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Research Article

Nontimber Forest Product Yield and Income from *Thaumatococcus daniellii* under a Mixed Tree Plantation System in Ghana

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Thaumatococcus daniellii is a wild sourced tropical understorey herb that is harvested for its foliage and fruits from which thaumatin—a proteinous sweetener—is extracted. With increased demand for natural sweeteners, uncontrolled harvesting of *T. daniellii* from the wild is suggested to be neither sustainable nor match industrial demands. This study determined the implication of controlled foliage harvesting of *T. daniellii* under a mixed indigenous tree plantation stand. *T. daniellii* plants within plots of dimension 3 m × 4 m were thinned to uniform foliage population of about 12 leaves/m^2 and subsequently harvested at 16 weeks interval for 64 weeks at four different foliage harvesting intensities: (i) no harvesting (control), (ii) 25% harvest, (iii) 50% harvest, and (iv) 75% harvest. Data on agronomic characters and total income from the sale of fruit and harvested foliage were collected and analysed. We found that foliage harvest intensity affected ($P < 0.001$) number of flowers in the order: 18 (control) > 6 (25%) ≥ 1 (50%) and 0 (75%). Foliage harvest intensity also significantly ($P = 0.036$) influenced fruit number and ranged from 11458/ha for the control to 4583/ha for the 75% harvest. Total income from fruit and foliage sales was greatest for the 50% harvest (US $ 17,191.32), followed by 75% harvest (US $ 12, 310.24) and lowest for the no harvest treatment (US $ 107.44). Thus, proper management of *T. daniellii* through controlled harvesting of the foliage under mixed tree plantation system could promote sustainable yield and income to farmers.

1. Introduction

Nontimber forest product (NTFP) exploitation has been recognized as potential alternative to forest management practices, such as clear-cut logging [1]. With a strong market and long-term value accruing from the harvest of NTFPs, their economic benefits could override the short-term gains of converting forests to other land-uses such as timber and agriculture [2]. *Thaumatococcus daniellii* (Benn.) Benth., a perennial wild understorey herb, is one of the promising NTFPs, whose economic potentials have not been fully exploited in most African countries, including Ghana. The plant belongs to the Maranthaceae family and in the order Zingiberales. It grows throughout the hot, humid tropical rain forest and coastal zone of West Africa. It is also known to grow over large areas of East and Central Africa. In Ghana, it is distributed in secondary forests with humid conditions [2, 3].

Thaumatococcus daniellii is harvested from the wild for its fruits, from which a protein based sweetener called thaumatin is extracted from the arils. Local people use thaumatin as sweeteners by licking the seeds to sweeten porridge or fermented palm wine [4]. Thaumatin is a recognized food additive and has potential in drug, confectionaries, and beverage manufacturing [1, 5]. The growing interest and increased demand for natural sweeteners and flavour enhancers, combined with existing international approval of thaumatin means the plant faces serious threat from massive harvest in secondary forests [3, 6, 7]. Additionally, the leaves of *T. daniellii* are used in local markets as packaging material to wrap vegetables, fish, cola nuts, and as a source of supplementary fodder for livestock in many African households [5, 8].

Fruit collection is reported to have provided employment to many people in Ghana [4, 5]. Ekpe and Ottou [4] reported that *T. daniellii* fruits were sold at \$0.50 kg^{-1} in the local markets. Between 1990 and 2012, the total production of arils from *T. daniellii* in Cote d' Ivoire ranged from 10,250 kg to 25,600 kg. Given \$16 kg^{-1} as average price for frozen aril, this production earned between \$160,000 and \$400,000 annually in exports to the UK [6]. Hence, there is an apparently untapped potential to improve rural livelihoods in West and Central Africa through cultivation of *T. daniellii* [6].

The exploitation of *T. daniellii* exclusively from the wild has been reported to be neither sustainable nor meet industrial demand [3]. Destruction of secondary forests due to poor harvesting techniques has led to yield reduction across its range. Farmers are being forced to travel further into reserved forests to find adequate supplies of foliage and fruits. Massive fruits collection from primary forests may result in loss of food and habitat for the insects and rodents such as grass cutters (*Thryonorays swinderianus*) and rats of the forest floor. In addition, during harvesting, a lot of stampeding occurs among harvesters resulting in seedlings trampling and destruction of the natural ecosystem [4, 6]. Because *T. daniellii* is a shade-tolerant plant, it has been argued that controlled harvesting under a mixed indigenous plantation system may promote sustainable yield, thereby reducing the frequency of harvest in primary forests [3]. With much emphasis on poverty alleviation in Sub-Saharan Africa, promoting the cultivation and management of *T. daniellii* in mixed tree-based systems may also serve as potential source of income generation to resource-poor farmers.

For a plant like *T. daniellii*, interest in both the foliage and fruits warrants appropriate management techniques for sound decision making. Despite both the foliage and fruits having great economic benefits, it is currently unknown to what extent defoliation will influence fruit production. This necessitates a study that could help to estimate the quantity of foliage that could be harvested at a time without adverse effects on fruiting. To date, the relationship between defoliation and fruiting with respect to *T. daniellii* stands is not well understood. The objectives of this study were to determine: (i) the impacts of variable foliage harvesting on fruit yield (number and weight), flowering, and specific leaf area of cultivated *T. daniellii* under mixed stands of seven most common agroforestry tree species in central Ghana and (ii) the potential income that could be obtained by local farmers from leaf and fruit collection. We hypothesized that (i) controlled foliage harvests of *T. daniellii* will not reduce fruit yield (i.e., fruit number and fruit wet weight), flowering, and stimulate compensatory growth with respect to specific leaf area and (ii) management of *T. daniellii* stands for both leaf and fruit collection will be more profitable in terms of gross income to local farmers as compared to sole fruit collection.

2. Materials and Methods

2.1. Study Area and Site Description. The present study was conducted in Oda-Kotoamso (05° 52′ N; 02° 29′ W), a town located in the Western Region of Ghana (Figure 1). The area lies in the hot humid tropical rain forest zone with an annual rainfall between 1400 and 2000 mm. There are two distinct rainy seasons from April to July and from September to November. The highest rainfall is recorded in June and July. There is a short period of dry season from December to March. A dry easterly wind, the Harmattan, blows in January and February. The average annual temperature is 26°C [3]. Local climate is largely influenced by the Sahara Dessert in the north and the Atlantic Ocean in the south.

Experimental plots were laid in 6-year old established stands of *T. daniellii* under a uniformly spaced mixed stand of agroforestry trees. The tree stand, averagely aged 10 years, consisted of species including *Entandrophragma angolense*, *Ceiba petandra* (L.), *Milicia excelsa* (Welw.), *Terminalia superba* (Engl.), *Khaya ivorensis* (Chev.), *Khaya senegalensis* (Desr.), and *Antrocaryon micraster* (Chev.). The average crown diameter, diameter at breast height, and height of the trees ranged from 2.0 m to 17.0 m, 0.12 m to 0.45 m, and 17.0 m to 57.0 m, respectively.

2.2. Experimental Design. The experimental set up was a randomized complete block design. There were four blocks and three foliage harvest treatments plus a control. There were total of 16 treatment plots each with a dimension 3 m × 4 m (12 m^2) and were spaced 5 m apart. To ensure homogeneity, treatment plots were situated within a perimeter defined by four different tree species. *T. daniellii* plants on each plot were then thinned to uniform leave population of 142 (12 leaves/m^2) after which the treatments were imposed. Treatments involved harvesting leaves and maintaining a specified leaf population per plot out of 142 at 16 weeks interval. Harvest treatments imposed on the remaining 142 leaves were T_1 = no harvesting (control), T_2 = 25% (36 leaves), T_3 = 50% (71 leaves), and T_4 = 75% (106 leaves).

2.3. Data Collection. Data were collected on fresh weight of harvested foliage, fruit number, and fruit fresh weight over 64 weeks at 16 weeks interval. Number of flowers per treatment was monitored over 12 weeks at 3 weeks interval. For specific leaf area (SLA) determination, 10 uniformly sized leaves were harvested from each treatment plot at week 64. The leaf area was measured with an AM-300 Leaf Area Meter (ABC BioScientific Ltd., Herefordshire, UK). The leaves were then oven-dried at 60°C for dry matter determination for three days [9]. Average leaf area and dry matter per treatment were then calculated. Specific leaf area was determined according to [9] as follows:

$$\mathrm{SLA} = \frac{\text{Average leaf area}\left(\mathrm{cm}^2\right)}{\text{Average leaf biomass}\left(\mathrm{g}\right)}. \qquad (1)$$

The market price of fresh fruits of *T. daniellii* was obtained at the fruit receiving station of the thaumatin extraction plant at Samartex Timber and Plywood Company, Samreboi, Ghana.

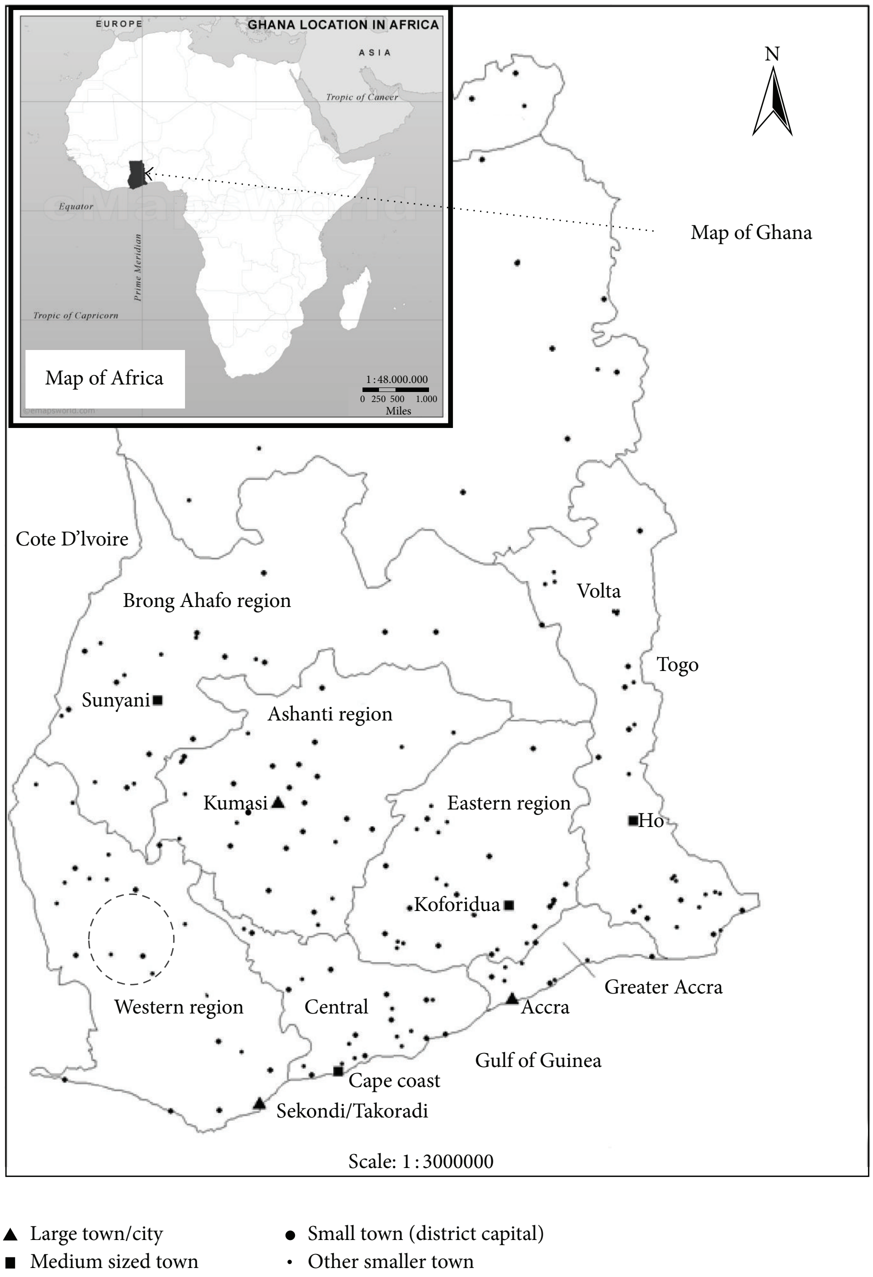


Figure 1: Location of the study area: Map of Africa (inset) and map of Ghana depicting the study area (marked with circle) within a humid tropical rainforest zone of Ghana.

The total income from fruit sale (TFI) over 64 weeks was calculated using the following

$$\begin{aligned}\text{TFI} = {} & \text{Price per kg of fresh fruits} \\ & \times \text{Total harvested fruits per treatment/ha.}\end{aligned} \tag{2}$$

To determine the potential incomes that could be obtained from the sale of leaves, samples of fresh harvested leaves were given to leave sellers to be sold on the market. Such leaves were sold in bundles. The fresh weights of 30 samples of bundled leaves were measured from three different markets and prices per bundle were recorded. Average weights of leave bundle and prices per bundles were calculated to obtain general market price per kilogram. The prices per kilogram of both fruit and leaves were converted into their dollar equivalent based on the prevailing local exchange rate. Total leaf income (TLI) that could be obtained from leaves sales over 64 weeks and percent reduction in fruit (PRF) yield were calculated according to the following:

$$\begin{aligned}\text{TLI} = {} & \text{Average price per kg leaf bundle} \\ & \times \text{Total harvested leaves per treatment/ha,}\end{aligned} \tag{3}$$

$$\text{PRF} = 100\% - \frac{[\text{Total fruit yield for harvest treatment} \times 100]}{\text{Total fruit yield for control}}. \quad (4)$$

2.4. Statistical Analyses. Analyses of Variance (ANOVA) by SAS PROC MIXED procedure [10] and Tukey's studentized ranged (HSD) test ($P < 0.05$) were used to compare the effect of different harvesting intensities on measured growth parameters. The assumption of normality and homogeneity of variance was assessed with the Kolmogorov-Smirnov test using the PROC UNIVARIATE procedure in SAS (data not shown). All data conformed to normal distribution. A parametric Welch's ANOVA test was used to deal with nonhomogeneous variances in situation where data transformations do not help achieve variance homogeneity. The linear model shown below was used as follows:

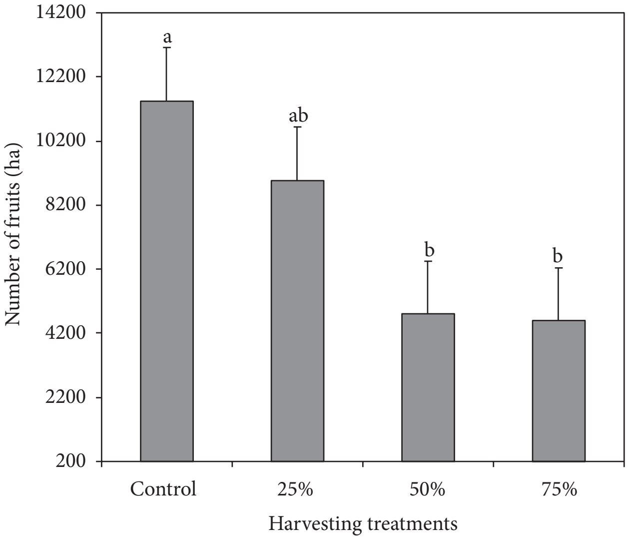
$$Y_{ij} = \mu + H_i + \beta_j + \mathrm{e}_{ij}, \quad (5)$$

where Y_{ij} is the value of measured parameter, μ is the population mean, H_i is the effect of the ith harvesting treatment, $i = T_1$ (control), T_2 (25%), T_3 (50%), and T_4 (75%), B_j is the effect of the jth block, $j = 1, 2, \ldots, 4$, and e_{ij} is the random variable error within the experiment.

A correlation analysis was also used to estimate the linear relationship between fruit numbers, fruit weight, number of flowers, and specific leaf area.

3. Results and Discussion

3.1. Effect of Foliage Harvest on T. Daniellii Growth. Foliage harvest significantly ($P = 0.036$) affected number of fruits. Fruit number decreased with increased foliage harvest intensity (Figure 2). Control stands produced the greatest number of fruits (11458/ha), but it was not different from that produced from the 25% foliage harvest (8958/ha). However, the number of fruits produced from the control stands was significantly greater than what was produced from stands with 50% (4792/ha) and 75% (4583/ha) foliage removals. The pattern of fruit production showed that fruit number declined with time for all treatments except for the control which recorded a sharp increase at week 64 (Figure 3). Apart from week 32 which recorded no fruits for the control stands, fruit production was greatest for the control stands compared to all other treatments over the 64 weeks. This could suggest a greater potential of *T. daniellii* to produce fruits if stands are not harvested. No significant difference ($P = 0.163$) was recorded among the different harvesting intensities in terms of overall weight of fruits produced (Figure 4).



Mean ± stderr
Control: 11458 ± 2132.03
25%: 8958 ± 743.85
50%: 4792 ± 852.71
75%: 4583 ± 1730.59

Figure 2: Effect of foliage harvest intensity on total fruit number of *T. daniellii* in the humid tropical rainforest zone of Ghana.

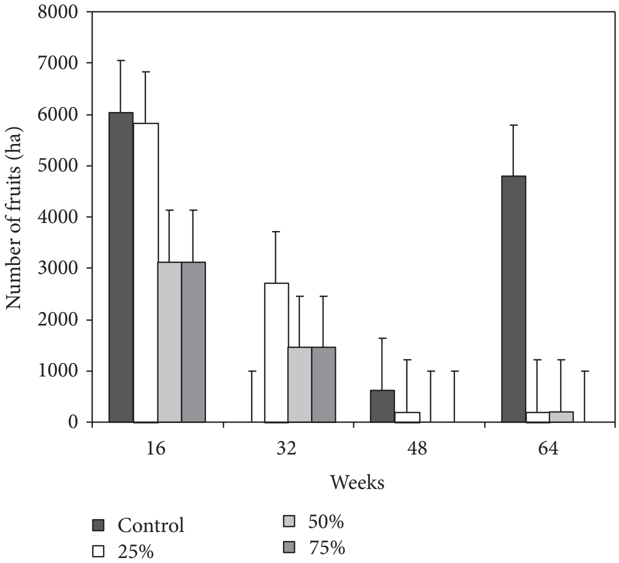
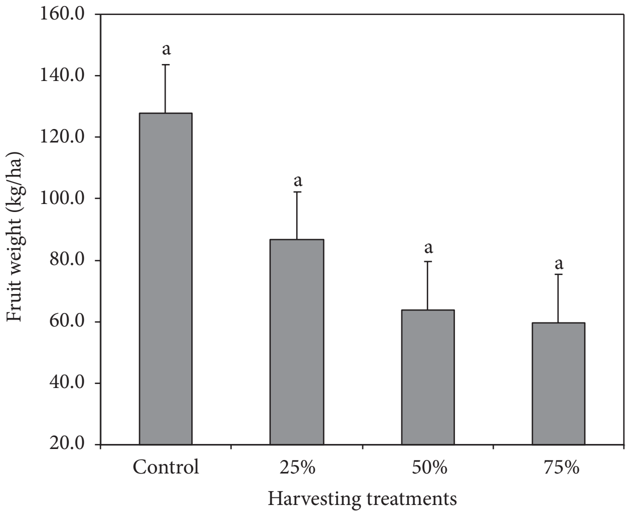


Figure 3: Total fruit number of *T. daniellii* in response to different foliage harvest intensities over 64 weeks.

The decreased fruit production of *T. daniellii* in relation to foliage harvest intensity, as reported by our study, is consistent with results from other studies. For instance, severe aboveground biomass removal of velvet leaf (*Abutilon theophrasti*) and ruderal herb (*Barbarea vulgaris*) resulted in fruit number decline with increasing severity of harvest [11, 12]. Conversely, *Caragana korshinskii* compensated for foliage harvesting by increasing fruit set, seed number per pod and seed biomass, and a decrease in fruit abortion [13]. *C. korshinskii* responses to foliage harvest were achieved by (i) drawing upon more nonstructural carbohydrate from roots to supply flower bud development and the flush of new foliage and (ii) supplying more photosynthetic assimilation to fruit development owing to increases in leaf-level photosynthetic rates [13]. The inability of *T. daniellii*



Mean ± stderr
Control: 127.9 ± 20.19
25%: 86.7 ± 5.41
50%: 63.9 ± 3.39
75%: 59.7 ± 25.79

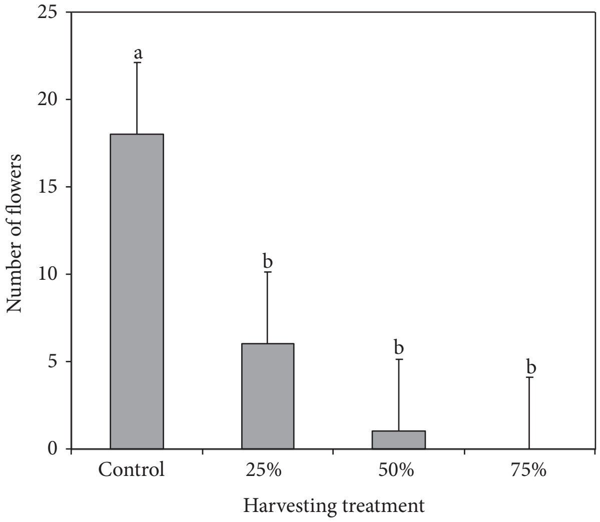
Figure 4: Effect of foliage harvest intensity on fruit weight of *T. daniellii*. Means (±SE) with similar letters do not differ significantly at 5% probability level.

to respond to increased foliage harvest through some of these physiological processes as exhibited by *C. korshinskii* perhaps accounted for the decreased fruit production. In addition, foliage harvest enhanced light penetration to the base of *T. daniellii* stands but possibly reduced leaf area that caused a decline in photosynthate production [14]. With the exception of the control, the 25%, 50%, and 75% of foliage harvest stands may have experienced rapid shedding of matured leaves while new ones developed. However, newly expanded leaves compete with older leaves for solar radiation, mineral nutrients, and assimilate such that leaves begin to senescence in sequence according to age [14]. Such young leaves, possibly, invest more resources into vegetative growth to the detriment of fruit production on harvested stands. Thus, the apparent availability of enough matured foliage on control stands could have facilitated the capture of light for synthesis and photosynthate accumulation needed for fruiting. This phenomenon explains why control stands produced more fruits than harvested stand.

Harvesting of leaves may have a negligible effect on exploited plant population if (i) individual plants survived the process; (ii) a sufficient number of healthy leaves are left on each plant for photosynthesis; (iii) the reproductive structures and apical buds are not damaged; and (iv) sufficient time is allowed between successive harvests for the plant to produce new leaves [15]. Collecting too many leaves from an individual plant can reduce the number of new ones and the number of flowers and fruits produced [16]. Although individual plants survived in our case, biomass harvest may have reduced leaf population to the extent that only few matured leaves remained for photosynthesis. Harvesting can also cause extensive damage to reproductive structures for fruit production. For example, a study on *Barbarea vulgaris* indicated that injury from foliage harvest significantly affected seed production and also the plants' life cycle. Seed production was lower in injured plants compared to in intact plants [11].

We found no significant ($P = 0.163$) difference in terms of total fruit weight (Figure 4). This result could imply that although control stands produced more fruits, the sizes of fruits could have been smaller than other harvested stands. A study of harvest regimes on five varieties of summer squash (*Cucurbita pepo* L.) reported significant influences on fruit size [17]. One variety produced larger fruits in the rainy season when leaves were harvested compared to no leaf harvest. This was attributed in part to high disease incidence in the rainy season that affected older leaves in the "no harvest" treatment compared to several young leaves that emerged in the "leaf harvest" treatment. These young leaves may have photosynthesized more efficiently than older diseased leaves [17]. For *T. daniellii*, possible differences in fruit sizes could be due to increased demand to support dense populations. Hence, control stands, in addition to fruiting, could have also channeled more resources to support physiological activities of increased populations. A study on *Rorippa palustris* revealed that defoliation and removal of axillary buds induced growth of new shoots from root buds [18]. Therefore, decreased flowering with respect to increased harvesting intensity of *T. daniellii* could imply that harvested stands invest resources into tiller production and replacement of lost tissues, whereas control stands channelled resources to flowering. The capacity for tiller recruitment was the most pronounced morphological distinction between perennial bunchgrass (*Schizachyrium scoparium*) with contrasting histories of herbivory [19]. Plants with a history of herbivory possessed a greater competitive ability to recruit a greater number of tillers than plants with no herbivory history [19]. Thus, the *T. daniellii* stands receiving various degrees of harvesting produced significantly lower number of flowers than the control.

Number of flowers significantly ($P < 0.001$) decreased with increased harvesting rate (Figure 5). Mean number of flowers recorded at week 64 was greatest for control (18 flowers) and lowest for 75% (no flower). The pattern of flowering of *T. daniellii* in response to treatments over 12 weeks showed that flower production decreased over time from week 51 in November to 60 in February (Figure 6). This could indicate that flowering peaks in the dry season and decreases towards the onset of the rainy season. Response to herbivores increases with increased frequency of defoliation. Such response also explains why removal of *Primula veris* leaves resulted in a decrease in flowering for 2 years [20]. With the exception of control stands that consistently produced flowers over the 12 weeks, none of the harvested stands recorded continuous flower production. The 75% foliage harvesting resulted in no flower production over the 12 weeks (Figure 6). Though flowering was observed for 25% (6 flowers) and 50% (1 flower) foliage harvest, fruit set was zero. This could be due to high rate of abscission among young flowers, limited pollination, or



Mean ± stderr
Control: 18 ± 8.87
25%: 6 ± 1.58
50%: 1 ± 0.76
75%: 0 ± 0

Figure 5: Effect of foliage harvest intensity on number of flowers of *T. daniellii*. Means (±SE) with different letters differ significantly at 5% probability level.

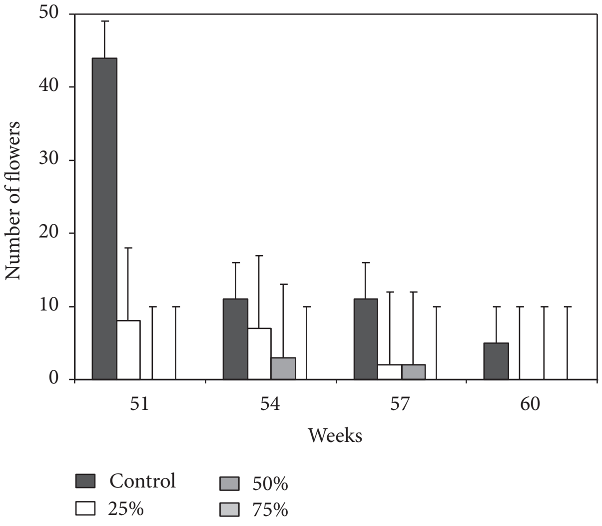
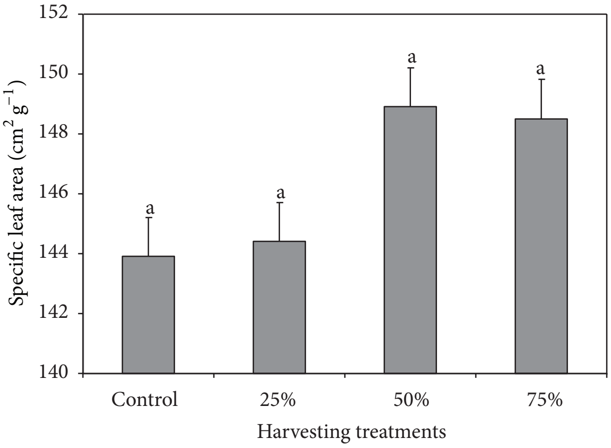


Figure 6: Pattern of flowering of *T. daniellii* in response to foliage harvest over 12 weeks.



Mean ± stderr
Control: 143.9 ± 1.95
25%: 144.4 ± 3.17
50%: 148.9 ± 3.39
75%: 148.5 ± 1.45

Figure 7: Specific leaf area response to *T. daniellii* foliage harvest intensity. Means (±SE) with similar letters do not differ significantly at 5% probability level.

limited nutrients [21] on such stands during the dry season.

No significant ($P = 0.498$) differences were observed among harvest treatments with respect to SLA after 64 weeks. Specific leaf area ranged from 143.87 $cm^2\,g^{-1}$ to 148.93 $cm^2\,g^{-1}$ (Figure 7). Control stands possessed more matured leaves than all other harvested stands. In a related study conducted on several plant species, no significant differences in SLA between recently matured leaves and older leaves were reported [22]. Specific leaf area is the light-catching area deployed per unit of previously photosynthesized dry mass allocated and is a major contributor to resource capture, usage, and availability [9, 23]. Decreasing SLA has been associated with greater allocation of biomass to structural components of the leaf rather than metabolic components [24]. Leaf area reflects expected return on previously captured resources [25]. For instance, *Lonicera japonica* allocated more C to secondary leaves and stems due to unlimited herbivory. Plants usually compensate for defoliation by replacing leaf tissue and changing intrinsic biomass allocation patterns [26]. In a study on the response of two grass species to a gradient of defoliation intensities, from 0 to 100% aboveground biomass removal, plants showed the same aboveground growth regardless of defoliation intensity due to stimulation of relative growth rate by defoliation [27]. Aboveground compensatory responses represent a key feedback process resulting in constant aboveground growth regardless of defoliation intensity [27]. Also biomass allocation to a leaf is dependent on the overall plant demand during its expansion and can be affected by concurrent events such as fruit-set [28]. Therefore, lack of significant ($P = 0.498$) differences in specific leaf area of *T. daniellii* could suggest that harvested stands possibly supply more photosynthate to leaf development owing to decreases in leaf-level photosynthetic rates, whereas control stands possibly invest in fruiting and below ground storage.

Fruit number had significant positive correlation with fruit weight ($r = 0.91$; Table 2). Hence, an increase in fruit number is strongly associated with increases in fruit weight. A study aimed at estimating fruit weight per grade of Cucumber (*Cucumis sativus* L.) found also a strong relationship between fruit weight and fruit number within each grade [29]. Also, custard apple (*Annona squamosa* L.), studied over three years

Table 1: An estimated income from fruit and leave harvest of *T. daniellii* stands over 64 weeks.

Foliage harvest intensity (%)	Total fruits (kg/ha)	Fruit income at \$0.21/kg	Total harvested leaf (kg/ha)	Leaf income at US \$0.55/kg	*Total income \$/ha
Control	511.60	107.44	0	0	107.44
25%	346.62	72.79	19,982.53	10,941.44	11,014.23
50%	255.64	53.68	31,298.75	17,137.64	17,191.32
75%	238.86	50.16	22,390.77	12,260.08	12,310.24

*Total income = Fruit income + Leaf income.

Table 2: Correlation coefficient (r value) among fruit number (FN), fruit weight (FW), and specific leaf area (SLA) of *T. daniellii* foliage harvested over 64 weeks.

Equation	r	P value
FW = 0.01FN + 9.9775	0.91	0.001^{***}
FW = 1.23SLA − 95.977	0.14	0.613^{ns}
FN = 59.83SLA − 1313.5	0.07	0.787^{ns}

***Significant correlation at 0.001 probability level; $^{\text{ns}}$no significant relationship at 5% significance level.

in Brazil, reported significant relationship between number of fruits and fruit yield (kg ha^{-1}). In this study, 99.3% of the variation in yield was explained by the variation in number of fruits [18, 30]. Specific leaf area had insignificant relationship with fruit number ($P = 0.787$) and fruit weight ($P = 0.613$).

3.2. Potential Incomes from Leaf and Fruit Harvest. The potential income that could be generated from *T. daniellii* leave and fruit harvest over 64 weeks is presented in Table 1. Generated income from fruit harvest increased with reduced foliage harvest intensity. Compared to the control which gave the highest fruit yield of 511.60 kg/ha and income of \$107.44, there were 32.3%, 50.0%, and 53.3% reductions in fruit yields, respectively, for 25%, 50.0%, and 75% foliage harvest treatments. Similarly, the percentage in fruit yield reductions between "no leaf harvest" and "leaf harvest" treatments for some varieties of summer squash (*Cucurbita pepo* L.) ranged between 2% and 45% [16, 31]. This could suggest that harvesting activities negatively impact on the fruiting of *Thaumatococcus daniellii* and cause a decline in incomes obtained from fruits as the degree of harvesting increases [1, 32]. Thus decreased incomes of \$72.79, \$53.68, and \$50.16 were obtained for 25%, 50.0%, and 75% foliage harvest treatments, respectively (Table 1).

Meanwhile, the highest leaf income of US \$ 17,137.64 was obtained for 50% foliage harvest. This suggests that 50% leaf harvest of stands could be sufficient to sustain enough leaf production over an extended period of time. Leaf income from 75% harvest stands, US \$ 12,260.08, was higher than US \$ 10,941.44 from 25% harvest stands. Though no income was generated for control stands from leaf harvest, 75% harvesting was also detrimental to fruit production and resulted in the lowest income of US \$ 50.16 (Table 1). The highest total income was US \$ 17,191.32 for 50% harvest stands followed by 75% and 25% harvest stands with incomes of US \$ 12,310.24 and US \$ 11,014.23, respectively. The lowest total income, US \$ 107.44, was obtained for the control due to lack of supplementary income from leaf harvesting (Table 1). The results suggest that management of *T. daniellii* for both leaf and fruit collection could be more economically beneficial than for sole fruit collection [17, 33]. This is because incomes that accrue from leaf harvest could compensate for incomes lost due to reductions in fruit yield. Considering the current demand for NTFPs, such as *T. daniellii*, this study showed how controlled harvesting of *T. daniellii* foliage inside agroforestry land-uses could reduce the over dependence on harvesting from wild sources and ultimately limit entry of local farmers into primary forest reserves.

4. Conclusions

The present study showed that management of *T. daniellii* for both leaf and fruit harvest could be more beneficial to local farmers as compared to fruit harvest only. The number of fruit per stand significantly decreased with increased foliage harvest. Income from the sale of fruits and leaves was greatest for the 50% harvest, intermediate for 25 and 75% harvest, and lowest for the no harvest treatment. The study income projection was based on the assumption of a ready market for both leaves and fruits. We did not account for losses incurred through rejection of rotten fruit by buyers, drying of foliage, and transportation costs. These, among other economic factors can influence the income level of fruits and leaves sale and are worth investigating.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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