REVISTA BRASILEIRA DE
FRUTICULTURA
Published by the Brazilian Society of Fruit Crops
ISSN 0100-2945

Genetics And Plant Breeding - Original Article - Edited by: Daniele Sartori

Genetic progress in 53 years of the Peach Breeding Program of Embrapa: Fresh market cultivars

Elisia Rodrigues Corrêa[1], Maicon Nardino[2*], Maria do Carmo Bassols Raseira[3], Isadora Moreira da Luz Real[4], Willian Silva Barros[1], Rodrigo Cezar Franzon[3]

[1] Department of Mathematics and Statistics/IFM-DME, Federal University of Pelotas/UFPel, Campus Capão do Leão, Capão do Leão-RS. Brazil.
[2] Department of Agronomy/DAA, Federal University of Viçosa, Viçosa -MG, Brazil.
[3] Embrapa Temperate Agriculture, Pelotas-RS. Brazil.
[4] Institute of Mathematics, Statistics and Physics/IMEF, Federal University of Rio Grande/ FURG, Campus Carreiros, Rio Grande -RS.
*Corresponding author. E-mail address: nardino@ufv.br

Abstract - A peach breeding program started in 1963, at the Experiment Station of Pelotas, nowadays Embrapa Clima Temperado, whose primary aim was developing cultivars adapted to mild winter conditions. Its first priority was to obtain cultivars of canning type fruits, and over the years, the fresh market cultivars acquired equal importance. This article analyzes the data of 84 fresh market cultivars, obtained in Pelotas, from 1964 to 2017, focusing on the following parameters: time of ripening, fruit development period, average fruit mass, number of fruits per tree, productivity per plant and total soluble solids. First, the data were tabulated, divided into two periods (1964-1984 and 1985-2017), and the descriptive statistical analysis was performed, followed by an analysis via mixed models and estimates of genetic progress via meta-analysis. The main results revealed a reduced fruit development period of the fresh market peaches belonging to that program. It was also observed a significant spread of the time of ripening (end of September or beginning of October until January), with a slight tendency for earliness. Genetic gain was observed for yield corresponding to 1.17 and 2.25% per year, for 1964-1984 and 1985-2017, respectively.

Index terms: *Prunus persica*; genetic gain; peach cultivars; fruit development period.

Progresso genético em 53 anos do Programa de Melhoramento de pessegueiro da Embrapa: cultivares para consumo fresco

Resumo: em 1963, começou na Estação Experimental de Pelotas, hoje Embrapa Clima Temperado, um programa de melhoramento de pessegueiro cujo objetivo fundamental era desenvolver cultivares adaptadas a condições de inverno ameno. Inicialmente, a prioridade era a obtenção de cultivares produtoras de frutos para enlatamento, mas, ao longo dos anos, cultivares para o mercado fresco adquiriram

Rev. Bras. Frutic., v.45, e-146 DOI: https://dx.doi.org/10.1590/0100-29452023146
Received 01 Oct, 2022 • Accepted 20 Jan, 2023 • Published May/Jun, 2023. Jaboticabal - SP - Brazil.

a mesma importância. Este artigo analisa dados de 84 cultivares, tipo mesa, desenvolvidos em Pelotas, de 1964 a 2017, focando nos seguintes parâmetros: época de maturação, período de desenvolvimento do fruto, massa média dos frutos, número de frutos por planta, produção por planta e conteúdo de sólidos solúveis das frutas. Inicialmente, os dados foram tabulados, divididos em dois períodos (1964-1984 e 1985-2017), sendo então realizada a análise estatística descritiva, seguida por uma análise de modelos mistos e estimativa do progresso genético via meta-análise. Os resultados mostraram uma redução no período de desenvolvimento dos frutos das cultivares tipo mesa, pertencentes a esse programa. Houve ainda uma ampliação do período de colheita (do fim de setembro ou início de outubro até janeiro), com uma leve tendência à maior precocidade. Verificou-se um ganho genético para produção por planta, correspondendo a 1.17 e 2.25% ao ano, para os períodos de 1964-1984 e 1985-2017, respectivamente.

Termos para indexação: *Prunus persica*; ganho genético; cultivares de pessegueiro; período de desenvolvimento do fruto.

Introduction

Peach, *Prunus persica* L. Batsch, is a temperate climate species with a dormancy period in which temperature plays a double role (MILECH et al., 2022). Low temperatures are important (together with short days) to induce dormancy as well as release the plant from it. The accumulation of cold temperatures necessary for breaking the dormancy of buds and allowing the plants to have a uniform and adequate leafing and flowering is known as chilling requirement, which depends on the cultivar. As the peach cultivation expanded to subtropical areas and even tropical areas of altitude, as observed in Brazil, it was necessary to develop cultivars with lower chilling requirements. Presently, this need has gained prominence, due to global warming. This aspect, together with differences in soils, humidity and local consumer's preference, direct the establishment of several breeding programs all over the world. Some of these programs have been developed in Brazil, including Embrapa's.

The peach breeding program in Pelotas started in 1963, at the Experimental Station of Pelotas, nowadays Embrapa Clima Temperado, relying on some foundation clones, such as cultivars Delicioso, Lake City, Amsdem, Abóbora, Cristal plus new introductions. However, even before that year, genotypes from the Experimental Station of Taquari, RS, were also introduced. Part of these genotypes were selections obtained from seeds introduced from the United States of America, including cultivars Taquari Precoce, Fonte Grande, Rubi, Carapuça, Interlúdio, Quinze de Outubro, Prenda, Prelúdio and Cardeal, whereas others were originated from hybridizations carried out in the Experimental Station of Taquari, such as 'Vespertino', 'Serôdio', 'Charrua', 'Carmin', 'Purpúreo', 'Prenda', 'Jóia', 'Robusto', 'Rubro', 'Pampa', 'Minuano', 'Brazão', 'Mimo', 'Belvedere', 'Vinho' and 'Finesse' followed by cultivars. Colorado, Cascata, Xavante, Montenegro, Sinuelo, Marli and Premier. The first cultivars, which resulted from crosses made in Pelotas, were 'Alvorada' (1969); 'Mimoso' (1968), 'Vila Nova' (1969), 'Fandango' (1971) and 'Vila Velha' (1969) (Estação Experimental de Pelotas). The two Stations worked so closely that it is kind of difficult to separate the achievements of one from the other, mainly in the first 15 years, since some selections introduced from Taquari were evaluated and released in Pelotas (RASEIRA et al., 2021). However, in the 1980's, a peach program was interrupted in Taquari. Nevertheless, other fresh market cultivars continue to be released by the Embrapa's programs, such as Chiripá (in 1975); BR1 and BR3 (in 1979); Della Nona (1982); Planalto, Guaiaca (1983);

Pilcha (1985); Sentinela (1985); Chinoca (1987); Pampeano (1993); Chula and Chirua (1999); Barbosa, Chimarrita and Charme (2000), BRS Rubimel (2007). BRS Kampai (2009), BRS Fascínio and BRS Regalo (2011), BRS RubraMoore (2017) and BRS Serenata (2020), besides BRS Mandinho (2012), which is a pentao peach (flat), (TOPP et al, 2008; RASEIRA et al, 2014, 2015, 2017 e 2020).

In the past, several varieties of fresh market peaches presented yellow flesh. Nevertheless, after the year 2000, among all new releases, only BRS Rubimel and BRS Mandinho produce yellow flesh fruits. This is understandable, since peach production in Brazil is almost exclusively sold in domestic market, and white peaches seem to be preferred by most Brazilian consumers. However, Brazilian white flesh peaches tended to be soft and easy to bruise during harvest, transport and pos- harvest management. Thus, special attention has been given to improve flesh firmness as well as fruit shape and color, and good advances were made, which allowed commercialization in distant markets and even abroad. However, these characteristics were not considered in the present study.

This article analyzes the data of fresh market cultivars, obtained in Pelotas, from 1964 to 2017, during harvest and pre-harvest. Thus, special attention has been given to the following parameters: time of ripening, fruit development period, average fruit mass, number of fruits per tree, productivity per plant and total soluble solids (for the latter, records were made available from 1985 onwards).

Material and Methods

Plant material data of fresh market cultivars from 53 years were analyzed in this study. Only named cultivars, restricted to those released by the breeding program and foundation clones of Embrapa Temperate Agriculture (ETA) in Pelotas, RS, Brazil, were used, which totaled 84 cultivars (Table 1).

Table 1 - List of the 84 genotypes analyzed in 53 years and their pedigree, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022.

Genotype	release year	FP	PP	FPFP	FPPP	PPFP	PPPP
Alfa	1971	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Alvorada	1969	Cardeal	OP	338-90FV	OP	-	-
Baronesa	1965	Hawai × Southland OP	OP	Hawai	Southland OP	-	-
Belverdere	1966	Delicioso × Interludio	OP	Delicioso	Interlúdio	-	-
Beta	1971	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Br 1	1979	Delicioso	Panamint	-	-	-	-
Br 3	1979	Pala	OP	Coral	Panamint	-	-
Brazão	1966	Delicioso × Interlúdio	OP	Delicioso	Interlúdio	-	-
Cai	1960	Delicioso	Lake City	-	-	-	-
Carapuça	1960	Southland × Jewel OP	OP	Southland × Jewel	OP	-	-
Cardeal	1960	338-90FV	OP	-	-	-	-
Carmin	1965	Delicioso	Taquari Precoce	-	-	Hawai × Southland	OP
Cascata	1968	Delicioso × Interludio	OP	Delicioso	Interlúdio	-	-
Charme	2000	Cascata 340	BR-1	NJ230 × FLA26.31	OP	Delicioso	Panamint
Chimarrita	1987	Babcock	Flordabelle	Strawberry × Peento	Strawberry × Peento	Fla 16-6	Flordawon

Genotype	release year	FP	PP	FPFP	FPPP	PPFP	PPPP
Chinoca	1987	Coral	Gang Shan Zuo Sheng	Delicioso × Interlúdio	OP	-	-
Chiripa	1975	Delicioso	Nectared5	-	-	-	-
Chirua	1995	BR1	Cascata 277	Delicioso	Panamint	Princesa	Colibri
Chula	1985	Delicioso	Panamint	-	-	-	-
Colorado	1968	Princesa	OP	Hawai × Southland OP	-	-	-
Coral	1965	Delicioso × Interlúdio	OP	Delicioso	Interlúdio	-	-
Coral 2	-	Delicioso × Interlúdio	OP	Delicioso	Interlúdio	-	-
Cristal Ijuí	-	-	-	-	-	-	-
Cristal Taquari	-	-	-	-	-	-	-
Delicioso	-	-	-	-	-	-	-
Delicioso Precoce	-	-	-	-	-	-	-
Delicioso de Livramento	-	-	-	-	-	-	-
Dellanona	1982	Delicioso × Nectared 5	OP	Delicioso	Nectared 5	-	-
Delta	1971	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Edmundo Perret	-	-	-	-	-	-	-
Escarlate	-	Robusto	Panamint	Delicioso	Taquari Precoce	-	-
Fandango	1971	Abóbora × Taquari Precoce	OP	Abóbora	Taquari Precoce	-	-
Brs Fascínio	2011	Chimarrita × Linda	OP	Chimarrita	Linda	-	-
Finesse	1968	Carapuça	Amarelinho	Southland × Jewel OP	Delicioso × Admirável	OP	-
Fonte Grande	1960	Hawai × Southland	OP	Hawai	Southland	-	-
Gama	1971	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Gaúcho	1989	-	Delicioso	-	-	-	-
Gaúcho Poa	-	-	-	-	-	-	-
Gaudério	1971	Delicioso × Interlúdio	OP	Delicioso	Interlúdio	-	-
Guaiaca	1983	Pelotas 40 × Aldrighi	OP	Pelotas 40	Aldrighi	-	-
Guapo	1972	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Gumerçu	1996	Introduction	-	-	-	-	-
Interlúdio	1960	Southland × Jewel OP	Southland	Jewel	-	-	-
Brs Kampai	2009	Chimarrita	Flordaprince	Babcock	Flordabelle	Complex parentage	-
Laçador	1997	Belvedere	OP	Delicioso × Interlúdio	OP	-	-
Mandinho	2012	Cascata 828	OP	Taquari 19	Fla6-12	-	-
Maragato	1997	Introduction	-	-	-	-	-
Marfin	1994	Coral	Gang Shan Zuo Sheng	Delicioso × Interládio	OP	-	-
Marli	1965	Delicioso	Prelúdio	PQ[1]	-	Delicioso	Interlúdio
Mimo	1966	Carapuça	Amarelinho	Southland × Jewel OP	OP	Delicioso x Admirável	OP
Mimoso	1968	Leader	Prelúdio	-	-	Delicioso	Interlúdio

Genotype	release year	FP	PP	FPFP	FPPP	PPFP	PPPP
Minuano	1968	Carapuça	OP	Southland × Jewel OP	OP	-	-
Montenegro	1966	Delicioso	Rubi	-	-	Soutland × Jewel	OP
Pala	1972	Coral	Panamint	Delicioso × Interlúdio	OP	-	-
Pampa	1966	Delicioso	Taquari precoce OP	-	-	-	-
Pampeano	1993	-	-	-	-	-	-
Pialo	1969	Vespértino	OP	Admirável	OP	-	-
Pilcha	1985/86	Precoce Rosado	OP	-	-	-	-
Planalto	1982	Coral	Babcock	Delicioso × Interlúdio	OP	Strawberry × Peento	Strawberry × Peento
Precoce	-	Introduction	-	-	-	-	-
Prelúdio	1966	Delicioso	Interlúdio	-	-	Southland × Jewel	OP
Premier	1968	Cardeal × 15 Novembro	OP	Cardeal	15 de Novembro	-	-
Prenda	1965	Hawai × Southland	OP	Hawai × Southland	OP	-	-
Princesa	1965	Hawai × Southland OP	OP	Hawai × Southland	OP	-	-
Purpurio	1965	Delicioso	Interlúdio	-	-	-	-
Querência	-	City Row29 OP	Seeds introduced from New Jersey	-	-	-	-
Quitéria 1	-	Introduction	-	-	-	-	-
Quiteria 2	-	Introduction	-	-	-	-	-
Quitéria 3	-	Introduction	-	-	-	-	-
Brs Regalo	2011	Chula	Chimarrita	Delicioso	Panamint	Babcock	Flordabelle
Rubimel	2007	Chimarrita	Flordarince	Babcock	Flordabelle	Complex parantage	-
Brs Rubramoore	2017	Cascata 1029	Chimarrita	Cascata 655	A 236	Babcock	Flordabelle
Rubro	1965	Delicioso	Rubi	-	-	Southland × Jewel	OP
Sentinela	1985/86	Premier	OP	Cardeal × 15 de Novembro	OP	-	-
Brs Serenata	2019	Cascata 845	Chimarrita	Chula	Fla7.2	Babcock	Flordabelle
Serôdio	1965	Admirável × Delicioso	OP	Admirável	Delicioso	-	-
Sigma	1971	Sunhigh × Redcrest	OP	Sunhigh	Redcrest	-	-
Sinuelo	1970	Prelúdio	Amarelinho	Delicioso	Interlúdio	-	-
Sulina	1979	Princesa	Premier	Hawai × Southland OP	OP	Cadeal × 15 de Novembro	OP
Vespertino	1965	Admirável × Delicoso	OP	Admirável	Delicioso	-	-
Vila Nova	1969	Cristal	Princesa	-	-	Hawai × Southland OP	OP
Vila Velha	1969	Cristal	Princesa	-	-	Hawai × Southland OP	OP
Vinho	1966	Delicioso × Interlúdio	OP	Delicioso	Interlúdio	-	-
Xavante	1968	Prelúdio	Amarelinho	Delicioso	Interlúdio	Delicioso × Admirável	OP
Xv De Outubro	1960	Hawai × Southland	OP	Hawai	Southland	-	-

FP: female parent; PP: male parent; FPFP: female parent of the mother; FPPP: male parent of the mother; PPFP: female parent of the father; PPPP: male parent of the father. OP: open-pollinated; - Unknown; [1]Introduction of experimental station of Pomiculture de Taquari.

This work follows the same methodology and analyzes the same variables used for a similar study with canning cultivars of the same breeding program (NARDINO et al., 2022).

We analyzed genetic progress, considering the genotypes listed in Table 1. The data were separated into the two following periods: the 1st period, from 1964 to 1984, and the 2nd period, from 1985 to 2017, due to the change of the germplasm location (environment) which differed in soil depth and altitude of the site.

Phenological data were recorded annually regarding the beginning of blooming and full bloom and the beginning and end of fruit ripening. Fruit shape and size, color of epidermis, pulp color, firmness, total soluble solids content, flavor, adherence to the endosperm, as well as plant health and productivity were yearly evaluated for each cultivar.

In the present study, however, only the variables beginning of ripening, fruit development period, average fruit mass, number of fruits per plant, yield and total solid soluble were analyzed. Beginning of maturation (MAT) was considered as the number of days from January 1st to the first harvest of the cultivar in the current season. Fruit development period (FDP) was classified as I and II. FDP I was equal to the number of days between the beginning of flowering and the beginning of harvest, and FDP II corresponded to the number of days between full bloom (more than 50% open flowers) and the beginning of harvest. The number of fruits (NF) was obtained by counting the number of fruits per plant (unit), and production (PD) per plant was obtained by multiplying the number of fruits per plant by their average mass (Kg), that is, $PD = FM \times NF$.

We highlight that, in the initial period, from 1964 to 1984, the total number of fruits was actually counted during fruit thinning by adding the number of fruits removed from the plant to the remaining ones. For this purpose, a manual counter was frequently used to help recording the numbers. However, due to the increased number of genotypes and reduced human resources to conduct this task, it was almost impossible to maintain the counting in the second period. We decided to assign a degree of production on a scale, as referred by Nardino et al. (2022). Total soluble solids (TSS) were measured in °Brix, from three to five fruits per cultivar and year, using a refractometer.

The data were grouped from the historical series of the breeding program. Once the selection became a cultivar, all the data available since the time it was selected were included in the calculations. We initially tabulated data and analyzed the descriptive statistics. The generalized mixed model adopted in its matrix form was represented by $y = X\beta + Z\lambda + \varepsilon$, where y is the vector of the observed phenotypic data; X and Z are the respective incidence matrices of fixed and random effects; β and λ are vectors of the fixed and random effects of year and genotype $\lambda \sim NID(0, I\sigma_\lambda^2)$, respectively; and ε is the vector of random errors $\varepsilon \sim NID(0, I\sigma_\varepsilon^2)$, (HENDERSON et al., 1959). The matrix equation was calculated by restricted maximum likelihood (REML) to obtain the best linear unbiased estimate (BLUEs) of the fixed effect of year with the corresponding covariance matrices and the best linear unbiased prediction (BLUPs) of the random effect of the genotypes.

Analyses of the weighted average genetic gains were implemented according to the method of adjusted means described by Breseghello et al. (1998), also employed in similar research by Nardino et al. (2022). The average genetic gain and its genetic covariance matrix were calculated for the number of years in which the trait was available, using generalized linear regression for the average BLUE of the $year$ in accordance with the equations:

$$\hat{\beta} = (X'V^{-1}X)^{-1}(X'V^{-1}Y)\begin{bmatrix}\hat{b}_0\\ \hat{b}_1\end{bmatrix},$$

$$\text{and } \hat{V}(\hat{\beta}) = (X'V^{-1}X)^{-1}$$

Where: $\hat{\beta}$ is the vector of the solutions of the generalized linear regression; X is the incidence matrix, formed by a row of 1's and one column indicating the years; V is the covariance matrix of the BLUEs of the type; Y is the covariance vector of the BLUEs of the *year* of the cultivar; $\hat{V}(\hat{\beta})$ is the covariance matrix of $\hat{\beta}$; $\hat{b}_0$ is the estimate of the intercept; and $\hat{b}_1$ is the estimate of the slope. The the *t-test* was applied to estimate the significance of the slope ($\hat{b}_1$). Further details on the method by which $\hat{V}(\hat{\beta})$ was determined were presented by Breseghello et al. (1998).

The relative genetic gain (G) per year was estimated as the ratio between the angular regression coefficient ($\hat{b}_1$) and the mean value estimated for 1964 (first phase) and 1985 (second phase), which estimated as a percentage according to the equation:

$$G\% = \left(\frac{\hat{b}_1}{\hat{y}_1}\right) \times 100$$

The equation below was adopted to estimate the total genetic gain (G_T) of the years of breeding program, which corresponds to the cumulative gains:

$$G_T = \left[\left(\frac{\hat{b}_1}{\hat{y}_1} + 1\right)^{y-1} - 1\right] \times 100$$

where y corresponds to the number of *years* in the period when the genetic progress was estimated. Further information can be found in Breseghello et al. (1998) and Morais Júnior et al. (2015). The t-test was applied to estimate the significance of each gain.

The statistical analyses were carried out using the Statistical Analysis Software System (SAS Institute, 2014) and the *univariate*, *glm*, *varcomp*, *glimmix* and *iml* procedures.

Some genotypes commercially released deserve attention either for some important traits for the breeding program or because they were more extensively planted. These genotypes were separated in an electronic spreadsheet for the conductance of the mixed model analysis. In this analysis, the year information was considered as fixed effect, and the genotype, a random effect, as demonstrated by the *metan* package (OLIVOTO; LÚCIO, 2020). After obtaining BLUP values for the genotype, the confidence intervals (95%) were obtained, and the graphics were built using the *ggplot* package (WICKHAM, 2016). With the BLUP values of the most important cultivars, genotypic distance was also analyzed using the Euclidean distance, through the *factoextra* package, and hierarchical grouping, through multi-scale *bootstrap*, using the *pv_clust* package with alpha of 0.95 and *nboot* 100.

Results

The results of the breeding program - as already pointed out - were divided into the two following periods: the 1st period, from 1964 to 1984, and the 2nd period, from 1985 to 2017, due to the change in the germplasm location (environment), whose differences were mentioned in the Material and Methods section. Subsequently, we conducted the stratification of gain estimates for each period separately and coded them as 1964 and 1985, respectively. The results are classified by period and by trait, as described below.

Variance components of random effects obtained for the generalized linear mixed model (GLIMIX) are shown in table 2. The joined genotypes and years observed are between the range of 37 and 81 genotypes and 14 and 33 years, for these traits. Considering the traits evaluated, MAT, FDP I, FDP II, FW and TSS, genetic variance surpassed environmental variance. On the other hand, the environmental variance affected NF and PROD (85-17) variables. In other words, environmental effects, mainly winter chill and spring frost, caused great variations in the expression of these traits over the years. The effect of the year was significant for all the evaluated traits, in both periods, according to the F test.

Maturation: Considering the first period (1964-1984), 25 % (q_1) of the genotypes started harvesting on day 332 of the year or earlier, whereas the other 75% started ripening at 360 days or later (q_3). During the second period, (1985-2017), ripening dates tended towards earliness, 323 and 348 days (Table 3). This tendency can be observed in Figure 1 (A and B).

Table 2 - Estimates of variance components for random effects and significance of the fixed effect (year) of the generalized linear mixed model for each variable and period, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022.

Trait	nº genotype#	nº year*	Covariance Parameter Estimates		Tests of fixed effects	
			Genotype± SE	Residual± SE	Year - F value	Pr>F
MAT (64 -84)	44	19	314.6 ± 69.6	58.1 ± 4.4	23.1	< 0.0001
MAT (85-17)	81	32	298.9 ± 49.9	81.1 ± 3.9	11.1	< 0.0001
FDP I (64 - 84)	44	18	174.8 ± 40.5	92.1 ± 7.1	3.4	< 0.0001
FDP I (85-17)	81	32	183.3 ± 32.3	101.4 ± 5.0	10.1	< 0.0001
FDP II (64-84)	44	18	174.8 ± 39.9	65.9 ± 5.3	4.5	< 0.0001
FDP II (85-17)	80	32	181.2 ± 32.0	78.6 ± 4.3	8.4	< 0.0001
NF (64-84)	37	14	24847.0 ± 7247.1	45120.0 ± 4061.1	3.6	< 0.0001
NF (85-17)	80	30	5121.6 ± 956.1	10532.0 ± 453.0	23.7	< 0.0001
FW (64-84)	44	19	426.6 ± 108.0	402.9 ± 30.6	1.9	0.01060
FW (85-17)	81	33	372.8 ± 67.8	358.1 ± 17.4	5.5	< 0.0001
PD (64-84)	37	14	265.3 ± 79.3	530.9 ± 49.1	5.4	< 0.0001
PD (85-17)	77	28	52.6 ± 11.7	106.1 ±6.6	13.4	< 0.0001
TSS (85 -17)	79	31	2.4 ± 0.4	2.3 ± 0.1	10.2	< 0.0001

number of genotypes evaluated during the period for the variable. * number of years considered during the period for the variable. SE: standard error

MAT (64-84) and MAT (85-17): Beginning of fruit ripening in the 1964-1984 and 1985-2017 periods; fruit development period FDP I (64-85) and FDP I (85-17) (considering the beginning of flowering and ripening) in the 1964-1984 and 1985-2017 periods. FDP II (64-84) and FDP II (85-17): fruit development period (considering the period from full flowering to ripening) in the 1964-1984 and 1985-2017 periods; NF (64-84) and NF (85-17): number of fruits in the 1964-1984 and 1985-2017 periods. FW (64-84) and FW (85-17): fruit weight in the 1964-1984 and 1985-2017 periods. PD (64-84) and (85-17): fruit weight in the 1964-1984 and 1985-2017 periods. TSS: soluble solids content in the fruits.

Fruit Development Period: Regarding the first period, 25% of the studied genotypes had a fruit development period equal to or inferior to 114 days (q_1), and 75% had FDP equal to or longer than 134 (Table 3; Figure 1 C and D). During the second period, the interquartile range was 22 days (Table 3).

Fruit Development Period II: In the first period (1964-84), 25% (q1) of the genotypes FDP II were equal to or less than 103 days and 75% (q3) were equal to 122 days or longer. For the second period (1985-17), the genotypes had the FDP between 100 and 119 days (Table 3). It is possible to observe a slight reduction in the FDP_II for both periods (Figure 1 E and F).

Number of fruits (NF): For the first period (1964-84), 25% (q1) of the genotypes presented a number of fruits corresponding to 70 fruits, whereas 75% (q3) of them had at least 438 fruits. In the second period (1985-17), the number of fruits was around 96 and 350 (Table 3). Figure 2 (A and B) shows this slight increment.

Average fruit weight: In the first period (1964-84), 25% (q1) of the genotypes presented an average fruit mass equal to or less than 88g, while 75% (q3) presented an average mass greater than or equal to 125g. In the second period (1985-17), 25% of the genotypes had fruit weight around 80 and the others, equal to or above 115 g (Table 3). Figure 2 (C and D) shows a slight increase in fruit weight in both periods.

Production per plant: In the first period (1964-84), 25% (q1) of the genotypes had average production per plant equal to or less than 9.72kg, while 75% (q3) presented yields greater than or equal to 47.84kg.plant $^{-1}$. For the second period (1985-17), the production per plant was around 11.77 and 32.68 kg, respectively (Table 3; Figure 2 E and F).

Total soluble solids content in fruits: The data were available only for the second period (1984-17). 25% (q1) of the genotypes presented total soluble solids equal to 10.5ºbrix, while for 75% (q3), they were higher than or equal to 13.8°brix (Figure 2G).

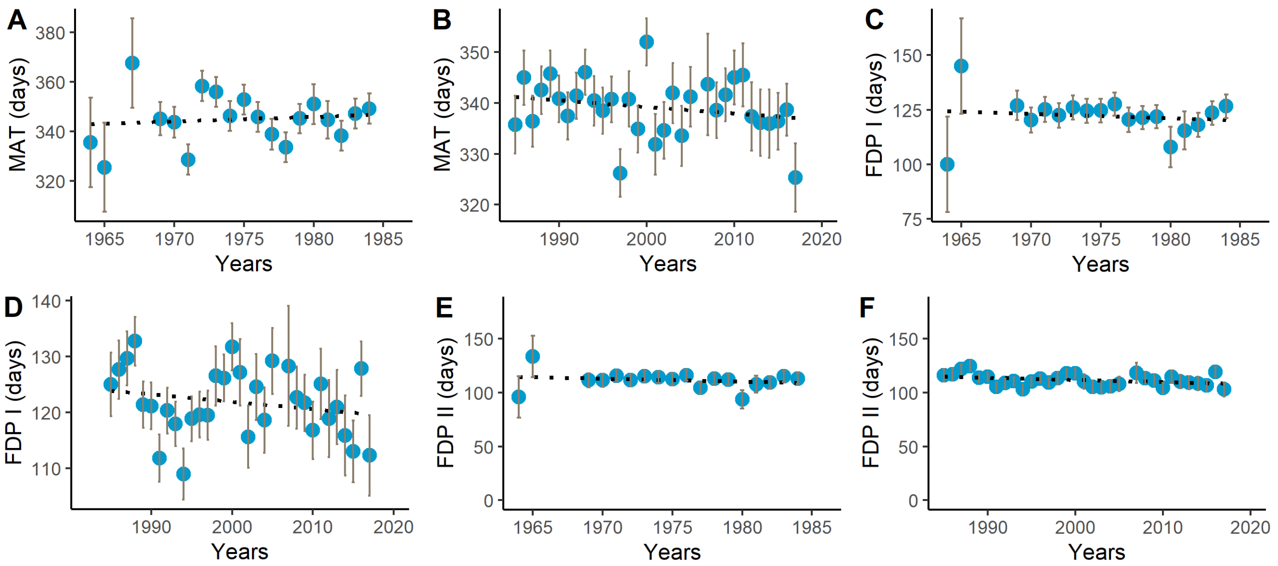

Figure 1 - General means of the genotypes in each year studied.

(A) Peach fruit maturing during the 1964-1984 period. (B) Peach fruit maturing during the 1985-2017 period. (C) Cycle considering the beginning of flowering during the 1964-1984 period. (D) Cycle considering the beginning of flowering during the 1985-2017 period. (E) Cycle considering the beginning of full flowering during the 1964-1984 period. (F) Cycle considering the beginning of full flowering during the 1985-2017 period. The circles represent the general and annual means and the vertical bars represent the confidence intervals for the means, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2021.

Table 3 - Results of descriptive statistics for the variables evaluated, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022.

Statistics (unit)	Min	q_1	mean	q_3	Sd	max
MAT_1964 (no. of days)	277.0	332.0	345.1	360	21.4	401
MAT_1985 (no. of days)	274.0	323.0	336.0	348	19.2	404
FDP I_1964 (no. of days)	70.0	114.0	123.8	134	16.7	180
FDP I_1985 (no. of days)	41.0	109.0	120.3	131	16.8	178
FDP II_1964 (no. of days)	65.0	103.0	113.2	122	15.9	172
FDP II_1985 (no. of days)	68.0	100.0	110.4	119	15.7	166
NF_1964 (no. of fruit)	10.0	70.0	299.3	438	304.1	1950
NF_1985 (no. of fruit)	4.0	96.0	224.7	350	145.1	550
FW_1964 (g)	40.0	88.0	107.1	125	28.3	222
FW_1985 (g)	4.0	80.0	98.6	115	26.6	214
TSS (°Brix)	5.4	10.5	12.2	13.8	2.3	19.8
PD_1964 (Kg)	0.96	9.72	32.4	47.84	29.9	177.1
PD_1985 (Kg)	0.44	11.77	23.3	32.68	15.0	80

MAT_1964, MAT_1985: Fruit maturation in the 1964-1984 and 1985-2017 periods (respectively); FDP I_1964, FDP I_1985: fruit development period (considering the beginning of flowering and maturing) in the 1964-1984 and 1985-2017 periods (respectively); FDP II_1964, FDP II_1985: fruit development period (considering full flowering and maturation) in the 1964-1984 and 1985-2017 periods; NF_1964, NF_1985: number of fruits in the 1964-1984 and 1985-2017 periods; FW_1964, FW_1985: fruit weight in the 1964-1984 and 1985-2017 periods; TSS: soluble solids content in the fruits; PD_1964, 1985: fruit weight in the 1964-1984 and 1985-2017 periods; Min: minimum observed value; q_1: first quartile; Mean: arithmetic mean; q_3: third quartile; sd: sample standard deviation and Max: maximum observed value.

The results of genetic gain estimates for the 1964-1984 and 1985-2017 periods for the studied traits are shown in Table 4. Five evaluated variables presented significant angular coefficients.

In the analysis of the significance of the angular coefficients of the variables evaluated, MAT (85-17) presented B_1 of -0,11 (*p >0,0130*); FDP II (85-17) with B_1 of -3,83 (*p >0,0005*); NF (85-17) with B_1 of 2,71 (*p >0,0000)*; PD (85-

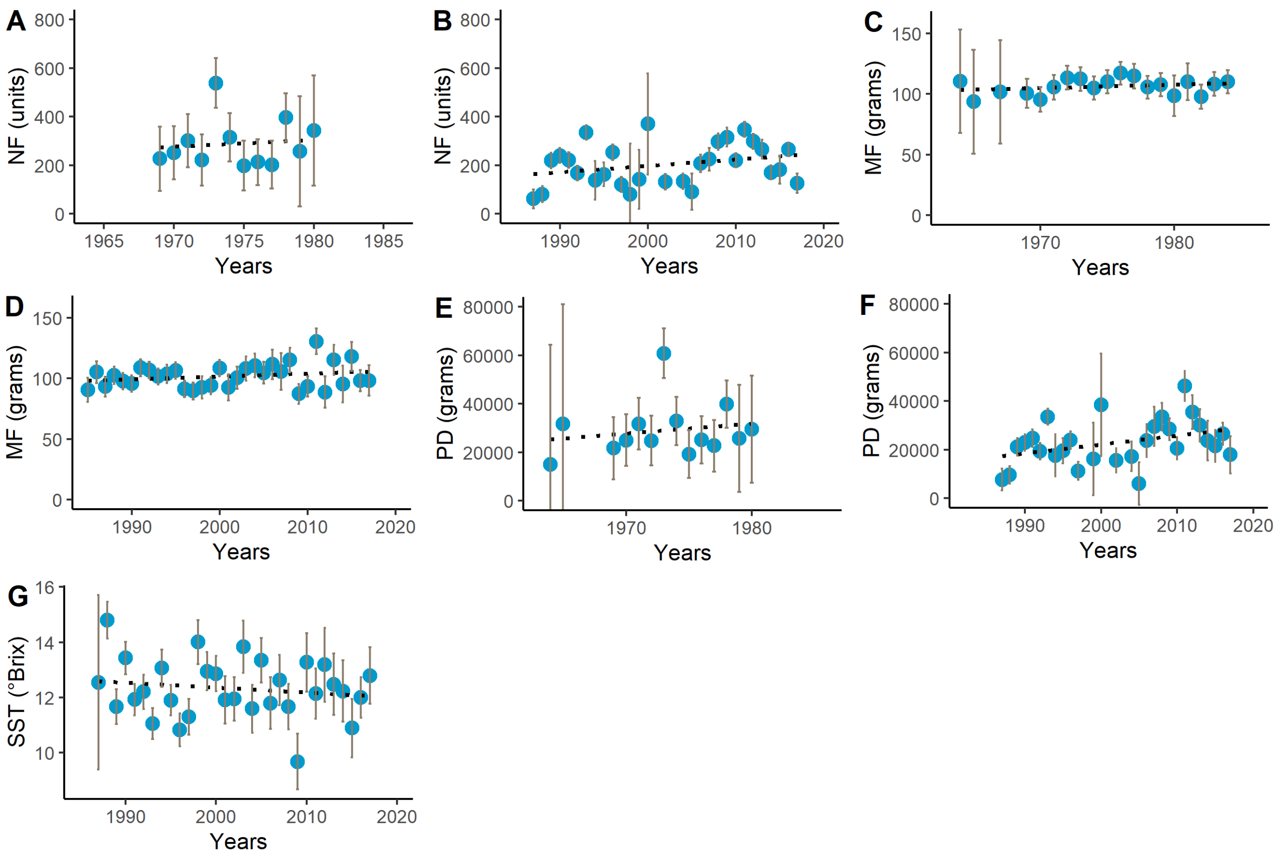

Figure 2 - Comparison between general means of the fresh market peach genotypes in each year.
(A) Number of fruits during the 1964-1984 period. (B) Number of fruits during the 1985-2017 period. (C) Fruit weight during the 1964-1984 period. (D) Fruit weight during the 1985-2017 period. (E) Production during the 1964-1984 period. (F) Production during the 1985-2017 period in grams/plant. (G) Mean total soluble solids content in ° Brix during the 1985-2017 period. The circles represent the general and annual means, and the vertical bars represent the confidence intervals for the means, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2021.

Table 4 - Genetic gain (mean) of each variable for maturing period, fruit development period, number of fruits and production per plant in the 1964-1984 and 1985-2017 periods, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022

Parameter	GL	B_0	B_1	tcalc- value	t tab-value	Pr > |t|	Ggen (annual %)	Ggen (full %)
MAT (64 -84)	19	345.86	-0.08	-0.86	2.14	0.4000	-0.02	-0.44
MAT (85-17)	32	341.49	-0.11	-2.63	2.04	0.0130	-0.03	-1.04
FDP I (64 - 84)	18	124.67	-0.15	-1.25	2.14	0.2257	-0.12	-2.16
FDP I (85-17)	32	122.18	-0.07	-1.42	2.04	0.1663	-0.06	-1.76
FDP II (64-84)	18	112.77	-0.06	-0.58	2.14	0.5660	-0.05	-0.99
FDP II (85-17)	32	114.21	-0.17	-3.83	2.04	0.0005	-0.15	-4.75
NF (64-84)	14	247.16	0.35	0.08	2.20	0.9389	0.13	1.53
NF (85-17)	29	175.44	2.71	7.87	2.05	0.0000	1.55	44.86
FW (64-84)	19	105.73	0.15	0.61	2.14	0.5464	0.14	2.65
FW (85-17)	33	99.64	0.08	0.87	2.04	0.3882	0.08	2.50
PD (64-84)	14	27.99	-0.03	0.66	2.23	0.5215	1.17	16.63
PD (85-17)	28	18.03	0.41	6.47	2.06	0.0000	2.25	62.98
TSS (85-17)	31	12.51	-0.03	-2.87	2.05	0.0073	-0.20	-6.29

B_0: intercept, B_1: slope; Ggen (annual%): annual genetic gain and Ggen (full%): total genetic gain. MAT_1964, MAT_1985: Fruit maturing in the 1964-1984 and 1985-2017 periods; FDP I_1964, FDP I_1985: fruit development period (considering the beginning of flowering and maturing) in the 1964-1984 and 1985-2017 periods; FDP II_1964, FDP II_1985: fruit development period (considering full flowering and maturing) in the 1964-1984 and 1985-2017 periods; NF_1964, NF_1985: number of fruits in the 1964-1984 and 1985-2017 periods; FW_1964, FW_1985: fruit weight in the 1964-1984 and 1985-2017 periods; TSS: soluble solids content in the fruits; PD_1964, 1985: fruit weight in the 1964-1984 and 1985-2017 periods.

17) with B_1 of 0,33 (*p >0,0000*) and TSS (85-17) with B_1 of 0,41 (*p >0,0073*).

During the first period for MAT (64-84), it was observed a negative slope with 0.02% of annual genetic gain. Throughout the second period, for MAT (85-17), the annual genetic gain was -0.03%. Regarding the FDP I (64-84) and (85-17), which means the cycle considering the beginning of blooming to harvest, the annual genetic gains were -0,12% and -0,06%, respectively, which reveals a small decrease. Concerning annual genetic gain for FDP II (64-84 and 85-17), which refers to the cycle in relation to full blooming, the values were -0,05% and -0,15%. In other words, there was a gain in the goal of the peach breeding program, which is shortening the cycle.

In reference NF (64-84) per plant, the annual genetic gain was 0,13%, and in the second period (85-17), the annual genetic gain was 1.55%. For FW (64-84), the annual genetic gain was positive, 0,14%; and for the second period (85-17), the annual genetic gain was 0,08%.

Regarding PD, which is the fruit yield per plant in kg, the following values of annual genetic gain were: for 64-84, 1,17%; and for 85-17, the annual genetic gain was 2,25 %, which is twice the value of the previous one. The positive gain values for fruit yield are relevant and advantageous for the purpose of the genetic breeding program.

Regarding the outstanding cultivars (either due to their importance for the peach breeding program of Embrapa or/and for being the most planted by fruit growers and still found in the area nowadays), the Best Linear Unbiased Prediction (BLUP) results for each trait are shown individually in Figure 3.

For beginning of harvest (Figure 3 a), a wide range was observed among genotypes. For example, \`Pampeano´ has an average of 294 days until maturity (corresponding to October 20), while \`Vila Nova´, \`Chiripá´ and \`Barbosa´ reach ripening stage after approximately 370 days (corresponding to January 4th of the following year, from the beginning of counting), that is, approximately 76 days of difference. The mean BLUP value was 338 days from January 1st until harvest. In reference to the initial cycle, FDP I, (Figure 3 b), 'Pampeano' and 'Vila Nova' had the shortest and the longest cycles, approximately 100 days from the beginning of blooming to harvest for 'Pampeano', and around 155 days for 'Vila Nova'. On the other hand, 'DellaNona'

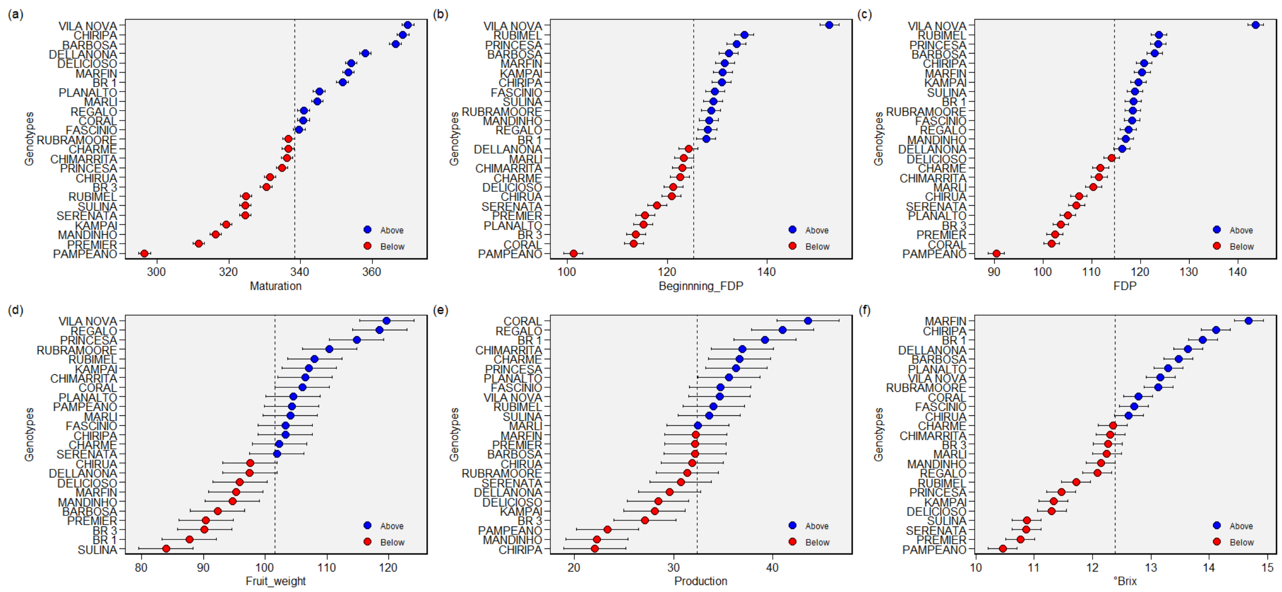

Figure 3 - Mean results of the most representative genotypes for the maturation variables (from January 1st (days)), number of days between the beginning of flowering and maturation, FDP, number of days between full flowering and maturation, ºBrix, fruit weight (grams) and production in kg/plant, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022.

had a mean cycle of 125 days, a value very close to that of the mean BLUP. Regarding the FDP II, which refers to full bloom (Figure 3 c), 'Pampeano' and 'Vila Nova' also presented the shortest and longest FDP, 88 and 148 days, respectively. The mean BLUP value was of 115 days, from full flowering until harvesting.

The heaviest weights were observed in fruits of cultivars Vila Nova and Regalo (Figure 3 d), with approximately 121 and 118 g.fruit^{-1}, respectively. The lightest average fruit weights were observed in the early ripening cultivar Sulina, with approximately 81 g.fruit^{-1}. The general mean of the most relevant genotypes was approximately 101 g.fruit^{-1}.

Considering yield evaluation (Figure 3f), cultivars Coral and Regalo presented averages of approximately 43.9 kg.plant^{-1} and were the most productive. Cultivars Chiripá and Mandinho, on the other hand, obtained the lowest productions (Figure 6), with BLUP values close to 21.2 kg/plant. The general mean of the BLUP value was approximately 30.6 kg.plant^{-1}. It should be pointed out that 'BRS Mandinho' is the only pentao peach of the group.

In the evaluation of total soluble solids content (Figure 3 d), the genotype 'Marfim' presented the highest average content (14.94°brix). On the other hand, genotypes 'Pampeano' and 'Premier' exhibited the lowest TSS content mean (10°brix). The mean BLUP value was 12.5º brix.

BLUP values for the traits cycle, yield and solid soluble contents were submitted to cluster analysis by Euclidean distance. Considering this group of traits, eight groups were formed (Figure 4). The largest group was formed by eight cultivars, namely, Chimarrita, Charme, Marli, RubraMoore, Fascínio, Regalo, Planalto and Coral. Cultivars Vila Nova and Pampeano did not group to any other, but each one formed an individual group.

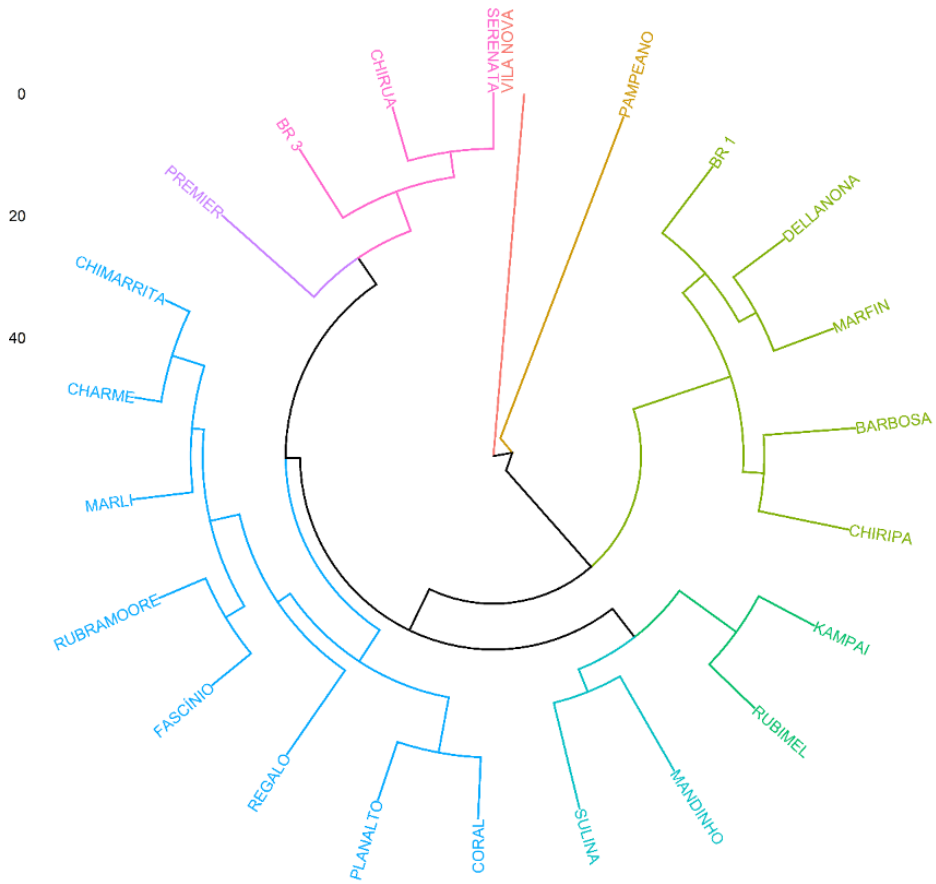

Figure 4 - Dendrogram of the currently most planted and cultivated peach cultivars, Embrapa Temperate Agriculture, Pelotas/RS-Brazil, 2022.

Discussion

During the second period, the maturation time variability increased. MAT leans on the growing degree hours (GDH) and cultivar stability and plasticity. The temperature in the first 30 to 45 days after blooming strongly affects this aspect (LÓPEZ; DEJONG, 2007, BONORA et al., 2013). However, considering the standard deviations for each genotype (Figure 3), time of ripening deviations were lower than those of production or fruit weight.

Fruit development period, considering beginning of blooming, presented less variability in the first period than in the second period, probably due to cooler and more regular winters in these first years, which resulted in more uniform blooming. On the other hand, in the second period, the large fluctuations in temperature during the winter (data not shown), combined with the search for developing cultivars with low chill requirement, increased variability.

According to Köppen climate classification, the region where the program is located is classified as Cfb, humid temperate climate, with hot and humid summers, without a dry season. There is a wide variation in temperature in winter, with an average minimum of -3°C and a maximum of 18°C (ALVARES et al., 2013). This variation affects FDP. It is interesting to note that even cultivars, such as the American cultivar Tropic Beauty, which according to the literature, has a cycle of 89 days (SARKHOSH et al., 2019), under the conditions of Pelotas/RS, has a longer cycle (112 days), as a consequence of temperature conditions. Sarkhosh et al. (2019) observed differences of 13 days between the FDP in Central and Southwest Florida, and of 20 days between central Florida and the north central region, for the same cultivar and year. The authors attributed the differences to a delay in flowering, due to insufficient cold and higher temperatures during the FDP, which reduced the cycle in the area where this occurred. Other authors had already observed differences in the cycle of the same cultivar depending on the temperature in the initial period of fruit development (coincident with the cell multiplication phase) (BOONPRAKOB et al., 1992; SOUZA et al., 2011, SOUZA et al., 2019).

In our study, the variability for FDP I among the years was higher than when the full blooming to harvest (FDP II) was considered. This was already expected, once these cultivars are of low chill requirement. Therefore, the occurrence of mild temperatures and the wide thermal amplitude throughout the day contributed to the appearance of numerous extemporaneous flowers, which hinders the estimation of the actual date of beginning of flowering.

Regarding the number of fruits, there was greater variability between genotypes than between years in the first period. In the second period, this variability was lower and tended to increase in relation to the general average, from the 2006-2007 harvest (except in three years). Coincidentally, it was from 2002 onwards that the work with producers and other research institutions was intensified. The genotypes were tested in different areas, with different soil and climate conditions, which leads us to believe that the cultivars resulting from this work, such as cvs. BRS Rubimel, BRS Fascínio and BRS Regalo, among others, presented greater plasticity. Productivity data (Figure 2 E and F) support this idea, since, in the last 10 years, they have rarely been below average.

There was little variability for average fruit weight among the years for the set of genotypes (Graphs 2C and 2D). It must be pointed out that the averages MF were not strictly related to the number of fruits. In other words, the low average mass was not caused by the greater number of fruits. The results lead us to believe that the new genotypes have the potential for high yields, even under dry periods, since the orchard was not irrigated, and some years had a dry period (data not shown). Deficit of irrigation during stages I and II of peach fruit growth did not affect yield, but during stage III, which is more likely to occur in the region where the study was conducted, fruit size was reduced (BERMAN; DEJONG, 1996; NAOR et al., 1999, RAHMATI et al., 2015, KARAMI et al., 2002, MIRÁS-AVALOS, 2013). Thus, the dry period may have affected some cultivars. However, on the average of the whole set of cultivars, no significant difference was reported. It is known that only around 30% to 40% of the fruit size in peach is due to genetic inheritance. Souza et al, 1998, found 32% for narrow-sense heritability. Fruit size is affected by various factors, including plant nutrition, soil and climate conditions and plant management (pruning, thinning, etc.).

The standard deviations of fruit mass in relation to the overall yearly average were smaller in the second period than in the first one. It is interesting to highlight that, in general, the cultivars with the highest average mass per fruit are also the most productive, that is, those with larger fruits also presented productivity equal to or above average. Among the cultivars released after 2002, BRS Kampai (Figure 5) is the only exception, probably because its early flowering is more favourable to frost damage.

As for the total soluble solids content, there was a slight reduction trend, which may be related to the reduced cycle and the development of earlier cultivars. This had been previously reported on research paper by Drougoudi et al. (2016, 2017). In recent years, reduced variability has been found between years, besides a slight tendency towards increased variability between genotypes in the same year (standard deviation within the year).

There was a tendency for earlier cultivars, mainly in the second period. The gain, however, was not evidenced, which is to be expected, since the breeding program sought to extend the harvest period, and thus both earlier genotypes than those available at the beginning of the program as well as later than them, were selected. On average, there was a greater advance towards precocity.

A correlation has already been found between FDP and ripening time (RAWANDOOZI et al., 2020). In the present study, precocity was also accompanied by a small reduction in the fruit development cycle, a result that must have been somewhat confounded by the differences in temperature and consequently heat accumulation, GDH (Growing degree hours), between years. Variations of 10 days, or even longer, in the cycle of the same cultivar are not rare in the region of Pelotas. Note that in relation to the cycle, the GDH is considered here as the accumulation of hours of temperature within the range considered suitable for the growth and development of the plant after full flowering. Therefore, it is different from the GDH in relation to dormancy, which would be the number of hours of heat needed for bud break and flower, after the satisfaction of cold accumulation to overcome dormancy (RICHARDSON, 1975).

High GDH accumulation in the first 30 days after flowering shortens the cycle and consequently reduces fruit size, considering the same management practices (LÓPEZ; DEJONG, 2007). On the other hand, lower temperatures in that period extend the FDP. A positive gain was observed, namely, increased average mass per fruit, mainly in the first period. However, except for this parameter and a small difference in relation to the shortening of the cycle, FDPI (which can be attributed to the variability of flowering due to the large temperature variations in recent years, in the months of July, August and September), the second period was superior in all other studied variables. Considering the fruit development cycle from full bloom to maturation FDPII, greater reduction was observed in the period from 1985 to 2017. Even so, the number of fruits and productivity obtained greater gain, compared to the first period. This can be attributed to the direction of the program, which prioritized, in the early years, obtaining genotypes that produced fruits for canning, which later tended to achieve a balance in importance between the two lines (table and canning types) (NARDINO et al., 2022).

It was observed a 6.29% reduction in total soluble solids (TSS), probably related to earliness of ripening. However, since in most genotypes the TSS is between 10º and 15º

Brix, on average, this reduction represents less than 1º Brix, with little or insignificant difference in flavor.

The most relevant gains were found for productivity. Together, the two studied periods obtained a 79.61% increase. Considering the official data (FAOSTAT, 2022), the average productivity was 5.85 ton.ha^{-1}, in 1964; and in 2017, it rose to 14.57 ton.ha^{-1}, therefore much higher than expected. It disregarded the fact that the national average does not reflect the productive potential of the new cultivars, so much so that according to IBGE data, the state of SP has an average above 20 ton.ha^{-1}, and in 2017, it corresponded to 23.01 ton.ha^{-1} (IBGE 2020). Of course, this is not only due to the Embrapa breeding program achievements, but much can be ascribed to management practices and cultivars from other breeding programs, mainly from the Instituto Agronômico de Campinas. However, the cultivars launched by Embrapa play an important role in productivity increase.

When comparing the progress achieved in the two periods, it can be concluded that the progress achieved in the development of fruits for processing (NARDINO et al., 2022) was greater than that for fruits for fresh consumption, except for the average fruit mass in the first period, in which the canned type decreased, and the table type increased. However, in the combination of the two, the canned type increase of 10 to 11g in each 100g of fruit surpassed the 5 to 6g increase of the table type. These differences can be attributed to the priority given for years to the processing line to the detriment of the in natura market type, which has only been prioritized in the last two decades.

Pampeano cultivar is the one with the earliest maturation and the shortest fruit development cycle. Flowering occurs, on average, in mid-July, with full flowering in the third decade of July and often in August, which results in a fruit development cycle of 90 days or less (RASEIRA et al., 2014). The cv. Vila Nova, on the other hand, has the longest cycle among the most interesting cultivars, shown in Figure 4.

Contrary to what might be expected, due to climatic variations, all the most important cultivars presented little variability in terms of the fruit development period. Considering only the main cultivars, the variability between years in the same cultivar was insignificant, both in terms of maturation and cycle (FDP). This is explained by the high heritability of this trait, which means being a trait whose genetic component is the main one. Dini et al., 2021, found high broad sense heritability and medium to high narrow sense heritability.

The harvest starts with the earliest cultivar (‘Pampeano’), at the end of September and extends until January with the later ones, ‘Vila Nova’ and ‘Chiripá’, which begin in the first days of January. This amplitude in the maturation period is important for allowing the producer to have a longer period of availability of the fruits in the market. Breeding programs, such as Embrapa’s, aim to extend the harvest period even further. As for the cycle from full bloom to maturation, only ‘Pampeano’ has a cycle around 90 days. ‘Chirua’, ‘Serenata’, ‘Planalto’, ‘BR3’, ‘Premier’ and ‘Coral’ have a cycle between 100 and 110 days. All the others have a longer cycle.

In general, the TSS content (Figure 1F) followed the maturation season, with the later ripening cultivars with higher TSS content, the mid-season ones around the average TSS and the early ones with lower values. There are reports of a correlation between both ripening time and cycle with the content of total soluble solids (BEKELE, 2018; RAWANDOOZI et al., 2020), although the values found correspond to a moderate to low correlation, as reported by Rawandoozi et al. (2020), for example, r = 0.48 with ripening season and (r = 0.39) with FDP.

Observing figure 4, it seems that most of the important cultivars developed by the program are earlier than cv. Delicioso, one of the most important, in the early 1960s, which was a founding clone of the breeding program for fresh market cultivars (BYRNE et al., 2000). On the other hand, the same is not true for the cycle. This must be due to the peculiar characteristic of this cultivar, which, despite being of low chill requirement, needs greater accumulation of heat for flowering and hence its PDF is shortened (CITADIN et al., 2001). This characteristic is so important in areas with low winter cold accumulation, but subject to frost that, as observed in Table 1, a large number of the main cultivars have 'Delicioso' as one of the ancestors, either as an immediate parent, as in BR1 and Chiripá, in the second generation of ancestors (such as 'Coral', 'BRS Regalo' or 'Della Nona') or in 3rd generation, as in 'Planalto', 'Chirua' and 'BR3'.

In general, based on the results obtained by the program, cv. Delicioso transmits good characteristics to its progenies, except for the average fruit mass, which tends to be equal to or below the general average. Regarding the average fruit mass and production per plant, all important cultivars are at least equivalent to cv. Delicious, but most of them are superior to it.

Phenotypic diversity studies are important guides in genetic breeding programs because they allow the analysis of the variability among a set of cultivars. In the present work, the highlighted cultivars were grouped according to the similarity for the five characteristics studied (Alpha=0.05%). The variables fruit development period and time of maturation were the ones that most differentiated the cultivars. The 23 cultivars were distributed in six groups with good diversity. The cultivars 'Pampeano' and 'Vila Nova' did not group with any of the others or with each other. They constitute very interesting material to be used in breeding.

Conclusions

As a consequence of the breeding effort over the years, due to the extension of the period of harvest, there was a significant spread of time of ripening (end of September or beginning of October until January), with a slight tendency for earliness and shorter cycle. There was also a small increase in the average fruit mass (5,15% at the end of the whole period). However, the most significant difference was the yield increase, particularly in recent decades. At the end of the period of 53 years, the yield increase was close to 78%.

Acknowledgments

We are thankful to Gilberto Kuhn, Everton Pederzolli and staff support with field work, for helping with data collection or orchard management. We also thank the previous breeders Sergio Sachs, Bonifacio Nakasu and Ascunia Feliciano. **Funding:** This work was carried out with the support of the Coordination for the Improvement of Higher Education Personnel (CAPES). **Conflicts of interest:** The authors declare that they have no competing interest and agreed to the publication of the manuscript in journal. **Availability of data and material:** Not applicable. **Code availability:** Not applicable. There is no conflict of interest.

Figure 5: BRS Kampai. Autor: Ciro Scaranari

Figure 6: BRS Mandinho. Autor: Rodrigo Franzon

References

ALVARES, C.A.; STAPE, J.L.; SENTELHAS, P.C.; GONÇALVES, J.D.M.; SPAROVEK, G. Köppen's climate classification map for Brazil. **Meteorologische Zeitschrift**, Berlin, v. 22, n.6, p. 711-28, 2013.

BEKELE, D. Review on factors affecting postharvest quality of fruits. **Journal of Plant Science and Research**, Hyderabad, v.5, n.2, 180p. 2018.

BRESEGHELLO, F.; RANGEL, P.H.N.; DE MORAIS, O.P. Ganho de produtividade pelo melhoramento genético do arroz irrigado no Nordeste do Brasil. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.34, n.3, 1999.

BONORA, E.; NOFERINI, M.; VIDONI, S.; COSTA, G. Modeling fruit ripening for improving peach homogeneity in planta. **Scientia Horticulturae**, Wageningen, v.159, p.166-71, 2013.

BOONPRAKOB, U.; BYRNE, D.H.; ROUSE, R.E. Response of fruit development period to temperature during specific periods after full bloom in peach. **Fruit Varieties Journal**, University Park, v. 46, p.137-40, 1992.

CITADIN, I.; RASEIRA, M.D.C.; HERTER, F.G.; DA SILVA, J.B. Heat requirement for blooming and leafing in peach. **HortScience**, Alexandira, v.36, n.2, p.305-7, 2001.

DINI, M.; RASEIRA, M. do C. B.; SCARIOTTO, S.; MARCHI, P.M.; MELLO-FARIAS, P. Peach phenological characters: heritability, maternal effect and correlation with brown rot. **Genetics and Molecular Research**, Ribeirão Preto, v.20, n.1, p.1-12, 2021.

DROGOUDI, P.; PANTELIDIS, G. E.; GOULAS, V.; MANGANARIS, G. A.; ZIOGAS, V.; MANGANARIS, A. The appraisal of qualitative parameters and antioxidant contents during postharvest peach fruit ripening underlines the genotype significance. **Postharvest Biology and Technology**, Amsterdam, v.115, p.142-50, 2016.

DROGOUDI, P.; GERASOPOULOS, D.; KAFKALETOU, M.; TSANTILI, E. Phenotypic characterization of qualitative parameters and antioxidant contents in peach and nectarine fruit and changes after jam preparation. **Journal of the Science of Food and Agriculture**, Chichester, v.97, p.3374-83, 2017.

HENDERSON, C.R.; KEMPTHORNE, O.; SEARLE, S.R.; KROSIGK, C. Von. The estimation of environmental and genetic trends from records subject to culling. **Biometrics**, Malden, v.15, p. 192-218, 1959.

IBGE. **Produção Agrícola Municipal. Sistema IBGE de Recuperação Automática (SIDRA)**. **Banco de Dados Agregados**. Brasília, DF: IBGE, 2020. Disponível em: *https://sidra.ibge.gov.br/home/pmc/brasil*. Acesso em: 12 mar. 2022.

MIRÁS-AVALOS, J.; ALCOBENDAS, R.; ALARCÓN, J.J.; VALSESIA, P.; GÉNARD, M.; NICOLÁS, E. Assessment of the water stress effects on peach fruit quality and size using a fruit tree model QualiTree. **Agricultural Water Management**, Amsterdam, v.128, p.1-12, 2013.

KARAMI, F.; LESSANI, H.; RASOULZADEH, S. Effect of water stress on fruit characteristics of peach (*Prunus persica* L.). **Journal of Horticultural Science**, Mashhad, v.33, p.749-54, 2002.

LÓPEZ G.; DEJONG, T. M. Spring temperatures have a major effect on early stages of peach fruit growth. **Journal of Horticultural Science & Biotechnology**, Oxfordshire v.576, n.82, p.507-12, 2007.

MILECH, C.G.; DINI, M.; FRANZON, R.C.; RASEIRA, M.D.C.B. Chilling requirement of four peach cultivars estimated by changes in flower bud weights. **Revista Ceres**, Viçosa, MG, v.69, n.1, p.22-30, 2022.

NARDINO, M.; CORRÊA, E.R.; RASEIRA, M. do C.B.; REAL, I.M.L.; BARROS, W.S.; FRANZON, R.C. Genetic progress over 53 years of the peach breeding program of Embrapa: canning genotypes. **Euphytica**, Dordrecht, v.218, p.1-15, 2022.

OLIVOTO, T.; LÚCIO, A. Metan: an R package for multi-environment trial analysis. **Methods Ecology Evolution**, Hoboken, v.459, n.11, p.783-89, 2020.

RAHMATI, M.; VERCAMBRE, G.; DAVARYNEJAD, G.; BANNAYAN, M.; AZIZI, M.; GÉNARD, M. Water scarcity conditions affect peach fruit size and polyphenol contents more severely than other fruit quality traits. **Journal of the Science of Food and Agriculture**, Chichester, v.95, n.5, p.1055-65, 2015.

RASEIRA, M. D. C. B.; FRANZON, R. C.; SCARANARI, C.; FELDBERG, N. P.; DALBÓ, M. A. BRS Serenata': a peach for fresh market. **Revista Brasileira de Fruticultura,** v. 42, n.4, p.1-5, 2020.

RASEIRA, M. do C.B.; FRANZON, R.C.; PEREIRA, J.F.M.; SCARANARI, C. The First Peach Cultivars Protected in Brazil. **Acta Horticulturae**, The Hague, v.1084, p.39-44, 2015.

RASEIRA, M. do C.B.; NAKASU, B.H.; BARBOSA, W. **Cultivares:** descrição e recomendação. *In*: RASEIRA, M. do C.B.; PEREIRA, J.F.M.; CARVALHO, F.L.C. (ed.). **Pessegueiro**. Brasília, DF: Embrapa, 2014. p.73-141.

RASEIRA, M. do C.B.; FRANZON, R.C.; SCARANARI, C.; FELDBERG, N.P.; DALBÓ, M.A. 'BRS RubraMoore': a fresh market peach for southern Brazil. **Journal of the American Pomological Society**, University Park, v.71, n.4, p. 236-9, 2017.

RASEIRA, M. do C.B.; FRANZON, R.C.; SCARANARI, C.; FELDBERG, N.P.; DALBÓ, M.A. 'BRS Serenata': a peach for fresh market. **Revista Brasileira de Fruticultura**, Jaboticabal, v.42, n.4, p.e-633, 2020.

RASEIRA, M. do C.B.; NAKASU, B. H.; FRANZON, R. C. **História do melhoramento genético do pessegueiro em Pelotas, RS.** Pelotas: Embrapa Clima Temperado, 2021. 48p. (Documentos, 505)

RAWANDOOZI, Z.; HARTMANN, T.; BYRNE, D.; CARPENEDO, S. Heritability, correlation, and genotype by environment interaction of phenological and fruit quality traits in peach. **Journal of the American Society for Horticultural Science**, Alexandria, v.1, p.1-12, 2020.

RICHARDSON, E.A.; SEELEY, S.D.; WALKER, D.R.; ANDERSON, J.L.; ASHCROFT, G.L. Pheno-climatography of spring peach bud development. **HortScience**, Alexandria, v.10, p.236-7, 1975.

SARKHOSH, A.; OLMSTEAD, M.; CHAPARRO, J.; ANDERSEN, P.; WILLIAMSON, J. **Florida peach and nectarine varieties**. Gainesville: IFAS Extension, 2019. (Circular, 1159).

SAS Institute. **Statisctical analysis system.** Version 9.4. Cary: STAT/SAS Software, 2014.

SOUZA, V.A.; BYRNE, D.H.; TAYLOR, J.F. Heritability, genetic and phenotypic correlations, and predicted selection response of quantitative traits in peach: II. An analysis of several fruit traits. **Journal of the American Society for Horticultural Science**, Alexandria, v.123, n.4, p.604-11, 1998.

SOUZA, F.; ALVES, E.; PIO, R.; CASTRO, E.; REIGHARD, G.; FREIRE, A.I.; MAYER, N.A.; PIMENTEL, R. Influence of temperature on the development of peach fruit in a subtropical climate region. **Agronomy***, Madison, v.9,* n.1, p.20, 2019.

SOUZA, A.P.; LEONEL, S.; SILVA, A.C. da. Basal temperature and thermal sum in phenological phases of nectarine and peach cultivars. **Pesquisa Agropecuária Brasileira**, Brasília, DF, v.46, n.12, p.1588-96, 2011.

WICKHAM, H. **ggplot2**: positioning elegant graphics for data analysis springer. 2nd ed. New York: Springer International Publishing, 2016. 260p.