oct.	44 d	23/Dec.	10/Jan.	18 c

continue...

Table 2. Continuation...

Cultivars	Flowering				Harvest		
	Beginning	Full bloom	End	Duration (Days)*	Beginning	End	Duration (Days)*
	Production cycles 2018/19						
‘Primorosa’	28/July	15/Aug.	30/Sept.	64 a	30/Dec.	19/Jan.	20 c
‘D’água’	25/July	30/Aug.	25/Sept.	62 b	19/Dec.	04/Jan.	16 d
‘Tenra’	17/July	08/Sept.	25/Sept.	70 a	17/Dec.	07/Jan.	21 b
CV (%)	7.92	15.28					

* Averages followed by the same letter do not differ from each other to the Scott–Knott grouping of means test (P ≤ 0.05).w

In pear trees, flowering time is an important feature due to the need to synchronize flowering with pollinating varieties (Kiprjanovski and Ristevski 2009). Thus, analyzing the flowering period, through the beginning and end of flowering, the ‘Tenra’, ‘Triunfo’, ‘Centenária’ and ‘Seleta’ pears had flowering synchrony (Table 1). As hybrid pear trees have a low germination rate of their pollen grains, between 11 and 20% on average (Nogueira et al. 2016), it would be important to cultivate three or four cultivars in subtropical regions of altitude.

Bettiol Neto et al. (2014) observed that in three production cycles, the full flowering of pear trees in Cwb climate occurred in August and, in the present work, in Cwa climate, there was a greater fluctuation of full flowering among cultivars. Pio et al. (2019) points out that phenology plays an important role in temperate cultivars introduced into the tropics, as it allows the duration of developmental stages to be characterized in relation to climate conditions.

In the four years of evaluation, it was observed that there was a coincidence in the flowering interval between the cultivars ‘Triunfo’, ‘Seleta’ and ‘Tenra’ (Tables 1 and 2). The cultivar ‘Tenra’ produced more fruits, almost twice as much as the cultivars ‘Triunfo’ and ‘Seleta’ (Table 3). But these three cultivars recorded higher average mass of their fruits, in relation to the general average the four years of evaluation. But it was the amount of fruit produced by the cultivar ‘Tenra’ that ranked it as the most productive (Table 4). Regarding the estimated yield, the cultivars ‘Triunfo’ and ‘Seleta’ did not differ, considering the overall average of the four years of evaluation.

It is noteworthy that the European cultivar ‘Packham’s Triumph’, showed regular productivity in the four production cycles (Table 4). This result is unprecedented for European pear cultivars under subtropical conditions, since it shows that floral differentiation and fruiting were efficient in the climatic conditions in which it was submitted. Pasa et al. (2011) reported production of 5.24 kg per plant with ‘Packham’s Triumph’ pear and 4.76 kg per plant with ‘William’s’ pear on 7-year-old plants grafted to the *P. calleryana* rootstock.

The fruits of ‘Packham’s Triumph’, ‘Triunfo’, ‘Cascatense’, ‘Primorosa’ and ‘D’água’ cultivars are of high caliber when produced in subtropical regions (Table 5). The number of soluble solids was not high, in contrast, the percentage of high malic acid is observed. This result reflects, therefore, the low ratio that can certainly be improved by using the efficiency of cultural treatments.

Regarding fruit quality, the cultivars ‘Shinseiki’, ‘Packham’s Triumph’, ‘William’s’, ‘Centenária’ and ‘Primorosa’ presented fruits with major ratio (Table 5).

Detailing the quality of the fruits, the cultivar ‘Cascatense’ presented higher soluble solids content, but the fruits have high acidity, such as the cultivars ‘Triunfo’, ‘Seleta’, ‘D’água’ and ‘Tenra’. This high acidity influenced the low ratio (total soluble solids / total titratable acidity) obtained by these cultivars (Table 5). The soluble solids content may indicate the degree of pear maturation, since 80% of this content corresponds to sugars.

Regarding fruit quality, according to the classification adopted by the market, fruit size, represented by the average fruit mass and soluble solids / titratable acidity, are the main quality parameters in the selection of cultivars adapted to a particular region (Pio et al. 2019). The joint analysis of these parameters becomes essential for the selection of cultivars.

For the study of genetic diversity through the UPGMA method, the dendrogram presented high cofenetic value (0.81) and the cutoff was considered close to 0.34 distance, based on the Mojena method (1977), obtaining the formation of three groups (Fig. 1). Group I was formed by the cultivars ‘Triunfo’, ‘Tenra’, ‘D’água’, ‘Seleta’ and ‘Cascatense’, representing 45.45% of the cultivars. Group II consisted of the cultivars ‘William’s’, ‘Shenseri’, ‘Packham’s Triumph’, ‘Primorosa’ and ‘Centenária’, while group III was formed only by ‘Le Conte’.

Table 3. Total number of fruits and average fruit mass of 11 pear cultivars cultivated in four productive cycles in subtropical altitude region.

Cultivars	2015/16*	2016/17	2017/18	2018/19	General average **
			Total number of fruits		
'Shinseiki'	25.25 Bc	52.75 Ab	56.25 Ac	56.75 Ae	47.75 b
'Packham's Triumph'	27.00 Ac	28.00 Ae	27.25 Af	31.00 Af	28.31 c
'William's'	6.00 Be	0.00 Bh	10.00 Bg	28.00 Af	11.00 c
'Triunfo'	42.50 Bb	26.50 Ce	38.75 Be	103.25 Ac	52.75 b
'Centenária'	45.25 Bb	35.00 Cd	49.50 Bd	92.00 Ad	55.44 b
'Seleta'	47.00 Bb	38.25 Cd	49.25 Bd	88.75 Ad	55.81 b
'Cascatense'	17.75 Cd	17.00 Cf	63.25 Bb	115.75 Ab	53.44 b
'Le Conte'	0.00 Bf	0.00 Bh	8.75 Ag	10.75 Ah	4.88 c
'Primorosa'	27.50 Ac	44.25 Bc	49.25 Bd	58.50 Ae	44.88 b
'D'água'	28.75 Ac	11.50 Bg	13.75 Bg	19.50 Bg	18.38 c
'Tenra'	98.75 Ba	60.50 Da	86.50 Ca	124.00 Aa	92.44 a
CV (%) Subplots		8.86			
CV (%) Plots		12.92	39.21		
Cultivars			Mean fruit weight (g)		
'Shinseiki'	72.05 Ad	78.33 Ad	62.60 Af	77.53 Ac	72.63 b
'Packham's Triumph'	138.00 Ab	134.33 Ac	128.28 Ad	98.05 Bc	124.68 a
'William's'	28.75 Ce	0.00 Ce	101.20 Ae	61.93 Bc	47.98 b
'Triunfo'	144.00 Cb	314.85 Aa	283.00 Ba	131.83 Cb	218.43 a
'Centenária'	129.38 Bb	199.33 Ab	230.00 Ab	90.00 Cc	162.18 a
'Seleta'	147.48 Ab	135.65 Ac	155.00 Ac	129.85 Ab	142.03 a
'Cascatense'	119.70 Ac	148.13 Ac	141.73 Ad	89.90 Bc	124.85 a
'Le Conte'	0.00 Bf	0.00 Be	128.50 Ad	114.33 Ab	60.70 b
'Primorosa'	140.35 Ab	128.13 Ac	136.53 Ad	113.75 Ab	129.70 a
'D'água'	177.58 Aa	150.13 Ac	167.40 Ac	194.53 Aa	172.40 a
'Tenra'	109.23 Bc	165.40 Ac	166.48 Ac	126.43 Bb	141.88 a
CV (%) Subplots		14.67			
CV (%) Plots		16.67	32.86		

* Averages followed by the same letter in uppercase in the row and lowercase in the column do not differ from each to the Scott–Knott grouping of means test ($P \leq 0.05$). Time (production cycles) constituting the main plots and the cultivars the split plots. **Averages followed by the same letter do not differ from each other by the Scott–Knott mean comparison test ($P \leq 0.05$).

Table 4. Yield ($P \cdot kg \cdot tree^{-1}$) and estimated yield ($P \cdot t \cdot ha^{-1}$) of 11 pear cultivars cultivated in four productive cycles in subtropical altitude region.

Cultivars	2015/16*	2016/17	2017/18	2018/19	General average **
			Yield ($P \cdot kg \cdot Tree^{-1}$)		
'Shinseiki'	1.83 Bd	4.13 Ad	3.50 Ad	4.38 Ad	3.45 d
'Packham's Triumph'	3.75 Ac	3.78 Ad	3.50 Ad	3.03 Ad	3.53 d
'William's'	0.18 Ae	0.00 Ae	0.98 Ad	1.78 Ae	0.75 e
'Triunfo'	6.23 Db	8.18 Cb	10.95 Bb	13.48 Ab	9.73 b
'Centenária'	5.90 Bb	7.03 Bb	11.48 Ab	8.28 Bc	8.18 b
'Seleta'	6.90 Bb	5.20 Cc	7.63 Bb	11.48 Ab	7.80 c
'Cascatense'	2.10 Bd	2.55 Bd	8.93 Ac	10.43 Ab	6.00 c
'Le Conte'	0.00 Ae	0.00 Ae	1.13 Ad	1.23 Ae	0.58 e
'Primorosa'	3.88 Bc	5.68 Ac	6.78 Ac	6.65 Ae	5.88 c
'D'água'	5.13 Ab	1.73 Bd	2.28 Bd	3.80 Ad	3.23 d
'Tenra'	10.73 Ba	10.03 Ba	14.35 Aa	15.63 Aa	12.68 a
CV (%) Subplots		17.09			
CV (%) Plots		22.97	30.87		
Cultivars			Estimated yield ($P \cdot t \cdot ha^{-1}$)		
'Shinseiki'	2.35 Bd	5.16 Ad	4.38 Ad	5.48 Ad	4.32 d
'Packham's Triumph'	4.65 Ac	4.71 Ad	4.36 Ad	3.80 Ad	4.38 d
'William's'	0.23 Ae	0.00 Ae	1.25 Ad	2.18 Ae	0.92 e

continue...

Table 4. Continuation...

Cultivars	2015/16*	2016/17	2017/18	2018/19	General average **
			Estimated yield (P·t·ha^{-1})		
‘Triunfo’	7.76 Db	10.25 Cb	13.68 Bb	16.86 Ab	12.14 b
‘Centenária’	7.36 B b	8.78 Bb	14.30 Ab	10.31 Bc	10.19 b
‘Seleta’	8.63 Bb	6.50 Cc	9.51 Bb	14.36 Ab	9.75 b
‘Cascatense’	2.64 Bd	3.15 Bd	11.17 Ab	13.01 Ab	7.49 c
‘Le Conte’	0.00 Ae	0.00 Ae	1.41 Ad	1.53 Ae	0.73 e
‘Primorosa’	4.82 Bc	7.08 Ac	8.47Ac	8.31 Ae	7.17 c
‘D’água’	6.38 Ab	2.15 Bd	2.83 Bd	4.76 Ad	4.03 d
‘Tenra’	13.40 Ba	12.52 Ba	17.93 Aa	19.54 Aa	15.85 a
CV (%) Subplots		17.08			
CV (%) Plots		22.88	30.89		

* Averages followed by the same letter in uppercase in the row and lowercase in the column do not differ from each to the Scott-Knott grouping of means test (P ≤ 0.05). Time (production cycles) constituting the main plots and the cultivars the split plots.** Averages followed by the same letter do not differ from each other by the Scott-Knott mean comparison test (P ≤ 0.05).

Table 5. Average fruit length (L, mm), average fruit diameter (D, mm), total soluble solids (TSS, in °Brix), titratable total acidity (TTA, g of malic acid·100 mL^{-1}) and ratio total soluble solids / total titratable acidity (TSS/TTA) of fruits of 11 pear cultivars cultivated in four productive cycles in subtropical altitude region, in the 2018/19 production cycle.

Cultivars	L (mm)*	D (mm)	TSS (°Brix)	TTA (g)	Ratio (%)
‘Shinseiki’	43.86 c	48.62 b	9.38 c	0.16 b	58.13 a
‘Packham’s Triumph’	76.76 a	74.49 a	8.08 d	0.14 b	61.90 a
‘William’s’	64.19 b	51.39 b	10.18 b	0.17 b	62.03 a
‘Triunfo’	74.10 a	74.48 a	8.13 d	0.30 a	26.58 b
‘Centenária’	68.83 b	61.43 a	9.14 c	0.19 b	48.28 a
‘Seleta’	68.81 b	68.86 a	10.02 b	0.39 a	25.43 b
‘Cascatense’	86.02 a	71.21 a	11.68 a	0.36 a	38.68 b
‘Primorosa’	79.41 a	69.03 a	8.9 c	0.18 b	49.06 a
‘D’água’	81.39 a	69.19 a	9.25 c	0.39 a	25.48 b
‘Tenra’	67.03 b	69.81 a	9.27 c	0.42 a	22.73 b
‘Le Conte’	68.09 b	68.77 a	9.20 c	0.42 a	22.75 b
CV (%)	11.98	7.94	6.40	22.03	23.27

*Averages followed by the same letter do not differ from each other to the Scott-Knott grouping of means test (P ≤ 0.05).

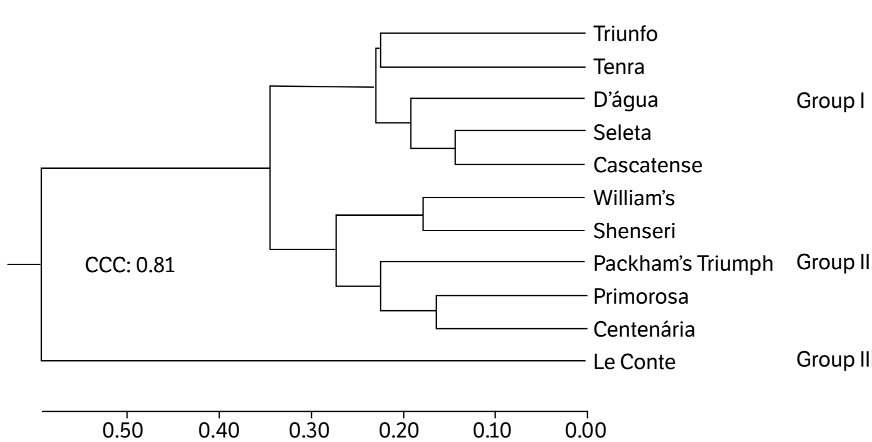

Figure 1. Dendrogram of genetic dissimilarity among the 11 pear cultivars, obtained by the UPGMA method based on 11 variables: number of fruits, mean fruit weight, yield, estimated yield, duration of flowering and duration of harvest, by four cycles, and average fruit length, average fruit diameter, total soluble solids, titratable total acidity and ratio (total soluble solids / total titratable acidity), the last productive cycle (2018/19).

Note: CCC: cophenetic correlation coefficient.

The variables evaluated in this study (four production cycles, general phenological and the chemical and physical characteristics of the fruits), can be considered representative because they were efficient in the dissimilarity analysis and later in the cultivars grouping. The relative contribution of the characters (Fig. 2) to diversity proposed by Singh (1981) showed that the most important variables for the genetic divergence of pear were fruit mass (49.6%), number of fruits (24.8%). and soluble solids / titratable acidity of the fruits (17.7%). This suggests that when selecting cultivars importance should be given to these characteristics, as well as the coincidence of flowering period between cultivars and yield.

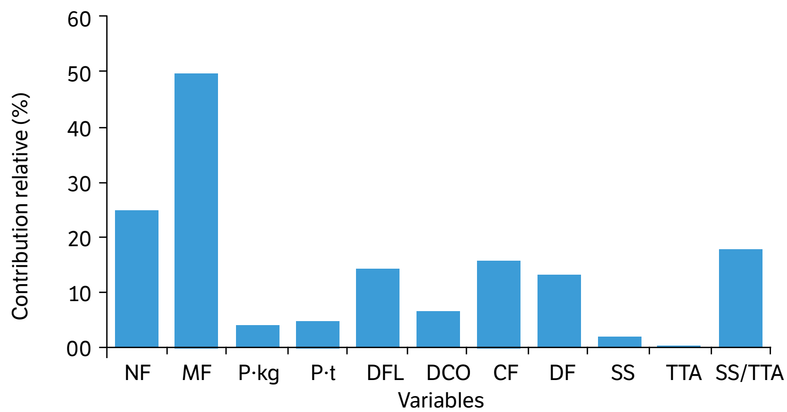

Figure 2. The relative contribution of the variables to the genetic diversity (Singh, 1981) of the 11 pear cultivars during the 2015/16, 2016/17, 2017/18 and 2018/2019 production cycles.

Note: NF: number of fruits; MF: mean fruit weight; P.kg: yield; P.t: estimated yield; DFL: duration of flowering; DCO: duration of harvest; L: average fruit length; DF: average fruit diameter; SS: total soluble solids; TTA: titratable total acidity; SS/TTA: ratio total soluble solids / total titratable acidity.

The genotype and genotype × environment biplot interaction was performed for the estimated yield data of different pear cultivars, using principal components (Fig. 3).

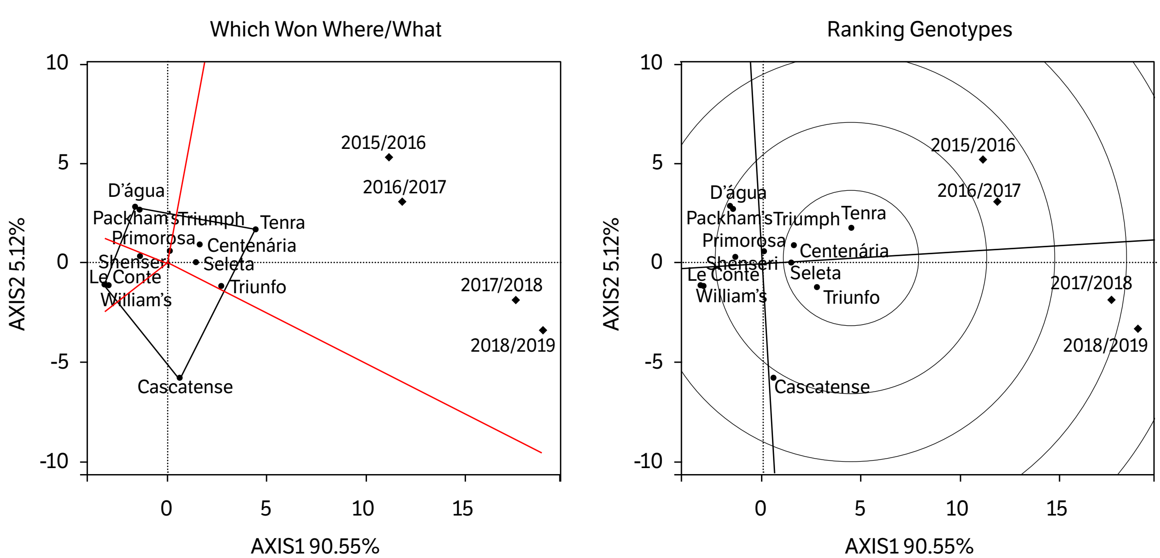

Figure 3. Genotype and genotype-environment interaction biplot plot obtained from the average yield of 11 pear cultivars evaluated in four yield cycles (2015–2019).

The best genotypic performance over the years (i.e., *which-won-when*) is shown graphically in Fig. 3a. Yan and Rajcan (2002) proposed the polygonal view of a biplot to visualize genotype and environment interaction. The vertex genotype in the polygon is the best for the years that fit this sector of the vertex genotype. The perpendicular lines on either side of the polygon are equality lines between adjacent genotypes (Yan and Tinker 2006). The equality line is very useful for comparing genotypic performance in a given year. Thus, the equality line between 'Tenra', 'D'água', 'Le Conte' and 'Cascatense' (Fig. 3a) indicates that 'Tenra' was better in all production cycles, followed by 'Centenária', 'Seleta' e 'Triunfo'.

Subsequently, the stability evaluation of cultivars for estimated yield was performed by their distances from the ideal genotype (Fig. 3b). The center of the concentric circles represents the position of an *ideal genotype* (Yan and Tinker 2006). The 'Tenra', 'Centenária', 'Seleta' and 'Triunfo' cultivars are closest to the concentric circle, so they are considered the most desirable in medium performance and stability in productivity. On the other hand, 'Le Conte' and 'William's' were the furthest from the ideal genotypic position and were therefore considered the most unstable.

Under subtropical conditions, temperate fruit cultivars may exhibit significant variability in their growth cycles. Winter conditions significantly influence the different phases of the annual pear growth cycle, especially the uniformity of sprouting, flowering and the time and duration of fruit harvest (Pio et al. 2019). According to Dinis et al. (2010), pollination and embryonic growth are strongly influenced by climatic conditions that vary from place to place at different altitudes and, over the years, often being the main cause of the variability of production. Thus, the choice of cultivars with low cold demands and tolerance to high temperatures during flowering make the production more consistent in the tropics.

In order to identify the most divergent cultivars that also present the highest averages in relation to the characters to be selected, the ranking was performed (Table 6), by the selection index proposed by Mulamba and Mock (1978), of the variables analyzed, allowing the selection of superior cultivars. Selection based on more characteristics than production, analysis by selection index represents a good alternative, because in this methodology the gain is balanced among all variables considered in the construction of the index (Cruz et al. 2021). The lower value indicates a more favorable match between all characters set for selection. Thus, based on the sum of ranks, it was possible to identify that the cultivars 'Tenra', 'Cascatense', 'Triunfo' and 'Seleta' are promising for the expansion of pear cultivation in subtropical regions. These cultivars are expected to provide the formation of populations most likely to obtain individuals with high potential for agronomic traits.

Table 6. Classification based on the rank summation index of 11 pear cultivars in the subtropics region in relation to 11 agronomic and phenological traits.

Cultivars	Agronomic and phenological traits											Rank summation index
	NF	FW	P	P.t	DFL	DCO	L	D	SS	TA	Ratio	
'Shenseri'	6	9	8	8	9	5	10	10	4	10	3	82
'Packham's Triumph'	8	8	7	7	7	9	4	1	10	11	2	74
'Williams'	10	11	10	10	10	10	9	9	2	9	1	91
'Triunfo'	5	1	2	2	1	7	5	2	9	5	7	46
'Centenária'	3	3	3	3	8	8	6	8	7	7	5	61
'Seleta'	2	4	4	4	6	2	7	7	3	3	9	51
'Cascatense'	4	7	5	5	3	4	1	3	1	4	6	43
'Le Conte'	11	10	11	11	11	11	11	11	11	6	11	115
'Primorosa'	7	6	6	6	5	1	3	6	8	8	4	60
'D'água'	9	2	9	9	4	6	2	5	6	2	8	62
'Tenra'	1	5	1	1	2	3	8	4	5	1	10	41

NF: Number of fruit; FW: Fruit weight (g); P: Production per tree (kg); P.t = estimated yield (t. ha^{-1}); DFL: Duration of flowering (days); DCO: Duration of harvest (days); L: fruit length (mm); D: Fruit diameter (mm); SS: soluble solids (°Brix); ATT: Total acidity; Ratio: (SS/TA).

The study of genetic divergence associated with the use of selection index technique for pear cultivars is an important step in the process of breeding and selection, since in this methodology the gain is balanced among all variables considered in the index construction (Cruz et al. 2021). Studies using selection indices, particularly the Mulamba and Mock (1978) indices, in pear trees are scarce. However, the simultaneous selection of pear variables allowed the choice of four cultivars ('Cascatense', 'Triunfo', 'Seleta' and 'Tenra').

By interpreting productive and qualitative data for the selection of cultivars of any fruiting plant for a given region and testing the results for a comparison of averages, it is difficult for a cultivar to stand out in all evaluated variables. This implies a subjective interpretation of the data, since usually the most productive cultivars have smaller, more acidic fruits with non-standard coloration due to high shading (Tadeu et al. 2019).

CONCLUSION

The cultivars 'Tenra', 'Triunfo' and 'Seleta' are the most suitable for cultivation in regions with subtropical altitude climate. They are genetically similar, more adapted and stable and have full or partial synchronized flowering for satisfactory productivity.

Studies to increase the floral induction is necessary to reach the productive potential of 'Packham's Triumph' cultivar cultivation in regions with subtropical altitude climate.

AUTHORS' CONTRIBUTION

Conceptualization: Pio R. and Bisi R. B.; **Methodology:** Pio R. and Farias D. H.; **Investigation:** Pio R.: Bisi R. B.: Farias D. H.: Peche P. M.: Fazenda L. H. V. and Silva A. D.; **Writing – Original Draft:** Pio R. and Bisi R. B.:; **Writing – Review and Editing:** Pio R.: Bisi R. B.: Farias D. H.: Peche P. M.: Fazenda L. H. V. and Silva A. D.; **Supervision:** Pio R.: Bisi R. B. and Farias D. H.

DATA AVAILABILITY STATEMENT

All dataset were generated and analyzed in the current study.

FUNDING

Coordenação de Aperfeiçoamento de Pessoal de Nível Superior
[https://doi.org/10.13039/501100002322]
Finance Code 001

Conselho de Desenvolvimento Científico e Tecnológico
[https://doi.org/10.13039/501100003593]
Grant No. 425001/2018-0

Fundação de Amparo à Pesquisa do Estado de Minas Gerais
[https://doi.org/10.13039/501100004901]
Grant No. APQ-02264-18

ACKNOWLEDGMENTS

Not applicable.

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