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Genetics/ Original Article

Fruit and bean traits of the *Coffea canephora* genotypes most grown in western Amazon

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Abstract – The objective of this work was to quantify the genetic diversity and selection gains regarding the physical traits of the fruits and beans of the 86 *Coffea canephora* clones most grown in western Amazon. The clones were evaluated as to the effects of genotypes (G), years (Y), and the GxY interaction. Genetic progress was quantified considering combined selection and direct selection for coffee bean weight. Although there was a GxY interaction, based on repeatability estimates the plants presented a similar performance over time. A positive correlation was observed between fruit and bean weight, except for some genotypes, such as R22, AS5, and 'BRS 3210', which presented larger beans and smaller fruit, and as BG180, P42, LB60, G20, and N12, with larger fruit and smaller beans. Using selection for the main trait, the estimates of genetic progress were similar to those obtained through different selection indexes, through which 14 genotypes with a higher bean weight were selected. The evaluated *C. canephora* clones exhibit high genetic diversity for the selection of plants with higher grain mass.

Index terms: Conilon, cultivated clones, genetic diversity, Robusta, selection gain.

Características de frutos e grãos dos genótipos de *Coffea canephora* mais cultivados na Amazônia Ocidental

Resumo – O objetivo deste trabalho foi quantificar a diversidade genética e os ganhos com a seleção quanto às características físicas de frutos e grãos dos 86 clones de cafeeiro *Coffea canephora* mais cultivados na Amazônia Ocidental. Os clones foram avaliados quanto aos efeitos de genótipos (G), anos (A) e da interação GxA. O progresso genético foi quantificado, tendo-se considerado seleção combinada e seleção direta para peso dos grãos de café. Houve interação GxA, embora pelas estimativas de repetibilidade, as plantas tenham apresentado desempenho similar ao longo do tempo. Observou-se correlação positiva entre peso do fruto e dos grãos, exceto para alguns genótipos, como R22, AS5 e 'BRS 3210', que apresentaram grãos maiores e frutos menores, e BG180, P42, LB60, G20 e N12, com frutos maiores e grãos menores. Com uso da seleção para a característica principal, as estimativas de progresso genético foram semelhantes às obtidas com diferentes índices de seleção, por meio dos quais foram selecionados 14 genótipos com maior peso de grãos. Os clones de *C. canephora* avaliados apresentam alta diversidade genética para seleção de plantas de maior massa de grãos.

Termos para indexação: conilon, clones cultivados, diversidade genética, robusta, ganho de seleção.

Introduction

Coffee growing is an important agricultural activity carried out in tropical regions throughout the world, providing employment and income, in addition to being an important export item for several countries, such as Brazil, Vietnam, and Colombia (Bunn et al., 2015). Among coffee species, *Coffea canephora* Pierre ex A.Froehner is widely grown in tropical regions and is characterized by its high natural genetic variability and high yield potential in regions of low altitude and high temperature (Ferrão et al., 2021; Rocha et al., 2021; Partelli et al., 2022).

In western Amazon, there is a genuine opportunity for sustainable coffee cultivation that aligns with forest preservation (Oliveira & Araújo, 2015). This intensive practice predominantly takes place on small family-owned properties, ensuring that farmers can stay on the land. Additionally, the proximity to forests provides favorable conditions for the presence of natural coffee plant pollinators (Moraes et al., 2018; Depolo et al., 2022).

The evolution of coffee production in the Amazon can be exemplified by data from the Brazilian state of Rondônia, which is responsible for 97% of the coffee produced in this region (Acompanhamento…, 2023). According to this survey, in 2001, the state of Rondônia produced 1.9 million bags of coffee in 318 thousand hectares, with a mean yield of 8 bags per hectare, whereas, in 2024, a record production and yield of approximately 3.1 million bags are expected, with a mean yield of 51.6 bags per hectare, covering a 78% smaller area.

Regarding coffee clones, the number found in crop fields is still low. In the properties in western Amazon, the grown clones are: GJ8 and GJ25 in 89% of the crop fields, GJ3 in 80%, P50 in 64%, GJ5 in 41%, SK80 in 36%, and SK41 in 29% (Espindula et al., 2022). However, although intensively grown, these genetic materials are still unknown in many aspects.

To be grown, a clone should present a series of favorable traits, conferring greater benefits to the coffee grower than other genetic materials. However, even though the physical properties of the beans are an important yield component, they have not yet been fully exploited in plant selection and are less known than those of the clones that are more frequently grown (Partelli et al., 2021; Lourenço et al., 2022).

As to the classification of the physical properties of coffee beans, Marcolan (2009) highlighted that it is commonly performed in specific sieves for flat and peaberry beans. In the literature, Ferrão et al. (2021) characterized 600 accessions, whose fruit size was classified as small (4.72%), medium (72.85%), large (20.57%), and very large (1.85%), and grains as medium (52.37%), long (27.29%), and short (20.34%). Partelli et al. (2021), when evaluating 43 genotypes in the municipality of Nova Venécia, in the state of Espírito Santo, Brazil, found a mean of 22.5 g for 100-bean weight (100Bw). In Indonesia, Martono et al. (2022) observed that 75% of the fruits were rounded and 25% were elliptical, with a 100-fruit weight (100Fw) ranging from 101 to 274.7 g, with a predominance of characteristics of the Robusta variety. In the region of Ghana, Donkor et al. (2020) reported larger fruits associated with smaller grains, with no correlation between 100Fw × 100Bw. Ferrão et al. (2017) concluded that the beans of *C. canephora* present smaller dimensions than those of *Coffea arabica* L., with a weight of 12 to 15 g per 100Bw, which may reach from 18 to 22 g. Understanding this variability allows coffee growers to meet the requirements of certain niche markets, for which plant selection is key.

An alternative for the selection of plants with a set of favorable traits is the use of selection indexes (Cruz et al., 2021). One of the first selection indexes was developed by Smith (1936), which uses linear combinations of traits to consider the progress in plant selection, aiming to maximize the correlation between the index and the genotypic value of each individual. Other selection indexes are non-parametric, meaning that they do not need genetic parameters and can be applied in treatments of both random and fixed nature (Lessa et al., 2010). The index proposed by Mulamba & Mock (1978), for example, is based on the sum of the rank of the genotypes in relation to each trait, whereas the genotype-ideotype index (Cruz et al., 2021) considers ideal values for each trait estimated from original data, considering an ideal genotype.

The objective of this work was to quantify the genetic diversity and selection gains regarding the physical traits of the fruits and beans of the 86 *Coffea canephora* clones most grown in western Amazon.

Materials and Methods

The experiment was conducted in the experimental field of Embrapa Rondônia, located in the state of Rondônia, Brazil (8°48'05.5"S, 63°51'02.7"W, at 88 m above sea level). The predominant climate in the region, according to Köppen's classification, is of the Am type, tropical rainy with a dry winter, with a mean temperature of 26°C and a mean annual rainfall of 2,095 mm. According to Alvares et al. (2013), September is the hottest month of the year (27.1°C), and May is the coldest (24.9°C). The soil chemical properties under the grown *C. canephora* clones are shown in Table 1. The meteorological data in the study area, i.e., monthly accumulated rainfall and maximum, mean, and minimum temperatures, are presented in Figure 1.

The 86 clones most grown in western Amazon were evaluated in the 2020/2021 and 2021/2022 crop years. Of these genotypes, 19 are from the active germplasm bank of Embrapa Rondônia, 10 are BRS cultivars

Table 1. Chemical properties at the 0–10 and 20–40 soil depths under the *Coffea canephora* clones most grown in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil.

Environment	Soil depth (cm)	pH H_2O (1.0:2.5)	P(1) (mg dm^{-3})	K(1)	Ca(2)	Mg(2)	Al+H	Al(2)	OM(3) (g kg^{-1})	V (%)
				($cmol_c$ dm^{-3})						
Porto Velho	0–20	5.4	2.00	0.09	1.48	1.02	13.53	0.87	51	16
	20–40	4.9	2.00	0.05	0.39	0.37	13.37	1.65	41	6

(1)Obtained by the Mehlich I method. (2)Exchangeable Ca, Mg, and Al. (3)Organic matter by wet digestion using 1.0 mol KC.

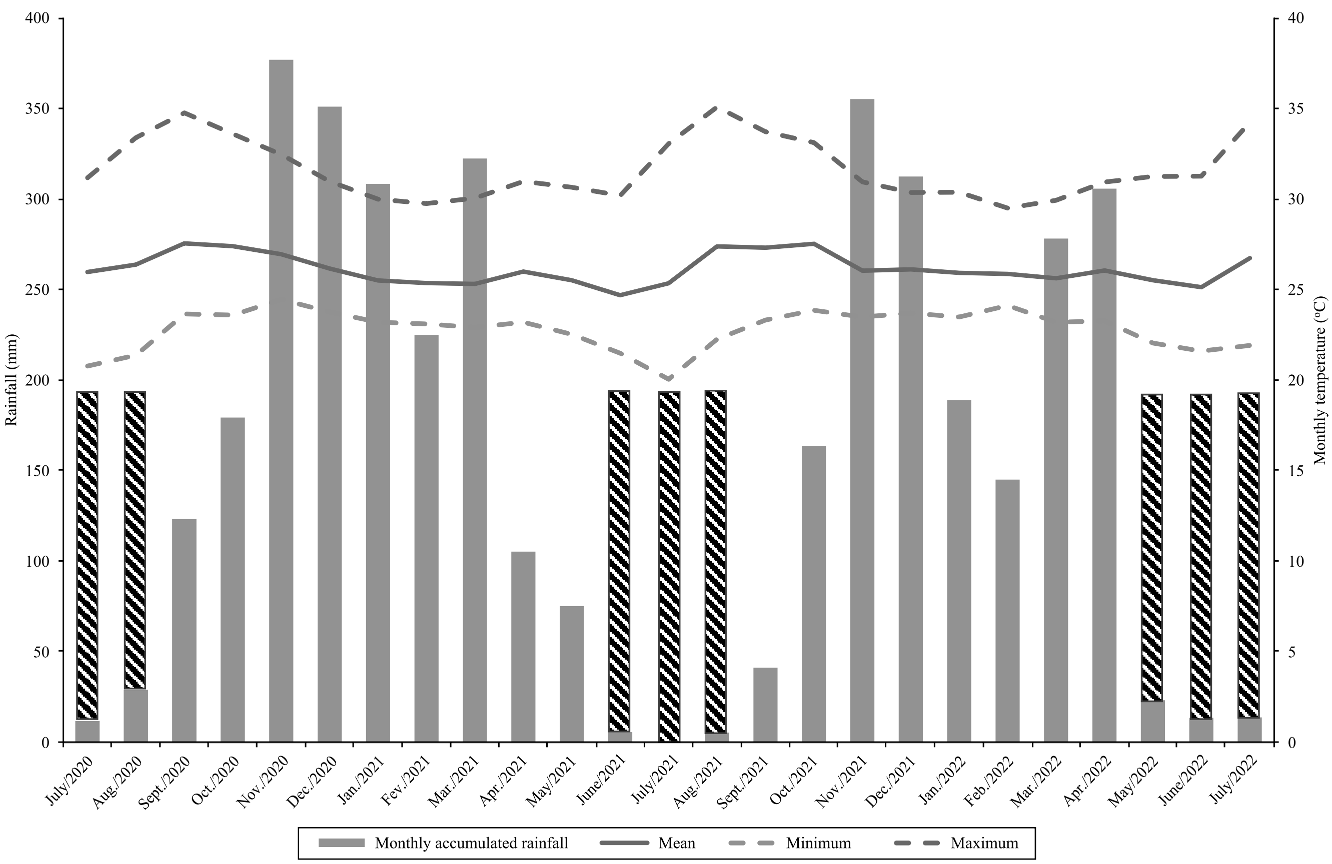

Figure 1. Monthly accumulated rainfall and maximum, mean, and minimum temperatures from July 2020 to July 2022 in the study area in the municipality of Porto Velho, in the state of Rondônia, Brazil. Data were recorded using the in WS-2902 weather station (Ambient, Chandler, AZ, USA). The area with diagonal strips represents supplementary irrigation managed in June, July, and August.

developed by Embrapa, and 57 are publicly owned materials cultivated in western Amazon (Table 2). The used experimental design was completely randomized, in a factorial arrangement with ten replicates to quantify the effects of genotypes (G), environments (year, Y), and the genotype x year interaction (G×Y). The experimental plot was composed of five plants grown at a spacing of 3×1 m. Soil, nutritional, crop, and phytosanitary management practices were carried out according to the recommendations for coffee growing in the state of Rondônia (Marcolan et al., 2009).

To ensure that each genotype was adequately represented, the samples were composed of a mixture of fruits harvested when each plant had at least 70% cherry fruit. The coffee fruit was selected at the cherry stage, then washed for the removal of impurities and defects, being left to dry naturally until reaching 11–12% moisture. After drying, the fruit was hulled, and the coffee beans were sieved.

A precision balance was used to evaluate the weight of 100 fresh coffee cherries (fruits) in grams, representing 100-fruit weight (100Fw). With a digital caliper, fruit length, width, and thickness were measured. After drying, the fruit was manually hulled by separating the husks from the beans (seeds), in order to measure the following dry-bean traits: 100Bw, measured in grams; and bean length, width, and thickness, in millimeters.

Table 2. The 86 *Coffea canephora* genotypes (clones) most grown in western Amazon in the municipality of Porto Velho, in the state of Rondônia, Brazil, evaluated in the 2020/2021 and 2021/2022 crop years for bean and fruit physical traits(1).

nº	Genotype	Origin	nº	Genotype	Origin	nº	Genotype	Origin
1	BAG19	Embrapa(2)	30	GB1	Gilberto Boon(3)	59	LB12	Laerte Braun(6)
2	BAG21	Embrapa(2)	31	GB4	Gilberto Boon(3)	60	LB15	Laerte Braun(6)
3	BAG22	Embrapa(2)	32	GB7	Gilberto Boon(3)	61	LB20	Laerte Braun(6)
4	BAG23	Embrapa(2)	33	AS1	Ademar Schmidt(3)	62	LB22	Laerte Braun(6)
5	BAG24	Embrapa(2)	34	AS2	Ademar Schmidt(3)	63	LB30	Laerte Braun(6)
6	BAG26	Embrapa(2)	35	AS3	Ademar Schmidt(3)	64	LB33	Laerte Braun(6)
7	BAG27	Embrapa(2)	36	AS5	Ademar Schmidt(3)	65	LB60	Laerte Braun(6)
8	BAG28	Embrapa(2)	37	AS6	Ademar Schmidt(3)	66	LB68	Laerte Braun(6)
9	BAG29	Embrapa(2)	38	AS7	Ademar Schmidt(3)	67	LB80	Laerte Braun(6)
10	BAG30	Embrapa(2)	39	AS10	Ademar Schmidt(3)	68	LB88	Laerte Braun(6)
11	BAG31	Embrapa(2)	40	AS12	Ademar Schmidt(3)	69	LB102	Laerte Braun(6)
12	BAG32	Embrapa(2)	41	R22	Ronaldo Vitoriano(3)	70	LB110	Laerte Braun(6)
13	BAG33	Embrapa(2)	42	R152	Ronaldo G Oliveira(3)	71	LB160	Laerte Braun(6)
14	BAG34	Embrapa(2)	43	VP156	Valdecir Piske(3)	72	N1	Nivaldo Ferreira(7)
15	BAG35	Embrapa(2)	44	P50	Valdecir Piske(3)	73	N2	Nivaldo Ferreira(7)
16	BAG38	Embrapa(2)	45	L1	Alcides Rosa(4)	74	N7	Nivaldo Ferreira(7)
17	BAG39	Embrapa(2)	46	BG180	Adilson Berger(4)	75	N8(G8)	Nivaldo Ferreira(7)
18	BAG40	Embrapa(2)	47	CA1	Carlos Alves Silva(5)	76	N11	Nivaldo Ferreira(7)
19	BAG41	Embrapa(2)	48	GJ1	Geraldo Jacomini(6)	77	N12	Nivaldo Ferreira(7)
20	'BRS 1216'	Embrapa(2)	49	GJ3	Geraldo Jacomini(6)	78	N13	Nivaldo Ferreira(7)
21	'BRS 2299'	Embrapa(2)	50	GJ5	Geraldo Jacomini(6)	79	N16	Nivaldo Ferreira(7)
22	'BRS 2314'	Embrapa(2)	51	GJ8	Geraldo Jacomini(6)	80	N17	Nivaldo Ferreira(7)
23	'BRS 2336'	Embrapa(2)	52	GJ20	Geraldo Jacomini(6)	81	N32	Nivaldo Ferreira(7)
24	'BRS 2357'	Embrapa(2)	53	GJ21	Geraldo Jacomini(6)	82	SK41	Sergio Kalk(7)
25	'BRS 3137'	Embrapa(2)	54	GJ25	Geraldo Jacomini(6)	83	SK80	Sergio Kalk(7)
26	'BRS 3193'	Embrapa(2)	55	GJ30	Geraldo Jacomini(6)	84	WP6	Wanderley Peter(7)
27	'BRS 3210'	Embrapa(2)	56	GJ31-131	Geraldo Jacomini(6)	85	P42	Wanderly Bernabé(8)
28	'BRS 3213'	Embrapa(2)	57	LB07	Laerte Braun(6)	86	AR106	Aldinei Raasch(9)
29	'BRS 3220'	Embrapa(2)	58	LB10	Laerte Braun(6)			

(1)Of the evaluated genotypes, 19 are from an active germplasm bank, 10 are developed by Embrapa (including cultivars), and 57 are already in the public domain. (2)Municipality of Ouro Preto do Oeste. (3)Municipality of Alta Floresta do Oeste. (4)Municipality of Rolim de Moura. (5)Municipality of Novo Horizonte do Oeste. (6)Municipality of Nova Brasilândia do Oeste. (7)Municipality of Cacoal. (8)Municipality of Alto Alegre dos Parecis. (9)Municipality of São Miguel do Guaporé.

The significance of the clone effects and the homogeneity of residual variances were verified before the combined analysis in order to quantify the GxY interaction effect, according to the following model described by Cruz (2013):

$$Y_{ijk} = m + G_i + Y_j + GY_{ij} + e_{ijk}$$

where Y_{ijk} refers to the observation of the ith genotype in the jth measurement, m is the experimental average, G_i is the effect of the ith genotype, Y_j is the effect of the jth measurement, GY_{ij} is the effect of the interaction between the ith genotype and the jth measurement, and e_{ijk} is the experimental error. The effects of genotypes were interpreted as fixed effects, and the effects of measurements, as random effects.

From the estimates of the mean square expected values, repeatability was estimated as follows (Cruz, 2013):

$$r = C\hat{O}V(Y_{ij}Y_{ij'}) / \sqrt{\hat{V}(Y_{ij})\hat{V}(Y_{ij'})} = \varnothing_p^2 / \varnothing_p^2 + \sigma_{et}^2$$

where r is the repeatability coefficient, $Ø_p^2$ is the quadratic component combined with the variance of permanent environmental effects, and $Ø_{et}^2$ is the temporary environmental variance associated with the experimental error.

Stability and adaptability were interpreted using the centroid method, considering ideotypes of known response as references of maximum and minimum performance (Rocha et al., 2005; Nascimento et al., 2009). The ideotypes identified by the B+F+ and B-F- abbreviations are characterized as exhibiting the highest and lowest values for fruit and bean traits, respectively. In addition, B+F- represents the ideotype with maximum values for bean traits and minimum values for fruit traits, whereas B-F+ identifies the ideotype with minimum values for bean traits and maximum values for fruit traits.

Genetic progress was quantified, considering direct gains, correlated response, and the use of selection indexes. The correlated response, which evaluates changes in traits associated with selection for a primary characteristic, was estimated by considering evaluations across both harvests, following the expression (Resende, 2016):

$$R(y/x) = k.r_{(x,y)}.h_x.h_y.\ \sigma_y$$

where R(y/x) is the indirect genetic gain in trait y as a result of selection for trait x; k is the standardized selection differential; $r_{(x,y)}$ is the correlation between traits x and y; h_x is the heritability of trait x; h_y is the heritability of trait y; and σ_y is the phenotypic standard deviation of trait y.

The obtained genotypic values were used to quantify genetic progress through the Mulamba & Mock sum of ranks index (Mulamba & Mock, 1978), the Smith & Hazel index (Smith, 1936), and the genotype-ideotype index (Cruz, 2013).

The Mulamba & Mock sum of ranks index (Mulamba & Mock, 1978) involves summing the ranks of genotypes, which are ordered based on their genetic values for each trait. The genotypes are classified in descending order of their genetic values for the evaluated traits.

The classical index proposed by Smith (1936) comprises a linear combination of several economically significant traits, with weighting coefficients estimated to maximize the correlation between the index and the genotypic aggregate. This aggregate is determined by another linear combination of genetic values weighted by their respective economic values (Cruz, 2013). The expected gain for trait y, when selection is performed based on the index, is given by the expression:

$$\Delta g_{y(x)} = DS_{y(x)} h_y^2$$

where $\Delta g_{y(x)}$ is the expected gain for trait y when selection is practiced using the index, $DS_{y(x)}$ is the selection differential of trait y compared to index x, and h_y^2 is the heritability of trait y.

In the genotype-ideotype index (Cruz, 2013), estimated distances between genotypes and reference values are considered, defined by the observed maximums and minimums, according to the expression:

$$G_i = \left[1/n \sum_{j=1}^{n} \left(x_{ij} - m_j \right)^2 \right]^{0.5}$$

where G_i is the genotype-ideotype distance; x_{ij} is the score of the principal component analysis technique for the i-th genotype on the j-th principal component; and m_j is the score associated with the ideal reference on the j-th principal component. The analyses were carried out on the GENES software (Cruz, 2013).

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Results and Discussion

The effect of the GxY interaction was observed for the physical traits of *C. canephora* fruits and beans, which is an indicative that some clones have a different response between the first and the second harvests (Table 3). In this case, the performance of the genotype should be investigated individually in each measurement, aiming at differentiating the clones that show a greater repeatability in their response.

In the analysis of repeated measurements, repeatability is interpreted to quantify the ability of a genotype to maintain its performance over time (Ramalho et al., 2016). The higher estimates obtained for the physical traits of *C. canephora* beans (from 90.10 to 98.14) and fruit (from 91.08 to 94.40) indicate that the response of the studied clones is maintained from one harvest to another (Table 3). These estimates of high magnitude are an indicative that there are genotypes that maintained their performance over time and that the number of measurements was adequate to estimate the genotypic values and gains from selection.

Taking into account biennial coffee farming, i.e., a differentiated performance in two-year cycles, differences of 0.05 g in coffee bean weight and of 2.49 g in fruit weight were observed between the mean values of the first and second measurements in the 2020/2021 and 2021/2022 crop seasons, respectively (Table 3). These differences are considered small when considering the differences among the studied genotypes. Regarding coffee bean weight, for example, the contrast between clones SK41 and BAG31 was 14.24 g in the first measurement and 15.08 g in the second, which is equivalent to a difference approximately 200 times greater than that observed between the harvest seasons. In relation to fruit weight, clones N7 and BAG41 exhibited a difference of 131.03 g in the first measurement and of 112.10 g in the second, which is equivalent to a difference approximately 50 times greater than that between the harvest seasons. The greater variability of genetic nature is directly associated with the gains to be obtained from plant selection.

When evaluating the performance of 20 coffee clones over time, Rocha et al. (2021) concluded that the selection of the highest-yielding clones should consider both a superior performance and the maintenance of such superiority. In the present study, in the first harvest season, clones with a lower yield, but with a high yield in the following years, such as 'BRS 3137', were identified, as well as clones that exhibited less repeatability over time, which were discarded in plant selection.

The relationship between the estimates of error variance and the means of the traits indicates a good experimental accuracy (Table 3). The experimental coefficient of variation ranged from 1.77 to 8.27 for bean physical traits and from 4.41 to 6.15 for fruit physical traits. According to Cruz et al. (2021), estimates lower than 10%, such as these, can be classified as low, indicating a good experimental accuracy. The trait measured with the greatest accuracy was 100Bw, and the one with least accuracy was bean thickness. This lower accuracy in the measurement of bean thickness is associated with the lower variability of genetic nature observed for this trait. Considering this interpretation,

Table 3. Summary of variance analyses of the physical traits of the fruit and beans of the *Coffea canephora* genotypes (clones) most grown in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil(1).

Source of variation	Bl	Bw	Bt	100Bw	Fl	Fwd	Ft	100Fw
Clones (C)	15.99**	12.06**	10.20**	53.97**	13.97**	11.62**	11.21**	17.87**
Years (Y)	0.95^{ns}	38.26**	1.54^{ns}	14.63**	6.42**	27.89**	49.05**	70.42**
C × Y	4.06**	5.24**	2.04**	43.74**	3.14**	3.54**	2.76**	19.26**
$Mean_{overall}$	9.09	6.55	4.21	16.31	14.86	13.16	10.75	131.74
$Mean_{1year}$	9.10a	6.50a	4.22a	16.28a	14.92a	13.09a	10.64a	132.99a
$Mean_{2year}$	9.08a	6.60a	4.20a	16.34a	14.82a	13.24a	10.86a	130.50a
CVe	5.60	5.01	8.27	1.77	5.74	4.41	6.15	4.66
r^2	93.74	91.71	90.19	98.14	92.84	91.39	91.08	94.40
CVg	9.79	8.53	8.03	19.06	8.19	6.04	7.31	18.79
CVg/Cve	1.74	1.70	0.97	10.77	1.43	1.37	1.19	4.03

(1)Means followed by equal letters do not differ by Scott-Knott's test, at 5% probability. Bl, bean length; Bw, bean width; Bt, bean thickness; 100Bw, 100-bean weight; Fl, fruit length; Fwd, fruit width; Ft, fruit thickness; 100Fw, fresh weight of 100 coffee cherries (fruits); CVe, experimental coefficient of variation; r^2, genotypic coefficient of determination; and CVg, genetic coefficient of variation. **Significant at 1% probability. ^{ns}Nonsignificant.

the traits can be ordered according to the degree of accuracy in their measurements, as follows: 100Bw > fruit width > 100Fw > bean width > bean length > fruit length > fruit thickness > bean thickness.

The genetic coefficient of variation (CVg) was also interpreted in relation to the experimental coefficient of variation (CVe). The CVg/CVe ratio showed a wide amplitude from 0.97 to 10.77 for bean traits and from 1.19 to 4.03 for fruit traits. Estimates higher than 1.0 indicate adequate conditions for obtaining gains from selection. Traits 100Bw and 100Fw showed the highest estimates for this ratio, which is an indicative of a greater success in the selection of beans and fruit for a greater weight rather than for length, width, and thickness.

The physical traits are naturally correlated, since the size and weight of the fruit and beans are directly associated. The estimates of correlation between the physical traits of beans and fruit were positive and significant, with a magnitude ranging from r = 0.43, for fruit width and bean length, to r = 0.90 for 100Bw and bean width (Figure 2). The high correlation between 100Bw and 100Fw (r = 0.86) indicates that the selection of plants with a greater bean weight also favors the selection of plants with a greater fruit weight. These associations are an indicative that the constituent parts of the fruit increase in proportion to the increase in fruit weight, since all traits show a positive association with bean weight.

If considered individually, the magnitude and the direction of the correlations mean that selection based on a single trait may result in undesired changes in other traits. These changes are called correlated responses, and their direction should be considered in plant selection (Spinelli et al., 2018). Some studies, for example, have shown an association between a larger bean size and the outturn index, a measure of crop efficiency understood as the relationship between the weight of ripe fruit and of hulled coffee beans (Partelli et al., 2021; Fialho et al., 2022; Lourenço et al., 2022). However, Lourenço et al. (2022) also observed that the increase in fruit dimensions may result in a greater husk weight in relation to bean weight.

Gains from selection for a greater bean weight were compared with those obtained with different selection indexes, which consider the selection of plants that have a set of favorable traits (Table 4). Selection for the main trait, bean weight, showed a total selection gain of 70.4 and 76.01% in the first and second crop seasons, respectively. In general, the gains from selection for the main trait were comparable with those estimated by the selection indexes, which showed similar magnitudes. The Smith & Hazel index (1936), which considers linear combinations of the evaluated traits, had a higher estimate of gains from selection (GS) in the first measurement (GS = 73.5). However, the genotype-ideotype index (Cruz, 2013), which considers the Euclidean distance between the studied genotypes and an ideal plant of maximum performance, presented a higher estimate of gains in the second measurement (GS = 77.06). The similar results observed for these different selection indexes are attributed to positive associations among the traits that favor the selection of beans with larger dimensions and with a greater weight.

A total of 14 genotypes were selected. Of these, some were selected by all selection indexes, whereas others were selected only by some of them. In terms of a greater bean weight, the selected clones may be classified in the following order: SK41 > N7 > SK80 > L1 > R22 > LB10 > N13 > AS5 > R152 > N8(G8) > N1 > 'BRS 3210' > 'BRS 2336' (Table 4). Clones SK41 and N7 differ from the other genotypes due to their greater bean weights, which correspond to selection gains of

Trait	Bl	Bw	Bt	100Bw	Fl	Fw	Ft	100Fw
Bl								
Bw	0.63							
Bt	0.45	0.67						
100Bw	0.78	0.90	0.73					
Fl	0.77	0.53	0.48	0.72				
Fw	0.43	0.66	0.61	0.65	0.57			
Ft	0.46	0.77	0.60	0.71	0.56	0.77		
100Fw	0.70	0.77	0.70	0.86	0.78	0.76	0.81	

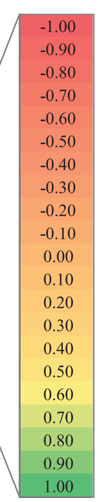

Figure 2. Correlation matrix between the following physical traits of the beans and fruit of the *Coffea canephora* genotypes (clones) most grown in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil: Bl, bean length; Bw, bean width; Bt, bean thickness; 100Bw, 100-bean weight; Fl, fruit length; Fwd, fruit width; Ft, fruit thickness; and 100Fw, fresh weight of 100 coffee cherries (fruits).

49.96 and 46.66%, respectively; in both measurements, the 100Bw of these clones was higher than 45 g.

The scattering of the values obtained for bean weight and fruit weight in the first and second measurements are consistent with the high estimates of repeatability observed, indicating that most of the genotypes maintained their response over time (Figure 3). Characterizing a *C. canephora* germplasm bank with 600 accessions evaluated in one environment with a single measurement, Ferrão et al. (2021) found that 4.72, 72.85, 20.57, and 1.85% of the genotypes were classified as having a small, medium, large, and very large fruit size, respectively. In present study, 40.69% of the genotypes were classified as large and very large for bean weight, whereas and 51.16% were classified as large and very large for fruit weight. Partelli et al. (2021) evaluated 43 genotypes of *C. canephora* grown in the municipality of Nova Venécia, in the state of Espírito Santo, Brazil, in 2017, and obtained a mean 100Bw of 22.5 g. In the present study, the biennial average value for 100Bw was 16.31 g, with a range of 10.0 to 25.1 g.

Despite the significant and positive correlation between fruit and bean weights (r = 0.86) (Figure 2), some genotypes showed larger deviations regarding this ratio. Clone N7, for example, has very large beans, just as SK41, but significantly larger fruit than this other genotype.

To interpret all traits of all genotypes in the two measurements simultaneously, the centroid method was used, which considers the performance of the clones in relation to ideal references of maximum and minimum performance. The ideal references of

Table 4. Estimates of genetic progress (%) obtained by selection indexes and by univariate direct and indirect selection for physical traits of the beans and fruits of the *Coffea canephora* genotypes (clones) most grown in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil[(1)].

	Gain from selection in 2020/2021 (i = 10%)								
Index	Bl	Bw	Bt	100Bw	Fl	Fwd	Ft	100Fw	GS
Genotype-ideotype (Cruz, 2013)	14.42	14.16	10.81	33.81	8.14	7.08	6.33	27.84	73.2
Smith & Hazel (Smith, 1936)	15.62	13.3	9.68	34.9	9.68	5.85	5.21	25.02	73.5
Mulamba & Mock (1978)	14.32	13.88	11.07	33.63	8.15	6.55	5.65	26.6	72.9
Direct selection (BDM)	12.59	12.53	9.44	35.79	9.5	6.51	5.41	27.31	70.4
	Gain from selection in 2021/2022 (i = 10%)								
Index	Bl	Bw	Bt	100Bw	Fl	Fwd	Ft	100Fw	GS
Genotype-ideotype (Cruz, 2013)	14.16	15.93	13.52	33.45	11	10.95	11.07	30.45	77.06
Smith & Hazel (Smith, 1936)	13.91	14.06	12.06	36.88	11.08	9.28	9.04	28.58	76.91
Mulamba & Mock (1978)	14.16	15.93	13.52	33.45	11	10.95	11.07	30.45	77.05
Direct selection (BDM)	14.64	13.28	11.2	36.89	11.05	8.59	8.26	27.13	76.01
	Genetic progress in the 2020/2021 and 2021/2022 crop years								
Genotype	Bl	Bw	Bt	100Bw	Fl	Fwd	Ft	100Fw	GS
SK41	26.29	19.59	9.67	49.96	18.49	7.08	6.68	31.54	105.51
N7	9.51	22.27	18.24	46.66	8.94	14.14	7.01	45.88	96.68
SK80	14.35	21.08	15.88	37.99	8.52	11.62	14.74	28.72	89.30
L1	12.30	6.45	5.73	25.76	4.74	2.90	3.18	19.38	50.24
R22	15.33	6.89	3.83	34.14	6.85	0.95	3.15	11.28	60.19
LB10	10.51	5.45	14.07	32.73	10.78	12.31	8.27	32.08	62.75
N13	4.95	11.01	10.69	25.99	5.77	8.19	9.61	32.40	52.65
AS5	12.48	6.73	0.50	35.16	10.38	-3.17	-0.16	6.85	54.87
R152	14.45	3.20	3.79	25.77	8.65	2.64	1.35	21.99	47.21
N8(G8)[(2)]	6.78	10.29	11.38	25.62	7.43	7.19	7.95	31.87	54.06
N1[(2)]	4.80	8.49	5.82	23.74	7.63	8.21	12.44	27.33	42.85
'BRS 3210'[(2)]	13.91	0.95	0.63	14.88	11.16	-2.07	-4.25	8.53	30.36
'BRS 2336'[(3)]	13.41	0.07	2.52	15.58	11.03	1.70	-1.34	17.76	31.58

[(1)]Bl, bean length; Bw, bean width; Bt, bean thickness; 100Bw, 100-bean weight; Fl, fruit length; Fw, fruit width; Ft, fruit thickness; 100Fw, weight of 100 fresh coffee cherries (fruits); GS, gain from selection associated with bean traits; and BDM, bean dry matter at 12% moisture. [(2)]Genotype selected only by the Smith & Hazel index (Smith, 1936). [(3)]Genotype selected only by the Mulamba & Mock index (Mulamba & Mock, 1978).

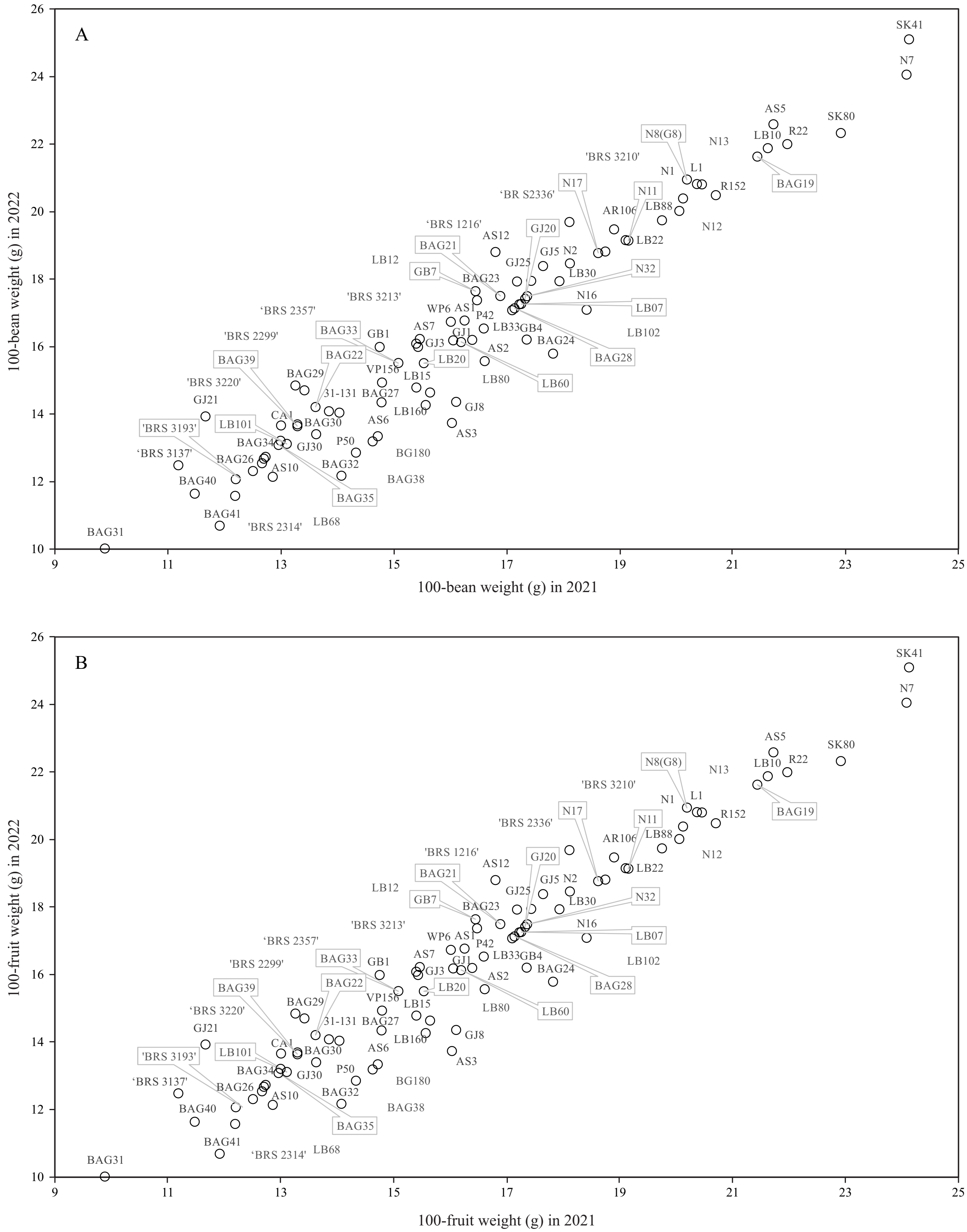

Figure 3. Scatter plot for the bean weight (A) and fruit weight (B) of the 86 *Coffea canephora* genotypes (clones) most grown over the 2020/2021 and 2021/2022 crop seasons in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil. Genotypes are described in the Table 2.

maximum and minimum values for the physical traits of *C. canephora* beans and fruit were identified by: B+F+ and B-F-, representing the ideal references of maximum values for bean traits and minimum values for fruit traits, respectively; and B+F- and B-F+, representing minimum values for bean traits and maximum values for fruit traits, respectively (Figure 4).

Clones N7, SK41, and SK80 were the ones that most drew near the ideal reference of maximum values for fruit and bean physical traits, whereas genotypes BAG31, BAG41, AS10, and 'BRS 3137' drew near the ideal reference of minimum values for fruit and bean physical traits. Other clones, such as R22 and 'BRS 3210', showed different proportions of beans and husk, drawing near the ideotype of maximum values for bean traits and minimum values for fruit traits. Moreover, genotypes BG180, P42, LB60, G20, and N12 were characterized by imbalance, being associated with minimum values for beans traits and maximum values for fruit traits.

Currently, the Brazilian criteria for registering new clones consider genotypes of the species *C. arabica* as a reference. However, this species shows many differences regarding the descriptors of *C. canephora*, such as self-incompatibility, multi-stemmed growth, a higher plant vigor, and a lower bean weight. In the present study, the bean weight trait was organized in five classes, ranging from very small, for clones with a 100Bw from 9.9 to 12.8 g, to very large, with a 100Bw from 20.6 to 24.6 g.

Few clones, notably BAG19, LB10, R22, AS5, SK80, N7, and SK41, exhibited very large beans, whose size was so different from that of the other genotypes that the hulling equipment needed be adjusted before the

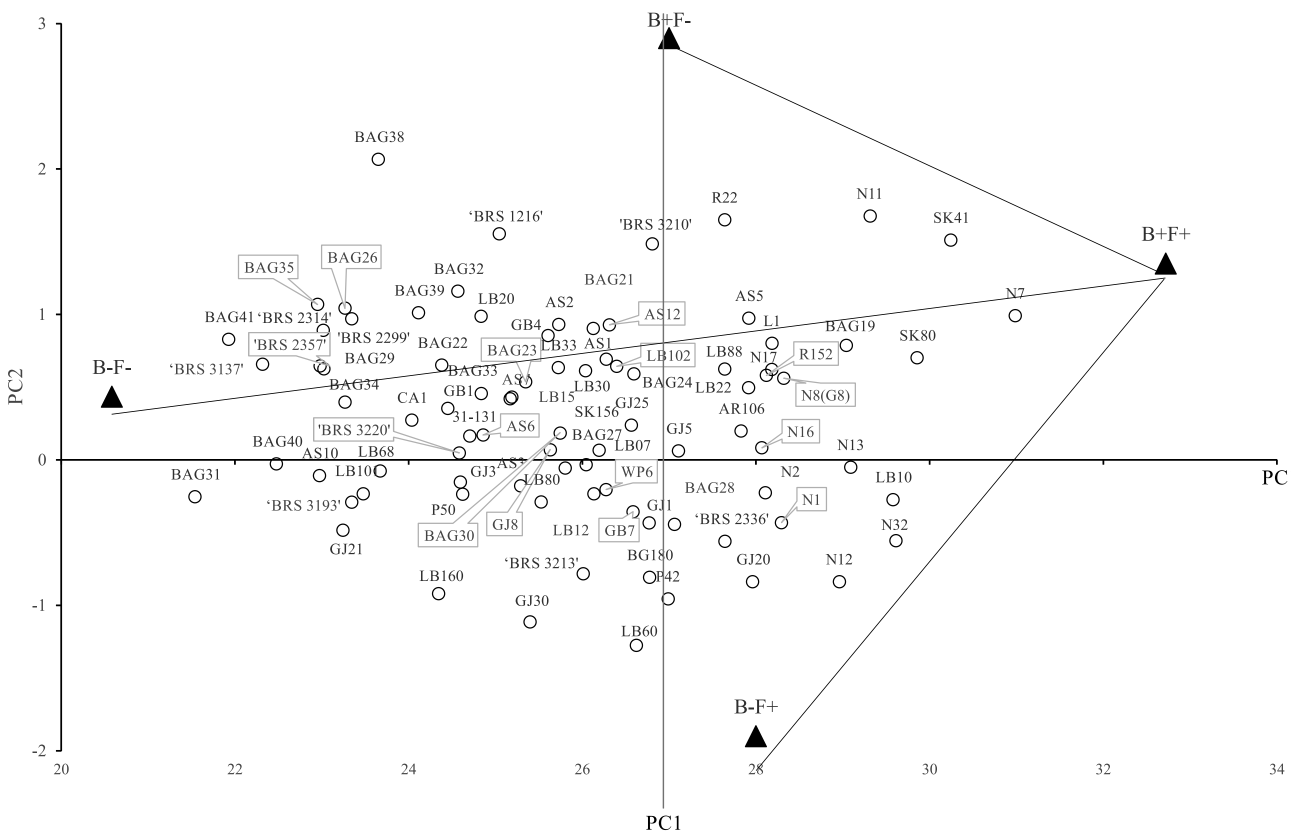

Figure 4. Scatter plot for the first two principal components (PC) of the physical traits of the fruit and beans of the 86 *Coffea canephora* genotypes (clones) most grown over the 2020/2021 and 2021/2022 crop seasons in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil. The ideotypes covered by the abbreviations B+F+, B-F-, B+F-, and B-F+ show: the highest values for fruit and bean traits, the lowest values for fruit and bean traits, maximum values for bean traits and minimum values for fruit traits, and minimum values for bean traits and maximum values for fruit traits, respectively. Genotypes are described in the Table 2.

hulling process so as not to break them. In relation to 100Bw, the registered *C. canephora* cultivars were classified in different groups, with BRS 3210, BRS 2336, and BRS 1216 producing beans classified as large (Teixeira et al., 2020).

The genotypes were also organized in five different groups for the fruit weight trait (Table 5). Although plants with a greater fruit weight tend to have a greater bean weight, exceptions were observed for clones R22, AS5, and 'BRS 3210', which are characterized as

Table 5. Classification for fruit weight, fruit shape, bean weight, bean length, and bean width of the 86 *Coffea canephora* genotypes (clones) most grown in western Amazon, in the municipality of Porto Velho, in the state of Rondônia, Brazil.

Trait	Class	Interval	No.[1]	Genotype
Fruit weight (g)	Very small	79<96	3	BAG41, BAG31, BAG38
	Small	96<105	13	BAG35, 'BRS 3193', 'BRS 3137', CA1, AS10, BAG26, BAG29, 'BRS 2299', 'BRS 2357', BAG34, 'BRS 2314', LB101, P50
	Medium	105<131	25	BAG40, BAG39, LB68, BAG32, GJ31-131, GJ21, LB20, BAG22, LB15, BAG33, AS6, LB160, BAG30, GJ8, GB4, 'BRS 3220', 'BRS 1216', GB1, BAG23, LB12, 'BRS 3213', BAG27, AS3, LB102, LB30
	Large	131<157	31	LB80, BAG24, GJ3, GJ1, BAG21, LB60, AS1, LB07, LB22, LB33, GJ30, AS2, AS5, BG180, GJ25, 'BRS 3210', VP156, AS7, N17, GJ5, P42, R22, N16, BAG28, WP6, AS12, LB88, GB7, N11, AR106, N2, 'BRS 2336'
	Very large	157<195	13	BAG19, L1, R152, GJ20, N1, SK80, SK41, N12, N8(G8), LB10, N13, N32, N7
Fruit shape[2]	Oblong	0.9<1.0	9	GJ30, BAG39, LB60, BAG31, AS2, LB12, BAG21, LB22, GJ31-131
	Round	1.0<1.2	58	LB20, LB102, BAG30, BAG41, N17, GJ8, AR106, AS7, WP6, LB30, BAG29, GJ5, N7, 'BRS 3220', BAG28, 'BRS 1216', 'BRS 2314', N2, LB101, SK80, 'BRS 3193', N13, 'BRS 2357', BAG32, BAG34, CA1, BAG26, LB10, BG180, AS12, BAG38, N1, BAG19, BAG24, GJ3, 'BRS 3137', LB68, N8(G8), LB80, BAG22, GJ25, GB1, LB160, LB07, BAG35, L1, N11, GJ20, 'BRS 2299', AS6, GJ1, BAG33, BAG23, BAG40, P42, GB4, LB15, N32
	Elliptical	1.2<1.3	19	VP156, GB7, R152, R22, AS1, LB33, AS10, 'BRS 3213', BAG27, N16, 'BRS 2336', LB88, AS3, N12, SK41, GJ21, P50, 'BRS 3210', AS5
Bean weight (g)	Very small	9.9<12.8	12	BAG31, BAG41, BAG40, 'BRS 3137', 'BRS 2314', 'BRS 3193', BAG26, AS10, LB68, GJ30, BAG34, GJ21
	Small	12.8<13.9	12	BAG35, CA1, LB101, BAG32, 'BRS 3220', BAG39, 'BRS 2299', BAG30, P50, BAG38, BAG22, GJ31-131
	Medium	13.9<16.9	27	AS6, LB160, 'BRS 2357', BAG29, BAG27, VP156, AS3, BG180, LB15, LB80, GJ8, BAG33, GB1, LB20, GJ3, 'BRS 3213', AS7, AS2, LB12, LB60, GJ1, WP6, AS1, P42, GB4, BAG24, BAG23
	Large	16.9<20.6	28	GB7, LB33, BAG28, BAG21, LB102, LB7, GJ20, N32, 'BRS 1216', GJ25, N16, AS12, LB30, GJ5, N2, N17, 'BRS 3210', 'BRS 2336', LB22, N11, AR106, LB88, N12, N1, N8(G8), L1, R152, N13
	Very large	20.6<24.6	7	BAG19, LB10, R22, AS5, SK80, N7, SK41
Bean length (mm)	Short	6.9<8.5	22	BAG31, LB160, BAG41, GJ21, BAG39, 'BRS 2357', 'BRS 3193', LB68, GJ30, LB101, LB12, AS10, 'BRS 3137', BAG35, 'BRS 2314', LB20, LB60, BAG34, BAG30, LB102, BAG40
	Medium	8.5<10.0	49	AS7, GJ8, AS6, AS2, BAG38, BAG29, GB1, GJ31-131, BG180, AS3, GJ3, 'BRS 2299', BAG23, BAG32, BAG24, 'BRS 1216', 'BRS 3220', BAG33, BAG26, P50, LB30, N2, BAG28, BAG21, LB33, AR106, LB15, AS12, N17, LB07, WP6, GJ5, LB22, P42, GB4, LB80, GJ25, BAG22, 'BRS 3213', N1, N13, N12, GJ1, AS1, N8(G8), GJ20, N32, GB7, BAG19
	Long	10.0<11.6	15	N7, N16, LB10, LB88, BAG27, L1, AS5, 'BRS 2336', 'BRS 3210', SK80, R152, VP156, R22, N11, SK41
Bean width (mm)	Narrow	5.5<6.0	16	BAG40, LB68, BAG22, 'BRS 2314', 'BRS 3137', BAG31, AS10, BAG41, LB160, BAG26, BAG34, LB101, GJ21, AS6, AS3, BAG29
	Medium	6.0<7.0	52	GJ31-131, 'BRS 2299', BAG27, 'BRS 3193', BAG39, 'BRS 3220', BAG33, BAG35, BAG32, CA1, 'BRS 3213', GB1, 'BRS 2357', WP6, N16, GJ25, BG180, GJ3, P50, GJ30, VP156, AS7, BAG38, LB80, AS2, LB07, GJ1, GJ8, GB7, LB15, P42, 'BRS 2336', BAG24, BAG23, 'BRS 3210', LB30, LB102, BAG21, LB33, N32, R152, AS1, BAG28, LB12, GB4, BAG30, N2, LB20, GJ5, AS12, LB10, LB60
	Wide	7.0<8.1	18	L1, AS5, R22, LB88, N1, LB22, GJ20, 'BRS 1216', N8(G8), N13, N12, AR106, BAG19, N17, N11, SK41, SK80, N7

[1]Number of genotypes in each class. [2]Ratio between fruit length and width. The range for each interval was established using Scott-Knott's test, at 5% probability.

having larger beans and smaller fruit, and for BG180, P42, LB60, G20, and N12, which are differentiated by larger fruit and smaller beans. The obtained results contribute to an understanding of the variability of coffee yield components, considering evaluations over time of clones that are intensively grown in western Amazon, but whose bean and fruit traits were previously little known in the literature.

Conclusions

1. The *Coffea canephora* genotypes most grown in western Amazon have high a genetic diversity.
2. The high estimates of genetic progress show the potential for selection gain regarding an increased grain mass in the *C. canephora* genotypes most grown in western Amazon.
3. The identification of reference plants for bean weight allows of selecting genotypes that exhibit a series of favorable characteristics.

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