AGRO PRODUCTIVIDAD

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Plant selection using a sequential decision algorithm based on an ideotype

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ABSTRACT

Objective: Develop a sequential decision algorithm to select plants in populations without repetitions based on an ideotype, using a logical process that employs everything from spreadsheets to programming languages.

Design/methodology/approach: A sequential algorithm based on conditional logic is proposed that implements a multi-criteria filtering process. The algorithm can be implemented on different numerical analysis platforms as it is based on a sequential logical decision process. To validate its application, a selection was made from a population of 60 coffee plants (*Coffea arabica* L.) of the Sarchimor T5296 variety, using Excel as the platform and the AND function due to its accessibility.

Results: Nine plants were selected that exhibited the desired characteristics of yield, plant height, canopy diameter, bienniality (I), and resistance to orange leaf rust, demonstrating the algorithmic selection capability.

Limitations on study/implications: The method has limitations inherent to its binary sequential design: (1) it does not differentially weight the importance of criteria, (2) it does not consider negative correlations between characters in simultaneous selection, and (3) it depends on thresholds defined *a priori*.

Findings/conclusions: The algorithm made it possible to select plants with behavior similar to or superior to the ideotype in contexts where conventional statistical methods are not applicable because they require replicated experimental designs.

Keywords: Plant breeding, Numerical method, Sequential logic, Phenotypic traits.

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INTRODUCTION

Ideotypes are biological models based on traits like productivity, physiology, and environmental adaptation. These traits help select the best plants for genetic improvement (Donald, 1968; Dickmann *et al.*, 1994; Carbajal-Friedrich and Burgess, 2024). An ideotype helps identify potential parent plants in a population by their phenotype (Gauffreteau, 2018). To use this method, we need to define the desirable traits in plants. These traits relate to production and responses to biotic and abiotic factors (Dickmann *et al.*, 1994). Trials are crucial for studying how a plant population performs and for choosing the

best individuals based on the ideal type criteria through mass selection (Breseghello and Coelho, 2013). The trials should involve enough plants to find those with the desired traits (Cortina *et al.*, 2013).

However, traditional selection methods can be slow and biased. Many plant breeders perform these tasks by hand, which leads to inefficiencies (Azimzadeh *et al.*, 2010). Researchers have developed various numerical and computational methods to improve this. Hazel's selection indices (1943) assign weights to traits based on their economic importance. Pešek and Baker (1969) focus on desired genetic gain. Mulamba and Mock (1978) suggest a non-parametric index to rank traits' importance. Mendes *et al.* (2009) suggest using standardized trait measurements and choosing those with the best scores. Rocha et al. (2018) introduced the FAI-BLUP Index, which selects genotypes close to the ideotype. The MGIDI by Olivoto and Nardino (2021) selects genotypes nearest to ideal values.

In coffee cultivation (*Coffea arabica* L.), the main selection indices are: Mulamba and Mock index, standardized values index, FAI-BLUP Index, and MGIDI (Piza *et al.*, 2023; Berny Mier and Teran *et al.*, 2025). Evaluated traits include: productivity, rust resistance (*Hemileia vastatrix* Berk & Broome), resistance to fruit rot (*Colletotrichum kahawae* J. M. Waller & Bridge), number of empty fruits, cup quality, and size (Mishra, 2019). The implementation of these indices in coffee cultivation typically involves the use of statistical packages such as SAS or R, which need programming knowledge (Rahimi and Debnath, 2023). Specific R packages exist for MGIDI and FAI-BLUP Index (Resende, 2016; Olivoto and Nardino, 2021). Many multivariate selection methods must at least three replicates for each genotype. This is necessary to estimate variance and genetic parameters with precision. This requirement restricts their use in everyday situations: (1) established commercial plantations, (2) germplasm banks with one individual per accession, (3) smallholder populations, and (4) species in domestication.

This paper presents a new algorithm for selecting the best ideotype in populations with limited replicates. The algorithm follows a logical process and works on many platforms, like spreadsheets and programming languages.

MATERIALS AND METHODS

Development of the sequential algorithm

The algorithm uses a sequential filtering process in which each criterion of the ideotype functions as an independent logical filter. A plant is selected when it meets all conditions at the same time (Equation 1).

$$\textit{Selected individual} = C1 \text{ AND } C2 \text{ AND } C3\ldots \text{ AND } Ci \qquad (1)$$

Where: AND represents the logical conjunction operator; *Ci* is a condition of the type: *Ci*: Variable_i θ Threshold_i with $\theta \in \{<, >, \leq, \geq, =\}$ according to the selection criteria established in the ideotype.

To demonstrate its accessibility, it was implemented in Excel$^{©}$, although the logical process is platform-independent and can be implemented in any environment that supports conditional operations (R, Python, SAS, database systems, etc.). The logical function used was "AND", which allows determining whether all the conditions of a test are true. When plants meet all the conditions of the ideotype (phenotypic traits), the function shows the true value of the argument (Equation 2). The variables and parameters (ideotype) used to demonstrate the application of the algorithm were: minimum average yield (X1), bienniality index I (X2), maximum plant height (X3), maximum canopy diameter (X4), and rust resistance index IRs (X5).

$$\textit{Selected individual} = \text{AND}\left(\textit{Yield} > X1, l < X2, \textit{Height} < X3, \textit{canopy} < X4, \textit{IRS} < X5\right) \quad (2)$$

The ideotype for the population of plants of the Sarchimor T5296 variety was defined by two variables related to fruit productivity (yield and bienniality), two related to plant morphology (plant height and canopy diameter), and one related to rust resistance (Figure 1). For productivity, a minimum yield of 4,000 g was considered, and for bienniality,

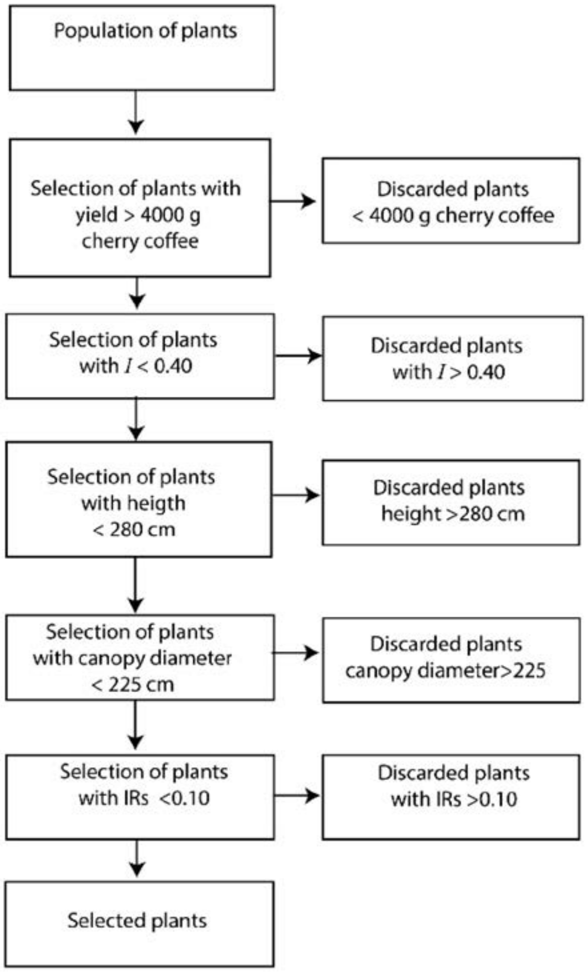

Figure 1. Flowchart for implementing the plant selection algorithm.

the index proposed by Hoblyn *et al.* (1937) with an $I>0.40$ was considered. In terms of morphology, the aim is to develop compact plants, establishing a maximum height of 280 cm and a maximum canopy diameter of 225 cm. Regarding resistance to *H. vastatrix*, the rust resistance index proposed by Couttolenc-Brenis *et al.* (2023) with an $IRs>0.1$ was used.

Vegetative material

The algorithm and the Excel© function were tested with data collected between 2020 and 2022. This data was from a group of 60 plants of the Sarchimor T5296 variety. This material comes from crossing the Timor Hybrid CIFC 832/2 with Villa Sarchi 971/10. This was done in 1959 at the Coffee Rust Research Center (World Coffee Research, 2019). In 2016, certified seed was acquired from the Los Cafetalones farm in San Juan Acotenango, Guatemala, and in July 2017, the plantation was established at the Teocelo Experimental Site as part of the project "Strategy to strengthen state innovation centers and boost the productivity and quality of Mexican coffee", under the agreement between INIFAP and AMECAFÉ.

Location

The plants are in the rust-resistant variety garden, part of the coffee germplasm bank. This is at the Teocelo Experimental Site in Teocelo, Veracruz. The site is located at a latitude of 19° 23' 34.1" N and longitude of 97° 00' 03.5", at an elevation of 1,250 meters above sea level. Annual rainfall is 2,063 mm. The average temperature is 20 °C. The max average reaches 25 °C, and the min average is 14 °C. The soils are from andosol-type volcanic ash (Couttolenc-Brenis *et al.*, 2023).

Variables

In 2021, morphological variables were measured: plant height and canopy diameter. The average yield was obtained during the 2019-2020, 2020-2021, and 2021-2022 harvest cycles. The biennial variation was estimated using the bienniality index proposed by Hoblyn *et al.* (1937), Equation 3, to represent the variation between one harvest and another. The Resistance Index (IRs) to *H. vastatrix* was estimated using Equation 3 (Couttolenc-Brenis *et al.*, 2023).

$$I=\frac{1}{n-1}\sum\left(R_{T1}-R_{T0}\right)/R_{T0}+\left(R_{T2}-R_{T1}\right)/R_{T1}+\ldots\left(R_{Ti}-R_{Tn}\right)/R_{Tn} \qquad (3)$$

Where: I=Bienniality index; R_{T0}=Yield at time 0; R_{T1}=Yield at time 1; R_{T2}=Yield at time 2; R_{Ti}=Yield at the ith time; R_{Tn}=Yield at the nth time.

$$IRs=\left(PS\cdot NHI\right)/\left(PT\cdot NHT\right) \qquad (4)$$

Where: IRs=Resistance Index; PS=Pustules with sporulation; PT=Total pustules; NHI=Number of infected leaves; NHT=Total number of leaves.

Statistical analysis

To determine if there were significant differences between the observed and estimated variables, a t-test was conducted using the statistical software Infostat© (Di Rienzo *et al.*, 2011). The program also provided key statistics, including the mean, standard deviation, and coefficient of variation.

To characterize the population and contextualize the selection results, phenotypic correlation analyses were performed using Pearson's coefficient among the five ideotype variables. Additionally, principal component analysis (PCA) was employed to visualize the multivariate structure of the population and the positioning of the selected plants. Efficiency analysis was conducted by calculating the percentage of plants eliminated at each stage of sequential filtering in R.

RESULTS AND DISCUSSION

The t-test revealed significant differences ($p<0.05$) among the 60 Sarchimor T5296 plants regarding the observed and estimated variables that define the ideotype. These results indicated that at least one plant may possess the desired traits for selection in the coffee breeding program. Among the five variables, the highest coefficient of variation (CV) was found in IRs at 52.42%, followed by average yield at 34.64%. This suggests that exceptional individuals can be identified within this Sarchimor population for further evaluation in new cultivar development.

Previous studies, such as Cardoso *et al.* (2016), reported yield CVs ranging from 7.68 to 9.32, while rust resistance variables had CVs from 12.79 to 14.67. Botelho *et al.* (2010) found CVs of 28.32 for yield and 38.2 for rust severity in progenies from the Catimor and Icatu cross. However, these studies did not factor in yield variation for genetic improvement, which is determined by the biennial index (I) (Hoblyn *et al.*, 1937; Merga *et al.*, 2023). The Sarchimor T5296 population showed an average I of 0.42, indicating significant biennial variation, compared to 0.31 reported by Merga *et al.* (2023) in a genotype trial in Ethiopia. Some individuals in the population had I values below 0.40, making them candidates for selection.

Phenotypic Correlation

The phenotypic correlation matrix (Figure 2) highlighted significant relationships among five key traits for genetic improvement. The strongest association ($p<0.001$) was between yield and plant height (0.73), indicating that taller plants tend to be more productive,

Table 1. T-test values to identify significant differences in the variables of the population of Sarchimor T5296

Variable	n	Mean	SD	CV	Min	Max	T	p
Average yield (g)	60	3549.37	1229.44	34.64	624.87	5502.40	22.36	<0.0001
Bienniality index(I)	60	0.42	0.09	20.89	0.34	0.74	37.08	<0.0001
Height (cm)	60	247.78	31.36	12.65	150.00	313.00	61.21	<0.0001
Canopy diameter (cm)	60	192.43	24.51	12.74	115.00	242.50	60.81	<0.0001
Resistance index (IRs)	60	0.06	0.03	51.41	0.02	0.18	15.07	<0.0001

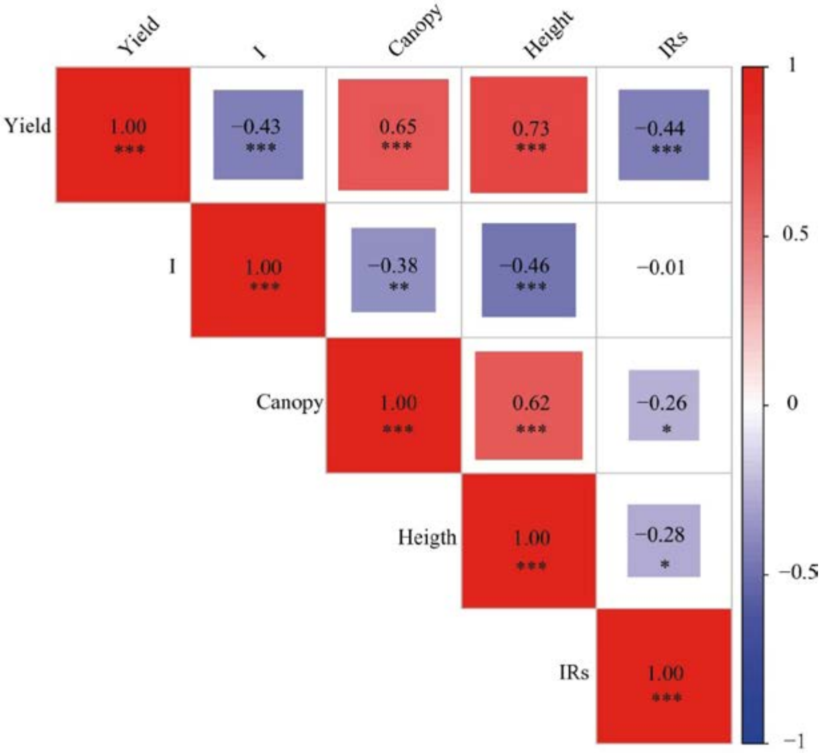

Figure 2. Phenotypic correlations between the variables used to select plants. Asterisks indicate the significance level of the correlation between variables (* $p<0.05$, ** $p<0.01$, *** $p<0.001$).

making height a valuable trait for indirect selection. Yield also showed a significant positive correlation ($p<0.001$) with canopy diameter (0.65), emphasizing that vegetative vigor, reflected in structural dimensions, is vital for productivity. To select materials, one of these variables could be prioritized, or the vigor index proposed by López *et al.* (2021) could be utilized, as both demonstrated a high correlation (0.62, $p<0.01$).

A notable finding was the negative correlation ($p<0.05$) between yield and bienniality (−0.43), suggesting that increased biennial expression could affect yield potential, highlighting a critical trade-off for plant breeders (Merga *et al.*, 2023). Additionally, bienniality was negatively associated with IRs at −0.01, which was not significant.

IRs showed a significant negative correlation ($p<0.001$) with yield (-0.44), indicating that rust resistance negatively impacts productivity, which is why this factor is commonly included in genetic improvement programs (Cardoso et al., 2016; Berny Mier and Teran et al., 2025). In summary, this correlation network informs selection: enhancing vigor (height/diameter) will improve yield, but caution is needed to avoid inadvertently increasing bienniality and maintaining low IR levels.

Implementation of the Sequential Algorithm

Using Excel's "AND" function, the algorithm selected nine plants from the 60 (Table 2). The yield variable eliminated 38 plants, plant height discarded five more, the biennial index excluded four, canopy diameter eliminated four plants, while IRs did not eliminate

Table 2. Characteristics of Sarchimor T5296 plants selected using the algorithm.

Planta	Yield (g)	Height (cm)	I	Canopy diameter (cm)	IRs
14	4388.93	0.37	272	225	0.04
18	4719	0.36	278.5	192.5	0.05
20	4219.87	0.34	249	192.5	0.03
25	5452.6	0.35	244	215	0.02
46	4287.87	0.34	270	162	0.06
47	5502.4	0.38	280	205	0.05
48	4215.47	0.37	262	205	0.08
51	5159.13	0.38	234	216	0.06
53	4524.8	0.37	278.5	182.5	0.05

any (Figure 3). Yield was the most effective variable for discarding plants, followed by height, canopy diameter, and bienniality.

This selection method is straightforward, for having the flexibility to implement it in Excel, though it has limitations compared to more advanced numerical approaches and

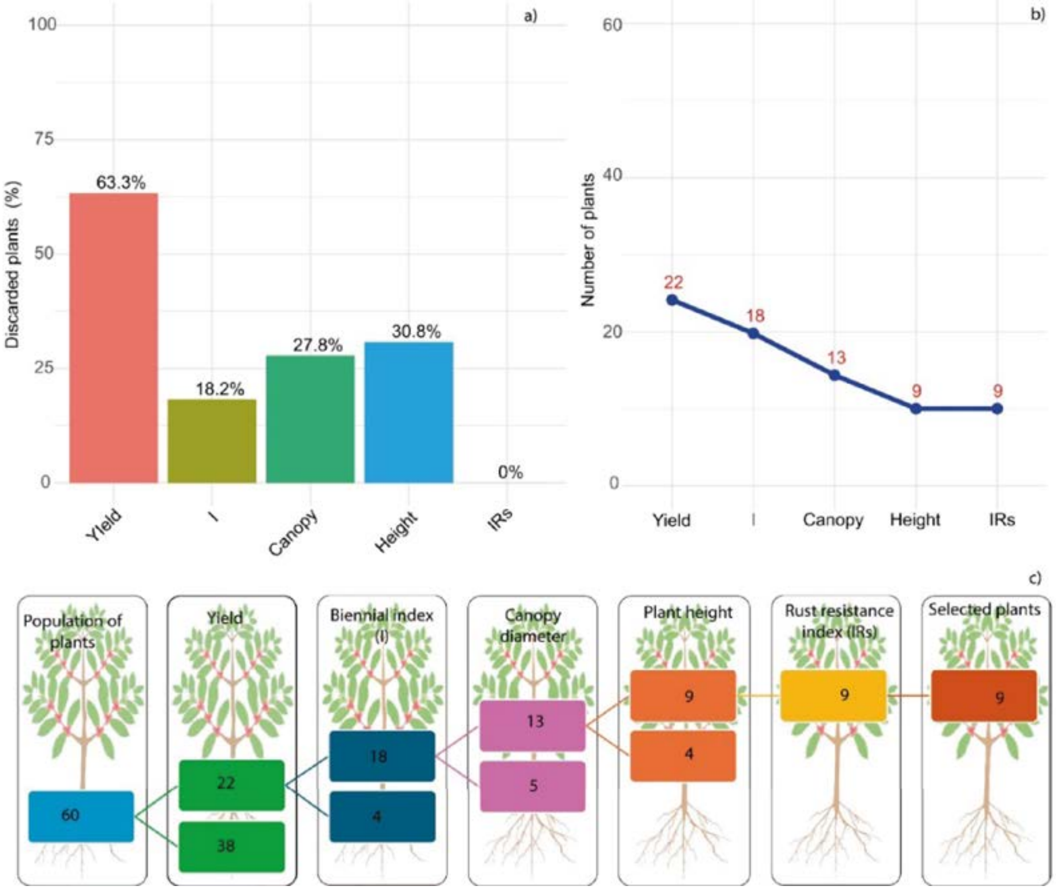

Figure 3. Selection process for the nine individuals with desirable traits for progeny trials. (a) Efficiency of each criterion for discarding plants at each selection stage. (b) Plants remaining selected at each stage. (c) Diagram of the overall selection process, highlighting selected and discarded plants.

specialized software. Azimzadeh *et al.* (2010) suggested using a selection index with a genetic algorithm in MATLAB, which requires knowledge of genetic parameters, complicating its use without prior population information. Alternative methods include multivariate techniques, such as MGIDI proposed by Olivoto and Nardino (2021) or FAI-BLUP by Rocha *et al.* (2018), which also require replicates of each genotype, making them unsuitable for populations without individual replicates, like the one used to validate the proposed sequential selection algorithm.

Another option to the sequential algorithm is developing a selection index using importance coefficients for the evaluated variables. These coefficients can be estimated based on economic importance (Hazel, 1943; Cerón-Rojas *et al.*, 2023) or the desired genetic gain for each trait (Pešek and Baker, 1969), though their application is limited for selecting individuals based on an ideotype (Rodrigues *et al.*, 2017).

In coffee genetic improvement, methods based on multivariate analysis have been employed (Moreira *et al.*, 2022; Paredes-Espinosa *et al.*, 2023; Piza *et al.*, 2023; Berny Mier and Teran *et al.*, 2025; Suela *et al.*, 2025), including the Mulamba and Mock selection index (Piza *et al.*, 2023) and the sum of standardized variables index (Piza *et al.*, 2023). These methods require at least three replicates for each evaluated material, making them unsuitable for selecting individuals from non-replicated populations, unlike the proposed sequential algorithm, which works directly with individual phenotypic values, making it applicable in coffee plantations lacking replicated experimental designs.

Additionally, the proposed method adapts to available resources, from spreadsheets to advanced computational pipelines. While other methods rely on specific computational environments (R packages, SAS), this approach democratizes scientific selection, enabling technicians and producers without advanced statistical training to use it. Each selection criterion is clear and adjustable, allowing for modifications to different conditions and breeding objectives. It also facilitates changes to the ideotype by identifying which criteria are most restrictive in a given population.

Characteristics of the Selected Plants

The mean test (t-test) comparing the nine plants selected by the algorithm revealed significant differences ($p<0.05$) in each selection attribute (Table 3). The PCA indicated that 76.7% of the variation in the plant population was explained by the first two principal components, with principal component 1 (PC1) accounting for 56.2% and principal component 2 (PC2) accounting for 20.5%. PC1 primarily represented yield ($\cos2>0.81$), height ($\cos2>0.75$), and canopy diameter ($\cos2>0.66$). Bienniality was similarly represented in both components (PC1 $\cos2>0.364$ and PC2 $\cos2>0.365$). Finally, IRs was represented in CP2 ($\cos2>0.64$, Figure 4). The selected plants cluster in the positive quadrants of CP1, with plants 18, 46, 48, 51, and 53 in the positive quadrant of CP2, and plants 14, 47, 20, and 25 in the negative quadrant. All are closely associated with yield, canopy diameter, and height (Figure 4).

Plant 20 exhibited a lower bienniality level (I), a compact shape (combination of canopy diameter and height), and a lower Susceptibility Index (IRs), aligning with the PCA findings, as it was closest to the center among the selected plants (Figure 4). In terms of

Table 3. Comparison of means (t-test) of the selection parameters among the nine plants selected using the algorithm.

Variable	n	Mean	SD	S.E.	CV	T	p(Bilateral)
Yield (g)	9	4718.9	522.11	174.04	11.06	27.11	<0.0001
Height (cm)	9	263.11	16.95	5.65	6.44	46.57	<0.0001
Canopy diameter (cm)	9	199.5	19.42	6.47	9.73	30.82	<0.0001
IRs	9	0.05	0.02	0.01	36.08	8.32	<0.0001
I	9	0.36	0.02	0.01	4.32	69.5	<0.0001

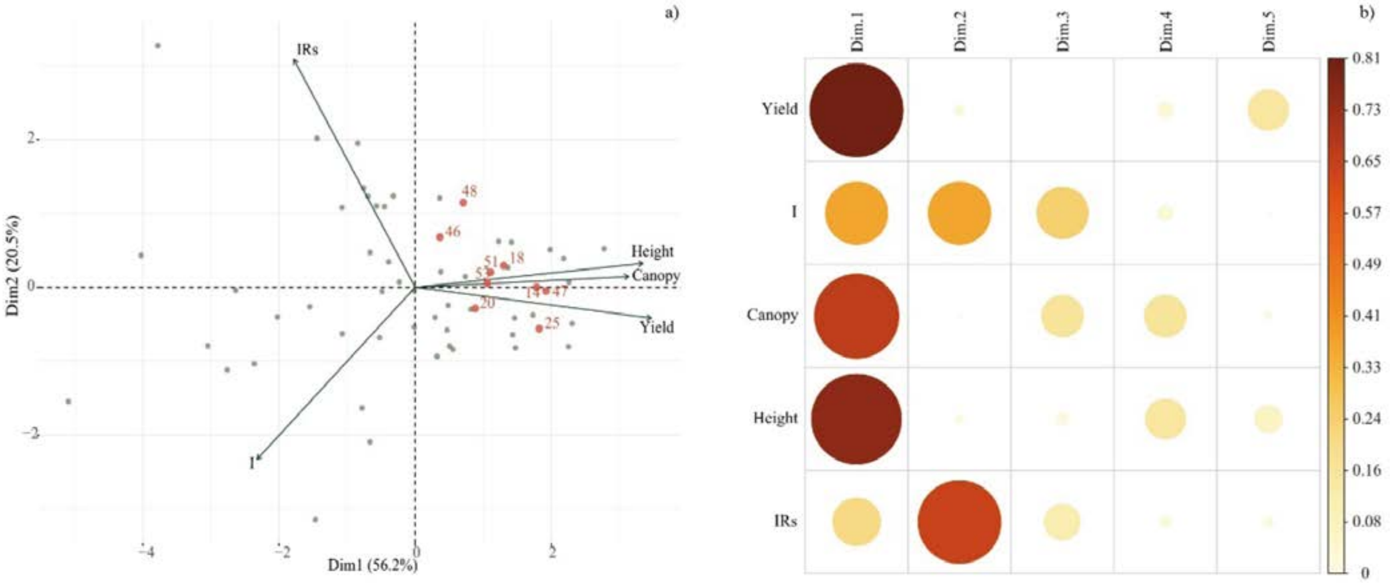

Figure 4. Representation of the population of 60 plants in the two main components. (a) Biplot graph illustrating the proximity of the nine selected plants to the morphological variables and yield. (b) Quality of representation of the variables used for selection, where circle size indicates the degree of representation in the principal components (PC). (PC1=Dim1, PC2=Dim2).

yield, plant 25 achieved the highest average (5452.6 g) over three harvest cycles. Comparing the performance of these nine plants with results from Botelho *et al.* (2010), Cardoso *et al.* (2016), and Piza *et al.* (2023), they show promising potential for further development.

CONCLUSIONS

The sequential algorithm based on conditional logic enables mass selection by ideotype in populations without replicates, addressing a methodological gap in genetic improvement programs. Its primary contribution is making scientific selection accessible in scenarios where traditional methods based on replicated designs are not feasible. As a methodology independent of numerical analysis programs, it can be implemented in Excel by plant breeders without programming expertise.

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