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Seasonal Climatic Variation and Flowering Intensity of Garcinia kola (Heckel) in a Humid Forest Plantation

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Abstract

Aim of study: The study designed to assess seasonal climatic variation and flowering intensity in *G. kola* in a humid forest plantation.

Area of study: The study was conducted in the mono-plantation of *Garcinia kola* in the Swamp Forest Research station of the Forestry Research Institute of Nigeria, Onne, Rivers state, Nigeria. The plantation consists of 103 trees at 5×5m spacing.

Material and methods: Climatic data were sourced from meteoblue.com. Flowering intensity was determined by the estimation of the total flower production per tree: total number of flower buds per inflorescence was determined by visual counting and then extrapolated for the total number of inflorescences per twig, total number of twigs per branch and total number of branches per tree to determine the average flowering intensity per tree. A total of 9 trees and twenty-five inflorescences per tree, were sampled. Data was analysed using covariance and analysis of variance.

Main results: Rainfall, wind speed, and flowering intensity varied significantly ($p \leq 0.05$) between seasons; seasonal rainfall variation influence on flowering intensity varied with tree gender.

Research highlights: Rainfall is the flowering cue of the plantation; we recommend that farmers target low to moderate rainfall seasons for high fruit and seed yields.

Keywords: Climate-Variation, Flowering-Intensity-Variation, Rainfall, Seasonal, Tree-Gender

Mevsimsel İklim Değişimi ve Garcinia kola (Heckel) Türünün Nemli Orman Plantasyonundaki Çiçeklenme Yoğunluğu

Öz

Çalışmanın amacı: Bu çalışma, nemli bir orman plantasyonunda *G. kola*'nın mevsimsel iklim değişimini ve çiçeklenme yoğunluğunu değerlendirmek amacıyla tasarlanmıştır.

Çalışma alanı: Çalışma, Nijerya Ormancılık Araştırma Enstitüsü'nün Onne, Rivers Eyaleti, Nijerya'daki Bataklık Ormanı Araştırma İstasyonu'nda bulunan *Garcinia kola*'nın tek türlü plantasyonunda gerçekleştirilmiştir. Plantasyon, 5x5 m aralıklarla dikilmiş 103 ağaçtan oluşmaktadır.

Materyal ve yöntem: İklim verileri meteoblue.com'dan elde edilmiştir. Çiçeklenme yoğunluğu, her bir ağaçtaki toplam çiçek üretiminin tahmin edilmesiyle belirlenmiştir: Her bir infloresans başına çiçek tomurcuğu sayısı görsel olarak sayılmış ve ardından her bir dal başına infloresans sayısı, dal başına dal sayısı ve ağaç başına dal sayısı ekstrapole edilerek her bir ağaç için ortalama çiçeklenme yoğunluğu hesaplanmıştır. Toplamda 9 ağaç ve her bir ağaçtan 25 infloresans örneklenmiştir. Veriler kovaryans ve varyans analizleri kullanılarak analiz edilmiştir.

Temel sonuçlar: Yağış, rüzgar hızı ve çiçeklenme yoğunluğu mevsimler arasında önemli ölçüde ($p \leq 0.05$) değişiklik göstermiştir; mevsimsel yağış değişiminin çiçeklenme yoğunluğu üzerindeki etkisi ağaç cinsiyetine göre farklılık göstermiştir.

Araştırma vurguları: Yağış, plantasyonda çiçeklenmenin belirleyici unsurudur; çiftçilere yüksek meyve ve tohum verimi elde etmek için düşük ila orta yağışlı mevsimleri hedeflemelerini öneriyoruz.

Anahtar Kelimeler: İklim-Değişimi, Çiçeklenme-Yoğunluğu-Değişimi, Yağış, Mevsimsel, Ağaç-Cinsiyeti

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Introduction

Flowering is the consequence of tree response to ecological variables such as precipitation and rainfall (Bawa & Dayanandan, 1998; Parmesan, 2006). The entire process of tree reproduction beginning from flower bud formation to seed or fruit production are all climate dependent. The flowering pattern or behaviour of any population is often the outcome of natural selection or a fixation of the adaptive response of the species to the climate of its growth environment. Flowering as a key factor of the plant reproductive process is the basis of the survival of pollinators, and the continued existence of species. Climatic shifts, such as those engendered by climate change, that could hamper flowering inadvertently spells doom for the existence of plant species. Climate change impact on flowering holds the risk of early flowering, scanty or increased flowering intensity, poor fruit or seed set, increased abortion or gynoecium drop rate, extinction of species that are unable to flower due to unfavourable climatic conditions (Anderson et al., 2012). Seasonal climatic variation and flowering intensity interaction has been affirmed by several authors (Saavedra et al. 2003; Petanidou et al., 2014; Afifah et al., 2022; Meng et al., 2022). For example, seasonal variation in temperature, and rainfall have been reported to influence changes in flowering intensity of tropical species (Cortés-Flores et al., 2017). Sometimes the climatic factor that controls flowering intensity is seasonal variation in day length pattern (Abrahamczyk et al. 2011). Other climatic factors that have been reported to influence flowering intensity in the tropics are irradiance and photoperiod (Meng et al. 2022).

Garcinia kola is an evergreen tropical rainforest species found in West and Central Africa within which Nigeria and Cameroon are considered the areas of highest endemism (Isawumi, 1993; Manourova et al, 2019). Almost every part of *G. kola* plant is of medicinal value; however, the most popularly used produce from the tree is the seed. The seed is revered for its antibiotic properties and is the reason it is of high commercial value. *G. kola* wood use in roofing has been on the increase due to the natural durability of the timber. Hence, generally the species is regarded as a multipurpose tree species (Okonwko et al., 2020). *G. kola* is mostly found in moist or coastal forests, lowland rainforests, and derived savannah in West Africa, a distribution pattern largely influenced by rainfall and temperature and therefore makes the species susceptible to climate change impact (Agwu et al., 2020). In a recent study, Agwu et al. (2020) reported a shrinkage in the range of the *G. kola* in West Africa occasioned by climate change. In Nigeria *G. kola* occurs primarily in the lowland rainforests and coastal (moist) forest areas. For example, Keay et al. (1989) reported the species presence in Ogun state (Omo forest reserve), Edo state (Okomu forest reserve), Anambra state (Nnewi), Rivers state (Degema), and Cross-River state (Ikom) while, Onyekwelu et al. (2015) in an assessment of fruit trees within rainforest and derived savannah ecosystems in Ondo state were unable to record *G. kola's* presence in the derived savannah ecosystem. *G. kola's* soil preference is sandy-loam; however, it has been reported to grow in several soil variants within its range with fine roots that carry arbuscular mycorrhiza variety (Bechem et al., 2014).

Rainfall and temperature are key climatic variables that reportedly control the spread of *G. kola*. Hence, understanding the effect of climate on flowering intensity is important for the conservation and sustainability of the species. Flowering intensity measures the rate of flowering of trees, which in turn determines the rate of reproductive success. Whereas, Agwu et al. (2020) using climatic models predicted future range shrinkage of *G. kola* due to climate warming; they failed however to show if the local extinctions is going to be through impacts on tree growth or the flowering intensity (i.e. diminished flowering intensity). This is also against the backdrop of paucity of studies on the impact of climate warming on the physiology, growth, phenology, and flowering intensity of the species. The objective of this study was therefore to assess the influence of seasonal climatic variations on flowering intensity of *G. kola* in a humid forest plantation in order to assess the hypothesis that flowering intensity of *G. kola* in the humid forest plantation is temperature controlled.

Materials and Methods

Study Area

The study was carried out in the artificial mono-plantation of *Garcinia kola* within the Swamp Forest Research station, of the Forestry Research Institute of Nigeria (FRIN), Onne Rivers state Nigeria: it is located on latitude 4°42' -10°32'N and longitude 7°10' - 32°46'E and has a mean annual rainfall of 2,400mm, relative humidity of 78%, and a mean annual temperature of 26°C. The area is a mangrove transition forest zone with soil that is 82% sand, 6% silt, and 12% clay with a mean pH of 4.7. The plantation consists of thirteen 23-year-old trees and eighty 13-year-old trees at 5×5m spacing. Flowering and fruiting began in the 13-year-old and 23-year-old trees at the age of 8 years but the 23-year-olds have flowered and fruited for approximately 15-years already. The plantation is trioecious with invariant female trees, inconstant male trees, and hermaphrodite trees, indicative of an evolving dioecy (Okonkwo & Omokhua, 2022).

Data Collection and Analysis

Climatic data were sourced from meteoblue.com with permission. Climatic data collected to characterize the climate of the *Garcinia kola* plantation were: day and night temperatures (ºC), rainfall (mm), atmospheric pressure (mb), visibility (km/h), humidity (%), and wind speed (km/h). Flowering intensity was determined by counting the total flower production per tree after Okonkwo and Omokhua (2022). A total of 9 trees were sampled i.e. three trees per gender and twenty-five inflorescences per tree. Total number of flower buds per inflorescence was determined by visual counting and then extrapolated for the total number of inflorescences per twig (Figure 1), total number of twigs per branch and total number of branches per tree to determine the average flowering intensity of a tree (Sankanur, 2013). Covariance analysis was used to evaluate the pattern of relationship between flowering intensity and climatic variables; seasonal variation of climate and flowering intensity was analysed with analysis of variance (ANOVA), while Tukey's method was used for mean separation.

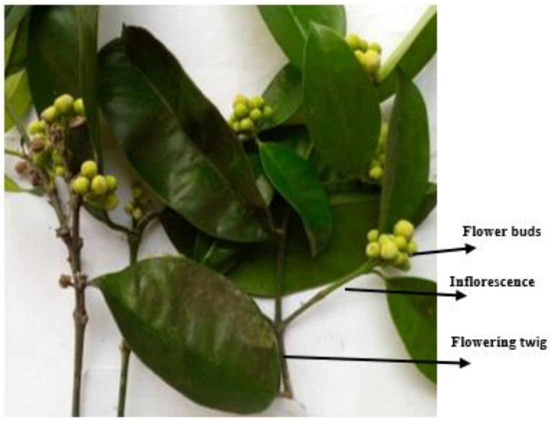

Figure 1. Flowering twig of male *G. kola* tree

Results

Seasonal Flowering Intensity Variation.

Seasonal flowering intensity variation was partitioned into the three tree genders (male, female, and hermaphrodite) in the trioecious plantation; analysis of variance showed that seasonal flowering intensity varied significantly ($p \leq 0.05$) between the genders (Table 1).

Table 1. Analysis of variance (ANOVA) of seasonal flowering intensity variation

Source	SS	df	MS	F	p-value
Between Season (Female)	5.177	2	2.589	9.236	0.000*
Error	9.249	33	0.280		
Total	14.426	35			
Between Season (Male)	204.488	2	102.244	1.2662	0.006*
Error	2664.617	33	80.746		
Total	2869.106	35			
Between season (Herm)	283.657	2	141.828	7.728	0.002*
Error	605.622	33	18.352		
Total	889.278	35			

*P ≤ 0.05: significant at α = 0.05, Herm = hermaphrodite

Female tree flowering intensity was significantly highest in season 1 (2018/2019) 2.4±0.4 buds, followed by season 3 (2020/21) 1.8±0.5 buds, while, the significantly lowest was season 2 (2019/20) 1.5±0.7 buds; male tree flowering intensity was significantly highest in season 1 (21.3±3 buds), followed by season 3 (17.8±12 buds), and the significantly lowest was season 2 (15.7±9.5 buds); hermaphrodite tree flowering intensity was significantly highest in season 1 (15.2±2.2)buds, followed by season 2

(11.6±5.2 buds), and the significantly lowest was 10.6±4.8 (Table 2).

Table 2. Seasonal flowering intensity variation

	Female	Male	Hermaphrodite
1	2.4±0.4^a	21.3±3^a	15.2±2.2^a
2	1.5±0.7^b	15.7±9.5^b	11.6±5.2^b
3	1.8±0.5^b	17.8±12^b	10.6±4.8^b

**Means with same letter are not significantly different (p > 0.05). Flowering intensity was partitioned into the three tree sexes in the plantation viz: female=trees bearing female flowers only; male=tree bearing male flowers only; hermaphrodite=trees bearing male and female flowers on individual tree; season 1=2018/19; season 2=2019/20; season 3=2020/21

Seasonal Climate Variation

The climate of the plantation was characterized over three flowering (reproductive) seasons viz: 2018/19 (season 1), 2019/20 (season 2), and 2020/21 (season 3). Analysis of variance showed that while there were significant (p ≤ 0.05) seasonal variation in rainfall and wind speed in the *G. kola* humid forest plantation, temperature, humidity, visibility, and pressure did not vary significantly (p ≥ 0.05) (Table 3).

Table 3. Analysis of variance (ANOVA) of climatic variables

Sources	SS	df	MS	F	p-value
Day Temperature(ºC)	4.087	2	2.043	0.447	0.643
Night Temperature(ºC)	0.227	2	0.114	0.178	0.838
Pressure (mb)	2.842	2	1.421	0.493	0.615
Humidity (%)	18.024	2	9.012	0.040	0.961
Rainfall (mm)	85308.31	2	42654.16	3.875	0.031
Visibility (km/h)	3.699	2	1.850	1.269	0.295
Wind speed (km/h)	236.224	2	118.112	6.223	0.005

** Bold p-values are significantly different (p ≤ 0.05)

Mean separation however, showed that season 2 recorded significantly the highest mean rainfall (243.64±119.97 mm), followed by season 3 (167.12±83.62 mm), while the least was season 1 (126.18±94.26 mm); season 1 recorded significantly the highest wind speed (11.04±6.43 km/h), this is followed by season 2 (6.3±6.16 km/h), and the least significantly different wind speed was recorded in season 3 (5.0±8.97 km/h) (Table 4)

Table 4. Seasonal climate variation in the humid forest plantation

Season	Temp D	Temp N	RF	WS	Press.	Vis.	Hum.
1	31.36±1.7^a	23.11±0.8^a	126.18±94.3^b	11.1±6.4^a	1011.64±1.6^a	8.11±0.4^a	82.04±7.0^a
2	31.98±2.5^a	23.18±1.0^a	243.64±120.0^a	6.3±6.1^b	1011.73±1.5^a	7.36±1.9^a	80.38±10.4^a
3	32.14±1.8^a	22.98±0.5^a	167.12±83.6^c	5.0±9.0^b	1011.09±1.8^a	7.93±0.6^a	81.62±21.5^a
Mean	31.83±2.0^a	23.09±0.8^a	178.98±99.3^d	7.5±7.2^b	1011.49±1.6^a	7.8±1.0^a	81.35±13.0^a

**Means with same letter are not significantly different (p ≥ 0.05) at α = 0.05. Temp D = day temperature (ºC); Temp N = night temperature (ºC); RF = Rainfall (mm); WS = wind speed (km/h); Press. = pressure (mb); Vis. = visibility (km/h); Hum. = humidity (%). Season 1 = 2018/19; season 2 = 2019/20; season 3 = 2020/21

Relationship Between Rainfall, Wind Speed, and Flowering Intensity

Covariance analysis (Table 5 & Figure 2) showed that in season 1 which recorded significantly low rainfall 126.18±94.26 mm and significantly high wind speed highest 11.04±6.43 km/h, the female tree flowering intensity varied positively with rainfall and wind speed; while the male and hermaphrodite tree flowering intensity varied negatively with rainfall and wind speed; in season 2 which recorded the significantly the highest rainfall 243.64±119.97 mm and significantly lower wind speed 6.3±6.16 km/h than season 1, female tree flowering intensity varied negatively with rainfall but positively with wind speed; while male tree flowering intensity varied positively with rainfall but negatively with wind speed, and hermaphrodite tree behaviour was similar to that of the female tree: it varied negatively with rainfall but negatively with wind speed; in season 3 which recorded significantly low 167.12±83.62 mm rainfall and wind speed 5.0±8.97, female tree flowering intensity varied positively with rainfall and wind speed, male tree flowering intensity varied positively with rainfall but negatively with wind speed and the hermaphrodite tree varied positively with rainfall and wind speed.

Table 5. Covariance analysis of rainfall, wind speed and flowering intensity relationship

	Season 1	Season 2	Season 3
	Female Tree		
Precipitation	11.24	-6.49	2.51
Wind	0.54	0.49	0.13
	Male tree		
Precipitation	-78.32	211.24	194.12
Wind	-2.03	-5.10	-2.66
	Hermaphrodite		
Precipitation	-105.43	-126.84	216.51
Wind	-4.12	6.00	2.52

**Season 1=2018/19; Season 2=2019/20; Season 3=2020/21

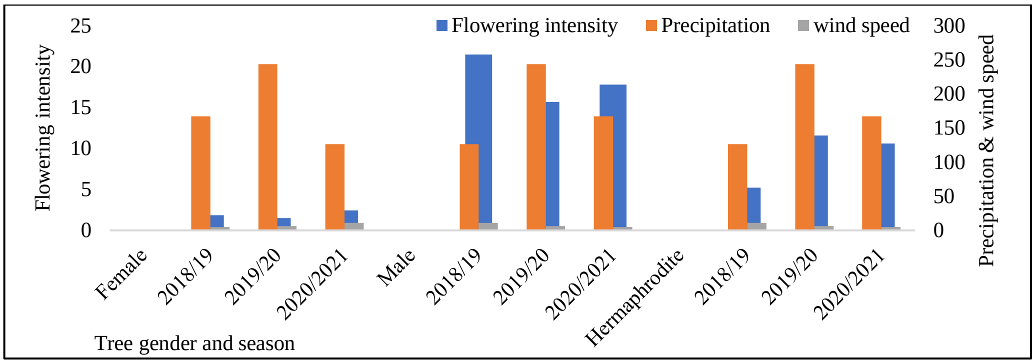

Figure 2. Seasonal flowering intensity variation between tree genders

Discussion

The *Garcinia kola* humid forest plantation in this study showed significant seasonal flowering intensity variation. This is in agreement with Martins et al. (2021) who reported seasonality in flowering and flower conspicuousness in a southern Brazil woodland. Seasonality of flowering behaviour is normally an adaptive traits in plants that is aimed at maximizing reproduction (Morellato et al., 2016). Hence, reproduction is timed to capture optimum weather conditions, resource and pollinator availability in order to achieve maximum reproductive success (Cortés-Flores et al. 2017). According to Martins et al. (2021) the selective pressure exerted by pollinators is a key factor that influences flowering intensity alongside other biotic and abiotic factors.

There were also significant seasonal variation in flowering intensity between the three different genders (male, female, and hermaphrodite). This again is corroborated by Gao et al. (2021) who reported that differences in trade-offs associated with sexual functions and resource use are responsible for variations in flowering patterns between different genders. According to Okonkwo and Omokhua, (2022) flowering intensity variations between genders is often driven by mating competition. Whereas the male flower flowering intensity is significantly influenced by pollinator competition, female trees are more controlled by resource availability than mating competition due to the high reproductive cost of the female function (Ashman, 2000).

Of the six climactic factors (temperature, rainfall, humidity, visibility, wind speed, and pressure) investigated in this study only rainfall and wind speed varied seasonally. This agrees with Abrahamczyk et al. (2011) who reported rainfall, temperature, and day length as the flowering cues of tropical plant species. Seasonal climatic variability has been reported by several authors (Akoun, 2000; Von Holle et al. 2010; Scaven & Rafferty 2013) and according to Pezzulli et al. (2005) it is the normal outcome of the yearly rotation of the earth round the sun.

We found that the pattern of seasonal covariation between flowering intensity and climate was such that female trees flowering intensity varied positively with significantly low and not significantly high rainfall but negatively with significantly high rainfall;

male trees varied positively with not significantly high and significantly high rainfall but negatively with significantly low rainfall; hermaphrodite trees varied positively with not significantly high rainfall but negatively with significantly high and significantly low rainfall; while, wind speed variation with flowering intensity was inconsistent. This gives the impression that while low to moderate rainfall is favourable for significantly high flowering intensity in female *G. kola* trees, male trees require the opposite, and hermaphrodite trees require intermediate rainfall. This is in agreement with Agwu et al. (2020) who reported that rainfall is a key determinant of the natural range of Garcinia kola. The result is in agreement with the general consensus in literature (Liu et al. 2018; Zhou et al. 2018; Rodriguez-Garcia et al. 2019) on differences in resource and environmental requirement of different plant genders.

Conclusion

Climate and flowering intensity varied significantly between seasons in the *G. kola* humid forest plantation; climatic variables that varied significantly between seasons were rainfall and wind speed while, temperature, humidity, visibility, and pressure did not vary significantly. Female tree flowering intensity varied positively with significantly low rainfall and significantly high wind speed in season 1 (2018/19); and also varied positively with significantly low rainfall and wind speed in season 3 (2020/21); but varied negatively with significantly high rainfall but positively significantly low wind speed in season 2 (2019/20); thus indicating that significantly high rainfall negatively influenced female tree flowering intensity while the role of wind speed was inconsistent with the pattern of flowering intensity. Male tree flowering intensity varied negatively with significantly low rainfall and significantly high wind speed in season 1 (2018/19); and varied positively with significantly high rainfall but negatively with significantly low wind speed in season 2 (2019/20); and also varied positively with high (not significantly) rainfall and significantly low wind speed in season 3 (2020/21); thus implying that high and significantly high rainfall positively influenced male tree flowering intensity while again the role of wind speed was inconsistent with the pattern of flowering intensity. Hermaphrodite tree flowering intensity varied negatively with significantly low flowering intensity and significantly high wind speed in season 1 (2018/19), and also negatively with significantly high rainfall but positively with significantly low wind speed in season 2 (2019/20), and varied positively with high (not significantly) rainfall and significantly low wind speed in season 3 (2020/21); this shows that the hermaphrodite tree flowering intensity-rainfall relationship was intermediate to the male and female tree and the role of wind speed was inconsistent. The study therefore suggests rainfall as the flowering cue of *G. kola* in the humid forest plantation and that seasonal rainfall variation influenced the flowering intensity of the tree genders in the plantation differently. Significant rise in rainfall in the plantation area translates to low female tree flowering intensity, high male and hermaphrodite tree flowering intensity. Hence, the hypothesized range loss of the species from climate warming is possibly going to be due to diminishing female tree flowering intensity and low regeneration potential. There is however the need for a longer duration of study than three seasons to further test the hypothesis and corroborate these findings vis-à-vis the changing climate; furthermore, provenance investigations of climate-flowering intensity relationship in *G. kola* along rainfall gradients is also another study frontier of relevance in this regard. We recommend that annual weather information be used by *G. kola* farmers and tree owners to identify seasons of significant high and low rainfall in order to prepare for seasons of low and high fruit yields based on the findings of this study. This will help tree owners to be properly prepared and avoid the disappointment they already face during low yield seasons.

Ethics Committee Approval

N/A

Peer-review

Externally peer-reviewed.

Author Contributions

Conceptualization: H.O., G.O.; Investigation: H.O.; Material and Methodology: H.O.; Supervision: G.O., U.C.; Visualization: H.O.; Writing-Original Draft: H.O.; Writing-review & Editing: H.O., G.O., U.C; Other: All authors have read and agreed to the published version of manuscript.

Conflict of Interest

The authors have no conflicts of interest to declare.

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