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Multivariate Data Analysis of Growth and Fertilization Response in Jamaica Genotypes (Hibiscus Sabdariffa L.)

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Abstract. Jamaica is a crop of significant agricultural value, recognized for its adaptability. Despite its high demand in international markets, cultivation has declined in Mexico due to challenges such as marketing issues, climate change, soil degradation, and competition from other crops. This study emphasizes the importance of responsible agricultural practices, particularly sustainability, which aims to reduce reliance on pesticides and chemical fertilizers. We investigated the responses of three Jamaica genotypes under conditions with and without fertilizer application. The proposed methodology included two multivariate descriptive analysis: principal component analysis to elucidate the phenotypic behavior of each genotype, and factor analysis to identify the interdependence among response variables. Results indicated that the Campeche genotype exhibited the highest yield, followed closely by Guerrero, demonstrating favorable responses under both experimental conditions.
Keywords: factor analysis; *Hibiscus Sabdariffa L.*; interaction; multivariate analysis; mapping variables; principal components analysis.

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1 Introduction

Hibiscus sabdariffa L. commonly known as Jamaica sorrel, or red sorrel, rozelle, Jamaica sorrel, Flower, Dart Flower, Jericho Rose, Red Tea, Indian roselle, Acid Quetmia, Karkade, Guinea Sorrel, Guinea Sour, holds significant economic importance due to its diverse applications in food, medicine and industry. The calyxes are utilized for a variety of purposes, including infusions, syrups, flours, dressings and beverage preparations. Additionally, the seeds serve as bird feed and are used to oil extractions [1]. The leaves and young shoots are consumed as vegetables, used as fodder, and applied in the production of natural dyes, and organic fertilizers [2]. Jamaica is noted for its medicinal properties, including emollient and sedative effects, as well as its ability to lower cholesterol and triglyceride levels, reduces blood pressure, facilitate the pulverizes of kidney stones, and potentially prevents cancer [3]. Globally, approximately 150 thousand t of dried Jamaica calyxes are produced annually, with China and Thailand being the leading producers. Notably, Thailand prioritizes quality in its production process, in contrast to china.

Other countries, including Mexico, Egypt, Senegal, Tanzania, Mali, serve as significant suppliers Hibiscus, however, the majority of production is primarily utilized domestically. Mexico is the main producing country in the American continent [4] with a production of 7 thousand t of dried hibiscus per hectare [5]. In Mexico, Jamaica is mainly cultivated in the states of Guerrero, Oaxaca and Michoacán, although there are other producing regions distributed on the Pacific slope and the Gulf of Mexico. Apparent consumption, according to [4] is around 17,921.34 t, although 50% of this is imported to satisfy demand China and Sudan are the countries that export the largest volume of Jamaica to Mexico.

Regarding the morphology of the Jamaica, it is relevant to mention that the flowers are borne separately in the axils of the leaves. The sepals at the base of the flowers are solitary and hermaphrodite, characterized by bracteoles consisting of 8-10 segments joined at the base of the calyx. The calyx itself is reddish, succulent and accrescent during fruit development, forming a large, dark red cup with short peduncles with imparts an acidic flavor [6]. The petals are 4-5 cm long, yellow or white, with a purple spot at the base and a slightly protruding staminal column. Regarding the morphology of the Jamaica, for further information consult [7]. Roselle, is a plant that is characterized by its adaptation to warm environments and susceptible circadian cycle [8], this leads to the opening of stomata during the day and closure at night, so it is said that it is susceptible to short photoperiod and needs continuous light with an estimated temperature of 21 to 25 ° C [9]. In addition, it can reach of 1.9 m according to the genetic material and the planting date (they consider May-June successful). Likewise, the calyxes are harvested 10 to 15 days after flowering when they reach vegetative maturity, being brittle and with a red base. In addition, it is important to harvest at the most opportune moment, as mentioned in [10]. The calyxes are harvested when the flower has fallen and before the capsules dry and open to let out the already ripe seeds (between 15 to 20 seeds per berry), otherwise, the quality of these decreases.

On the other hand, multivariate analysis (MA) facilitates the examination of diverse variable types across various frameworks and has been successfully employed in agricultural research [11]. For example, Acevedo [12] studied the impact of onion crop management with furrow irrigation by studying the impact on the soil and its level of degradation, and analyzed the effect on the conventional maize cropping system. The MA was carried out with soil samples in three strata and the determining variables or attributes define the biological, physical and chemical structure of the stratum. Likewise, Milena [13] used a component analysis (PCA) where she included the genera Agapostemon, Apis and Melipona of the tomato and the plant with autogamous pollination. Data were recorded was for each fruit at maturity to identify quality. Its results, the sum of their principal components being 100%, show that weight and polar diameter are the main variables associated with economic importance. In conclusion, the appropriate genus for effective pollination in production was Agapostemon.

Finally, although Guanajuato is not a producer of the main Jamaica crop, there are reasons to study the crop's ability to survive and recover from adverse conditions, so that production can become more stable and reliable over time. It can even be considered an alternative crop or cover crop [14]. Considering the above, the proposed study is a multivariate analysis of three Jamaica genotypes planted under rainfed conditions during the autumn-winter season with an experimental design by blocks that incorporates over 20 variables influencing genotype performance, along with a factor analysis to explore and mapping variables.

2 Materials and Methods

The crop was established on the experimental lands of the Tecnológico Nacional de México Roque/I.T. Roque, located at km 8 of the Celaya-Juventino Rosas highway, in the state of Guanajuato, Mexico. The region is characterized by a semi-warm climate and belongs to the least arid zones within the BS climate category. The average annual rainfall is 650 mm, with an average annual temperature between 18ºC and 22.1ºC [15]. The soil was of the crumb-clay type and the hibiscus genotypes were Campeche, Hidalgo and the native seed of Guerrero, it is unknown if they are varieties.

The seeds were established in 128-cavity Styrofoam germination trays in January with continuous irrigation and a nutrient application of Triple 16 at a rate of 2 g L-1 of water, transplanting was carried out in March 2023 at a distance of 50 cm between plants. Weed control was achieved using herbicide Sunfix300 (Paraquat) at a rate of 1 L ha-1. Manual weeding was conducted in conjunction with application. Chemical fertilization followed a regimen of 120-80-00, employing (Urea) as the nitrogen source and triple calcium superphosphate as the source of phosphorus. Each plant received individual fertilization, with applications of 10.43 g of Urea and 6.95 g of triple calcium superphosphate.

2.1 Data Description

2.1.1 Treatments

The experimental design followed a randomized complete blocks design, comprising two blocks and six treatments. The treatments were as follows: (1) CaCF (Campeche genotype under fertilizer), (2) CaSF (Campeche genotype without fertilizer), (3) GroCF (Guerrero genotype under fertilizer), (4) GroSF (Guerrero genotype without fertilizer), (5) HgoCF (Hidalgo genotype under fertilizer), and (6) HgoSF (Hidalgo genotype without fertilizer).

2.1.2 Variables evaluated

Evaluated morphological variables included: plant height (AlPlPrin), length of the large secondary branch (LRaSecGr), length of small secondary branch (LRaSecCh), number of secondary branches of the main stem (NoRaSecPal), number of total secondary branches (NoRaSecTot), number of fruits of the main stem (NoFrRaPal), number of fruits of the large secondary branch (NoFrRaSecG), number of fruits of the small secondary branch (NoFrRaSecCh), weight of fresh fruit on the small branch (PeFrRaCh), fresh weight of berry on the small branch (PeBayRaCh), fresh weight of calyx on the small branch (PeCaRaCh), fresh weight of the fruit on the large branch (PeFrRaG), fresh weight of the calyx on the large branch (PeCaRaG), fresh weight of the berry on the large branch (PeBaRaG), fresh, weight of the fruit on the main branch (PeFrRaPal), calyx fresh weight on main branch (PeCaRaPal), fresh weight of berry on main branch (PeBaRaPal), total fresh fruit weight of plant includes calyx and seed (PeTotFrPl), total fresh weight of plant calyx (PeTotCaPl), total fresh weight of plant berry (PeTotBaPl).

Analysis of variance (ANOVA), multiple mean comparison test (Tukey, $P \leq 0.05$), principal component analysis and factor analysis were performed using SAS software (Version 9.1), in addition to the analysis of genotype-environment interaction was analyzed utilizing the SREG model (GEA-R_v4.1). The resulting graphs enhanced the understanding of genotype-environment interaction [14], with the study units (UE) consisting of six treatments organized into two blocks, each featuring three distinct Jamaica genotypes.

3 Results

3.1 Analysis of variance

Based on the analysis of variance, it is observed (Tables 1 to 4) that the effect of genotypes was the most important in the generation of variability in plant height and length of secondary branches, number of fruits on branches, fresh weight of branches, weight of berries on large branches, total weight of fruits and calyces ($p \leq 0.01$). This effect surpassed the variability introduced by fertilization treatments, which significantly influenced the fresh weight of calyces and berries of the small branches, as well as the fresh weight of calyces on the main branch ($p \leq 0.01$).

The fertilization treatments presented statistically significant differences in several variables, including the number of total secondary branches and the main stem, number of fruits in the large secondary branch, fresh weight of berries in the large branch, calyx, and berries in the main branch, as well as in the fresh weight of fruits of the whole plant ($p \leq 0.05$) and with $p \leq 0.01$ in the number of fruits of the main branch, the fresh weight of calyx on the small branch, and of fruits on the main branch. Due to the values of variability generated, fertilization occupied the third place of importance.

The genotype variation factor accounted for over 80% of the variability in the variables LRaSecGr, NoFrRaSecG, NoFrRaSecCh, PeCaRaG, PeTotCaPl. In contrast, the treatment variation factor contributed to 50% of total variability in the variables NoRaSecTot, PeCaRaCh and PeFrRaPal. The findings underscore the consistency of the experimental process.

The coefficients of variation were deemed adequate, reveling a general trend of increasing values as the duration of plant exposure to the environment extended. The coefficients varied from 15.2% for the length of the secondary branches to 16.5 % for the number of fruits of the main branches, and 18.1% for both the large and small secondary branches. Notably, the coefficients for fresh weights were lower, likely due to heightened physiological and photosynthetic activity during the stages of development and fruiting. The coefficients of variation for all variables indicate the reliability of the experiment design and evaluation.

Table 1. Mean squares from the individual analysis of variance for agronomic variables.

			Branch length secondary		**Number of branches secondary**
Sources Variation	**Grades Freedom**	**Plant Height**	**Big**	**Small**	**Main stem**
Genotype	2	16610.68**	21084.22**	15899.84**	155.79**
Treatments	1	8385.12**	4293.55**	12693.55**	217.01**
Blocks	1	74.01	156.05	696.88	13.34*
Gen*Treat	2	609.08	248.22	422.93	19.68*
Error		310.8	204.2	349.92	2.85
CV(%)		10.16	9.13	15.23	15.77

[1] **:P ≤ 0.01.; CV: Coefficient of variation.

Table 2. Mean squares from the individual analysis of variance for agronomic variables.

	Number of fruits on the branch		
Sources Variation	**Principal Big secondary**	**Large Small secondary**	**Minor**
Genotype	11713.55**	4392.09**	289.68**
Treatments	4950.12**	238.34**	53.38**
Blocks	308.34*	0.34	0.05
Gen*Treat	801.5**	71.43*	12.93
Error	95.05	9.14	2.56
CV(%)	16.56	18.16	18.18

[1] **:P ≤ 0.01.; CV: Coefficient of variation.

Table 3. Mean squares from the individual analysis of variance for agronomic variables.

	Fresh Weight			
	Small branch		**Big branch**	
Sources Variation	**Calyx**	**Berry**	**Fruit**	**Berry**
Genotype	1767.26**	820.29**	7296.12**	997.55**
Treatments	5547.55**	875.01**	6160.5**	320.88*
Blocks	40.5	1.12	10.88	72
Gen*Treat	1108.43**	147.93*	114.29	12.05
Error	47.9	28.57	55.44	20.92
CV(%)	12.62	16.42	7.49	14.3

[1] **:P ≤ 0.01.; CV: Coefficient of variation.

Table 4. Mean squares from the individual analysis of variance for agronomic variables.

	Fresh Weight		
	Principal		**Plant**
Sources Variation	**Calyx**	**Berry**	**Fruits**
Genotype	844.38**	1631.26**	4986370.26**
Treatments	1850.34**	654.01**	1835208.68**
Blocks	284.01*	62.34	74949.01
Gen*Treat	226.05*	98.59*	199514.43*
Error	67.83	22.35	30144.77
CV(%)	13.03	14	15.9

[1] **:P ≤ 0.01.; CV: Coefficient of variation.

3.2 Multiple range test means

Tables 6 and 7 demonstrate that the Campeche variety is the most distinguished in terms of fruit production and fresh yield. These findings underscore its potential as a highly productive cultivar for enhancing agricultural output. This variety presented higher values in berry and calyx weight, further establishing its superiority in these characteristics

Table 5. Mean comparison test (Tukey) for agronomic and yield variables of three Jamaica varieties of Jamaica, Celaya, Guanajuato, 2023.

		Branch length secondary		Number of branches secondary
Genotype	**Plant Height**	**Big**	**Small**	**Main stem**
Campeche	195.46 a	180.5a	123.63 b	13.62 a
Guerrero	180.67 b	165.5b	148.13 a	9.58 b
Hidalgo	144.33 c	123.33c	96.6 c	8.91 b

Means sharing the same letter are not statistically different (Tukey, $p \leq 0.05$).

Table 6. Mean comparison test (Tukey) for agronomic and yield variables of three Jamaica varieties of Jamaica, Celaya, Guanajuato, 2023.

Genotype	Number of fruits on the branch			
	Principal	**Large** **Big secondary**	**Minor** **Small secondary**	**Small Branch Weight Fruit**
Campeche	37.12 c	32.08 a	12.62 a	117.42 a
Guerrero	58.12 b	11.04 b	7.95 b	94.66 b
Hidalgo	81.29 a	6.83 c	5.88 c	84.25 b

Means sharing the same letter are not statistically different (Tukey, $p \leq 0.05$).

On the other hand, branching has a significant effect on the different varieties of Jamaica, as shown in Table 6. The Hidalgo variety shows a greater amount of fruit on its main branch compared to Guerrero and even Campeche. However, this does not guarantee that its total production is as high as that of the Campeche variety.

Table 7. Mean comparison test (Tukey) for agronomic and yield variables of three Jamaica varieties of Jamaica, Celaya, Guanajuato, 2023.

Genotype	**Weight**	**Large branch**		**Main Branch**
	Fresh	**Calyx**	**Berry**	**Fresh**
Campeche	112.75 a	67.95 a	39.41 a	115.54 a
Guerrero	106.63 b	57 b	28.25 b	106.75 b
Hidalgo	79.52 c	40.41 c	28.25 b	79.75 c

Means sharing the same letter are not statistically different (Tukey, $p \leq 0.05$).

Overall, the Hidalgo variety exhibited challenges in growth and yield. Although the Guerrero variety was not the most exceptional, its performance in the development of the key variables was comparable to the average of the Campeche variety, particularly in terms of calyx weight on the main branch, where the values were identical (see Table 7).

Table 8. Mean squares from the individual analysis of variance for agronomic variables of Jamaica, Celaya, Guanajuato, 2023.

Genotype	**Weight**	**Total**		**Principal Branch**
	Fruit	**Calyx**	**Berry**	**Calix**
Campeche	1598.88 a	102558 a	694.46 a	67.95 a
Guerrero	960.25 b	606.63 b	458.21 b	65.04 a
Hidalgo	716.17 c	438.88 c	319.54 c	56.54 b

Means sharing the same letter are not statistically different (Tukey, $p \leq 0.05$).

3.3 Principal Component Analysis (PCA)

In the principal component analysis PCA, the first two components explained 100% of the variance observed in the entire experiment. The first component explained 83.3% of the variance, while the second component contributed an addition of 16.66%.

The most significant variables contributing to the observed variability in CP1 were the total weight of berries on the plant and the secondary branch, followed by the number of fruits on the shorter secondary branches, the weight of fruits on the main branch, and the weight of the calyx on the plant. In CP2, the length of smallest secondary branch and the total number of secondary branches on the plant emerged as key factors. This analysis provides a comprehensive understanding of the overall experiment.

Additionally, it was observed that all variables were located in quadrants I and IV, particularly those with the exception of the length of the smallest secondary branch, which presented a response pattern opposite to the calyx weight of the smallest branch, since as one increased, the other decreased. A similar relationship was noted between calyx weight, plant height and weight of the main branch calyx in relation to the number of fruits on the main branch. This inverse correlation also occurred between the total number of secondary branches and the calyx weight of the smaller branch (Figure 1).

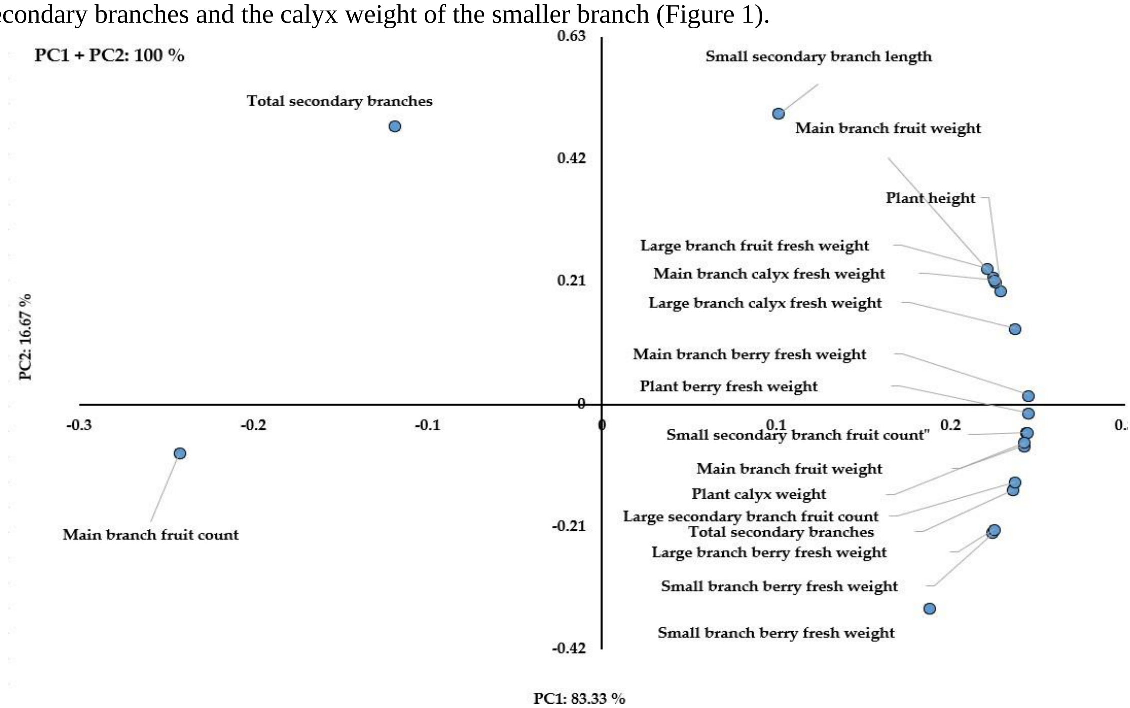

Fig 1. Cartesian plane with the eigenvalues of the variables evaluated in the field of three hibiscus genotypes, Celaya, Guanajuato, 2023.

The small secondary branch fruit count, the main branch berry weight, and the total berry weight per plant were key define the response of the Campeche genotype. In contrast, the Guerrero genotype exhibited a distinct response pattern, with the highest values observed in small secondary branch length, total secondary branch count, and calyx, weight of the small branches. The Hidalgo genotype displayed the lowest values across these parameters when compared to the Guerrero and Campeche genotypes. Consequently, the three genotypes were distinguished by markedly contrasting response patters (Figure 2).

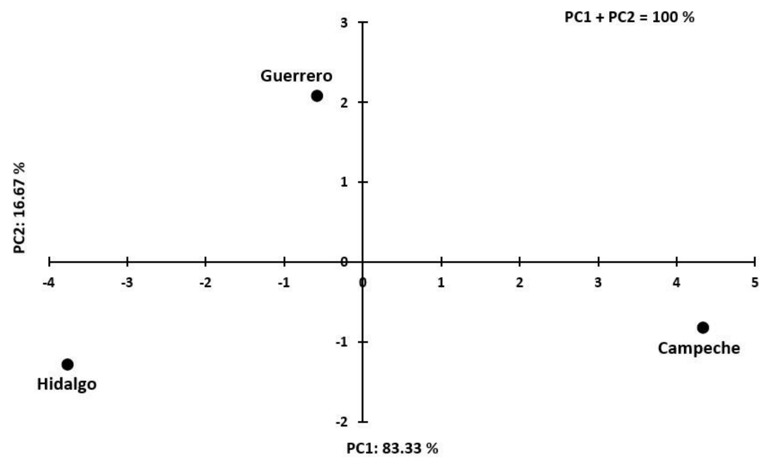

Fig 2. Cartesian plane illustrating the dispersion in the response of three genotypes of Jamaica, Celaya, Guanajuato, 2023.

3.4 Analysis of the genotype x fertilization interaction

Furthermore, the Campeche genotype exhibited superior plant height (Figure 3), under both fertilization treatments, surpassing the Guerrero genotype by 14.8 cm and the Hidalgo genotype by 51.1 cm. A difference of 36.3 cm was observed between the latter two genotype for the same variable. These findings indicate that the Campeche genotype demonstrated the highest adaptability to both fertility conditions, likely due to its phenotypic plasticity streaming from its genetic structure (Table 4).
Following the factor analysis, Figure 3 illustrates the relationship between Jamaica genotypes and treatment conditions. The vertices of the dotted line graph correspond to the three genotypes of Jamaica; Campeche, Guerrero and Hidalgo, respectively. The vectors represented by arrows are the two treatments: with fertilizer and without fertilizer.

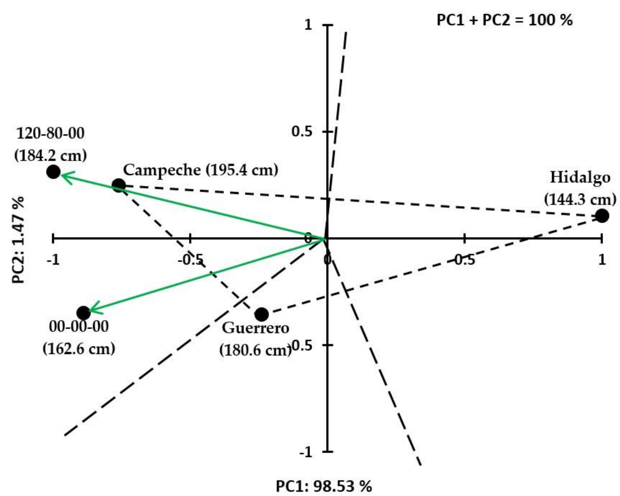

Fig 3. Genotypes-fertilization interaction of three Jamaica genotypes on plant height, Celaya, Guanajuato, 2023.

In addition, the Campeche genotype exhibits both exceptional productivity and resistance to environment factors under both treatments. Notably, calyx yield is consistently derived from the smaller branches, further emphasizing its remarkable adaptability to diverse conditions.

In this regard, the correlation of variables identified through factor analysis is illustrated in Figure 4. It can be asserted that an increase in the number of secondary branches correlates with a higher fresh weight of fruit in the small branches. Another notable relationship is the positive correlation between plant height and the weight of the calyx on the large branches. Furthermore, the total fruit weight is significantly correlated with the number of fruits on both large and small secondary branches; however, no substantial relationship was observed between the weight of the calyx and the length of the small secondary branch.

4 Conclusions

In conclusion, the Jamaica crop, renowned for its significant nutritional value and increasing global demand, is also capable of thriving in semi-arid climates and soils of limited fertility. Consequently, it is crucial to optimize agricultural practices to enhance the development of improved varieties that are adapted to a range of climatic conditions. This study utilized a randomized complete block design involving three Jamaica varieties, with the evaluations of 20 morphological variables. Through principal component analysis, key phenotypic traits with substantial impact were identified.

Furthermore, the response of the Jamaica varieties to different treatments was assessed using factor analysis. In summary, the Campeche variety exhibited superior resistance under both treatment conditions.

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