

## Phenology of *Sclerocarya birrea* (A. Rich.) Hochst. Provenances

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### Abstract

Phenology study was conducted to assess 22 genotypes of *Sclerocarya birrea* (A. Rich.) Hochst, collected from West, Eastern and Southern Africa. Assessments were done on time for bud onset, flower opening, leaf flush, fruit set, fruit maturity period and fruit production. Highly significant ( $P < 0.001$ ) variations between provenances were obtained in all the phenological traits assessed including variations between sexes in time from flower bud set to anthesis. There was flowering overlaps and synchrony between provenances and sexes with males flowering earlier than females. So far two subpopulations have emerged within the trial referred to as early and late flowering genotypes. The early flowering included provenances from Mozambique, and Swaziland while the late flowering encompassed provenances from Malawi, Zimbabwe, Namibia, Tanzania and Zambia. Fruit maturity period ranged from  $76 \pm 2$  to  $192 \pm 15$  days. The early flowering genotypes flowered, fruited and matured between August and January while the late genotypes flowered and fruited from September to May. There were highly significant ( $P \leq 0.001$ ) variations in fruit yield of *S. birrea* provenances between 2016/2017 and 2017/2018 seasons with the former being more productive than the later confirming that *S. birrea* fruit yield is not constant across seasons due to seed mating effects. There were very strong positive relationship ranging  $r = 0.81$  to  $r = 0.78$  between leaf flush, bud set, flower opening and fruit set significant at ( $P < 0.001$ ). Some trees classified as females in the first year as based on flowers were found have male flowers which calls for more detailed investigations into this sex change behaviour.

### Keywords:

Leaf Flush;  
Sex Change;  
Genetic Relatedness;  
Synchrony;  
Dioecious Species;  
Anthesis.

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## 1- Introduction

*Sclerocarya birrea* (A. Rich.) Hochst is an important multipurpose indigenous fruit tree of high social, cultural and commercial value in Africa [1, 2]. The species is common and widespread throughout the semi-arid, deciduous savannas in sub-Saharan Africa [3]. In Malawi, the species occurs mainly in hot dry areas between 500 and 1,000m above sea level with mean annual rainfall of 900–1,000mm and mean annual temperature of 22 – 23°C [4]. Ecological distribution, biological description and uses of *S. birrea* are well explained by Mkwezalamba et al. [5] and Nyoka et al. [6]. Briefly, the tree of *S. birrea* is famously known because of its fruits which are used to make products of economic importance such as Amalura beer and the oil which are sold worldwide.

In order to sustain the supply of Marula fruit production, domestication initiatives started in the 1990s in SADC region [7] and in Israel [8]. An international provenances trial of 22 genotypes of *Sclerocarya birrea* was established in Mangochi in 1999 to evaluate growth, tolerance to pest and diseases, adaptability (survival), fruit productivity and quality in order to select genotypes with superior traits and well adapted to local conditions for the domestication. The purpose of this study was to examine the phenology (inflorescence development) of the 22 provenances of *S. birrea*. Phenology reveals the transformational mechanisms of plant life, timing of recurrent life cycle stages (phenophases). The timing of flowering phenology within and between populations is of fundamental biological importance because of

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its influence on total seed production, dispersal, pollinator abundance and fitness [9]. More importantly the synchronization of flowering phenology between sexes is crucial in ensuring gene mixture through increased outcrossing and effective fertilization [10].

Since the establishment of the International Provenance trial of *S. birrea*, published papers on survival percentage [11], vegetative growth and fruit production [6, 12, 13], morphometric fruit traits [5], have been written on the trial. But no study has been conducted on the trial to address issues of phenology. The information on the phenology of *S. birrea* genotypes is pertinent for successful selection for domestication and breeding program [14]. It is also important in assessing barriers to seed and fruit set [15].

In order to study the phenology of *S. birrea* we aimed to answer the following questions: (1) Do all the geographic populations have the same flowering time and length of flowering? (2) Are there variations between populations in time for bud set, flower opening, leaf flush and fruit set? (3) Do variations exist between sexes from flower bud set to anthesis? (4) Is there flowering synchrony between male and female trees? (5) Does provenance vary in the duration for fruit maturation? (6) Are there variations in fruit productivity between seasons?

## 2- Materials and Methods

### 2-1- Study Site and Experimental Material

The study site and experimental material has been well described by Mkwezalamba et al. [5] and Nyoka et al. [6]. Briefly, the trial was established in February 1999 in the Palm Forest Research, Mangochi (14°28'S, 35°14'E, and 469 m above sea level) (Figure 1) with twenty populations of *S. birrea ssp. caffra* and one population of *S. birrea ssp. birrea* (Table 1). The trial was laid out as a randomized complete block design replicated four times. The plot size was a 20-tree row plot. The spacing was 5 m between row plots and 4 m between trees within a plot. There were, therefore, 80 trees per population in the test. Weather during the study period are given in Figure 2.

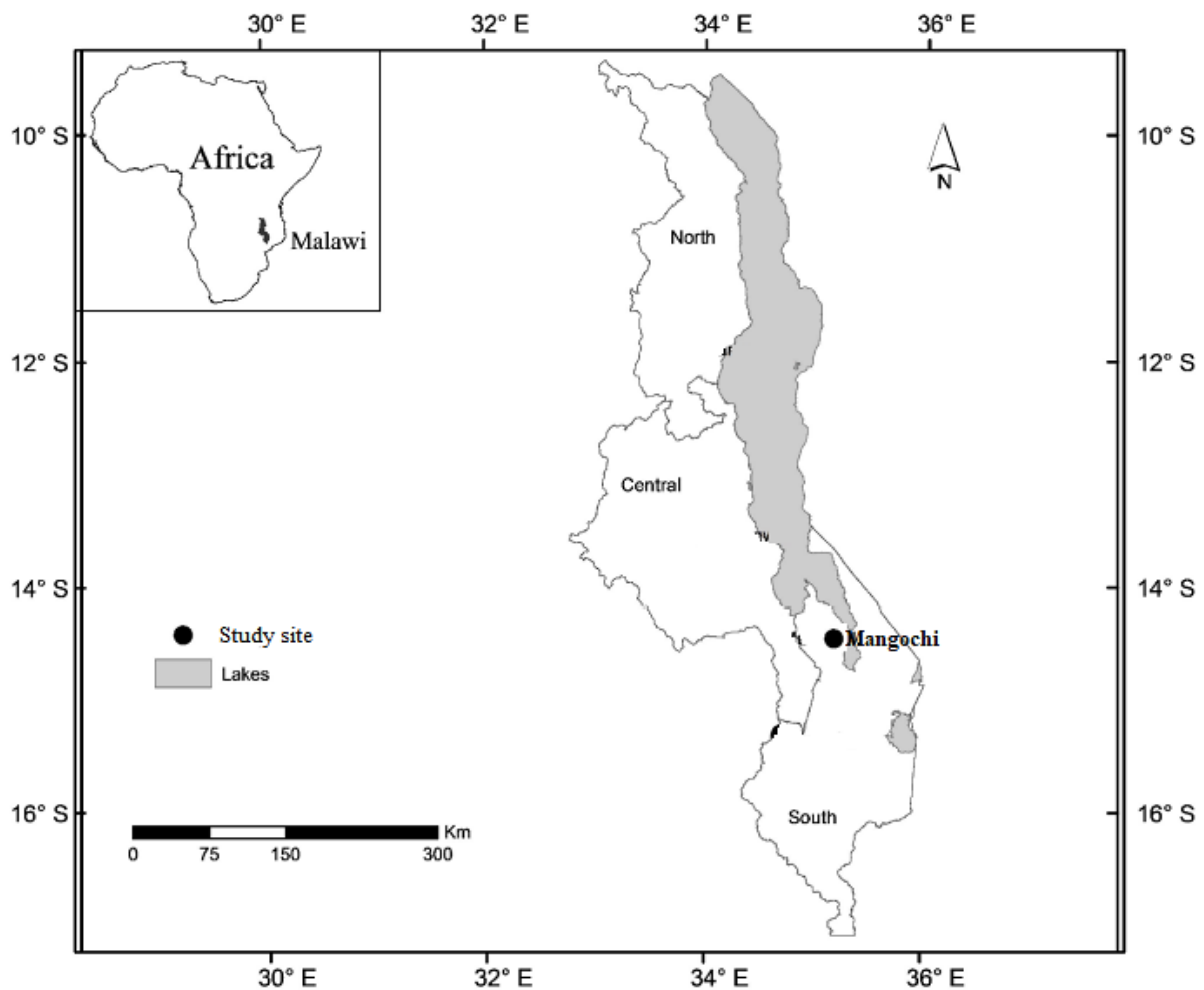


Figure 1. Map of Malawi showing the location of the study site

**Table 1. Geographic details of the Marula germplasm tested in Malawi**

Provenance name	Country	Species	Number of families	Latitude	Longitude	Altitude (m)
Ntcheu	Malawi	<i>S. birrea</i> ssp <i>caffra</i>	19	14°39'S	34°46'E	300–600
Mangochi	Malawi	<i>S. birrea</i> ssp <i>caffra</i>	20	14°02'S	34°53'E	200–600
Chikwawa	Malawi	<i>S. birrea</i> ssp <i>caffra</i>	10	16°46'S	35°17'E	100–300
Rumphu	Malawi	<i>S. birrea</i> ssp <i>caffra</i>	20	10°59'S	33°45'E	900–1200
Marracuene	Mozambique	<i>S. birrea</i> ssp <i>caffra</i>	17	25°58'S	32°95'E	0–200
Magunde	Mozambique	<i>S. birrea</i> ssp <i>caffra</i>	20	24°95'S	32°92'E	0–200
Moamba	Mozambique	<i>S. birrea</i> ssp <i>caffra</i>	20	25°55'S	32°55'E	0–200
Oshikondilongo	Namibia	<i>S. birrea</i> ssp <i>caffra</i>	16	17°35'S	15°45'E	1030
Kalimbeza	Namibia	<i>S. birrea</i> ssp <i>caffra</i>	15	17°34'S	24°34'E	967
Ohangwena	Namibia	<i>S. birrea</i> ssp <i>caffra</i>	20	17°30'S	15°55'E	1144
Kalanga	Swaziland	<i>S. birrea</i> ssp <i>caffra</i>	20	26°45'S	31°45'E	239
Siavonga	Zambia	<i>S. birrea</i> ssp <i>caffra</i>	16	16°30'S	28°00'E	520
Choma	Zambia	<i>S. birrea</i> ssp <i>caffra</i>	14	17°00'S	27°00'E	1300
Ngundu	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	13	20°50'S	32°50'E	457
Biriwiri	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	15	19°50'S	32°40'E	1500
Matebeleland North*	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	14	18°00'S	29°00'E	996
Mudzi	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	15	16°17'S	32°45'E	400
Muzarabani	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	15	19°50'S	32°40'E	600
Matebeleland South*	Zimbabwe	<i>S. birrea</i> ssp <i>caffra</i>	15	21°00'S	32°45'E	388
Magamba (Handeni)	Tanzania	<i>S. birrea</i> ssp <i>caffra</i>	9	5°40'S	38°12'E	530
Missira	Mali	<i>S. birrea</i> ssp <i>birrea</i>	19	13°43'N	8°27'W	352
Chigongwe (Dodoma)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	9	6°04'S	35°45'E	920
Mialo (Kondoa)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	9	5°03'S	36°21'E	1150
Mandimu (Singida)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	3	5°04'S	35°08'E	1460
Mkata (Kilosa)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	6	7°22'S	37°50'E	430
Ubena (Bagamoyo)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	9	6°11'S	38°10'E	305
Chalinze (Bagamoyo)	Tanzania	<i>S. birrea</i> ssp <i>birrea</i>	8	6°55'S	38°20'E	550

\* Locality name not given.

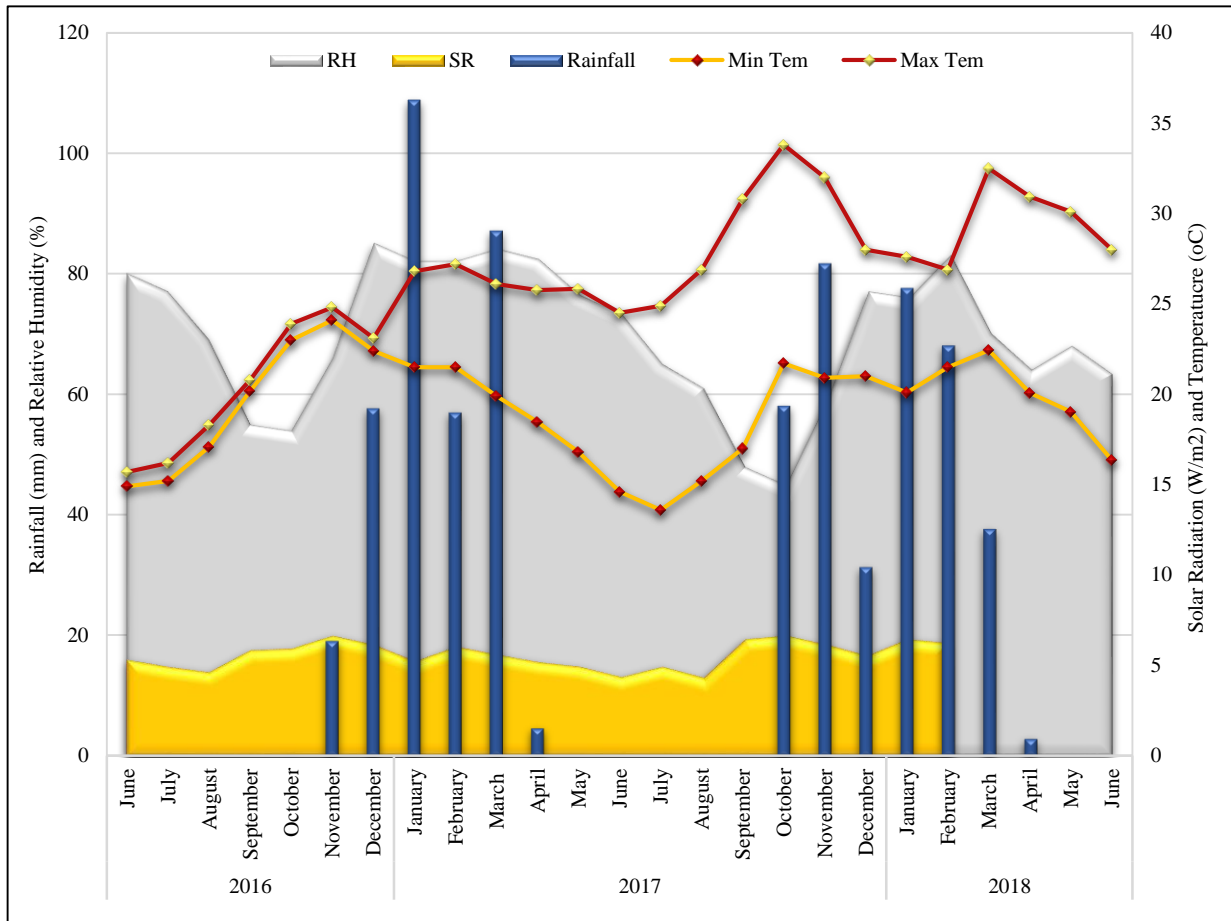


Figure 2. Weather from June 2016 to June 2018 for the study area

2-2-Data Collection

At age 18 of *S. birrea*, the trial was assessed for bud onset, flower opening and leaf flush for both male and female individual trees except for the bulked provenance from Tanzania. Assessments on fruit set, fruit maturity period and productivity were done on fruiting female trees. Fruit productivity assessment was done in two consecutive fruiting seasons (2016/2017 and 2017/2018). The assessment was done using the procedure described by Khanduri *et al.* [16].

2-3-Statistical Analysis

The data on time for leaf flush, bud formation to anthesis, fruit onset to maturity and productivity were tested for normality and homogeneity. After the two criteria were met the data were subjected to analysis of variance (ANOVA) using MINITAB 17.0 with provenances and block as fixed factors. Differences between treatments means were separated using Fischer’s least significant difference (LSD) at the 0.05 level. Pearson correlation coefficients were calculated to determine the relationship between leaf flush, bud set, flower opening and fruit set. A summary of the research methodology is presented in Figure 3.

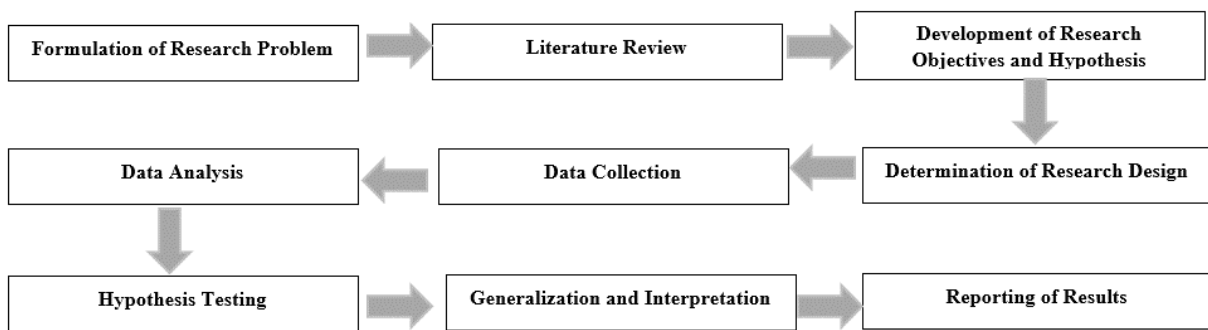


Figure 3. Research Methodology Flow Chart

### 3- Results

#### 3-1- Variations among Provenances of *S. Birrea* in bud Set, Bud Opening, Leaf Flush, Fruit Set, Fruit Maturity Period and Production

The results on the parameters studied (bud set, bud opening, leaf flush, fruit set, fruit maturity period and fruit production) are presented in Tables 2 and 3 and Figures 4 and 5. The results indicate that there were significant ( $P<0.001$ ) differences among provenances on all the parameters studied. The first provenances to set buds included Marracuene, Magunde, Moamba, Kalanga and Missira within a range of  $242\pm 3.7$  and  $256\pm 1.9$  days.

The first group in flower opening comprised of Marracuene, Magunde, Moamba, Kalanga and Missira provenances within the range of  $246\pm 3.4$  and  $262\pm 3.3$  days. On leaf flushing, the superior provenances were Marracuene, Magunde, Moamba and Kalanga with a leaf flushing mean days ranging from  $249\pm 3.6$  to  $264\pm 0.7$ . Furthermore, the results indicate that Missira, Marracuene, Magunde, Moamba and Kalanga, populations were the earliest in fruit set within range of  $254\pm 4.1$  to  $266\pm 3.5$  days.

The early maturing provenances included Missira, Marracuene, Magunde, Moamba and Kalanga that matured within a range of  $76\pm 2.0$  to  $94\pm 1.8$  days. Provenances with highest number of fruits in 2016/2017 season included Kalimbeza, Chikwawa, Moamba, Magunde and Marracuene while in 2017/2018, Kalimbeza and Moamba, produced highest number of fruits within the range of  $614\pm 270$  to  $308\pm 146$  fruits respectively.

#### 3-2- Variations between Sex in Days from Bud to Anthesis

Variations between males and females in number of days from bud set to flower opening were highly significant ( $P<0.001$ ) (Figure 6). The males reached anthesis within the range of  $5.0\pm 0.4$  and  $8.0\pm 0.8$  days while females reached anthesis within  $4.0\pm 0.3$  and  $7.0\pm 2.0$  days. The males that took the longest period (8 days) to reach anthesis included Ohangwena and Chikwawa provenances while Missira had the shortest period of about 5 days. Amongst the female trees, Mudzi, Biriwiri and Kalanga had the longest period of 7 days between bud set and flower opening while Magamba, Mangochi and Siavonga took the shortest period within a range of ( $4.0\pm 0.0$  to  $5.0\pm 1.00$ ) days.

#### 3-3- Relationship between Leaf Flush and Phenology Characteristics

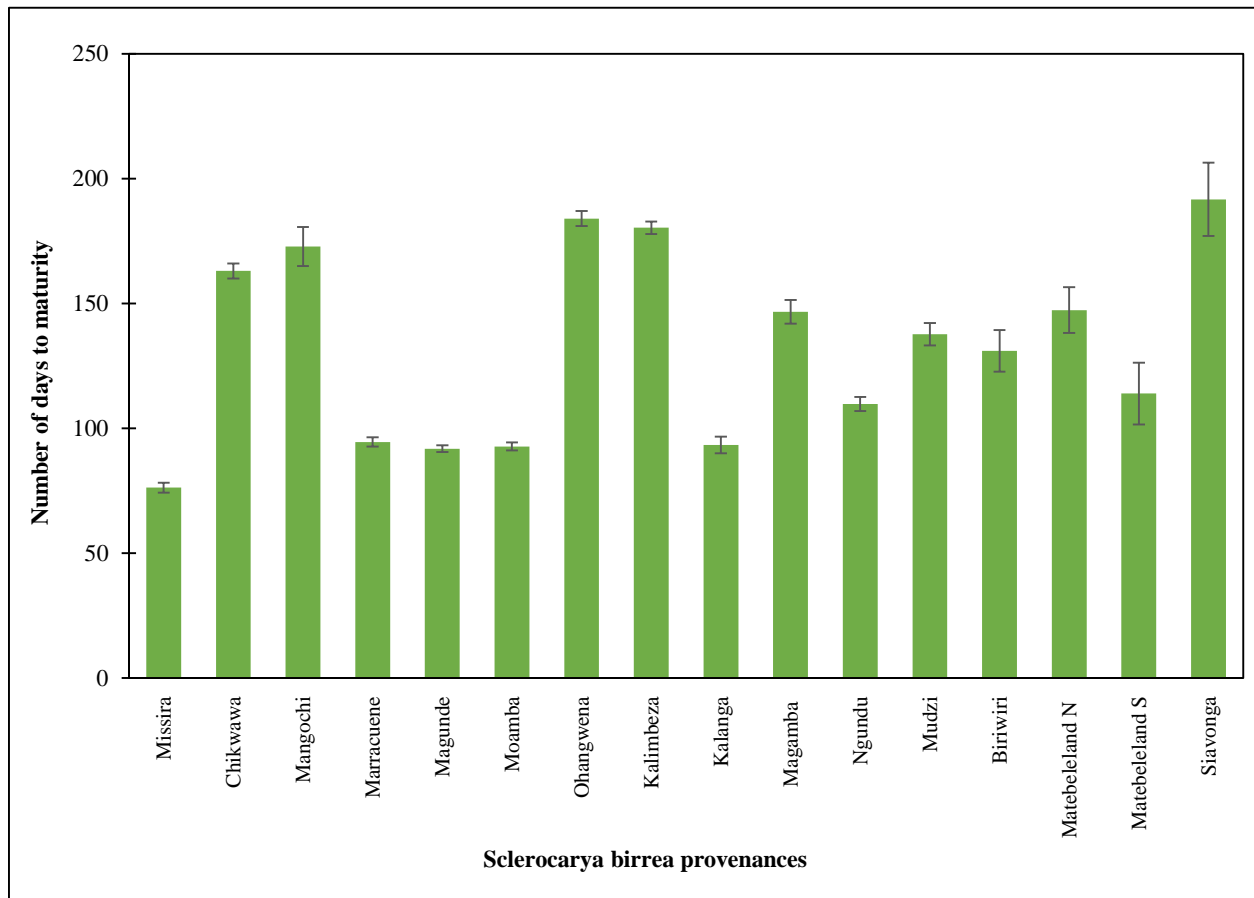
There were significant ( $P<0.001$ ) positive correlation between leaf flush and phenology characteristics (bud set, flower opening and fruit set). The correlation between leaf flush and phenology characteristics (bud set, flower opening, and fruit set) were 0.80, 0.81 and 0.78 respectively.

**Table 2. Number of flowering trees, time of bud set, bud opening, leaf flush and fruit set (Mean and range)  $\pm$  Standard error**

Provenance	Number of trees flowering	Time of Bud set range	Time of Bud set (mean)	Time of Bud opening range	Time of Bud opening (mean)	Time of leaf flush range	Time of Leaf flush (Mean)	Time of fruit set range	Time of Fruit set (Mean)
Missira	12	234-277	253 $\pm$ 4.0	239 - 281	257 $\pm$ 4.1	270 - 304	290 $\pm$ 3.2	242 - 283	260 $\pm$ 4.0
Chikwawa	2	282 - 298	290 $\pm$ 8.0	287 - 304	296 $\pm$ 8.5	280 - 304	292 $\pm$ 12.0	290 - 308	299 $\pm$ 9.0
Mangochi	4	266 - 304	292 $\pm$ 9.0	272 - 308	296 $\pm$ 8.4	275 - 304	289 $\pm$ 7.6	275 - 311	299 $\pm$ 8.4
Marracuene	33	229 - 273	247 $\pm$ 1.6	234 - 274	253 $\pm$ 1.6	215 - 277	259 $\pm$ 2.0	240 - 277	256 $\pm$ 1.5
Magunde	16	232 - 267	249 $\pm$ 3.0	239 - 270	254 $\pm$ 2.8	239 - 280	260 $\pm$ 2.8	242 - 273	260 $\pm$ 2.6
Moamba	10	227 - 265	242 $\pm$ 3.7	236 - 270	246 $\pm$ 3.4	237 - 270	249 $\pm$ 3.6	240 - 275	254 $\pm$ 4.1
Ohangwena	2	263 - 276	270 $\pm$ 6.5	270 - 279	275 $\pm$ 4.5	274 - 276	275 $\pm$ 1.0	274 - 282	278 $\pm$ 4.0
Kalimbeza	7	272 - 301	282 $\pm$ 3.4	277 - 306	288 $\pm$ 3.3	277 - 300	287 $\pm$ 3.3	279 - 291	287 $\pm$ 1.7
Kalanga	3	252 - 258	256 $\pm$ 1.9	255 - 265	262 $\pm$ 3.3	263 - 265	264 $\pm$ 0.7	259 - 270	266 $\pm$ 3.5
Magamba	14	278 - 299	285 $\pm$ 1.8	281 - 302	289 $\pm$ 1.7	288 - 304	298 $\pm$ 1.6	283 - 310	292 $\pm$ 1.7
Ngundu	11	265 - 296	275 $\pm$ 2.5	269 - 299	281 $\pm$ 2.3	263 - 294	280 $\pm$ 2.9	272 - 302	284 $\pm$ 2.3
Mudzi	3	285 - 297	292 $\pm$ 3.5	295 - 307	299 $\pm$ 3.8	296 - 304	300 $\pm$ 2.3	299 - 310	302 $\pm$ 3.5
Biriwiri	3	261 - 282	271 $\pm$ 6.1	268 - 288	277 $\pm$ 5.8	272 - 291	282 $\pm$ 5.5	272 - 291	281 $\pm$ 5.6
Matebeleland North	3	259 - 305	283 $\pm$ 13.3	264 - 310	288 $\pm$ 13.3	267 - 319	297 $\pm$ 15.5	267 - 315	292 $\pm$ 13.9
Matebeleland South	7	265 - 292	282 $\pm$ 3.7	272 - 297	287 $\pm$ 3.5	277 - 301	288 $\pm$ 3.4	276 - 301	291 $\pm$ 3.4
Siavonga	3	270 - 298	287 $\pm$ 8.6	274 - 304	292 $\pm$ 9.2	277 - 304	287 $\pm$ 8.4	277 - 308	296 $\pm$ 9.5

**Table 3. Total number of fruiting trees per provenance in 2016/2017 and 2017/2018 seasons**

Provenances	2016/2017	2017/2018
Missira	9	12
Chikwawa	6	3
Mangochi	3	3
Ntcheu	4	1
Rumphi	1	0
Marracuene	34	33
Magunde	19	16
Moamba	12	9
Oshikondilingo	1	1
Ohangwena	2	2
Kalimbeza	6	7
Kalanga	7	4
Magamba	14	14
Ngundu	11	12
Mudzi	3	2
Biriwiri	3	3
Muzarabani	4	1
Matebeleland North	5	3
Matebeleland South	7	7
Siavonga	5	2
Choma	2	1
<b>Total</b>	<b>157</b>	<b>137</b>

**Figure 4. Fruit maturity period (onset – maturity) for sixteen provenances of *S. birrea* that had fruits**

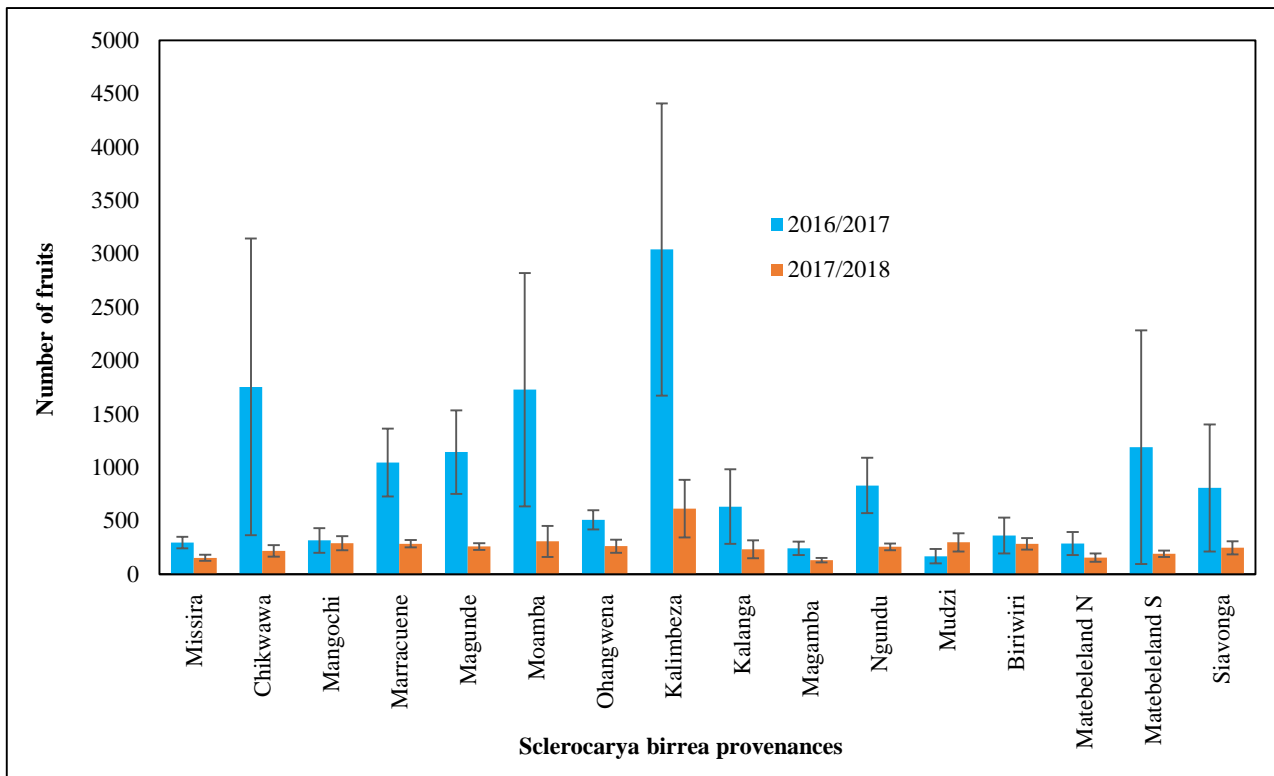


Figure 5. Fruit production for 2016/2017 and 2017/ 2018 fruiting seasons

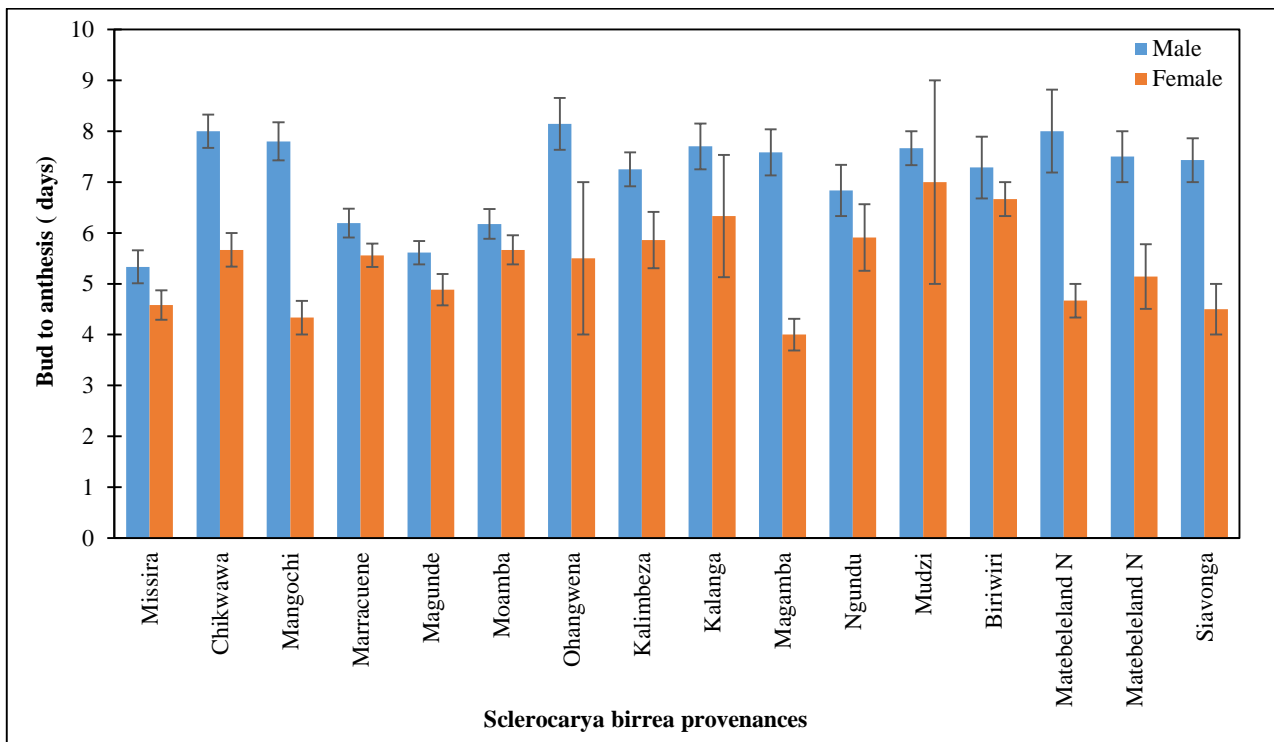


Figure 6. Variation between male and female in number of days from budding to anthesis among provenances of *S. birrea*

## 4- Discussion

### 4-1- Variations in Time for Bud Set to Flower Opening (Anthesis)

The results of this study have shown wide variability between provenances of *S. birrea* in bud set to anthesis with an extended flowering period of about 57 days starting from August and ending October. The time for flower opening corresponded with time of bud set implying that provenances that were first to set buds also reached anthesis earlier but with a lot of tree to tree variations. The flowering initiation time of August is consistent with what [12] had reported at



age three to four years on the same provenances trial. The long flowering period among different genotypes of *S. birrea* enhanced overlapping between different genotypes and flowering synchrony between males and females which will permit cross pollination if so desired without the need to collect, process and store pollen in a breeding programme. From the results five provenances comprising of Marracuene, Moamba, Magunde, Kalanga and Missira emerged as early flowering while the other 15 provenances including, Chikwawa, Mangochi, Ohangwena, Kalimbeza, Magamba, Siavonga, Ngundu, Biriwiri, Mudzi, Matebeleland North and Matebeleland South were classified as late flowering genotypes. Two distinctive groupings were evident basing on flowering time although there was slight overlap in September among genotype. The existence of two distinct groups based on flowering time can be used to create two breeding populations from selections of the superior trees in the trial. However, among the early flowering provenances, selections from Missira cannot be combined with the selections from the other early flowering provenances as this genotype belongs to the subspecies *birrea* while Marracuene, Moamba, Magunde and Kalanga to *caffra*.

The results suggest that variations in flower bud set to anthesis may either be due to origin of *S. birrea* provenances or genetic because the genotypes are sharing same environmental conditions. Site had no influence on the early or late flowering of provenances possibly they were influenced by locality of origin such as latitude and altitude for example Marracuene, Magunde, Moamba and Kalanga (Table 1). The late flowering trait in different genotypes doesn't seem to correspond with latitudinal and altitudinal influence across provenances probably this might be evident at country level (Table 1). Despite that Chikwawa and Mangochi (Malawi) synchronized with Mudzi, Matebeleland North, Matebeleland South, Magamba, Ngundu (Zimbabwe), Siavonga (Zambia) and Kalimbeza (Namibia) genotypes but they are from different ecological zones in terms of latitude and altitude, this therefore may signify genetic influence [12, 13]. This is in agreement with reports of Munthali et al., [17] where similarities in phenotypic and genetic attributes between geographically different populations of *Adansonia digitata* were attributed to genetic closeness. Consequently, the overlapping in flowering between populations, provide opportunities for hybridizing selections made in the populations without the need for storing pollen and conducting control pollinations which is expensive. The overlapping of flowering give confidence that the geographic populations may not necessarily be maintained through isolation based on origin.

The trait for early flowering in *S. birrea* is good in selection process for domestication as it corresponds with early fruiting and maturity which may be preferred by farmers [18]. Early fruit maturity is advantageous as it coincides with lean period (December and January) and may fetch higher prices on the market. In addition, variations at provenance and individual level are more specific and useful during selection for domestication and breeding programs while flowering overlaps and synchrony enriches the genetic composition of the progenies due to increased outcrossing [19]. According to Giménez-Benavides et al., [20] early flowering plants flower for longer periods resulting into high fruit yield however current findings have shown that the early flowering genotypes of *S. birrea* flowered the least number of days with no significant variations in fruit yield. On the contrary Rios et al., [21] in the study of *Chamaedorea pinnatifrons* (Arecaceae) found out that the late flowering females with lower synchrony presented the highest reproductive success but *S. birrea* fruit yield showed no significant variations among the early and late flowering genotypes in the two reproductive seasons although this may require continued monitoring for subsequent seasons because of 'seed masting' effect [22].

We concluded that the variations observed between populations of *S. birrea* are largely influence by genotype and origin. This is consistent with published reports on the same trial [5, 12, 13], which attributed variations in vegetative growth, fruit traits and productivity of *S. birrea* to genetic influence.

#### **4-2- Differences between Males and Females in Days from Bud Set to Anthesis**

Generally, the development of male flower buds and females started in the same months (August to October). The results have shown that in all populations the female flowers were developing in tandem with male flowers. This shows that the flowering ensures availability of pollen to influence effective fertilization. The results also revealed variations in period of flower bud initiating and opening between provenances. The earlier flowering in males of *S. birrea* is associated with the competition among individuals of the population for greater dispersal of gametes while delayed flowering in females enabled them to synchronize with males at the peak of their flowering intensity for increased pollination [10, 23, 24]. The longer period from bud to anthesis in males suggest that males requires longer period for pollen development for increased pollination capacity while females need shorter period for pollen reception to ensure seed set [24]. This agrees with the report of Fonseca et al., [25] on dioecious species of *Baccharis platytypoda* where distinctive variations between sex in flowering initiation and duration existed and Forrest [26] in a Protandry study where most male dioecious plant species reached flowering peak before females. In a related scenario, Williams and Adam [27] in the study of *Guioa semiglauc* (Sapindaceae) species reported males reaching anthesis one to three weeks earlier before the opening of female flowers. Consequently, in cases of isolated populations, phenological shifts may lead to reduced chance of pollination between female's plants and pollinator populations that could potentially result in the extinction of both populations [28] or limited number of successful pollinators. Therefore, reproductive synchronization between and within populations of *S. birrea* and extended flowering period in males is an important trait as it provides opportunities for pollination without resorting to pollen storage if and when pollination between



selected trees in different provenances is envisaged. Hence differences in flowering time between different provenances, future design of fruit orchards should group those genotypes that synchronize in flowering including males and females and plant them at same place to ease management and further selection for future breeding programmes.

#### 4-3- Leaf Flush

The present results have revealed extensive variation in time for leaf flush within and between provenance levels denoting some provenances as early while others as late leaf flushers. The early leaf flushers included Moamba, Marracuene, Magunde and Kalanga while the late flushers comprised of Missira, Magamba, Ngundu, Biriwiri, Mudzi, Matebeleland North and South, Kalimbeza, Ohangwena, Mangochi, Chikwawa, and Siavonga. Early flushing in Moamba, Marracuene, Magunde and Kalanga is associated with latitude in the locality of origin (Table 1). According to Murali and Sukumar [29] early flushers are more advantageous than the late ones as the early flushers produce new leaves before the emergence of herbivorous insects. This is in consistent with the findings of the current study where late flushers such as Siavonga, Chikwawa and Mangochi provenances of *S. birrea* that flushed late in October to November had all their leaves defoliated while the early flushing genotypes were not affected. Consequently, the losing out of leaves is crucial as it affects photosynthetic activities that eventually affects physiological processes within the tree resulting in stunted growth and poor productivity [30].

Latitudinal gradient and temperatures are reported to influence leaf flushing phenology in many tree species [31, 32]. However, Elliott *et al.*, [33] and Rivera *et al.* [34], attributed leaf flushing phenology among species around the world to water storage in deep soils and photoperiodic induction of leafing. In the current study leaf flushing coincided with increasing temperatures (Figure 1) and displayed variations that showed a pattern of originality mainly basing on latitude, elevation and temperatures [12]. The results support the findings of Kaszkurewicz and Fogg [35] reported in Friedman *et al.*, [32] where latitudinal difference between 34.9 and 47.6°N resulted in delayed date of leaf flush of *Populus deltoides* by 44 days. Likewise, latitude differences in place of origin of *S. birrea* genotypes had an influence in time of leaf flush for example latitudinal variations between Marracuene (25°58'S) and Mangochi (14°02'S) brought about 30days difference in leaf flush between provenances [13]. On the same note Chikwawa (Malawi) and Siavonga (Zambia) provenances with a minimal latitudinal difference between 16°46'S and 16°30'S respectively flushed new leaves at the same period. The differences in time of leaf flush were largely influenced by latitude of origin. The provenances also displayed individual tree to tree variations signifying genetic variability within provenances. Individual variations are mostly valued and used in selection for domestication or breeding programs [19]. The trait for early flushing among others is important in selection for domestication as it enhances tree growth, reproduction and protection from herbivorous insects.

#### 4-4- Period of Fruit Set to Maturity

Extensive differences between provenances in fruit maturity period were revealed. Provenances such as Marracuene, Moamba, Magunde (Mozambique) and Kalanga (Swaziland) could be classified as early maturing, intermediate in the case of Ngundu, Mudzi, Biriwiri, Matebeleland South, Matebeleland North (Zimbabwe) and Magamba (Tanzania). The class of late maturing were provenances of Chikwawa, Mangochi (Malawi), Ohangwena, Kalimbeza (Namibia) and Siavonga (Zambia).

Missira sub species *birrea* a provenance from North West Africa (Table 1) was among the early fruiting and maturing genotypes however it differed with other provenances at fruit maturity and in time for leaf flushing. The fruits of Missira provenance ripened whilst in the tree like mangoes and dislodges there after unlike other provenances of subspecies *caffra* where fruits drop from the canopy while green and ripens on the ground after a few days depending on the prevailing temperatures [36]. A second observed difference was in leaf flush where Missira put up new leaves about 30 days after fruit set while the rest of the provenances of subspecies *caffra* flushed new leaves within a range of 2 -9 days after or before fruit set (Table 2). The long time lag between fruit set and leaf flush in Missira provenance suggest that the genotype is capable of storing adequate food resources to sustain the plant during the reproductive phase [37]. The phenology behaviour of Missira appears to be largely influenced by genotype and locality of origin.

*S. birrea* provenances also displayed high tree to tree variation in period of fruit maturation. The observed variation is important for fruit tree like Marula since the maturity is well spread for a period of seven months. This is ideal for price stabilization and also farmers will have sufficient time to make Marula products without the fruit spoiling or farmers resorting to storage. Late maturing trait can also be economically valuable as fruits mature off peak when demand and price are likely to be high. Furthermore, accurate determination of fruit maturity plays an important role in its timely planning for harvesting, packaging, transportation and the guarantee of commodity quality [38].

#### 4-5- Fruit Productivity of *S. Birrea* in 2016/2017 and 2017/2018 Seasons

The results indicated significant variations between the two seasons with higher fruit production in 2016/2017 season as compared to 2017/2018 season. Some individual trees that had high fruit yield during the first season performed

poorly in the second while other families stayed dormant without flowering (Table 3). The 2016/2017 fruiting season was characterized by cooler temperatures as compared to 2017/2018 which had cooler nights but very high day temperatures (Figure 1). Furthermore, in 2017/2018 season by October, the site had received more rainfall than the 2016/2017 season during same period of time suggesting that poor fruit yield in 2017/2018 season was not primarily influenced by rainfall rather by high temperatures during the flowering phase [39]. Furthermore, reports from previous studies [5, 13] plus the current results have indicated that at age 18 some provenances/ families have not yet started fruiting suggesting long precocity period for example the Rumphii genotype. This behaviour was also reported in the wild populations of *Macadamia* and *Dacryodes edulis* where some trees started producing fruits at age 20 and 22 respectively [40]. Hence continued monitoring is required on those provenances the have not yet started flowering.

Periodicity in fruit production among *S. birrea* provenances was also reported by other researchers [12, 14, 40-42] indicating that many individual trees of *S. birrea* become reproductively inactive in a season following a high fruit reproductive season and referred the phenomenon as ‘mast seeding’ behaviour. Nevertheless, mast seeding behaviour is a demerit to domestication because famers require satisfactory fruit yield yearly. Premature fruit shedding and sex change were also observed among some populations. According to Diallo et al., [43] fruit abortion is an adaptation that permit plants to match fruit and seed number with the available resources across a range of environmental circumstances. Tree to tree variations in fruit production are of paramount importance and commonly used by geneticists during selection for domestication and tree breeding. It offers a wider chance for a combined selection to be carried out both at provenance, family and individual tree level to attain high genetic gains [17, 44]. Therefore, continued monitoring for fruit production and sex change among genotypes is required for several consecutive seasons before effecting selection of those trees that do not exhibit mast seeding.

#### **4-6- The Relationships between Leaf Flush and Flowering Phenology Traits**

The strong association between leaf flush, bud set, flower opening and fruit set corresponded to locality of origin basing on latitude and altitude (Table 1) in the early flowering provenances (Moamba, Magunde and Marracuene and Kalanga) while in the late flowering there was a lot of diversity both in locality of origin basing on latitude and elevation at provenance level. However strong association basing on latitude could be noted at country level. The strong relationship between the reproductive phase and leaf flush suggest the need for food production to sustain fruit development and seed maturation in females and vegetative growth in males although the new leaves do not photosynthesize immediately after flush [45]. However, the strong association is important because as soon as the new leaves attain the green colouring matter would start manufacturing food using solar energy [30]. The manufactured food would then replenish the used up food reserves during leaf flush and flowering phases as well as for continued plant growth, maintenance and sustenance of fruit development up to maturation.

### **5- Conclusion**

The study has revealed substantial variation between and within provenances in time of leaf flush, bud initiation to flower opening (Anthesis), fruit set to maturity with increased flowering synchrony between male and female trees as well as overlaps between populations. The variations in fruit yield and maturity period between and within provenances are adequate to warrant selection for domestication. This study has also generated information of prime importance to tree breeders for instance variations in genetic traits between and within provenances including early flowering, maturity period and productivity. Therefore, the existence of variations in different traits offers a wider chance for combined selection to be carried out both at provenance and individual family level to attain high genetic gains from tree breeding programs. Basing on differences in flowering time between different provenances future design of fruit orchards should group and plant those genotypes that flower at the same time to ease management and further selection for breeding programs. Future studies should investigate change of sex among genotypes, premature flower bud and fruit shading as well as continued study in fruiting behaviour of different provenances.

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### **8- Conflict of Interest**

The authors declare no conflict of interest.

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