



Coffea canephora breeding: estimated and achieved gains from selection in the Western Amazon, Brazil

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ABSTRACT: Gain from selection is an important criterion in quantifying the efficiency of breeding programs. This study quantified the selection gain estimated under experimental conditions and realized gain achieved in the field, seeking to interpret the efficiency of the *Coffea canephora* selection. For that purpose, we considered experiments that began in 2004 with directed hybridizations to obtain new hybrid progenies. From a breeding population composed of 288 hybrid individuals, 12 genotypes were selected in experimental conditions from 2005 to 2012, with amplitude in the estimated gains from 127.70 to -19.19%. Those genotypes were evaluated from 2012 to 2018 in clonal tests in four environments of the Western Amazon. The environment that exhibited the greatest correlation between the predicted genetic values and the realized genetic gain observed in the field was the environment of Ouro Preto do Oeste, RO (0.67), the location in which the plants were selected, followed by the environments of Alta Floresta D'Oeste, RO (0.44), Rio Branco, AC (0.43), and Porto Velho, RO (0.37). Experimental conditions showed that the effect due to dominance deviations was approximately three times greater than the additive effect. Nine clones exhibited higher genetic gains in the experimental conditions and at field, and two clones exhibited lower estimated gains and lower field performance. The clone G17-P7 exhibited high genetic gain under experimental conditions and low field performance. The selection in experimental conditions was positively correlated with plant performance in the field ($r=0.55$), which allows reduction of the original breeding population to a set of more promising clones to be grown in multiple environments, optimizing time and resources.

Key words: Conilon, Robusta, hybrids, genetic progress.

Melhoramento do *Coffea canephora*: ganhos de seleção estimados e realizados na Amazônia Ocidental

RESUMO: O ganho com a seleção é um dos critérios mais importantes para avaliar a eficiência de programas de melhoramento de plantas. O objetivo desse trabalho é quantificar a associação entre o ganho de seleção estimado em condições experimentais e o ganho de seleção realizado em campo, buscando quantificar a eficiência do melhoramento do *Coffea canephora*. Para isso, foram considerados experimentos iniciados com a hibridação direcionada para obtenção de progênies no ano de 2004, a avaliação de testes de progênies em condições experimentais no período de 2005 a 2012, e avaliações em diferentes ambientes da Amazônia Ocidental no período de 2012 a 2018. De uma população composta por 288 indivíduos estruturados em nove progênies de irmãos completos foram selecionados 12 genótipos com amplitude de 127,70 a -19,19% em suas estimativas de ganho com a seleção, para serem avaliados em quatro ambientes da Amazônia Ocidental. O ambiente que apresentou maior correlação entre os valores genéticos preditos e o ganho realizado foi Ouro Preto do Oeste - RO (0,67), local em que as plantas foram selecionadas, seguido pelos ambientes de Alta Floresta D'Oeste - RO (0,44), Rio Branco - AC (0,43) e Porto Velho - RO (0,37). Avaliações em condições experimentais mostraram que os efeitos devido aos desvios de dominância foram aproximadamente três vezes maiores do que os efeitos aditivos. Nove clones apresentaram maiores estimativas de ganho em condições experimentais e nos ensaios de campo, e dois clones apresentaram menores estimativas em ambas condições. O clone G17-P7 apresentou altas estimativas de ganho em condições experimentais e baixo desempenho em campo. A seleção em único ambiente esteve positivamente correlacionada com o desempenho dos cafeeiros em campo ($r=0,55$), permitindo reduzir a população de melhoramento original em um conjunto de clones de maior potencial agrônomo.

Palavras chave: Conilon, Robusta, híbrido, progresso genético.

INTRODUCTION

Estimates of gain from selection are considered an important criterion to quantify the efficiency of breeding programs, which can be

understood as the increase in plant performance after at least one selection cycle (CRUZ & REGAZZI, 2001; RESENDE, 2002). The genetic progress can be interpreted from different perspectives, seeking to compare breeding populations or different selection

methods (FALCONER & MACKAY, 1996). However, the different approaches often lead to the same point in question, the association between the predicted genetic values and the realized genetic gain, observed in field conditions (XU et al., 2017).

In the field breeders base their activity on the principles of plant breeding to monitor the degree of kinship and genetic diversity among the parents, seeking to maximize gains from selection (MONTAGNON et al., 2008; GILES et al., 2018; OLIVEIRA et al., 2018). Although, there are different estimators of the genetic progress, all consider that selection gain is a function of the selection intensity (i), of the heritability (h^2), and of the selection differential (SD) (FALCONER & MACKAY, 1996; RESENDE 2002).

Understood as the genetic potential of the plant to transform energy from the sun to coffee beans, coffee plant yield (measured in bags of coffee grains per hectare) is an important characteristic in development of new cultivars (FERRÃO et al., 2008; RAMALHO et al., 2016, SPINELLI et al., 2018). The *Coffea canephora* species has two distinct botanical varieties (CHARRIER & BERTHAUD, 1988; DAVIS et al., 2006, MUSOLI et al., 2009) that are grown in the Western Amazon region: the Conilon botanical variety, characterized by plants of bush-type growth, drought tolerance, and greater susceptibility to diseases; and the Robusta botanical variety, characterized by upright growth, larger sized fruit and leaves, lower drought tolerance, and greater resistance to pests and diseases (ROCHA et al., 2015).

Separation of breeding populations into their botanical varieties allows hybrid genotypes to be obtained, taking advantage of higher vigor manifested in intervarietal crosses (MONTAGNON et al., 2008; TEIXEIRA et al., 2017). From directed hybridizations between Robusta and Conilon parents, a breeding population of 288 genotypes was evaluated in a diallel design structured in randomized blocks in the experimental field of Embrapa Rondônia from 2005 to 2012 (TEIXEIRA et al., 2017, MORAES et al., 2018).

From that breeding population, 12 hybrid clones ($i=4\%$) were selected, which were evaluated in different regions of the Western Amazon from 2012 to 2018 (MORAES et al., 2020). In 2019, the best clones, called Robustas Amazônicos (Amazon Robustas), were registered in the Ministry of Agriculture and recommended for planting in the region, as monoclonal cultivars (MAPA/RNC, 2019).

Considering the greater complexity and cost associated with breeding of perennial species, it is important to consider the efficiency of selection activities (RESENDE, 2002; SILVA et al., 2018).

An assertive way of quantifying this efficiency is comparing the estimates of selection gain, obtained under experimental conditions with the gain achieved in the field, in different environments and management conditions (CRUZ & REGAZZI, 2001).

This study quantified the association between selection gain estimated under experimental conditions and realized gain achieved in the field, seeking to interpret the efficiency of plant selection in the development of new *C. canephora* cultivars.

MATERIALS AND METHODS

Evaluations under experimental conditions

This study considers a set of experiments performed over 15 years: directed hybridization to obtain hybrids progenies in 2004, evaluation of progeny tests under experimental conditions from 2005 to 2012, and field evaluations in different environments of the Western Amazon performed from 2012 to 2018.

In 2004, directed hybridizations were made between parents of the Conilon and Robusta botanical varieties to obtain nine full-sib progenies, structured in four replications of eight plants, for 288 genotypes (SOUZA et al., 2013; TEIXEIRA et al., 2017). Hybridizations were performed using plants of the botanical variety Conilon as male pollen donors. To estimate coffee bean yield in bags of hulled coffee, coffee fruit from each plot was harvested and weighed on an analytical balance. After that, 3-kilogram samples were used to obtain the relation between uncleaned coffee production and coffee plant yield measured in bags of 60 kg of coffee grain per hectare:

$$Yield = \frac{\left(\frac{uc}{np}\right)}{60} * nplants * prop$$
 where *Yield* is coffee yield in bags per hectare; *uc* is uncleaned coffee production per plot (kg); *np* is the number of plants per plot; *nplants*: refers to the number of plants per hectare; *prop* is the proportion between hulled coffee and uncleaned coffee expressed in percentage; and 60 corresponds to the weight of a bag of hulled coffee in kilograms.

The mean yield of three crop seasons (2006–2007, 2007–2008, 2008–2009) was evaluated in the experimental field of Embrapa Rondônia - Ouro Preto do Oeste, RO, considering a complete block diallel design. To obtain estimates of additive and dominance genetic values, the following model was considered (RESENDE, 2002):

$$y = Xr + Za + Wp + Tf + e$$
 where *y* is the data vector; *r* is the vector of repetition effects (assumed as fixed) added to the overall mean; *a* is the vector

of individual additive genetic effects (assumed to be random); P is the vector of plot effects (random); f is the vector of dominance effects of the full-sib family (random); and e is the error or residual vector (random). The uppercase letters represent the incidence matrices of the main effects.

The genotypic value (g) of the hybrid plants can be defined by the sum of the overall mean (u), of the additive effects (a), and of the effects due to dominance deviations (d), ($g = u+a+d$). From the additive and dominance effects in relation to the mean value, the selection gain under experimental conditions was estimated according to the following expression (RESENDE, 2002):

$GS(\%) = \frac{a+d}{\bar{x}} \cdot 100$ where $GS(\%)$ is gain from selection expressed in percentage; a is an additive effect; d is effects due to dominance deviations; and \bar{x} is the overall mean.

Based on this evaluation under experimental conditions, 12 clones were selected for evaluation in different environments of the Western Amazon, which equals a selection intensity of 4%. The clones were identified according to the number of their plot in the field and of their progeny. The clone G15-P8 for example, identifies plant 15 of progeny 8 (Table 1).

Clonal competition trials in field

In December 2012 and January 2013, four final clonal competition trials were set up in different environments of the Western Amazon, described below:

Clonal competition test n°1: The trial in Ouro Preto do Oeste was conducted in the experimental field of the Empresa Brasileira de Pesquisa Agropecuária at 10°43'55.3"S and 62°15'23.2"W, at 245 meters above sea level. The climate of the municipality is type "Aw" by the Köppen classification, defined as

Table 1 - Estimates of genetic parameters and of gains from selection of 12 hybrid genotypes of mean hulled coffee yield over three crop seasons (2006-2007, 2007-2008, 2008-2009) evaluated in progeny test. Ouro Preto do Oeste – RO.

Genotype	PV	a	d	a+d	Gain(%)
G15-P8	111.72	19.34	40.45	59.79	127.70
G10-P8*	80.95	12.22	24.15	36.37	77.68
G17-P7	81.18	12.85	19.16	32.01	68.37
G19-P9	82.17	12.23	24.46	36.69	78.36
G16-P7*	75.87	12.63	18.65	31.28	66.81
G12-P8	83.7	10.95	21.24	32.19	68.75
G13-P8*	79.22	9.66	18.29	27.95	59.70
G20-P7*	54.69	5.81	3.04	8.85	18.90
G9-P4	77.89	3.93	18.71	22.64	48.36
G14-P4*	53.31	0.52	8.52	8.00	17.09
G11-P6	50.68	-0.74	-0.71	-1.45	-3.10
G18-P2	39.65	-7.49	-1.54	-9.03	-19.29
-----Genetic parameters-----					
σ_a^2	178.52				
σ_{plot}^2	22.4				
σ_{prog}^2	68.14				
σ_e^2	221.46				
σ_f^2	490.53				
h_a^2	0.36+-0.08				
h_g^2	0.91				
c_{plot}^2	0.04				
c_{fam}^2	0.14				
μ	46.82				

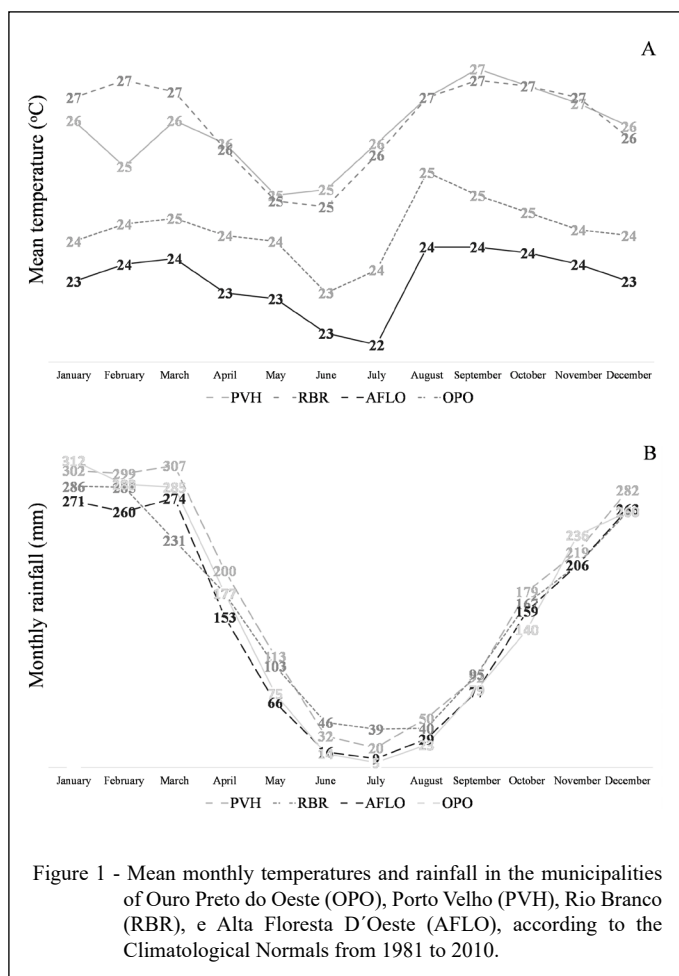
PV: phenotypic value, a: additive value, d: value due to dominance effects, μ : overall mean, σ_a^2 : additive genetic variance, σ_{plot}^2 : plot variance, σ_{prog}^2 : progeny variance, σ_e^2 : residual variance, σ_f^2 : phenotypic variance, h_a^2 : narrow-sense heritability, h_g^2 : broad-sense heritability, c_{plot}^2 : coefficient of determination of the plot effects, c_{fam}^2 : coefficient of determination of the family effects.

tropical humid with a dry winter and rainy summer. Mean annual temperature ranges from 21.2 °C to 30.3 °C, and the highest temperatures occur in July and August. Mean annual rainfall is 1939 mm and mean relative humidity is 81% (ALVARES et al., 2013) (Figure 1). In this environment, the soil chemical characteristics at the depth of 0 to 20 cm are pH, 5.20; P, 15.00 mg/dm³; K, 0.23 cmolc/dm³; Ca, 2.42 cmolc/dm³; Mg, 0.66 cmolc/dm³; Al+H, 4.95 cmolc/dm³; Al, 0.10 cmolc/dm³; OM: 18.40 g/kg; and V, 40.00%.

Clonal competition test n°2: The trial in Porto Velho was set up in the experimental field of the Empresa Brasileira de Pesquisa Agropecuária at 8°48'05.5"S and 63°51'02.7"W at 88 meters above sea level. The predominant climate in the region is tropical rainy with a dry winter, type "Am" (Köppen), with mean temperature of 26.0 °C and mean annual rainfall of 2095 mm. September is the hottest month of the year (27.1 °C), and May is the coldest month

(24.9 °C) (Alvares et al., 2013) (Figure 1). In this environment, the soil chemical characteristics at the depth of 0 to 20 cm are pH, 5.40; P, 2.00 mg/dm³; K, 0.09 cmolc/dm³; Ca, 1.48 cmolc/dm³; Mg, 1.02 cmolc/dm³; Al+H, 13.53 cmolc/dm³; Al, 0.87 cmolc/dm³; OM, 50.90 g/kg; and V, 16.00%.

Clonal competition test n°3: The trial in Rio Branco, AC, was set up at Embrapa Acre. Local coordinates are 10°1'30.98"S and 67°42'21.77"W at 180 meters above sea level. The predominant climate is tropical humid, type "Aw" (Köppen), with a well-defined dry season from June to August. Water deficit ranges from 50 to 100 mm.year⁻¹. Mean annual rainfall is 1998 mm. The mean annual temperature is near 24.9 °C, with October as the hottest month and July as the driest month (ALVARES et al., 2013) (Figure 1). In this environment, the soil chemical characteristics at the depth of 0 to 20 cm are pH, 5.45; P, 3.78 mg/dm³; K, 0.15 cmolc/dm³; Ca, 2.10



cmolc/dm³; Mg, 0.55 cmolc/dm³; Al+H, 1.88 cmolc/dm³; OM, 11.18 g/kg; and V, 59.80%.

Clonal competition test n°4: The trial of the Alta Floresta D'Oeste, RO, environment was conducted on a private property at 12°08'23.06"S and 61°59'29.41"W at 436 meters above sea level. The climate classification is tropical humid "Aw" (Köppen). The mean annual temperature is near 23.4 °C. Mean annual rainfall is 1783 mm (ALVARES et al., 2013). In this environment, the soil chemical characteristics at the depth of 0 to 20 cm are pH, 6.00; P, 24 mg/dm³; K, 0.64 cmolc/dm³; Ca, 8.25 cmolc/dm³; Mg, 0.97 cmolc/dm³; Al+H, 5.45 cmolc/dm³; Al, 0.00 cmolc/dm³; OM, 30.30 g/kg; and V, 64.00%. The mean monthly temperatures and rainfall in these environments are summarized at Figure 1.

The clonal competition trials were conducted in a randomized block design with three replicates of eight plants per plot with dimensions of 3 m × 1.5 m, with eight open pollination genotypes

(Table 2). The randomization restriction was performed in the field to maximize homogeneity within each block. To estimate the yield of different clones in the 2015–2016, 2016–2017, and 2017–2018 crop seasons, coffee beans were harvested from each plot and weighed on an analytical balance. Soil, nutritional, crop management, and phytosanitary practices at each trial site were conducted according to the recommendations of the Coffee Growing Production System in Rondônia (MARCOLAN et al., 2009). The trials received complementary irrigation according to the need of each environment from the first flowering period up to the beginning of the rainy period, which is from July to October.

After verifying the homogeneity of variances of the data, a combined analysis of variance was performed to quantify the effect of the G×E interaction, according to the model described by Cruz & Regazzi, 2001:

$$Y_{ijk} = m + G_i + B/A_{jk} + A_j + GA_{ij} + E_{ijk} \quad \text{where}$$

Table 2 - Mean hulled coffee yield evaluated over three crop seasons (2015-2016, 2016-2017, 2017-2018) in four environments of the Western Amazon of 12 clones selected under experimental conditions and 8 controls evaluated in four environments of the Western Amazon.

Clone	OPO(-)	PVH(-)	RBR(-)	AFLO(+)	Pi
125	44.3	42.7	66.6	95.5	9
160	44.6	38.2	58.0	66.7	14
120	29.5	32.2	33.7	61.2	16
2299	43.9	66.5	59.1	87.3	8
453	36.9	14.5	34.9	44.6	18
657	55.7	11.9	33.6	48.7	17
636	16.7	9.2	32.5	36.0	20
3193	42.4	43.4	53.0	78.7	12
G9-P4	57.0	55.6	71.4	60.0	11
G10-P8*	80.2	60.9	76.4	111.4	2
G11-P6	28.5	44.8	51.6	86.1	13
G12-P8	61.8	34.1	65.3	86.9	10
G13-P8*	76.9	72.3	67.5	91.0	3
G14-P4*	54.8	58.9	69.6	96.2	5
G15-P8	63.3	53.8	63.7	82.7	6
G16-P7*	76.6	90.9	90.6	106.5	1
G17-P7	37.7	38.6	47.3	78.1	15
G18-P2	28.0	16.8	23.5	43.1	19
G19-P9	78.1	54.2	47.5	102.2	4
G20-P7*	54.1	56.6	64.0	87.2	7
Mean	50.6	44.8	55.5	77.5	

(-): unfavorable environments, (+): favorable environments, OPO: Ouro Preto do Oeste - RO, PVH: Porto Velho RO, RBR: Rio Branco (AC), AFLO: Alta Floresta D'Oeste - RO, Pi: classification according to Lin & Binns (1988). * Clones registered in the Ministry of Agriculture and recommended for planting in Western Amazon regions (RNC/MAPA, 2019).

Y_{ijk} refers to the observation of the i^{th} genotype in the k^{th} block, and in the j^{th} environment; m is the experimental average; G_i is the effect of the i^{th} genotype (clone effect); B/A_{jk} is the k^{th} block's effect within the j^{th} environment; A_j is the effect of the j^{th} environment; GA_{ij} is the effect of the interaction between the i^{th} genotype and the j^{th} environment (G×E interaction effect); and E_{ijk} is the experimental error. The genotypes were considered to have random effects, while the blocks and environmental effect were considered to be fixed.

The estimator proposed by Lin & Binns (1988) was used to quantify the clones adaptability and stability. Plant performance was interpreted considering the sum of the realized gain observed in different environments, estimated according to the following expression (CRUZ & REGAZZI, 2001):

$GS_{(\%)} = \frac{DS \cdot h^2}{\bar{x}} \cdot 100$ where $GS_{(\%)}$ gain with selection, expressed in percentage, DS is selection differential, h^2 is heritability, and \bar{x} is the mean of the experiment. Statistical analysis was performed using the Genes and Selegen software (CRUZ, 2016; RESENDE, 2002).

RESULTS AND DISCUSSION

Comparison between the genetic progress estimated under experimental conditions and the realized field gain should be interpreted considering both the effects of the environment, that affect plant performance, as well as the different presuppositions of analysis.

Under experimental conditions, the progeny and genotype effects are of a random nature by representing a sample of the genotypes that can be obtained by directed hybridization. Imbalance is also a factor to be considered, resulting from differentiated plant vigor that causes mortality as years go by. An additional factor is the lower precision of the individual genetic effects, since each genotype is represented by only one plant in the field. However, in working with related individuals, the additive gene effects and the effects due to dominance deviations can be estimated, increasing accuracy in the selection of lower heritability traits such as hulled coffee yield (RESENDE, 2002; ROCHA et al., 2015).

While narrow-sense heritability is associated only with additive values, broad-sense heritability is associated with both effects (CRUZ

& REGAZZI, 2001). Vegetative propagation of the clones allows the same genotype to be cultivated on a large scale, taking advantage of the additive effect of the genes (a) and due to the effects of dominance deviations (d) (RAMALHO et al., 2016; SILVA et al., 2019; PARTELLI et al., 2020). The estimates of narrow-sense heritability and broad-sense heritability exhibited an expressive difference in magnitude ($h_a^2=0.36$ and $h_g^2=0.91$) (Table 1).

On average, the effect due to dominance deviations was 2.98 times greater than the additive effect (Table 1). The effects due to dominance deviations are important for *C. canephora* breeding, resulting in the higher vigor of the hybrid plants associated with the expression of the best traits of the Conilon and Robusta botanical varieties (MONTAGNON et al., 2008; TEIXEIRA et al., 2017, LUNA et al., 2017).

From a breeding population composed of 288 individuals structured in nine progenies, a group of 12 genotypes were selected for evaluation in different environments (Table 1). The plant selection was based in their yield over three crop seasons and for exhibiting other desirable agronomic traits, such as rust resistance, favorable crop architecture and beverage quality (TEIXEIRA et al., 2017, SOUZA et al., 2018). The selected clones showed estimates of genetic progress with an amplitude from 127.70 to -19.19% (Table 1). Clones with lower estimates of gain from selection were also selected because of their better beverage quality (G14-P4), low plant architecture (G11-P6), and rust resistance (G18-P2).

Often the yields observed under experimental conditions are not the same as those obtained by coffee growers (XU et al., 2017). Several factors, such as edaphic and climatic conditions, soil fertility, water availability, occurrence of pests and diseases, and plant management practices, affect genotype performance. Evaluation in multiple environments allows to quantify the change in the coffee plant performance in different locations. Defined as genotype x environment interaction, the change in plant performance resulting from the individual adaptation responses of each genotype, is a characteristic of the coffee plant (MORAES et al., 2020).

Unlike evaluations under experimental conditions, the trials conducted in different environments are characterized by the fixed nature of the genotype effects (since they do not represent a population sample), the low plot mortality due to the evaluation of many plants per clone, the

impossibility of decomposition of the additive and dominance effects through evaluation of non-related genotypes, and the change in performance of clones from one environment to another due to the genotype \times environment interaction.

Combined analysis of variance of the field trials shows that the effects of the genotype \times environment interaction (G \times E) were significant ($P < 0.01$). The significant effect of the G \times E interaction indicates that the genotypes had differentiated performance in the environments, decreasing the agreement between the selection gain estimated under experimental conditions and the realized gain measured in the field. Estimates of broad-sense heritability (h_g^2) greater than 0.80 (Table 3) indicate the predominance of the genotypic effect in field trials. The ratio between the coefficient of genetic variation and the coefficient of environmental variation greater than one (CVg/CVe=1.65) also indicate a suitable condition for obtaining gain from selection in field trials (FERRÃO et al., 2008; DUBBERSTEIN et al., 2020).

The environmental quality index (I_j), estimated from a contrast between the mean of each environment and the overall mean, was interpreted

to classify the environments in relation to their contribution to clone performance, as favorable or unfavorable. The Alta Floresta D'Oeste environment was the only classified as favorable for the crop, with a mean yield over three years of 77.5 bagha⁻¹. The environments of Rio Branco, AC, Ouro Preto do Oeste, RO, and Porto Velho, RO, had mean yields of 55.5, 50.6, and 44.8 bagha⁻¹; respectively, and were classified as unfavorable for growing coffee (Table 2).

Besides the lower mean temperature, the Alta Floresta D'Oeste environment differentiated from the others by the lower soil acidity, greater base saturation of an Eutrophic Red Argisol (Figure 1). According to agricultural zoning in the region (BRASIL, 2008), the municipality of Porto Velho -RO has less suitable conditions for coffee growing in their Dystrophic Yellow Latosols.

The non-parametric methodology of Linn & Binns (1988) allows the classification of the clones in relation to ideal references of maximum yield in all environments (Table 2). The clones G16-P7, G10-P8, and G13-P8 had the best performance levels in all environments (Table 3). According to Teixeira et al., (2020), the clone G16-P7 also presents high sieve

Table 3 - Summary of analysis of variance of mean hulled coffee yield evaluated over three crop seasons (2015-2016, 2016-2017, 2017-2018) in four environments of the Western Amazon region (Ouro Preto do Oeste - RO, Porto Velho RO, Rio Branco - AC, Alta Floresta D'Oeste - RO), in clonal competition trials set up with 12 selected clones and 8 controls.

SV	DF	SS	MS	F
Blocks/Environment	8	2742.99	342.88	
Genotypes	19	73997.73	3894.62	13.30**
Environments	3	36763.32	12254.44	19.43**
G x E	57	16696.95	292.93	2.95**
Residue	152	15091.80	99.29	
Total	239	145292.79		
-----Genetic parameters-----				
σ_a^2	300.14			
$\sigma_{g \times e}^2$	64.55			
σ_e^2	99.29			
h_g^2	92.47			
$r_{x,y}$	64.69			
μ	57.09			
CVe	17.45			
CVg	30.35			
CVg/Cve	1.74			

SV: source of variation, DF: degrees of freedom, SS: sum of squares, MS: mean square, F: F test, σ_g^2 : genotypic variance, $\sigma_{g \times e}^2$: variance of the genotype \times environment interaction, σ_e^2 : residual variance, h_g^2 : broad-sense heritability, $r_{x,y}$: intraclass correlation, μ : overall mean, CVe: coefficient of experimental variation, CVg: coefficient of genetic variation, CVg/Cve: ratio between the coefficients of genetic and environmental variation.

classification and nematode resistance. The full-sib clones G10-P8 and G13-P8 of high field yield, also differentiated by their high sieve classification, rust resistance, and uniformity of maturation (SANTOS et al., 2017, SANTOS et al., 2018). In 2019, the clones G10-P8, G13-P8, G14-P4, G16-P7, and G20-P7 were registered in the Ministry of Agriculture and recommended for planting in Western Amazon regions (MAPA/RNC, 2019).

The environment that had the highest estimate of the correlation between the predicted genetic values under experimental conditions and actual gain measured in the field was the Ouro Preto do Oeste, RO environment (0.67), followed by the environments of Alta Floresta D'Oeste, RO (0.44), Rio Branco, AC (0.43), and Porto Velho, RO (0.37) (Table 4). The highest correlation estimate was observed in the same environment in which the plants were selected, which exhibited an estimate of approximately 0.70; compared to other environments had estimates near 0.40. The mean temperatures showed higher difference between the environments than the rainfall (Figure 1). The environments of Porto Velho and Rio Branco were also more similar than the environments of Ouro Preto do Oeste and Alta Floresta D'Oeste (Figure 1).

The selection in a single environment was positively correlated with plant performance in the field ($r = 0.55$), allowing a reduction in the original breeding population with the selection of only the most promising clones to be evaluated in multiple environments, optimizing time and resources. The evaluation of the G×E interaction is indispensable for developing new coffee cultivars, reducing the risks of increasing the scale of growing selected plants.

More used for annual crop or short cycle species, studies of genetic tendency seek to quantify changes in the genetic values of populations over time, through diverse selection cycles (XU et al. 2017, ALKIMIM et al., 2020). In long-life-cycle perennial species, decades are necessary to evaluate two or more selection cycles. The comparison between the estimates of genetic progress under experimental conditions and realized field gain may be quantified considering four quadrants in a scatter plot (Figure 2). The A and C quadrants represent the selection gain estimated under experimental conditions that diverged from the realized gain achieved in the field, whether because they exhibited low values under experimental conditions and high values in the field (Quadrant A) or because they exhibited high values under experimental conditions and low values in the field trials (Quadrant C) (Figure 2).

Table 4 - Estimates of gain from selection under experimental conditions and the realized gain achieved in field trials evaluated in four different environments of the Western Amazon of 12 clones selected under experimental conditions.

Clone	-----Realized Selection Gain in field-----					$\sum SG$	
	Estimated SG	Diallel SG	SGOPO%	SGPVH%	SGRBR%		SGAFLO%
G9-P4	48.36	48.36	12.82	24.09	28.74	-22.59	43.06
G10-P8	77.68	77.68	58.64	36	37.63	43.75	176.02
G11-P6	-3.10	-3.10	-43.54	0.06	-7.08	11.11	-39.45
G12-P8	68.75	68.75	22.21	-23.93	17.67	12.12	28.07
G13-P8	59.70	59.70	52.1	61.25	21.73	17.42	152.5
G14-P4	17.09	17.09	8.41	31.47	25.39	24.14	89.41
G15-P8	127.70	127.70	25.29	20.15	14.75	6.64	66.83
G16-P7	66.81	66.81	51.48	102.83	63.22	37.37	254.9
G17-P7	68.37	68.37	-25.4	-13.86	-14.72	0.81	-53.17
G18-P2	-19.29	-19.29	-44.68	-62.54	-57.63	-44.44	-209.29
G19-P9	78.36	78.36	54.43	20.86	-14.36	31.8	92.73
G20-P7	18.90	18.90	7.04	26.29	15.31	12.54	61.18
r			0.67	0.37	0.43	0.44	0.55

SG: selection gain, Diallel SG: Selection gain estimated in experimental conditions, SGOPO%: realized field selection gain in Ouro Preto do Oeste – RO, SGPVH%: realized field selection gain in Porto Velho – RO, SGRBR%: realized field selection gain in Rio Branco – AC, SGAFLO%: realized field selection gain in Alta Floresta D'Oeste – RO.

$\sum SG$: sum of the realized field selection gain in all environments, r: correlation between the estimated gain in experimental conditions and the realized field gain.

No genotype was clustered in quadrant A and only the clone G17-P7 was in quadrant C, indicating that that clone had high estimates of gain under experimental conditions and low performance in the field.

The convergent quadrants are those that exhibited high estimates under experimental conditions and high values in the field (Quadrant B), or low estimates under experimental conditions and low performance in the field (Quadrant D). Clones G11-P6 and G18-P2 clustered in Quadrant D of low performance under experimental conditions and in the field. The other clones clustered in quadrant B, which represents the plants that stood out under experimental conditions and in evaluations in the field, with mean yield over three years of 71.7 bag. ha⁻¹ in all environments, 25.5% superior to the overall mean of 57.1 bag. ha⁻¹ observed in the trials. The clones G16-P7, G10-P8, and G13-P8 had mean yields over three years in all the environments of 91.2, 82.2, and 76.9 bag. ha⁻¹, which equal selection gains of 59.6, 44.0, and 34.7%, respectively.

Plant selection may be defined as a science and as an art (Cruz & Regazzi, 2001). The

efficiency of breeding programs depends on the association between the selection gain estimated under experimental conditions and the realized gain achieved in the field, which is affected by the different presuppositions of analysis and by the effect of the environment.

Some clones were selected in an empirical manner by coffee growers that are grown for years because of their superior performance and favorable agronomic traits. Nevertheless, in the face of limitations of time, laborers, and resources, breeding programs should be based on scientific principles to efficiently select plants of superior performance.

CONCLUSION

Experimental conditions showed that the effect due to dominance deviations was approximately three times greater than the additive effect and was associated with greater performance of the vegetative propagated hybrid clones. Although, its limited by the experimental conditions in a single environment, the clones selected under experimental conditions exhibited estimates of gain from selection that

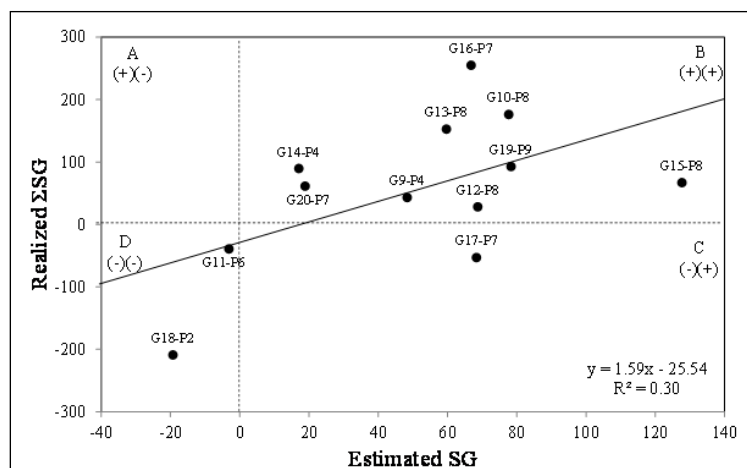


Figure 2 - Scatter plot of the estimated selection gain (SG) obtained under experimental conditions (x) and the sum of the realized gain (Σ SG) achieved in the field (y) of 12 clones evaluated in four different environments of the Western Amazon. Quadrant A(+)(-): low estimates under experimental conditions and high performance in the field trials, Quadrant B(+)(+): high estimates under experimental conditions and high performance in the field trials, Quadrant C(-)(+): high estimates under experimental conditions and low performance in the field trials, Quadrant D(-)(-): low estimates under experimental conditions and low performance in the field trials.

correlated positively with field performance allowing reduction in the original breeding population, optimizing time and resources.

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DECLARATION OF CONFLICTS OF INTERESTS

The authors declare no conflict of interest. The founding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, and in the decision to publish the results.

AUTHORS' CONTRIBUTIONS

All authors contributed equally for the conception and writing of the manuscript. All authors critically revised the manuscript and approved of the final version.

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