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Effect of climatic conditions on flowering and fruiting of *Tamarindus indica* (Fabaceae)

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This study examined effects of climatic conditions on patterns of flowering and fruiting of tamarind (*Tamarindus indica* L.). Data were recorded over a period of 26 months in two contrasting climatic zones. The monitoring revealed that irrespective of climatic zones, flowering starts by the end of the dry season when hygrometry begins to rise and lasts two to three months. Fruiting begins around the peak of the rainy season and reaches the ripening stage six to eight months later during the dry season. Flowering and fruiting abilities weakly varied with climatic conditions. Flowering durations and active phases seemed to be significantly longer ($p < 0.001$) under wetter climatic conditions (Sudan-Guinea zone) while fruiting parameters showed the opposite trend. Flowering length was found to be weakly correlated to climatic conditions while the latter variable was positively correlated to fruiting length. A negative correlation was observed between fruiting length and trees diameter; suggesting that the younger the tree, the longer the fruiting phase. These results provide insights into the patterns of phenological events of tamarind that could help in managing its populations and anticipating its flowering and fruiting shifting response to climate changes. Thorough research should however focus on modeling the combined effect of climate, soil, land use regimes and age of trees on the inter-annual variation of flowering and fruiting patterns and productivity.

Key words: Indigenous fruit trees, phenology, climate, Benin, West Africa.

INTRODUCTION

Non-timber forest products play a key role in the livelihoods of many rural communities and may be used as mean to ensure conservation of natural ecosystems (Marshall and Newton, 2003). Indigenous fruit trees such

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Table 1. Characteristics of the two climatic zones (climate data source:the local climatology and weather forecast institute, ASCENA).

Parameter	Sudan zone	Sudan-Guinea zone
Location	9°45'-12°25' N	7°30'-9°45' N
Rainfall regime	Unimodal	Unimodal
Rainfall (mm)	<1000	900-1110
Temperature (°C)	24-31	25-29
Relative humidity (%)	18-99	31-98
Soil	Hydromorphic, soils well drained and lithosols	Ferruginous with variable fertility
Climate type	Tropical	Tropical

as *Tamarindus indica* L. (Fabaceae), tamarinier (French), tamarind (English) or *Djêtami / N'djabé* (Fulfuldé: Fulani language) are daily used in rural households as food or medicine, and provide cash income to rural women (Fandohan et al., 2010a). It has been recently identified as one of the major agroforestry tree species to be prioritized for future crop in sub-Saharan Africa (Akinnifesi et al., 2008). For the above-mentioned goal to be realistic, thorough studies on ecological range, traditional importance, reproductive processes, phenological patterns, fruiting potential and genetic diversity at large scales (that is, countries and regions) are required. There have been extensive studies on biochemical, medicinal and nutritional properties, reproductive biology, morphology, cultivation and genetics of tamarind (El-Siddig et al., 2006). According to the latter authors, tamarind has a promising potential for domestication and may play a key role in strategies seeking to reduce poverty and malnutrition, especially in the developing world. Although the distribution range of tamarind in Africa evidences its plasticity under the tropics (Bowe and Haq, 2010), recent work has reported its populations to be sensitive to drought in its native areas (Diallo, 2001; Fandohan et al., 2010b). This study aims to provide some insights into the patterns of its phenology across a climatic gradient.

The growing number of studies on woody plants phenology has yielded various findings. It has been shown that patterns of phenological events in some species (e.g. *Combretum aculeatum* Vent. and *Acacia adansonii* (Guill & Perr) O.Ktze) greatly fluctuate with years whereas in some others (e.g. *Guiera senegalensis* GF.Gmel., *Ziziphus mauritiana* Lam.) are independent of the variation in climatic factors (Grouzis, 1991). Studies demonstrate that the patterns of phenological events of woody plants in warm climates are tightly linked with air hygrometry (Piot et al., 1980; Okullo et al., 2004), soil moisture (De Bie et al., 1998) and topography (Law et al., 2000).

Interest in the phenology of tamarind tree has risen during the second half of the last century. Recent works provided noticeable information on leafing strategy of this species, proportion of flowers and fruits loss and degree of synchronism of flowering and fruiting at individual and population levels. Tamarind is a semi-evergreen species showing leaf shedding and sprouting once a year, during a short period (one-two weeks) just before the rainy season, displaying scleromorphic features as adaptation to drought (De Bie et al., 1998). Flowering in this species is asynchronous at individual level but it is synchronous at population level (Diallo, 2001).

Nonetheless, at present, little is known about how climatic conditions alter its flowering and fruiting phenologies. Ignoring variations in climatic conditions and how they affect phenology may lead to erroneous generalizations of timing of phenological events and even misestimating variations in fruit production at inter-annual and inter-ecological range (De Bie et al., 1998; Assogbadjo et al., 2005).

This study aimed at assessing the extent to which flowering and fruiting abilities in tamarind vary with climatic conditions, and how the latter alters the period of active flowering and fruiting active phases.

MATERIALS AND METHODS

Study area

This study was conducted in two climatic zones of Benin (West Africa) hosting natural populations of *Tamarindus indica*: The Sudan zone and the Sudan-Guinea transition zone. Table 1 summarises location and characteristics of the two climatic zones.

Data collection

Due to resource limitation, a total of forty four trees (20 in the Sudan-Guinea zone and 24 in the Sudan zone) with $D_{1.30}$ ≥10 cm were randomly selected for flowering and fruiting monitoring. To facilitate data collection, trees were sample depending on accessibility of their location. It was not possible for a single person to be collecting the data at every location at the same time. Thus, data were collected synchronically by the main author aided by well trained field technicians residing in each zone.

Flowering and fruiting of all sampled individuals were monitored for a two-year period (February 2008 to January, 2010). Flowering and fruiting abilities were considered as two categorical variables with two possible values. Each sampled individual was attributed the value 1 if flowering, otherwise 0, and again 1 if fruiting, otherwise, 0. Four stages of flowering and four stages of fruiting were distinguished and respectively coded from 1 to 4 following

Table 2. Phenological events.

	Phenophase stages			
	1	**2**	**3**	**4**
Flowering	*Start of flowering*: appearance of the first buds of flowers	*Flowering*: first flower buds are opening whereas others are appearing	*Full flowering*: most of flowers are opened	*End of flowering*: no more new flowers appear
Fruiting	*Start of fruiting*: first developing fruits	*Fruiting is going on*: presence of first full size green fruits	*Fruiting*: presence of fully developed brown fruit	*Peak of fruiting*: most of fruits are ripened

Table 3. Effect of climatic conditions and years on flowering and fruiting ability of tamarind: results of the GLM with binomial error distribution.

Factors	Flowering ability					Fruiting ability				
	Df	**Dev**	**Resid. Df**	**Resid. Dev**	**Pr(>Chi)**	**Df**	**Dev**	**Resid. Df**	**Resid. Dev**	**Pr(>Chi)**
Zone	1	26.89	2	39.57	<0.001	1	14.47	2	31.50	<0.001
Years	1	32.25	1	7.32	<0.001	1	19.60	1	11.90	<0.001

Df, degree of freedom; Resid, residual; Dev., deviance.

Okullo et al. (2004) and Kelly et al. (2007) as described in Table 2. Four variables were defined from the stages described in Table 2; (i) length of flowering and length of fruiting respectively include the period (expressed in days) between the stages 1 and 4, and (ii) length of active phase of flowering and length of active phase of fruiting respectively include the period (expressed in days) between the stages 2 and 3. During the data collection phase, information on fruit harvesting techniques was also recorded. Finally, climatic condition was also considered as a categorical variable with two possible values: 0 if Sudan zone and 1 if Sudan-Guinea zone.

Data analysis

Effects of climatic conditions and year on flowering and fruiting abilities (whether a tree flowers or fructifies in a given year) were assessed using a generalized linear model (GLM) based on binomial error distribution while effects of climatic conditions on the length of flowering and fruiting and lengths of active phases of flowering and fruiting were analyzed using the GLM based on either Poison or Negative binomial error distribution in R software (R Core Team, 2015). The negative binomial error distribution was used to overcome the over dispersion which was not corrected by the quasi poisson error distribution (Crawley, 2007). To test whether flowering and fruiting lengths and active phases correlate with trees $D_{1.30}$ the Pearson correlation coefficient was used in package Hmisc (Frank et al., 2014) of R software.

RESULTS

Effect of climatic conditions on flowering and fruiting abilities

Significant differences (p<0.001) were found in flowering and fruiting abilities between climatic zones and years (Table 3). Irrespective of climatic conditions, all sampled trees flowered during the first year (Figure 1a). Little differences were observed in fruiting ability among climatic conditions in the first year (Figure 1b). In the Sudan zone however, 5% of trees faced total immature fruit abortion whereas 12.5% did not fruit at all after the flowering phase. In the Sudan-Guinea zone, 25% of trees faced total fruit abortion (Figure 1b).

During the second year of the study, no important changes were observed in flowering and fruiting abilities of surveyed trees in the Sudan zone (Figure 1a and b); fructification failures were also noticed on the same individuals. In contrast, no tree flowered and thus did not bear fruits in the Sudan-Guinea zone (Figure 1a and b).

Figure 2 summarizes timing of phenological events in the two climatic zones. In the Sudan-Guinea zone, flowering started at the end of March and ended early in June while fruiting started in June and reached ripening peak in December in the first year (Figure 2a). In the Sudan zone, flowering started in April and ended in June while fruiting started in July and reached ripening peak between January and February in the first year (Figure 2b). In the second year, some changes were observed in the timing of these phenological events in the Sudan zone: Flowering started in May instead of April and fruiting started in October instead of August (Figure 2b). This implies delays of approximately 30 and 60 days, respectively (Figure 2b). In the second year in the Sudan-Guinea zone, surveyed tree did not flower and thus did not fructify (Figure 2a).

Effect of climatic conditions on flowering and fruiting lengths and active phases

The effect of climatic conditions on both flowering length

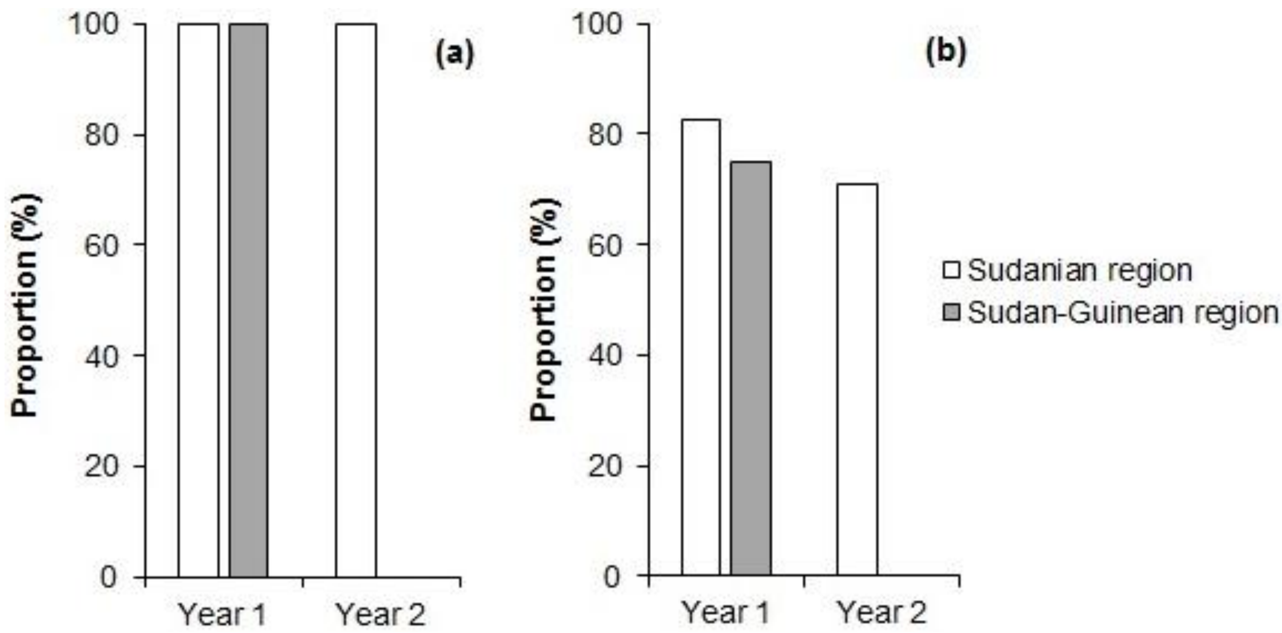

Figure 1. Proportion of tamarind trees flowering (a) and fruiting (b) across climatic zones and years of monitoring.

Table 4. Effects of climatic conditions on the length of flowering, fruiting and their active phases: results of the generalized linear model using either Poisson or negative binomial error distribution.

Responses	Df	Dev.	Resid. Df	Resid. Dev	Pr(>Chi)
Flowering length NB	1	9.74	42	43.92	0.002
Active flowering length PO	1	18.08	42	28.86	<0.001
Fruiting length NB	1	8.06	42	44.71	0.005
Active fruiting length NB	1	16.88	42	44.57	<0.001

NB, Negative binomial error distribution; PO, Poisson error distribution; Df, degree of freedom; Resid, residual; Dev., deviance.

and active phase was found to be significant ($p <0.05$; Table 4). The mean durations for both total length and length of active phase of flowering were observed to be shorter in the Sudan-Guinea than in the Sudan zone (Figure 3a), respectively (56.00 ± 2.90 and 30.20 ± 0.25 days) and (70.92 ± 3.88 and 37.71 ± 1.33 days). Significant differences were also encountered for fruiting length and active phase ($p <0.05$ and Table 4). Contrarily to flowering, both fruiting length and active phase duration were shorter in the drier Sudan than in the Sudan-Guinea zone (Figure 3b), respectively (166.75 ± 8.69 and 122.29 ± 5.83 days) and (196.30 ± 2.98 and 150.25 ± 2.32 days). In addition, the standard errors were relatively lower in the Sudan-Guinea zone than in the Sudan zone, suggesting little tree to tree variation within the former zone as compared to the latter one.

Length and active phase of flowering were weakly correlated with $D_{1.30}$ (Table 5). In contrast, a significant negative correlation was observed between total length of fruiting and $D_{1.30}$ but not for length of active phase of fruiting (Table 5).

DISCUSSION

Results from this study indicate that climatic conditions have a significant impact on flowering and fruiting phenologies of *T. indica*. Under both climatic conditions, the beginning of flowering coincided with the end of the dry period whereas the active phase of the fructification took place during the rainy months. This suggests that the reproductive physiology of tamarind might be dependent on a climatic factor of which the variation is regular year-round. Such observations match with the hypothesis that phenological events' timing is linked with the variation in air hygrometry and rainfall. These observations are also consistent with Okullo et al. (2004) who noticed that there is a positive relationship between phenology timing and atmospheric relative humidity. On the other hand, the fruit ripening peak was reached

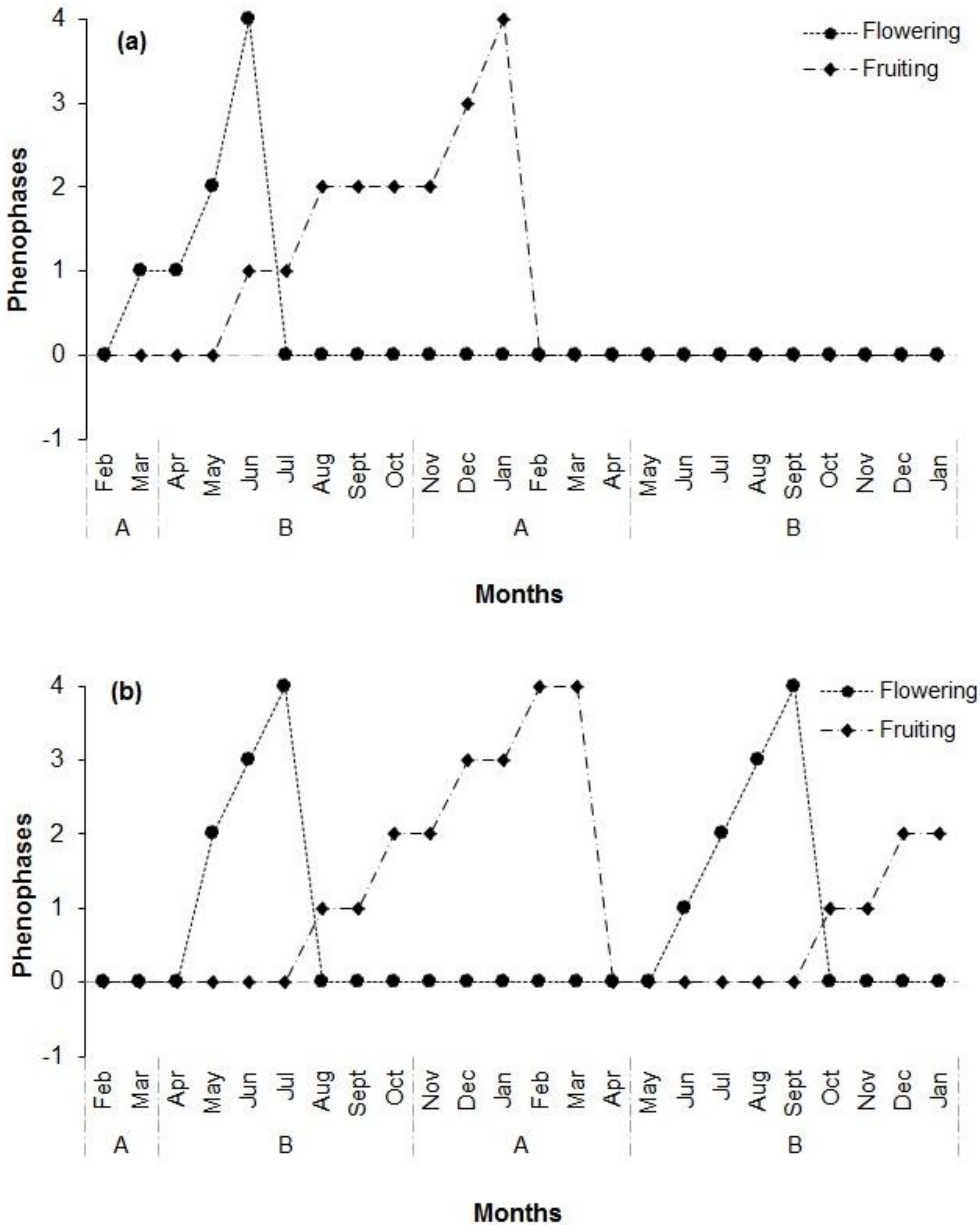

Figure 2. Temporal pattern of flowering and fruiting of *T. indica* in (a) the Sudan-Guinea zone and (b) the Sudan zone. A, dry season; B, rainy season.

during the dry seasons. It has been illustrated that hygrometry reduction is critical for tamarind fruit ripening (Morton, 1987).

For most investigated variables, the standard errors did not support synchronism of phenological events at population level. However, tree-to-tree variations were lower in the Sudan-Guinea zone, suggesting a tendency to phonological synchrony. According to Diallo (2001),

Table 5. Pearson correlations between $D_{1.30}$ and phonological parameters.

Phenological variables	$D_{1.30}$
Flowering length	$+0.12^{ns}$
Flowering active phase	$+0.17^{ns}$
Fruiting length	-0.51***
Fruiting active phase	-0.20^{ns}

Significance: ^{ns} $p > 0.05$; ***$p < 0.001$

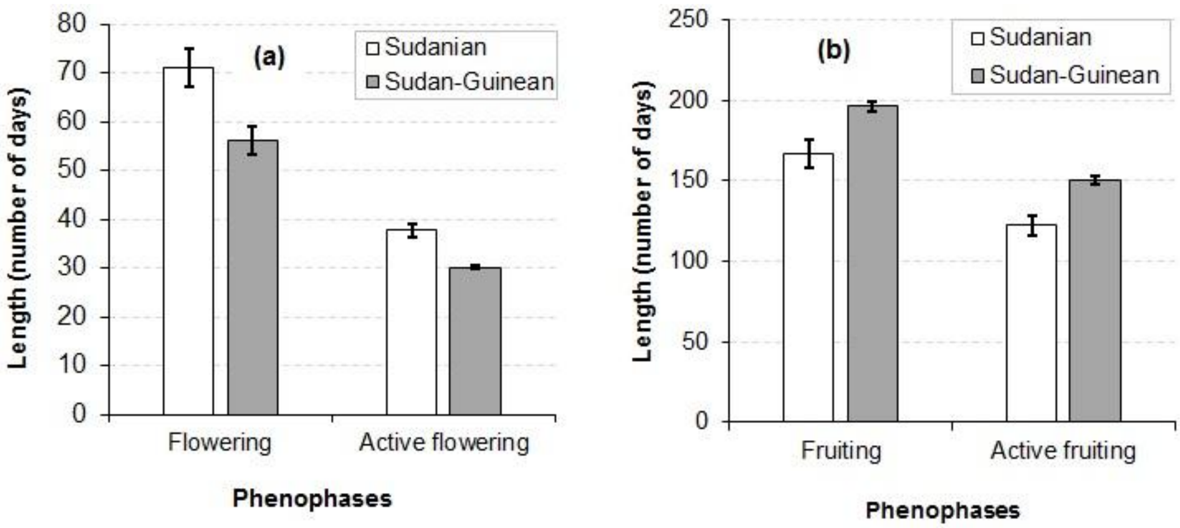

Figure 3. Variation of total length and length of active phases of flowering (a) and fruiting (b) in the studied zones. Errors bars represent the standard errors.

synchrony is an adaptation strategy developed against water scarcity in the Sahel and the Sudan zones. Flowering and fruiting activities may also intrinsically be timed to coincide with favourable weather conditions for optimizing performance (Khan, 1999). This may explain the observed inter-annual shifting in the timing of phenological events.

During the two years of observation, some trees showed either total flower abortion or overall immature fruit abortion after normal flowering. Fruit or flower abortions can be due to resource limitation (Stephenson, 1981). However, some individuals with very little differences in size and environmental conditions did not show such a problem (field observations). Abortion in tamarind can also be linked to sterility, poor floral visits by pollinators or high rate of self-pollination (Diallo et al., 2008). The same authors have pointed out that because flowering in tamarind at tree level is asynchronous, the absence of an effective pollinator (that can disseminate allo-pollen) at the right time of stigmatic receptivity will lead to a low rate of fecundated ovules and thus a poor reproduction. In addition, because one of the predominant pollinators of *T. indica* which is *Apis mellifera* L. mainly disseminates self-pollens, such disseminator, may increase the rate of self-fecundation and thus reduce fructification success.

Although this was not rigorously measured, failure of all trees to flower during the second year, in the Sudan-Guinea zone could be imputable to the fruit harvesting technique used by locals in this area. It was observed that while in the Sudan zone, fruits were collected without pruning the trees, this was not the case in the Sudan-Guinea zones. Pruning often results in reduction of photosynthetic capacity, and/or reallocation of resources or stored reserves from reproduction to vegetative growth (Gaoue and Ticktin, 2008).

Flowering length and active phase significantly differed between areas with different climatic conditions. Fruiting length and fruiting active phase were significantly longer in Sudan-Guinea zone (wetter zone) than in the Sudan zone while flowering length and flowering active phase showed the reverse trend. This suggests that the wetter the climate, the longer the fruiting length and active phase. This may be linked to; (i) larger size of fruits in wetter zones (Fandohan A.B., personal observations) so that they take longer to reach full size; (ii) earlier starting of the drought period or lower relative air humidity during that period in drier zones so that ripening takes place earlier. Results suggest a negative relationship between fruiting events and $D_{1.30}$: The larger the $D_{1.30}$ was, the lower the fruiting length was. This may be because larger trees gather faster, needed resources for reproduction due to a higher photosynthetic capacity and a more powerful root system. However, this hypothesis should be further confirmed.

Conclusion

This study provides information on the functional rhythms of *Tamarindus indica* in relation to climatic conditions. Climatic conditions seemed to significantly affect phenological events. Such information has several practical implications such as biotic indicator of climatic variations and may be relevant in predicting flowering and fruiting shifts in response to changes in climatic conditions. Nevertheless, interpretations should be taken with great caution because observed trends may result from many other confounded idiosyncratic and environment effects related to the life story of each tree, that is, past fire stress, disease, pest attacks, etc. In addition, successful fruiting in one year may be at the cost of vegetative growth so that some woody plants alternate supra-annual schedules of low and high production years (Kelly and Sork, 2002). Hence, further long-term phenological studies should address how far exploitation regimes, climatic factors, soils, and age of the trees affect inter-annual variation of phenological events and productivity of tamarind trees.

Conflict of Interest

The authors have not declared any conflict of interest.

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