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Seasonal variations and flowering stages of cassava (Manihot esculenta Crantz) in agroecological zone V of Cameroon

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ABSTRACT

This study on the floral phenology of cassava (Manihot esculentus Crantz) conducted at the Nkoemvone agricultural research station (southern Cameroon) aimed to study the floral phenology of cassava according to sowing dates and varieties to better plan crossbreeding and help conserve and improve varieties in the face of current constraints. Four sowing dates were evaluated based on the quantity of parameters produced, such as average number of primary branches (NR), average branching level (NIR), average number of clusters (NF), and average rate of aborted clusters (Tm), and on the synchronization of parameter growth values: average height of primary branching (HR), average distance between branches (DR), and interval between sowing and flower or cluster emergence (ISF). The data were collected over a period of ten days after the emergence of the first branch and six and a half months after sowing. The results show three periods that influence floral phenology during the year, ranging from June to October for the first, November to mid-February for the second, and March to May for the third. The average values of NR (11.25±0.57 branches), NIR (4.25±0.09 branch levels), and NF (49.35±7.4 clusters) are significantly higher during the period from June to October compared to the other periods. On the other hand, the average value of Tm (41±5.1%) is significantly higher for the period from November to February. From the end of February to the end of May, no flowering stage was observed. Furthermore, the optimal development of the average values of HR (1.44±0.07 m and 1.31±0.04 m for the improved and local varieties, respectively) and DR (45.01±0.8 cm and 47.41±1.8 cm for the local and improved varieties, respectively) and the ISF (82 days after sowing for the local variety and 147 days after sowing for the improved variety) show insignificant differences and early flowering of both varieties for the sowing season (DI), allowing for more efficient crossbreeding. In conclusion, the best time of year for favourable floral development is from June to October for both varieties, which allowed us to make crosses. In addition, the best season is the beginning of the short rainy season in March. This work clearly indicates that the values of environmental factors differ from one season to another and that this difference significantly influences flowering in this species. Furthermore, this result could be useful to geneticists and breeders when setting up cross-breeding blocks to reduce the overall selection time.

Keywords: *floral phenology, flowering, synchronization, biotic, and abiotic.*

1. INTRODUCTION

Cassava (Manihot esculenta Crantz) is the main food for more than 800 million people in tropical areas, including 500 million in Africa. Its production is always growing at a faster rate [1]. Its production in Africa in general, and in Cameroon in particular, faces constraints related to low yields, mealybugs, high production costs, significant post-harvest losses, and the proliferation of viral, bacterial, and fungal infections [2]. Its tubers are experiencing increasingly high demand due to their socioeconomic importance and as a significant source of energy –[3]. Its adaptability to different soils and climatic conditions has led to its cultivation in favorable areas (Latin America) and less favorable ones, particularly in Africa and Southeast Asia [4]. According to ''[5], cassava production has generated direct employment, improved the incomes of smallholder farmers, and contributed to an overall increase in the national economy. Nevertheless, the urgent need to increase cassava production and profitability for sustainable food security persists.

However, the emergence of rapidly spreading viral diseases across the continent poses a major threat to smallholder farmers practicing subsistence agriculture –[6]. These farmers inadvertently contribute to the spread of these viruses through the exchange of infected cuttings, leading to a constant reduction in yields [7]. The development of improved genotypes is constantly demanded by both small-scale producers and industries. Despite the effective techniques employed by cassava producers to address these challenges, the intrinsic value of the variety remains central to productivity regardless of the technology used, highlighting the need for genetic improvement of our varieties [8].

In this context, genetic improvement, which involves creating new varieties by transferring genes between existing varieties, appears to be one of the solutions being considered. This technique requires knowledge of the plant's reproductive mode and the selection of the best genotypes '[9]. However, one of the major obstacles to successful crossbreeding remains the lack of control over the optimal flowering periods of the varieties likely to be used in genetic improvement.

Indeed, preliminary studies have shown that varieties with a low level of branching sometimes exhibit an absence of flowering and/or delayed flowering linked to the time of year –[10]. Another major obstacle in establishing crossing blocks is the lack of synchronization in flower emergence among the different varieties. It has been shown that some clones flower early (3-4 months after sowing) and others late, beyond 12 months[11,8]. In this case, the need to understand the flowering phenology of the parents involved in the different crosses is clearly evident[8].
Floral phenology is known as the central point of sexual reproduction in plant species, among all the phenological phases that a plant undergoes –[12]. It allows not only the identification of accessions capable of flowering and producing seeds but also the determination of the optimal time of year to establish crossing blocks[4].
In cassava, in particular, flowering is influenced by genetic material and especially by environmental factors (temperature, precipitation, photoperiod, and relative humidity) [13]. Recent studies have shown that temperatures below 22°C and above 34°C are unfavorable for flower production, while temperatures between 22°C and 28°C induce favorable flowering [11]. Furthermore, a relatively long photoperiod (12 to 19 hours/day) increases the production of flowers and seeds [13]. An increase in temperature above 30°C automatically leads to a low relative humidity level, which thus suppresses flowering induction and seed production –[14]. Precipitation of 80 mm per year induces favorable flower production [15]. Recent climate changes have led to disruptions, causing significant disturbances in plant growth parameters during their development cycles and within their biodiversity –– [16]. Indeed, the change in environmental conditions between different locations has caused different physiological responses in different plants, directly related to floral phenology, which can successfully induce or inhibit the production of flowers and seeds, among other things, in cassava –[17]. [8], évaluating the influence of environmental factors on flower production in cassava over six periods, showed that different planting periods significantly affect flowering. However, to our knowledge, no study has ever been conducted in Cameroon, despite the variation in environmental conditions observed from one locality to another, to propose appropriate planting dates for cassava varieties in specific areas, such as the bimodal rainfall forest zone in Cameroon. This study aims to determine the time of year that promotes good floral development and the season that allows for synchronized flowering, which is essential for establishing a genetic improvement program for this plant.

2. MATERIALS AND METHODS

2.1 Material

2.1.1 Study area

The study was conducted at the experimental plots of the Institute of Agricultural Research for Development (IRAD) station, Nkeomvone, Ebolowa, South Cameroon. This site is located at the humid forest agroecological zone of Cameroon, characterized by a bimodal rainfall pattern and four seasons. These include a short dry season from June 30 to August 15, a long dry season from November 15 to March 15, and two rainy seasons: one from March 15 to June 30 and the other from August 15 to November 15. This station is located at an altitude of 580 meters, at 24°95'4.1" N latitude and 11°08'12.4" E longitude (Figure. 1). The average temperature is 25°C, and the annual rainfall varies between 1500 and 2000 mm.

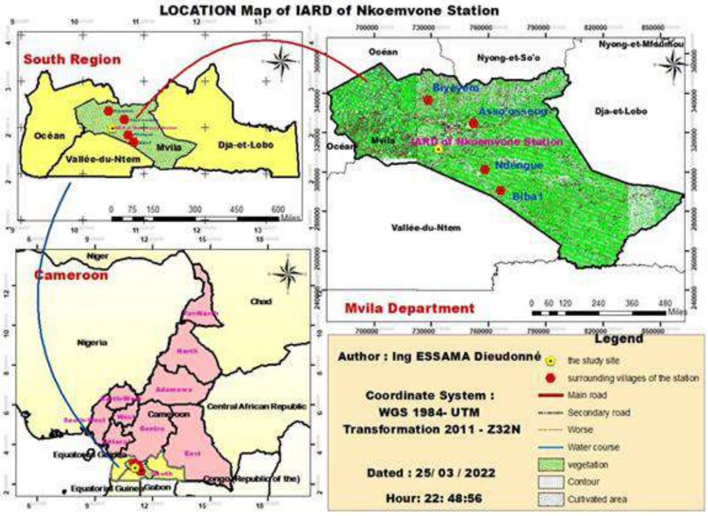

Figure 1. Mape presents the study site (Nkoemvone Agricultural Research Station)

2.1.2. Plant material

Two cassava varieties were used in this study (Table 1). One is a local variety (Ekobeli) highly valued by the local population and present in 99% of farmers' fields, but very susceptible to cassava mosaic disease [18]. The second variety (TME419) is an improved, mosaic-resistant variety. It is very rarely used by the local population [1].

Table 1. Characterization of the two varieties

Varieties Paramètres	Local	Improved
Name	*Ekobeli* (local name)	TME419
Disease (mosaic)	Sensitive	Resistant
Presence in the locality	Abondant	Very little used
Collection site	Peasant fields	IITA
Organoleptics	Very good	Good
Image of varieties in the field		

2.2. Methods

2.2.1. Experimental design

The experimental design was a completely randomized block design with two replications. Spacing of 1 m between planting holes and 1.20 m between rows per plot was maintained. The two central cuttings from each of the two rows were used to reduce edge effects, for a total of eight cuttings[8]. The length of the cuttings varied between 16 and 20 cm. They were planted obliquely at a 45° angle and inserted two-thirds of their length into the soil.
The observation period extended for more than six months from the sowing date (Table 2). However, the data collection period ranged from the first branching stage up to six and a half months. Based on the different floral phenophases observed at the various sowing dates, several parameters were evaluated at ten-day intervals [15]. During the dry seasons, the plants were watered to ensure their proper growth. The plots were continuously weeded and manually hilled to maximize their healthy development.

Table 2. Different periods of work

Years	Planting dates	Seasons of the year	Observation periods
2024	March 30	Short rainy season	March – January 30, 2024
2024	1er Jullu 1st	Short dry season	July - February 30, 2025
2024	September 1st	long rainy season	September - March 30, 2025
2024	November 1st	Long dry season	November - May 30, 2025

2.2.2 Assessment of the time that is most suitable for inducing good flowering

Effect of planting time on cassava branching was evaluated based on the number of primary branches, the level of branching of the branches, the height of the primary branches on the stems, and the distance between two branches.

The evaluation of primary branches was carried out by counting based on visual inspection over a 10-day interval. Counting was performed on cuttings with two to three stems, for a maximum total of 24 stems for each planting date. The formula of Santos et al. (2024), which is defined by: $X = \frac{\sum_{i=1}^{h} n_i}{h}.\ X$

represents the average number of primary branches per growing season (NR), the average height of primary branches for a given sowing date (HR), the average number of clusters per growing season (NF), the average number of aborted flowers for a given sowing date (NFA), and the number of values for NR, HR, NF, and NFA within each 10-day interval; h is the number of 10-day intervals, and i is defined as the 10-day interval.

The effect of the sowing period on the branching level (NIR) was evaluated by directly counting the number of branching levels on the different branches (primary, secondary, tertiary branching, etc.) at the end of the data collection period (six and a half months). The average branching level is compared between the different sowing dates.

The number of flowers was estimated by counting the clusters, starting from the emergence of the first inflorescences and over a 10-day interval in order to have new flowers in each interval [15]. The average number of aborted flower clusters (NFA) was estimated by counting the difference between the old and new flowers every 10 days. A cluster was considered aborted if it did not produce any capsules. The average rate of aborted clusters is calculated using the following formula: Tm = (NFA/NF) × 100, where Tm is the average rate of aborted clusters, NFA is the average number of aborted flowers, and NF is the average number of flowers. The average abortion rate for each sowing date was calculated and compared between the different sowing dates.

2.2.3 Identification of the sowing season that allows for synchronized flowering of the accessions.

The average heights of primary branching (HR) were determined by measuring the distance from the ground to the branch using a measuring tape on the branched stems. Data was collected at 10-day intervals on the new stems. The average branching height for an interval was estimated as the sum of heights of branched stems / total number of branched stems.

The distance between two branches (DR) was evaluated by measuring the distance separating two successive branches, specifically a primary branch and a secondary branch, and a secondary branch and a tertiary branch. The average distance is determined by summing the measured values and dividing by the total number of distances measured [8]. The evaluation of the sowing-to-flowering interval (ISF) for the different sowing dates was carried out by counting the number of days between sowing and the emergence of the first flower for the different varieties[13].

2.2.4 Statistical analysis

Following the various methods used, all collected data were analyzed using R software version 3.4.1. Graphical representations were created using Microsoft Excel 2016. For quantitative variables, the data were subjected to an analysis of variance (ANOVA) at a 5% significance level. If the ANOVA was significant, the data were subjected to a mean comparison test (Kruskal-Wallis test) to determine the most significant differences. Principal Component Analysis (PCA) was also used to highlight the similarities and differences between the variables studied. It also allowed for the distribution of the accessions in two dimensions by creating a biplot graph. Hierarchical Cluster Analysis (HCA) was performed to clearly identify possible phenotypic groups based on the quantitative variables.

3. RESULTS AND DISCUSSION

3. 1. Results

3.1.1. Influence of the time on flower development

The effects of different sowing dates on certain parameters allowed to define three main periods that influence the different stages of flowering (floral phenology) throughout the year. The first period extends from June to October, the second from November to February, and the third from March to May for the third. These parameters include, among others: The number of primary branches varies from 0 to 18 for the local variety and from 0 to 13 for the improved variety, depending on the sowing date. The lowest value is 0, corresponding to the November sowing date (DIV), with intermediate values for the other sowing dates (DII and DIII), and the highest values of 18 and 13 for the March sowing date (DI). Analysis of variance (ANOVA) indicates a significant effect of the variety/sowing date interaction for this parameter.

The level of branching varies from 0 for the November sowing date (DIV) to 6 for the March sowing date (DI), regardless of the variety, after six and a half months of observation. The number of clusters varies from 0 to several hundred for both varieties (local and improved). The sowing dates (DI and DII) produced an abundance of clusters, with an overabundance for DI. In contrast, the sowing dates (DIV and DIII) produced no clusters. The comparison of the means for the different sowing dates shows a significant. This result shows that flower production is highly dependent on the sowing date and, consequently, on environmental conditions. However, the interaction between varieties and sowing dates on these parameters indicates a non-significant effect, as both varieties have a favorable ability to flower under optimal conditions (Table 3).

Table 3. Significant effects of parameters (NR, NIR, NF and Tm) were observed between varieties and sowing dates

Sowing periods	NR		NIR		NF		Tm	
	V1	V2	V1	V2	V1	V2	V1	V2
Short rainy season (DI)	15±4,6ᵃ	8±4ᵇ	4,6± 0,7ᵃ	3,9±1ᵃ	60,57±8,9ᵃ	24,14±5ᵇ	17,7±0,2ᵇ	16,3±0,7ᵇ
Short dry season (DII)	15,5±4,2ᵃ	2,8±2bᶜ	1,9±0,6ᵇ	0ᶜ	19±2ᵇ	0ᵇ	32,7±0,5ᵃ	0ᶜ
Long rainy season (DIII)	14,23±4,1a	5,45±2,1c	0c	0c	0ᵇ	0ᵇ	0c	0c
Long dry season (DIV)	0c	0c	0c	0c	0b	0b	0c	0c

V1: Local variety; V2 : Improved variety, NRI : Average number of primary branches ; NIR : Average level of branching ; HRI : average height of primary branching; DR : average distance between two branches.

This result indicates that the quantity of the evaluated parameter values is very high during the period from June to October, regardless of the variety used. Sowing date (DI) corresponds to the period from June to October; (DII and DIII) correspond to the period from November to mid-February; and (DV) corresponds here to the period from March to May, as these sowing dates either produced or did not produce these parameters during those periods.

3.1.2. Planting season that allows for the simultaneous flowering of the accessions.

The optimal development of varieties according to the seasons of the year is based on the parameters below. The average height of the first branch varies from 1.26 to 1.76 meters, depending on the sowing date for the local variety and from 1.42 to 1.80 meters for the improved variety. Analysis of variance shows that the height does not vary significantly between the two accessions at a given sowing date, but it does vary significantly between the different sowing dates. The distance between two branches varies from 30 cm to 120 cm depending on the planting dates and different varieties. The shortest distances are observed in (DI) and the longest in (DII), while the other planting dates did not allow for more than two branching levels regardless of the variety. Calculating the averages of these distances and comparing them between varieties and planting dates yields interesting results. The analysis of variance shows a significant effect between the planting dates (Table 4).

For the first sowing date (DI), the first flowers appeared 82 days after sowing, approximately 2 months and 3 weeks, for the local variety (from March 30 to June 20) and 152 days after sowing, approximately 5 months (from March 30 to August 29) for the improved variety. Both varieties were able to produce within 6 and a half months and continued to flower until December, for a period of 4 months. For the second sowing date (DII), the local variety produced its first flowers after 147 days, approximately 5 months after sowing (July 1 to November 24). However, the improved variety did not produce any flowers during the 6 and a half months of observation (200 days after sowing).

For the third and fourth sowing dates (DIII and DIV), after 200 days from sowing, neither variety produced any flowers (September 1 –March 15 and November 1 –May 15, respectively). These results clearly show that only the short rainy season in March allowed the two varieties to be cross-pollinated. Furthermore, the differences observed between the two varieties during this season are due to the control of genetic factors, since only the second-order branches bear the grape clusters in the improved variety.

Table 4. Significant effect of parameters (HR and DR) between varieties and sowing dates

Sowing period	DR		HR	
	V1	V2	V1	V2
Short rain season (DI)	45,02±8b	47,4±18b	1,26±0,4b	1,4±0,4b
Short dry season (DII)	90,4± 36a	0c	1,4±0,4a	1,6±0,1a
Long rain season (DIII)	0c	0c	1,7±0,1a	1,7±0,3a
Long dry season (DIV)	0c	0c	0b	0b

3.1.3. Interaction effect of varieties/sowing dates on flowering stages

Analysis of variance (ANOVA) indicates that there is a significant effect of the variety/sowing date interaction for these parameters, particularly the average number of primary branches (Figure 2), the average level of branching (Figure 3), and the average distance between two branches (Figure 4).

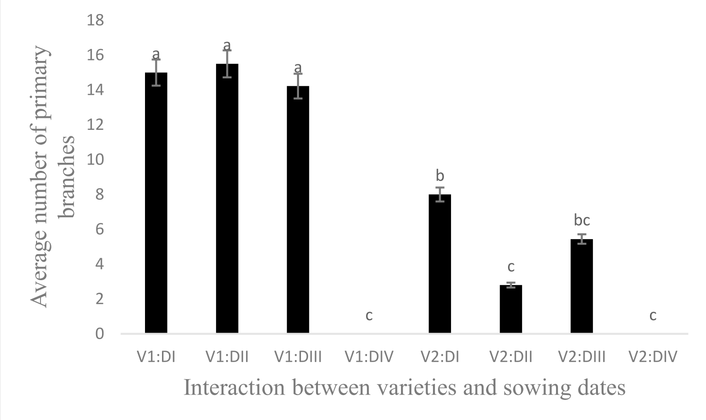

Figure 2. *Significant effect of variety/sowing date interactions on the number of primary branches. V1 DI; V1DII; V1DIII; V1DIV: Interaction between local variety/sowing date (I, II, III, IV) and V2DI; V2DII; V2DIII; V2DIV: Interaction between improved variety/sowing dates (I, II, III, IV).*

The emergence of flowers or flower clusters is closely dependent on the branching pattern of the stem, as the flowers emerge from the center of the branches. The interaction between variety and sowing date established for this parameter clearly shows that the number of branches is strongly influenced by environmental conditions and genetic factors. The high level of branching indicates an abundance of flowers, since normally all levels of branching would bear flowers.

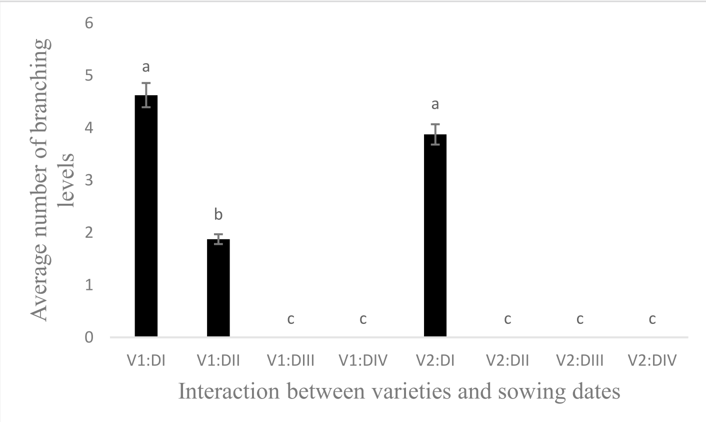

Figure 3. *Effet de l'interaction variété/dates de semis sur le niveau moyen de ramification. V1 DI ; V1DII ; V1DIII ; V1DIV: Interaction variété locale/date de semis (I, II, III, IV) etV2DI ; V2DII ; V2DIII ; V2DIV:Interaction variété améliorée/dates de semis (I, II, III, IV).*

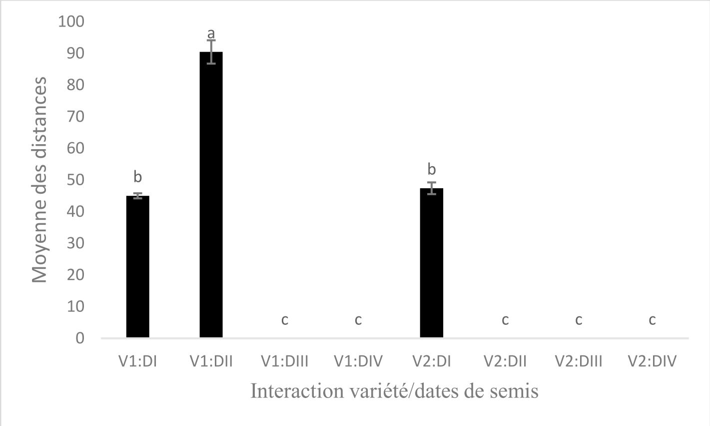

Figure 4. Significant effect of variety/sowing date interactions on the average distance between two branches. V1 DI; V1DII; V1DIII; V1DIV: Interaction between local variety/sowing date (I, II, III, IV) and V2DI; V2DII; V2DIII; V2DIV: Interaction between improved variety/sowing dates (I, II, III, IV).

The average distance between two branches is relatively short and consistent among individuals of the different varieties at the first planting date (DI). This resulted in vertical flowering along the field between the two varieties. The optimal flowering period in cassava tends to minimize this distance, allowing for rapid branching and thus the production of more flowers. Therefore, the time between the emergence of one branch and the next one is significantly reduced compared to the unfavorable period (DII). The difference between the planting seasons or dates creates variations in flowering time between the varieties, as shown in (Table 5) below.

Table 5. Deviation in flowering time due to variety/sowing date interaction

Varieties	Time interval between sowing and the appearance of the first flowers			
	DI (J)	DII(J)	DIII(J)	DIV (J)
Local	82	147	More than 200	More than 200
Improved	152	More than 200	More than 200	More than 200

The average rate of aborted flower clusters ranged from 49% for sowing date DII to 22.2% for sowing date DI for the local variety and 17.4% for the improved variety for sowing date (DI), with the other sowing dates not producing any flowers (Figure 5).

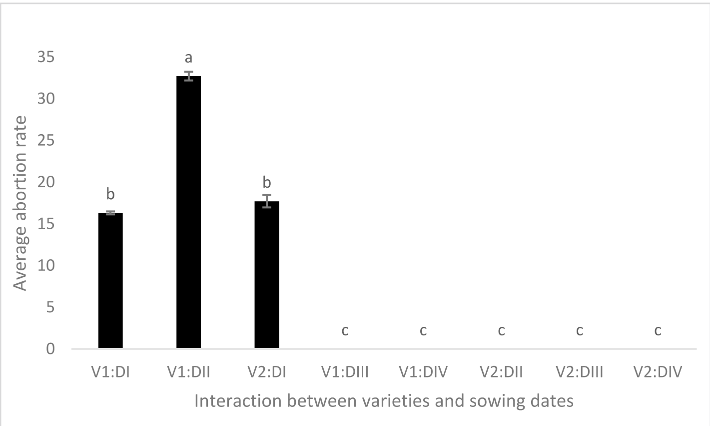

Figure 5. Variation in the interaction between variety and sowing dates on the average rate of aborted clusters. V1 DI; V1DII; V1DIII, V1DIV: Interaction between local variety/sowing date (I, II, III, IV) and V2DI; V2DII; V2DIII; V2DIV: Interaction between improved variety/sowing dates (I, II, III, IV).

This result shows that the average rate of aborted clusters varies from one sowing date to another and among different varieties. The influence of genotypes is relatively weak for this parameter. In short, the interaction between variety and sowing date of these parameters evaluated above should take into account both the genetic and environmental aspects simultaneously in this species.

Principal component analysis (PCA) indicates an influence of genetic and environmental factors on these parameters in the individuals. It was able to identify four groups of variety/sowing date interactions. It shows a wide distribution of individuals, indicating that the traits associated with these axes are phenotypically linked. In addition, we note the grouping of individuals on the axes opposite to the variables.

In Principal components analysis, dimension 1 (Dim1) explains the strong positive correlation of individuals (V1DII), and Dimension 2 (Dim2) explains the strong positive correlation of individuals (V1/DI and V1/DIII) and the negatively correlated individuals (V1/DIV and V2/DIV), which are closely positioned on the axis (Figure 6). The HAC dendrogram shows four groups of individuals (Figure 7).

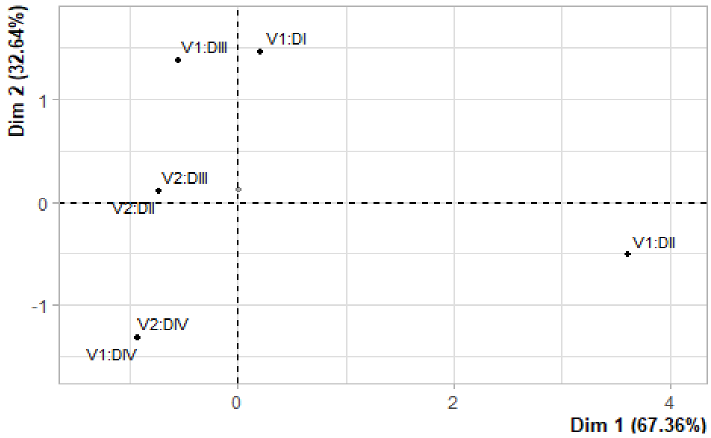

Figure 6. Principal component analysis of variety/sowing date interactions on the main axes

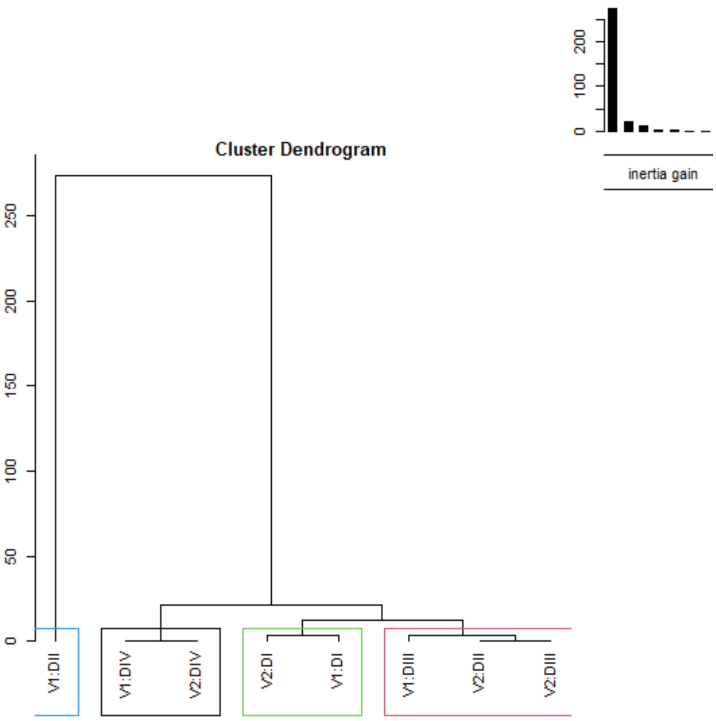

Figure 7. Dendrogram of individuals based on the variables studied

4. Discussion

The study of floral phenology in cassava allows us to understand certain reproductive phenomena. In perennial plants, the period of flower and seed production is well known. In agroecological zone V, this period remains poorly understood or unknown for cassava. Furthermore, the time between sowing and the appearance of the first flowers is also well known in trees and cultivated plants, varying from one species to another.

However, in cassava, this time varies considerably between varieties. Therefore, in order to determine their phenotypic performance for flower and seed production during the different seasons of the year, it is necessary to accurately understand the different aspects of floral phenology in this species.

4.1 The time of year that allows for good flowering

Cassava being an annual species with vegetative cycles varying from 7, 9, and 12 months, the 6.5-month data collection interval is highly significant. This result is similar to that of [8], who evaluated six cassava planting dates over one-year. The four planting dates allowed us to define three main periods that influence flowering throughout the year. These periods range from June to October for the first, from November to mid-February for the second, and from March to May for the third period. Planting date (DI) corresponds to the flowering period from June to October, (DII and DIII) correspond to the period from November to mid-February, and (DV) corresponds to the period from March to May, as these planting dates either produced or did not produce these parameters during those periods.

Furthermore, the two varieties used here have almost the same vegetative cycle duration when they are in this optimal growth period, which corresponds to the sowing date (DI). However, for the other flowering periods, their cycles are completely out of phase. Overall, this is explained by the fact that the right time of year coincides with the optimal values of external stimuli (environmental factors) [8]. That being said, an abundance of values for parameters such as NR, NIR, and NF is observed during the first flowering period. Conversely, the Tm value is higher in the second period, while the third period did not produce any results. The increased presence of these parameters during this period is justified by the influence of the accompanying environmental factors.

The average number of branches is very high for the first sowing date (DI), followed by (DIII and DII), and finally (DIV), ranked in decreasing order of values corresponding to these flowering periods. This is explained by the presence of optimal environmental conditions for these sowing dates during those periods. Precipitation is an important factor in inducing branching in this species; these results are similar to those of [19], who found that rainfall has a positive impact on the change in flowering dates for late-flowering species. In addition, another type of branching was observed at the nodes on the second sowing date (DII) after the return of heavy rains. The nodal branches are quite different from those of the central apical meristem, which are responsible for flowering. Although the number of branches is controlled by genetic factors, a significant increase is observed between June and October of the year. Branching is the precursor to flower emergence, and its intensity reflects the abundance of flowers in this species [8]. The interaction between varieties and sowing dates is also significant. It is in this context that recent studies have determined the heritability of this parameter in order to delineate the contribution of each factor. Since the heritability value is relatively low, it is concluded that this parameter varies very little from one accession to another. Branches may appear without bearing flowers or clusters (DIII), but the presence of branches indicates that the variety may have the capacity to flower. Flowers only appear at the center of the central apex of the branched stem (DI) according to [20].

The late emergence of branches inevitably translates into a limited number of flowers (DII). Stem branching in this species is the primary phase of floral phenology; it is in this order that pruning, the application of growth regulators, and the influence of photoperiod significantly induced the emergence of branches and, consequently, the abundance of flowers [21].

These periods can overlap depending on the parameters, in this case, the average level of branching. Staggered branching in cassava leads to a significant increase in flowers as the stem develops; these are the first stage of flowering. In addition, the stem can reach up to 8 levels of branching at the end of its cycle [8]. The cessation of branching almost dictates the end of flowering, as there is a final emergence of flowers at the apical apex surrounded by leaves without branches. The level of branching is very high during the June period and moderate for the November period and almost nonexistent for the March period. This is because the plants enter the flowering period during the appropriate time of year, which runs from June to October. The further away from this period, the lower the level of branching, eventually becoming zero. Cassava, being a species with staggered flowering conditioned by these branching levels, is affected by high temperatures compared to species with a single flowering period [22]. This time of year would have a good photoperiod because recent studies have shown that a high photoperiod (12 h 35/day) is positively correlated with the induction of branches in cassava [13].

Early flowering is correlated with the emergence of the first branches, which depends on the variety, particularly the local variety, which already bore flowers from the first branches, unlike the improved variety which only showed flowers on the secondary, tertiary branches, and so on, for the first planting date (DI). And if the conditions are not favorable, late flowering is observed on the secondary and tertiary branches for the local variety and no flowering on the improved variety (DII). If the environmental conditions are optimal and a sufficient level of stem maturity is reached, the plant flowers. The first planting date (DI) produced more flowers, followed by (DII), and none for the other planting dates. The justification is that all individuals that have reached a level of maturity during this period (June to October) begin to flower. The work of [23], showed that the optimal time of year is accompanied by a low temperature and a very high relative humidity to induce good flowering. Rain helps maintain flowering if it has already begun, for as long as possible. However, rain does not induce flowering; this result differs from that of –[24], who indicated that heavy rainfall induces good flowering in Erythronium grandiflorum, and those of [25,16], in tropical regions, thus explaining the differences between the two types of climate (the study being conducted in an equatorial climate). High levels of sunlight accompanied by high temperatures lead to a gradual decrease in flowering until it stops completely. This behavior was also observed by [15], highlighting that environmental factors have an impact on sexual reproduction in cassava.

The number of aborted flowers or clusters is estimated by the average abortion rate, which is quite high for the later sowing date (DII) and slightly lower for the earlier date (DI). The others showed no results, as they did not produce any flowers. This is explained by the fact that the favorable period of the year, which corresponds to the short dry season (June to August), had a relatively low temperature and good relative humidity, which helped reduce the average flower abortion rate (DI). Conversely, the long dry season was very intense with very high temperatures, thus increasing the abortion of flower clusters.

This contrasts with the work of [26], which shows an abortion rate of 84% to 94%. The interaction between variety and sowing date shows a non-significant effect between the genotypes, indicating only the influence of the sowing dates, and therefore, flower and fruit abortion would be very sensitive to weather variations. This work is similar to that of [27], who, working on the sweet cherry (Prunus avium), showed that an increase in climatic factors leads to massive flower and fruit drop. In this case, the contribution of genetic factors remains very low because flower drop would also depend on the genotypes involved [28]. Furthermore, the later sowing date (DII) experienced an abrupt cessation of flowering, meaning that the reproductive phenology of the plants is limited by the climate in highly seasonal regions. This work is similar to that of [29], who showed that the presence of high temperatures led to a high abortion rate and a cessation of flowering. In addition, the work of [30], on vines and trees showed a close relationship between flowering duration and weather conditions.

4.2 A good sowing date can allow for synchronized flowering of the accessions

Group flowering is a major challenge for this species because it facilitates hybridization between different genotypes. The March season demonstrates adequate development (synchronization in time and space) of the organs linked to floral phenology, and several parameters allow for its better assessment. The distance between the ground and the primary branch is relatively stable between the two varieties for the March season; that is, all individuals of both varieties have, on average, the same size at this sowing date. Furthermore, the average height is significantly greater from one sowing date to another, particularly in September, which is significantly taller than in March and July, while the November season did not produce any branching. The fact that (DIII) is cultivated at the beginning of the main rainy season explains the rapid height growth before branching. This study is similar to that of [31], on annual crops such as maize, which require sufficient rainfall for height growth. The sowing date (SD) thus allowed for a balanced size with slight, non-significant differences across all individuals, regardless of variety. This is explained by the fact that as soon as the plant transitions from the vegetative to the flowering stage, growth genes are transformed into production genes, notably the T florigens, which stimulate flowering in cassava [20, 32, 33]. An optimal sowing date shortens the length of branches between two branchings in March, thereby reducing the vegetative growth period and maximizing flower production by rapidly increasing the branching level. Conversely, an unfavorable sowing date lengthens the distance between branches, leading to an increased time between the emergence of two flower sets in cassava [8]. The interval between sowing and the first flower is significantly shorter in the local variety compared to the improved variety, indicating that this parameter varies from one variety to another. However, this difference is not significant for the March planting season, as it allows for successful crosses between the two varieties. This result is similar to that of [34], which showed that certain Arabidopsis genotypes planted under suitable climatic conditions allow for good growth and floral synchronization between the parents, enabling the desired crosses. Significant differences in flowering time can prevent successful crosses. Furthermore, the unfavorable seasons (July, September, and November) did not allow for synchronized flowering of the two varieties.

The variation in the time interval between the different sowing dates is due to the fact that plants reaching maturity during this period of the year enter the reproductive phase, resulting in early flowering. This is because the primary branches already bear flowers upon emergence, and therefore only the individuals planted in March were able to flower during this period. The July planting resulted in late flowering, and only in the local variety, while the September and November plantings produced no flowers at all. The reduction in the production cycle time has potentially a significant impact, although the increase in the number of flowers is not directly linked to early flowering, with a relatively very low number of flowers. However, it could accelerate selection cycles, as suggested by [35], by improving genetic gain in plant breeding programs.

4.3 Interaction between varieties and sowing dates on the flowering stages

In the present study, PCA was able to distinguish several groups of individuals based on the interaction between varieties/sowing dates and the variables studied. The projection of the different types of individuals onto the axes highlighted the four groups in relation to the different phenotypic data. This result is similar to that of [8], on cassava in Brazil. Therefore, some individuals could be representative of certain morphological characteristics. Furthermore, the study of flowering behavior in cassava should simultaneously consider both genetic and environmental factors, as the complexity of floral phenology regulation extends beyond the influence of environmental conditions and thus involves endogenous factors specific to the variety [36] [32].

5. CONCLUSION

The gradual but inevitable replacement of local varieties by improved varieties leads to a loss of genetic and varietal diversity. The objective of this work is to study the floral phenology of this species in two varieties according to the seasons to evaluate the time of year that allows for good flowering regardless of the variety, and the sowing season that could cause them to flower synchronously or in groups, in order to be able to cross them for the improvement and conservation of our local varieties. Under the conditions of this study, four sowing dates were evaluated on two varieties (local and improved) based on several phenotypic characteristics over a period of six and a half months after sowing, and data collection was carried out every ten days after the emergence of the first branch. The period of the year that allowed for good flowering was evaluated based on the average quantity of these parameters, notably the number of primary branches, the level of branching, the number of flowers or clusters, and the number of aborted flowers, depending on the variety and sowing date. These parameters vary considerably from one flowering period to another and from one season to another. The four sowing dates allowed us to define three main flowering periods during a year. This allowed us to conclude that the best time of year to induce good flowering is from June to October, because this period allows for good development of the flowering stages, ranging from branching, followed by the emergence of clusters and finally the emergence of female and male inflorescences. The best sowing season is the one that provides adequate development and maturity of the stem before entering this period of the year. In conclusion, the optimal planting season is March in agro-ecological zone V of Cameroon (humid forest zone with bimodal rainfall).

This result indicates that the choice of planting dates has a significant impact on flowering in cassava and should be taken into account when establishing crossing blocks, with a view to reducing the overall time required for breeding programs.

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Conflict of Interest
The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author Contributions
JAOI: Writing– review & editing, Writing– original draft, Conceptualization, Methodology, BCLLN: Writing– review & editing, Formal analysis, Visualization. LFMN: Formal analysis, Software. CD: Methodology, Supervision. BHN: Methodology, Supervision. JMB: Methodology, Supervision.

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