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Genotype × Environment Interaction in the Coffee Outturn Index of Amazonian Robusta Cultivars

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Abstract: The coffee outturn index, understood as the relation between the cherry coffee fruit harvested from the field and its respective processed grains, is an important component of the *Coffea canephora* bean yield. The aim of this study was to quantify the coffee outturn index of the Amazon Robusta cultivars grown in irrigated and dryland Western Amazon environments. According to the maturation cycle of each clone, washed samples of cherry coffee were collected considering a completely randomized factorial design for characterization of the effects of genotypes, environments, and the genotype × environment (G×E) interaction. The contrasting environments of Porto Velho, RO, and Ouro Preto do Oeste, RO, Brazil, represent most of the coffee growing sites located in Am and Aw climate types, cultivated in Red and Yellow Oxisols, typical of the Western Amazon. The weight reductions through drying exhibited a G×E interaction of the complex type, which is characterized by a change in the ordering of genotypes from one environment to another, whereas the weight reductions through hulling exhibited a G×E interaction predominantly of the simple type. The reduction in weight due to drying was more affected by the environment than reduction in weight after pulping. The clones BRS1216, BRS 3220, and BRS3137 had the highest outturn index estimates and the clones BRS2314, BRS3213, and BRS2336 had the lowest outturn index estimates. The clones BRS2299, BRS3210, BRS3193, and BRS2357 had performance near the mean value of this group of genotypes. Considered together, the genotypes had a mean outturn of 24.41%, with an amplitude from 22.5% to 27.2%.

Keywords: *Coffea canephora*; breeding; Robusta; Conilon; hybrids

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1. Introduction

Cultivation of the *Coffea canephora* is an important agricultural activity carried out in tropical regions throughout the world [1]. This coffee species is widely grown in countries such as Brazil and Vietnam and it is characterized by high genetic variability and yield potential, which are exploited in the selection of plants coming from divergent hybridizations [2–5].

In the Western Amazon, coffee growing can be genuinely sustainable and allied with forest preservation [6]. As it is a labor-intensive activity, mostly performed on small family-based properties, it favors continuity of farmers on the land and it benefits from nearness to forests, which contribute to the presence of natural pollinizers [7–9].

The outturn index is understood as the relation between the weight of the ripe fruit and the weight of the hulled coffee beans [10]. This relation has an impact on coffee yield because two clones of similar production potential can exhibit significant differences in moisture and husk contents, with impacts on the efficiency of the crop [3]. As coffee growing has evolved, the outturn index, which was previously considered of less importance, has come to be an important trait for the coffee grower, who invests in the use of technology and in growing clones of superior performance.

The weight relation between the ripe fruit and hulled coffee beans can be estimated considering two different steps: drying and pulping. During drying, the fruit loses most of the water in its tissues and takes on a dark color, when it comes to be called dry cherry coffee. Studying weight reduction in this step allows to identify plants that store less water in their fruit. In the following step, the fruit is pulped through separation of the seed from the dry hull of the fruit. A study of the weight reduction in this step allows inferences to be made regarding the relation between hull and coffee bean content. At the end of drying and pulping, the seeds are called hulled coffee beans.

Fruit set and bean formation in the fruit are traits affected by both the genotypes and the environments [11,12]. The most important environmental factors are the soil, altitude, management practices, harvest and post-harvest procedures, such as drying, hulling and storage, which interact with each other in expression of the physical traits of the coffee fruit and beans [13,14].

A change in performance of genotypes grown in different environments is important in selection, which should be conducted in different edaphoclimatic and crop management conditions to identify genotypes with wide or specific adaptabilities. Studies of G×E interactions test the hypothesis that plants change their performance when grown in different locations.

Significant effects of the genotype × environment interaction arise from a non-additive relation of genotype and environment effects, due to changes in plant performance according to growing location [15,16]. Because of this diversity among the Western Amazon environments, the occurrence of genotype by environment interactions of simple and complex types is expected, with the latter being characterized by differences in genotype performances when the plants are grown in different locations [17].

Embrapa Rondônia has sought to offer new options for coffee growing and to increase the genetic variability of coffee growing in the Western Amazon. For that purpose, it has developed ten new cultivars with high yield potential and with agronomic traits typical of the Conilon and Robusta botanical varieties [3,18].

In this scenario, the aim of this study is to characterize the outturn index of ten cultivars evaluated in different environments of the Western Amazon considering environment and genetic effects in the expression of this trait.

2. Materials and Methods

2.1. Field Trials

In December 2018 and January 2019, two clonal competition trials were set up in different environments of the Western Amazon, described below.

The trial in Porto Velho, RO (E1) was set up in the experimental field of the Empresa Brasileira de Pesquisa Agropecuária (Embrapa) at 8°48′05.5″ S and 63°51′02.7″ W at 88 m above sea level. The predominant climate in the region is tropical rainy with a dry winter, type "Am" (Köppen), with a 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) [19].

The trials in Ouro Preto do Oeste, RO, were conducted under dryland (E2) and irrigated (E3) conditions in the experimental field of Embrapa at 10°43′55.3″ S and 62°15′23.2″ W at 245 m above sea level. The climate of the municipality is type "Aw" by the Köppen classification, defined as tropical humid with a dry winter and rainy summer. With a mean annual temperature of 26 °C, the highest temperatures occur in July and August [19]. Crop treatments were carried out according to Marcolan et al., 2009 [20]. During the period of flowering, bean formation, and maturation of the fruit, climate data were recorded in Ambient Weather WS2902 smart weather stations (Figure 1). The chemical properties at the 0–10 and 20–40 depth layers are shown in Table 1.

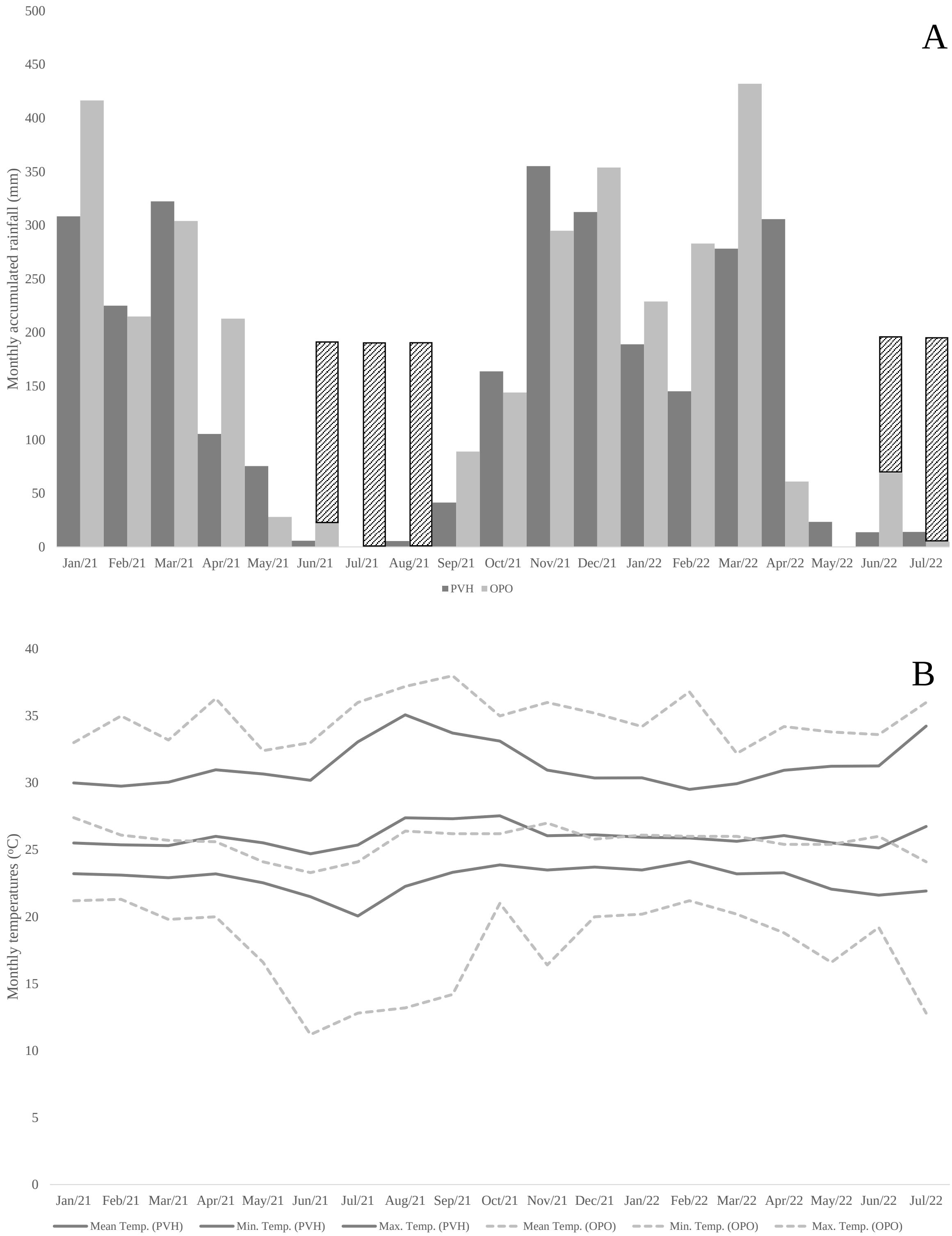

Figure 1. Monthly accumulated rainfall (**A**) and maximum, mean, and minimum temperatures (**B**) from January 2021 to July 2022 in the environments of Porto Velho and Ouro Preto do Oeste, measured in the smart weather stations of CEPLAC and of the Usina de Santo Antônio. The razored area (**A**) represents supplementary irrigation managed in the months of June, July, and August in the Ouro Preto do Oeste environment.

Table 1. Chemical properties at the 0–10 and 20–40 depth layers of clonal competition trials conducted in two contrasting environments of the Western Amazon.

Environments	Depth Layer	pH	P	K	Ca	Mg	Al+H	Al	OM	V
	(cm)		mg dm^{-3}	cmolc dm^{-3}					g kg^{-1}	%
Porto Velho, RO (E1)	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
Ouro Preto do Oeste, RO (E2, E3)	0–20	5.2	15.00	0.23	2.42	0.66	4.95	0.10	18	40
	20–40	5.4	8.00	0.32	2.71	0.88	5.94	0.00	17	40

pH in water (1:2.5); O.M. by wet digestion; P and K by the Mehlich I method; exchangeable Ca, Mg, and Al; OM: organic material using 1 mol KC.

2.2. Experimental Design

A completely randomized experimental design was used in a factorial arrangement with six replications to quantify the effects of genotypes and environments and of the genotype × environment interaction [21]. In this study, 10 cultivars developed by Embrapa, selected for growing across regions of the Western Amazon, were evaluated (Table 2). The cultivars, identified by the prefix BRS, are clustered in three different compatibility groups and exhibit different maturation cycles (early, medium, and late) [3,8].

Table 2. Listing of the clones evaluated in clone competition trials evaluated in three environments of the Western Amazon: E1—Porto Velho dryland, E2—Ouro Preto do Oeste dryland, E3—Ouro Preto do Oeste irrigated.

Clone	Maturation Cycle	Compatibility Group	Genealogy
BRS 1216	Medium	I	EMCAPA03 × IAC1675
BRS 2299	Medium	II	Open pollination
BRS 2314	Late	II	EMCAPA03 × IAC640
BRS 2336	Late	II	Open pollination
BRS 2357	Late	II	Open pollination
BRS 3137	Early	III	Open pollination
BRS 3193	Early	III	Open pollination
BRS 3210	Medium	III	EMCAPA03 × IAC2258
BRS 3213	Medium	III	EMCAPA03 × IAC2258
BRS 3220	Medium	III	EMCAPA03 × IAC1675

BRS genotypes were registered in MAPA/RNC (2019) (Teixeira et al., 2020). IAC: Instituto Agronômico de Campinas, EMCAPA: Empresa Capixaba de Pesquisa Agrícola.

The genotypes were harvested when 80% of the fruits were in the red-cherry stage, according to the maturation cycle of each genotype: early, medium, or late. Samples of washed cherry coffee collected separately for each clone were dried naturally on raised drying beds for a time ranging from 10 to 15 days until reaching a moisture content near 12%, evaluated in a Gehaka (G600) grain moisture meter. Samples of 250 g of dry cherry coffee were pulped in a Botini manual coffee pulping machine, followed by separation in a Pinhalense brand sieve set. From the reduction in weight observed in drying (estimated by the relation between the weight of the dry cherry coffee and the weight of the cherry coffee) and the reduction in weight observed in pulping estimated by the relation: weight of the coffee beans/(weight of coffee beans + weight of the hull), corrected to 12% moisture, the outturn index estimates were obtained according to the following expression:

$$Outturn\ index = \left(\frac{m_{dry\ cherry}}{m_{from\ field}}\right) \cdot \left(\frac{m_{beans}}{m_{beans} + m_{hull}}\right) \cdot F_{moist12\%} \quad (1)$$

where *Outturn index* was estimated by the reduction in weight that occurred in the drying process from the relation between the weight of the dry cherry coffee ($m_{dry\ cherry}$) and the weight of the coffee from the field ($m_{from\ field}$), together with the reduction in weight that occurred in the pulping process, estimated by the relation between the weight of the coffee beans (m_{beans}) and the weight of the fruit ($m_{beans} + m_{hull}$), corrected to 12% moisture ($F_{moist12\%}$). Moisture was determined with six replications in a Gehaka (G600) grain moisture meter and corrected to 12%, which is the moisture content at which coffee beans are traded [22].

The significance of the clone effect on the weight after drying and pulping in each environment was tested individually, according to the model described by Cruz et al., 2013 [21], as follows:

$$Y_{ij} = m + G_i + e_{ij} \quad (2)$$

where Y_{ij} refers to the observation of the ith genotype in the jth replication, m is the experimental average, G_i is the effect of the ith genotype, and e_{ij} is the experimental error of all of the observations in the experiment.

Subsequently, the homogeneity of residual variances was verified and combined analysis of variance was performed to quantify the G×E interaction effect, according to the following model described by Cruz et al., 2013 [21].

$$Y_{ijk} = m + G_i + E_j + GE_{ij} + e_{ijk} \quad (3)$$

where Y_{ijk} refers to the observation of the ith genotype in the jth environment, m is the experimental average, G_i is the effect of the ith genotype, E_j is the effect of the jth environment, GE_{ij} is the effect of the interaction between the ith genotype and the jth environment, and e_{ijk} is the experimental error. The genotypic effect was considered fixed and the environmental effect was random.

The centroid method was used to estimate stability and adaptability, considering the vector data of maximum and minimum genotype performances in each environment. These vectors provided references of the "ideal" minimum (min), medium (med), and maximum (max) performances of the genotypes in favorable (f) and unfavorable (uf) environments [17]. The clones were classified based on the Euclidean distance between the genotype and the known behavior reference (centroids), according to the following model:

$$D_{ik} = \sqrt{\sum_{j=1}^{n} (x_{ij} - c_{jk})^2} \quad (4)$$

where D_{ik} is the Euclidian distance from the ith genotype to the kth centroid ($k = 1, 2, \ldots n$), x_{ij} is the performance of the ith genotype in the jth environment, and c_{jk} is the performance of the kth centroid in the jth environment. Based on these distances (D_{ik}), the genotypes were classified as follows: I = high overall adaptability—max(f) and max(uf), II = adaptability specific to favorable environments—max(f) and min(uf), III = adaptability specific to unfavorable environments—min(f) and max(uf), IV = low adaptability—min(f) and min(uf), V = medium overall adaptability—med(f) and med(uf), VI = adaptability specific to favorable environments—max(f) and med(uf), and VII = adaptability specific to unfavorable environments—med(f) and max(uf) [23].

To quantify the adaptability and stability of the genotypes in different environments, the estimator proposed by Lin and Binns, 1988 [24] was considered to estimate the Euclidean distance between the genotypes and the ideal plant of superior performance in all environments. All statistical analyses were performed using the R Statistical Software [25] and the GENES software [21].

3. Results

Prior to interpretation of the combined analysis of variance, individual analyses of variance were considered to evaluate the quality and accuracy of the experiments in each of the environments. Low estimates of the coefficient of variation (CV < 10%) and of the low relation between the highest and lowest estimates of residual variance (5.9) indicate the quality of the individual experiments for carrying out combined analysis.

The environments were classified as favorable or unfavorable based on the environmental quality index (Ij), which is defined as the contrast between the performance of each environment and the mean of all of the environments [21]. The non-irrigated environment of Porto Velho (E1) was classified as unfavorable compared with the non-irrigated and irrigated environments of Ouro Preto do Oeste (E2 and E3), which exhibited positive environmental effects in expression of the outturn index ($I_{j\,E1} = -0.88$, $I_{j\,E2} = 0.30$, $I_{j\,E3} = 0.85$).

To evaluate this trait, the effects of genotypes and environments and of the genotype × environment interaction were interpreted (Table 3). Combined analysis indicates that the effects of genotypes, environments, and of the genotype × environment interaction were significant at 1% probability. When there is interaction, the response of the clone should be interpreted individually in each environment, considering the effects of genotypes and of environments (Table 3).

Table 3. Summary of F test and genetic parameter estimates of weight after drying and pulping and outturn of ten Amazonian Robusta cultivars evaluated in three environments of the Western Amazon.

SV	DF	Drying	Pulping	Outturn
Clones (G)	9	3.86 **	6.54 **	7.86 **
Environments (E)	2	537.38 **	45.84 **	133.29 **
G×E	18	28.31 **	20.19 **	11.31 **
Residue	150			
Total	179			
Overall mean		46.12	53.01	24.44
Mean E1		43.68 a	53.97 a	23.57 a
Mean E2		46.47 b	52.70 a	24.47 b
Mean E3		48.23 c	52.49 a	25.29 c
CV_e		1.65	1.72	2.37
H^2		74.13	84.72	87.29
CV_g		3.52	4.29	4.92

$CVe = 100 \cdot \sqrt{MSR}/\bar{x}$; $CVg = 100 \cdot \sqrt{\hat{\theta}_g}/\bar{x}$; $H^2 = \hat{\theta}_g/\hat{\sigma}_f^2$ SV: source of variation, DF: degrees of freedom, CVe: experimental coefficient of variation, H^2: coefficient of genotypic determination, CVg: genetic coefficient of variation, **: significant at 1% probability, $\bar{x}$: overall mean, $\hat{\theta}_g$: genotypic determination coefficient, $\hat{\sigma}_f^2$: phenotypic variance. Mean values of environments followed by the same lowercase letters do not differ statistically according to the Scott Knott test at 5% probability. E1—Porto Velho dryland, E2—Ouro Preto do Oeste dryland, E3—Ouro Preto do Oeste irrigated.

The coefficient of genotypic determination (H^2), understood as the relation between the genotypic and environmental variations, indicates that the weight of the coffee beans after pulping exhibits greater genotypic control than the weight maintained after drying the beans. The weight after drying exhibited greater differences among the environments compared with the weight after pulping, which exhibited a greater contrast among different genotypes (Table 4). The estimates of the experimental coefficient of variation (CVe) can be considered to be low, indicating that the experiment was well conducted, and the higher estimates of the genetic coefficients of variation (CVg) support the genotypic nature of the difference among the plants.

The weights remaining after drying showed a G×E interaction of the complex type, which is characterized by a change in the ordering of the genotypes from one environment to another (Figure 2). The clones BRS 1216, BRS 2299, BRS 2314, BRS 3137, and BRS 3193 had greater weights after drying in the irrigated environment compared with their performance in the dryland environments (Table 4 and Figure 2). The differentiated performance of the genotypes can be observed in a single representation by the difference among the lines that represent the outturn index in environments E1, E2, and E3 in the radar chart (Figure 2).

Table 4. Weight after drying, after pulping, and outturn index of ten Amazonian Robusta cultivars evaluated in three environments of the Western Amazon: E1—Porto Velho dryland, E2—Ouro Preto do Oeste dryland, E3—Ouro Preto do Oeste irrigated.

Clone	Weight after Drying (%)			Pi
	E1	E2	E3	
BRS 1216	44.10 c	46.83 b	50.50 b	3
BRS 2299	43.50 d	46.67 b	48.83 c	5
BRS 2314	44.70 b	45.00 c	47.17 d	6
BRS 2336	41.80 e	46.00 b	48.00 c	8
BRS 2357	42.30 e	44.33 c	42.83 f	9
BRS 3137	46.60 a	48.83 a	51.03 a	1
BRS 3193	43.80 c	47.17 b	51.01 a	2
BRS 3210	43.00 d	47.33 b	45.83 e	7
BRS 3213	41.70 e	42.83 d	44.00 d	10
BRS 3220	45.20 b	48.00 a	47.00 d	4
Clone	**Weight after Pulping (%)**			**Pi**
	E1	**E2**	**E3**	
BRS 1216	58.50 a	58.67 a	56.00 a	1
BRS 2299	53.50 c	51.83 e	51.17 e	7
BRS 2314	49.83 e	50.33 f	47.67 g	10
BRS 2336	54.33 c	53.00 d	51.17 e	6
BRS 2357	57.67 a	54.00 c	54.83 b	3
BRS 3137	50.33 e	50.83 f	52.00 e	8
BRS 3193	52.67 d	50.50 f	49.17 f	9
BRS 3210	52.50 d	52.83 d	54.17 c	5
BRS 3213	54.00 c	55.50 b	52.83 d	4
BRS 3220	56.33 b	55.00 f	56.17 a	2
Clone	**Outturn (%)**			**Pi**
	E1	**E2**	**E3**	
BRS 1216	25.96 a	27.45 a	28.43 a	1
BRS 2299	23.32 c	24.07 c	24.88 d	5
BRS 2314	22.23 d	22.67 d	22.52 f	10
BRS 2336	22.70 d	24.40 b	24.58 d	8
BRS 2357	24.33 b	23.95 c	23.50 e	7
BRS 3137	23.43 c	24.73 b	26.52 b	3
BRS 3193	23.11 c	23.95 c	25.00 c	6
BRS 3210	22.67 d	25.08 b	24.70 d	4
BRS 3213	22.47 d	23.65 c	23.32 d	9
BRS 3220	25.44 a	26.40 b	26.20 c	2

Mean values of clones followed by the same letters do not differ statistically from each other according to the Scott Knott test at 5% probability. E1—Porto Velho dryland, E2—Ouro Preto do Oeste dryland, E3—Ouro Preto do Oeste irrigated. The clones were ordered according to the general Pi of Linn and Binns, which orders the genotypes according to their proximity to an ideal reference of maximum performance in all environments.

The weight after pulping showed predominantly genotypic variation and a simple type G×E interaction, in which the genotypes tend to maintain their performance in different environments. The outturn index estimated by maintenance of weight after these two steps, drying and pulping, was of an intermediate level compared with the maintenance of weights after drying and pulping.

The clones that had the greatest weights after drying were BRS 3137, BRS 3193, and BRS 1216, while the clones that had the greatest weights after pulping were BRS 1216, BRS 3220, and BRS 2357. The cultivars with the highest outturn index were the clones BRS 1216, BRS 3220, and BRS 3137 (Table 4). The mean performance of the clones in all of the environments, discriminating the moisture, hull, and bean contents, is shown in Figure 2 (letter D).

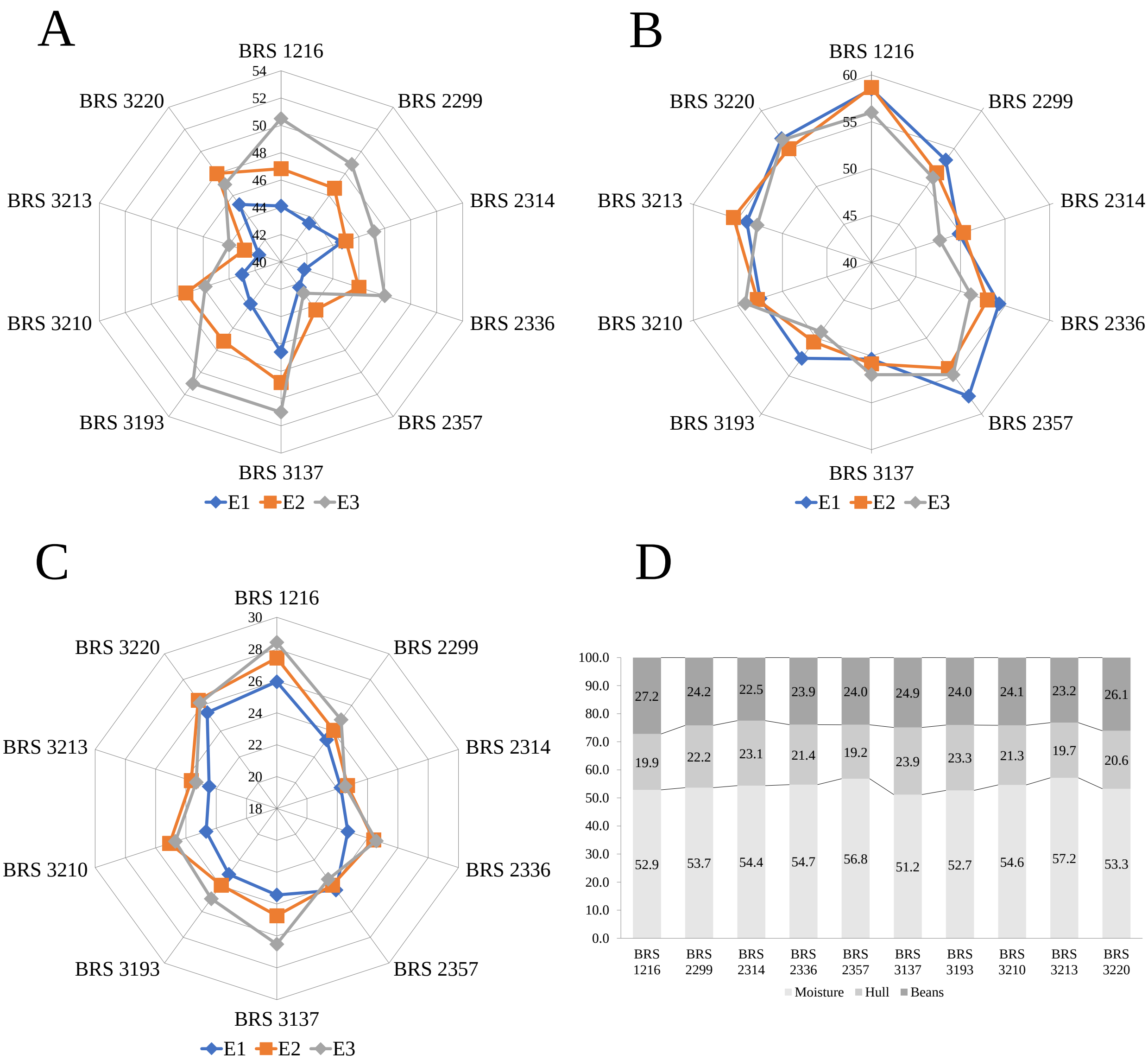

Figure 2. Distribution of weight values after drying (**A**), distribution of weight values after pulping (**B**), and outturn index estimates (**C**) of ten Amazonian Robusta cultivars evaluated in the environments of Porto Velho, RO, and Ouro Preto do Oeste, RO, without irrigation (E1, E2) and Ouro Preto do Oeste, RO, with irrigation (E3). The letter (**D**) identifies the average genotype performance in relation to their moisture, hull, and bean content.

The scatter plot of the first two principal components associated with reference points of maximum, minimum, and specific performance to favorable and unfavorable environments represents the outturn index of all genotypes in all of the environments (Figure 3). The genotypes BRS1216 and BRS2314 have a response similar to the ideotypes of maximum and minimum performance. The clone BRS 3220 had better adaptation to the unfavorable environment of Porto Velho, whereas the other clones had an outturn index near the mean of the cultivars. The clones of greatest weight after drying were better adapted to the favorable environments, while the higher weight after pulping is a trait of the clones of greater outturn index.

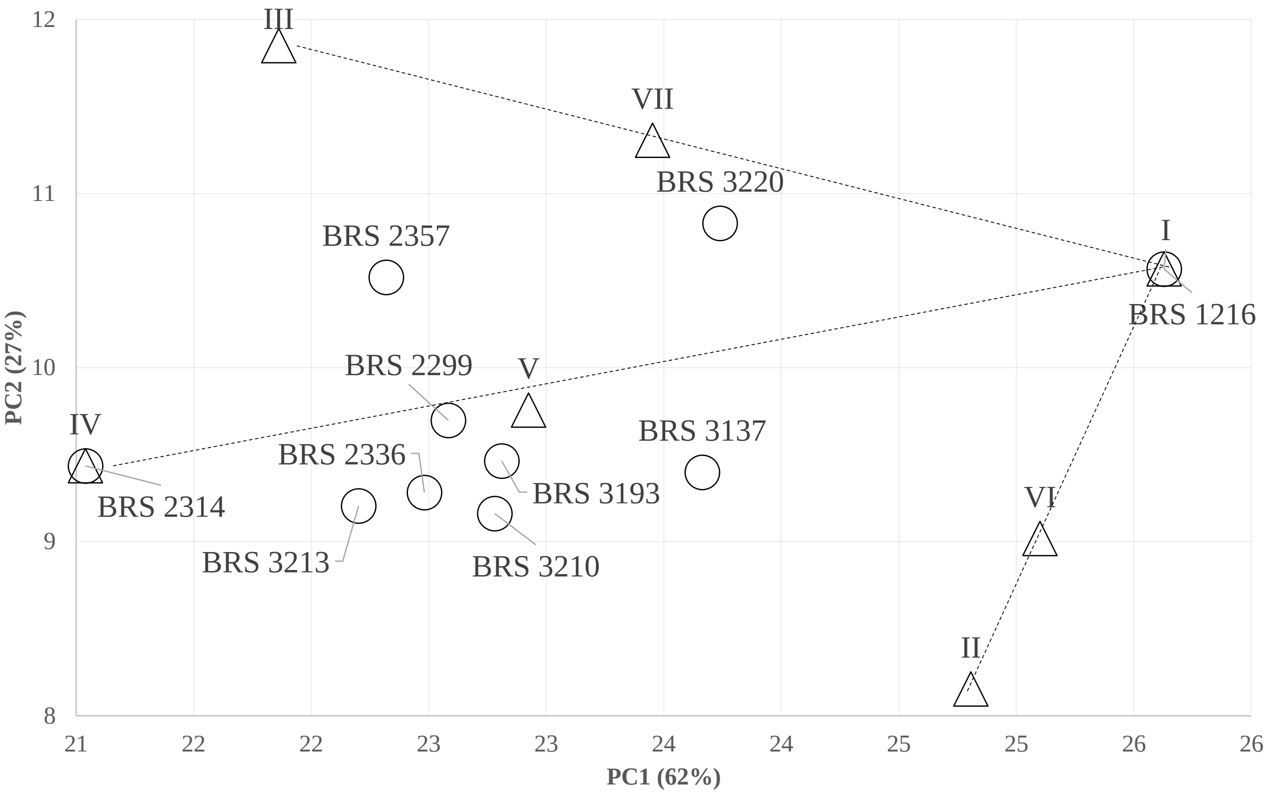

Figure 3. Scatter plot of the first two principal components of the outturn index of ten Amazonian Robusta cultivars evaluated in the environments of Porto Velho, RO (E1), and Ouro Preto do Oeste, RO, with and without irrigation (E2, E3). Roman numerals identify reference points of wide adaptation or specific adaptation to the environments evaluated.

4. Discussion

One of the main traits of the *C. canephora* coffee plant is its cross-pollination system, which is associated with wide natural genetic variability [5]. In general, in this species, the outturn index exhibits values ranging from 22% to 26% [1,10]. In the evaluation of 43 clones in a single environment in the municipality of Nova Venecia, ES, Partelli et al., 2021 [26] found an amplitude from 21.74% to 31.25%. Fialho et al., 2022 observed that the estimate of 25% may be used to represent most of the plants in a germplasm collection.

Although the outturn index is an important component of hulled coffee yield, this trait has not yet been greatly examined in breeding of *C. canephora*, and we did not find studies in the literature considering evaluation of the outturn in different environments. In *Coffea arabica* species, Gaspari-Pezzopane et al., 2005 [27] observed a tendency of an increase in outturn as the altitude of the environment increased. The same *C. arabica* line had 6% greater outturn when grown at 1280 m compared with growing at 950 m. The lesser difference in altitude of the environments in which *C. canephora* is grown in the Western Amazon resulted in lesser contrast among the genotypes' performance.

The region in which coffee is grown in the Western Amazon is in climate types Am and Aw, characterized as typical tropical climates, hot and humid, with low annual thermal amplitude and expressive daily thermal amplitude from May to September [19]. The Porto Velho environment is also characterized by acid soils of low natural fertility and Am type climate, an environment typical of the coffee plants grown in the North region of Rondônia state. Whereas the environment of Ouro Preto do Oeste is characterized by soils of greater fertility and Aw climate type, characteristic of the coffee fields in the South of this region, which has geographical indication called "Matas de Rondônia" (Rondônia Forests) [28].

The greater base saturation of the environment of Ouro Preto do Oeste (V = 40%), which favors plant growth in comparison with the environment of Porto Velho (V = 16%), also favored the greater outturn index observed in this environment, even under non-irrigated conditions. Although it is less than the contrast observed between locations of low and high altitudes, the difference observed in the Western Amazon environments is greater than the differences observed by Gaspari-Pezzopane et al., 2004 [12] upon comparing the outturn index from different parts of the plants (lower third, middle third, and upper third) and from different positions (north, south, east, and west exposure).

Nevertheless, not only the environment, but also genetic factors affected the outturn index of these coffee plants (Table 3). This species is differentiated by its greater adaptation to tropical regions and its high genetic variability for physical traits of the fruit, such as volume, weight, and shape, as well as hull, bean, and water content [4,29]. Significant effects of the genotype × environment interaction in coffee plants are also observed for other traits, such as hulled coffee yield and beverage quality [3,4].

The outturn index studied here is estimated considering the reduction in weight that occurred during drying and pulping. The reduction in weight due to drying was more affected by the environment than the reduction in weight after pulping. The clones BRS1216, BRS2299, BRS2314, BRS3193, and BRS3137 that had greater weights after drying in the irrigated environment are the clones that had greater adaptability to the environment of better growing conditions of Ouro Preto do Oeste (Figure 3). In this context, adaptability can be understood as the ability of a cultivar to respond to an improvement in environmental conditions.

As greater water availability favors bean formation and water deficit in the young green coffee cherry phase delays fruit growth [14], greater availability of water in the irrigated environment resulted in greater weights remaining after drying. The greater estimates of genetic parameters of the weight maintained after pulping also indicate that this trait is less affected by the environment and is more determined by genetics (Table 3 and Figure 2).

In the studies available in the literature, the discrimination between drying and pulping is a question even less explored, as the intrinsic outturn that considers only the step of pulping of the already dry fruit does not represent the final outturn index. Gaspari-Pezzopane et al., 2004 [12] evaluated the intrinsic outturn of 79 genotypes in a single environment, and they observed a variation from 48% to 62% in the weight maintained after pulping of 10 accessions of *C. canephora*.

In a practical manner, the farmer considers the ratio of 4:1 between the weight of the coffee fruit from the field and the weight of the hulled coffee [10]. However, the genetic variability in the outturn index has an impact on the final yield of the coffee crop. Of a total of 43 clones evaluated in a single environment by Partelli et al., 2021, a comparison between the genotypes of highest and lowest outturn indicate a difference of 9.51%, which represents a difference of approximately 10 bags in every 100 bags of hulled coffee, simply because of the difference in the outturn index among these materials.

A lesser contrast was observed between the most divergent clones BRS1216 and BRS2314 evaluated in this study (4.7%) (Table 4). This characterization is important for management of these plants, considering that the outturn is one of the components of final yield of hulled coffee, and this becomes important with the use of technologies in crop management.

Individual characterization of these cultivars allows them to be grown with flexibility in the composition of the crop fields, according to the grower's preference, and genotypes are selected for different reasons [3,18]. In addition to a superior outturn index, the clone BRS1216 also stands out for its greater yield potential in different environments, while the clone BRS2314 has been grown for its greater potential for producing a quality beverage [14].

Considered together, the genotypes had a mean outturn of 24.41%, with an amplitude from 22.5% to 27.2%. The clones BRS1216, BRS 3220, and BRS3137 had the highest outturn index estimates and the clones BRS2314, BRS3213, and BRS2336 had the lowest outturn index estimates. The clones BRS2299, BRS3210, BRS3193, and BRS2357 had performance near the mean value of this group of genotypes.

The selection of superior materials, plant nutrition, thinning, irrigation, and pest and disease control are activities that are part of the routine of coffee growers of the region of geographical indication called "Matas de Rondônia" [28]. With the yield increase, the outturn index comes to be an important trait that reveals expression of a genetic nature affected by the moisture, hull, and bean content of each genotype in different growing environments. Empirical field observations have shown a greater hull content of genotypes of the Robusta botanical variety, suggesting the importance of carrying out other studies considering the characterization and use of this genetic diversity.

5. Conclusions

The relation between the ripe fruit and hulled coffee beans is an important component of *C. canephora* bean yield. Although the outturn index is an important hulled coffee yield component, this trait has not yet been greatly exploited in breeding *C. canephora*. Genetic factors are important for this trait, which depends on the moisture, hull, and bean contents of each genotype. In general, greater soil fertility favored a greater outturn, even under non-irrigated conditions. A reduction in weight due to drying was more affected by the environment than a reduction in weight after pulping. The clones BRS1216, BRS 3220, and BRS3137 had the highest outturn index estimates and the clones BRS2314, BRS3213, and BRS2336 had the lowest outturn index estimates. The clones BRS2299, BRS3210, BRS3193, and BRS2357 had performance near the mean value of this group of genotypes. Considered together, the genotypes had a mean yield percentage of 24.41%, with an amplitude from 22.5% to 27.2%.

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