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Characteristics of Surian Flower, Fruit and Seed Productions (*Toona sinensis* (A. Juss.) M. Roem.) in Sumedang, West Java

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Abstrak: Pembangunan hutan rakyat memerlukan bekalan tetap benih berkualiti tinggi. Selain itu, pengurusan sumber benih *Toona sinensis* (surian) yang baik memerlukan pemahaman mendalam tentang faktor-faktor yang mempengaruhi pengeluaran. Kajian ini terutamanya bertujuan untuk mengetahui ciri-ciri pembiakan yang meliputi ciri-ciri pengeluaran bunga, buah dan benih surian, variasi pengeluaran buah dan biji antara pohon-pohon dan di antara cabang-cabang, dan faktor dendrometrik yang mempengaruhi pengeluaran buah dan benih. Pemerhatian ciri-ciri pengeluaran bunga dilakukan pada 99 bulir, ciri-ciri pengeluaran buah diperhatikan pada 128 bulir, dan ciri-ciri benih dinilai berdasarkan 890 buah. Jumlah buah per bulir berkisar antara 38 hingga 646. Bilangan biji dalam buah berjulat antara 1 hingga 35. Saiz buah berkaitan dengan jumlah biji berisi mengikuti persamaan regresi kuasa dua. Jumlah optimum benih berisi adalah 20 per buah. Diameter batang, lebar silara, tinggi dasar silara, dan jumlah sub-cabang berpengaruh positif terhadap pengeluaran bulir per pohon manakala ketinggian dasar silara (pokok) berpengaruh negatif terhadap pembentukan buah.

Kata kunci: Bunga, Buah-buahan, Benih, Hasil Benih, *Seed Set, Fruit Set*, *Toona sinensis*

Abstract: Community forest development requires a constant supply of high-quality seeds. In addition, sound management of *Toona sinensis* (surian) seed sources requires a deep understanding of factors affecting seed production. This present study investigated the reproduction characteristics of surian, including flower, fruit and seed productions, variations in the productions of fruits and seeds among trees and among branches, and dendrometric factors that influence the productions of fruits and seeds. Flower production characteristics were observed in 99 panicles, fruit production characteristics were observed in 128 panicles, and seed characteristics were evaluated based on 890 fruits. The number of fruits per panicle ranged from 38 to 646. The number of seeds in fruits ranged from 1 to 35. Fruit size was correlated to the number of filled seeds following a quadratic regression equation. The optimal number of filled seeds was 20 per fruit. Stem diameter, crown width, crown base height, and the number of sub-branches positively influenced the production of panicles per tree, while the crown base height (of the tree) negatively affected the fruit set.

Keywords: Flower, Fruit, Seed, Seed Yield, Seed Set, Fruit Set, *Toona sinensis*

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INTRODUCTION

Toona sinensis (surian) belongs to the family Meliaceae and is often found in community forests in West Java that are maintained and managed by farmers for various purposes. Community forest development requires a constant supply of high-quality seeds, which depends on the availability of well-managed seed sources. The development and management of surian seed sources requires an understanding of the factors affecting their productivity, and this understanding should begin by identifying the characteristics of surian flower, fruit, and seed productions.

Constraints on plant reproduction occur during all stages of the reproductive cycle. Failures in natural fruit formation are not only caused by self-pollination and high levels of self-incompatibility but may also involve several other factors, such as limited resources (Bawa & Webb 1984). Failures in seed formation can also be caused by several factors. Undeveloped ovules may result from a lack of fertilisation or ovule abortions resulting from a combination of genetic and/or resource factors before or soon after fertilisation (Webb & Bawa 1985).

Patterns in the productions of surian flowers, fruits and seeds have not been studied comprehensively until now, yet the production characteristics of flowers, fruits and seeds must be understood in order to determine the biological constraints of surian reproduction and to determine seed-source management techniques that provide optimal pollination for the purposes of seed production.

In general, the present study aimed to determine the reproductive characteristics of surian, including 1) production characteristics of surian panicles, flowers, fruits and seeds, 2) the variations in the productions of fruits and seeds among trees and among branches, and 3) dendrometric factors that influence the productions of fruits and seeds.

MATERIALS AND METHODS

Study Areas

This study was conducted at the Padasari Village (Cimalaka Sub-district), and the Sukajadi Village (Wado Sub-district), both situated in the Sumedang Regency, West Java. Average monthly rainfall, temperature, and humidity in Sumedang Regency from 2009 to 2012 are shown in Figure 1. Annual rainfall values and the numbers of rainy days in the sub-districts of Wado and Cimalaka are shown in Table 1. We chose 5 forest stands containing dense surian trees in both villages. The surian stands investigated in the Sukajadi village were located at 108°07'–108°06' E, 06°59' S, at an altitude of 660–860 m above sea level with undulating and sloping topography. The stands were smallholder forests surrounded by dryland farming areas. The Padasari study sites were located at 107°55'–107°56 'E, 06°46' S, at an altitude of 685–700 m above sea level with flat terrain. These stands were agroforests surrounded by pine forests, paddy fields, and settlements.

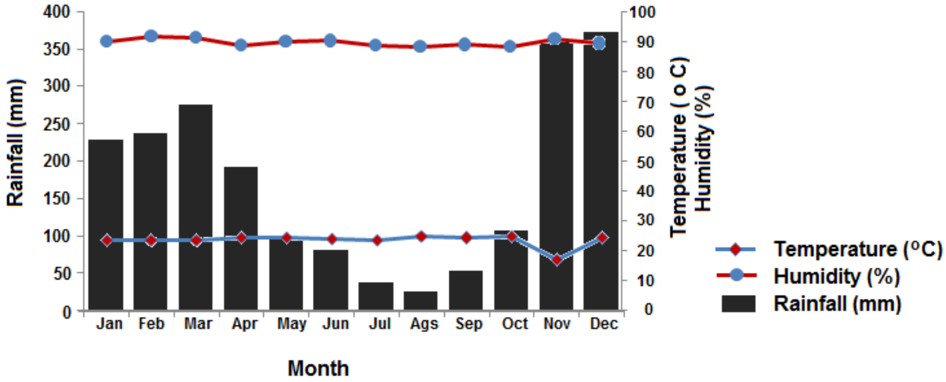


Figure 1: Average values of monthly rainfall, temperature and humidity in Sumedang Regency from 2009 to 2012. Data collected from Padjadjaran Climatological Station, Sumedang, at an altitude of 781 asl.

Table 1: Annual rainfall values and number of rainy days in the Wado and Cimalaka districts from 2004 to 2012.

Sub-district		Year								
		2004	2005	2006	2007	2008	2009	2010	2011	2012
Wado	Rainfall (mm)	2778	1932	2719	2751	2.719	2.255	3.672	3.688	5.182
	Rainy days (days)	146	105	124	141	124	113	203	146	171
Cimalaka	Rainfall (mm)	1972	2174	2188	2204	2.188	2.327	3.923	1.665	187
	Rainy days (days)	105	134	103	124	103	131	195	94	97

Sources: Badan Pusat Statistik (2008, 2012, 2013).

Observations were carried out from August 2011 to May 2013. Sampling and observation cannot be performed simultaneously, as surian flowering times do not occur simultaneously among trees (Pramono 2013). Observations were conducted in August 2011, November 2011, once a month from March to June 2012, November 2012, and May 2013.

Methods

All actively reproducing surian trees were identified in the selected stands. We counted the number of panicles per tree on 125 trees that were sampled randomly and the number of flowers and fruits on 99 and 128 panicles, respectively. The working samples used to characterise fruit traits consisted of 890 random mature fruits collected from 20 mother trees.

To study the quantitative variations in fruit and seed productions among trees and among sub-branches, we randomly sampled 10 fruits from 4 panicles of 4 trees at Sukajadi village and 4 trees at Padasari village. To study variations in fruit numbers among sub-branches, we sampled 3 trees at Sukajadi village. From each tree, 10 fruits were taken from 3 branches, and this procedure was replicated 3 times. The diameter and length of each fruit were measured using a caliper. The fruit coats were opened, and the numbers of empty seeds and filled seeds contained in each fruit were counted. Due to the small size of surian flowers, we did not count the number of ovules per flower; instead, in each case, we counted ovules by adding the number of filled seeds to the number of empty seeds.

To study the relationship between the dendrometric variables and the production variables of individual trees, we measured trunk diameters at breast height (DBH), total tree heights, crown lengths, crown widths, crown base heights, and numbers of branches for 30 trees that were sampled randomly from both areas. The variables of production considered in this study were as follows: the number of panicles per plant, the number of flowers per panicle, the number of fruits per panicle, the number of seeds per fruit, the number of ovules per flower, each seed set, fruit length, and fruit width, and the ratio of fruit width:length.

Data Analysis

The number of fruits per panicle, the number of flowers per panicle, fruit sizes, and the number of seeds per fruit are shown in the frequency graph displayed herein. These values were also reported as ranges, and mean values with standard deviations. Differences in the productions of fruits and seeds among plants and among branches were determined by one-way analysis of variance. Correlation and regression analyses and scatter diagrams were used to determine relationships among the production variables. Data analysis used Minitab 15 (Kuiper & Sklar 2013) and SPSS 16.0 (Pallant 2005) softwares.

RESULTS

Production Characteristics of Flowers, Fruits, and Seeds

The DBH of surian trees in the study sites ranged from 10.2 cm to 43.0 cm. The number of panicles per plant varied greatly, ranging from 2 to 165 panicles. The number of flowers per panicle ranged from 951 to 27,315 florets (Table 2), as shown by the frequency distributions in Figure 2.

Table 2: Data relating to tree size and flowers, fruits and seeds characteristics.

Variable	N	Range	Average
DBH (cm)	260	10.2–43.0	22.6 ± 5.5
Total height (m)	260	6.0–21.0	13.6 ± 3.0
Crown base height (m)	260	2.0–14.0	7.1 ± 1.2
Crown width (m)	260	1.0–7.0	4.1 ± 1.2
Panicles number/tree	125	2.0–165.0	35.7 ± 26.7
Flower number/panicle	99	951.0–27315.4	8104.3 ± 5853.8
Fruit number/panicle	128	38.0–646.0	232.7 ± 133.7
Fruit length (mm)	890	14.8–30.2	22.7 ± 2.7
Fruit width (mm)	890	7.0–13.7	10.8 ± 1.2
Fruit width:length ratio	890	0.4–0.7	0.5 ± 0.0
Filled seed number/fruit	890	1.0–34.0	15.3 ± 6.2
Seed set (%)	890	2.6–91.9	39.7 ± 16.0

Surian fruit lengths ranged from 14.78 to 30.21 mm with an average of 22.72 ± 2.75 mm, while surian fruit widths ranged from 6.95 to13.72 mm with an average of 10.76 mm ± 1.20 mm. Fruit width:length ratios ranged from 0.39 to 0.74 with an average of 0.48 ± 0.04. The number of fruits per panicle ranged from 38 to 646 with an average of 232 ± 133 fruits (Table 2), and most of the panicles studied had 150 to 200 fruits (Fig. 2).

Each surian fruit is a capsule with 5 carpels, and each carpel contains 7–8 winged seeds. The average total number of seeds/fruit observed in this study was 38.83 ± 1.79 seeds. The number of filled seeds per fruit varied from 1 to 34. While most of the fruits had 16–20 filled seeds per fruit (Fig. 2), some fruits contained only 1–3 filled seeds. The average number of filled seeds per fruit was 15.38 ± 6.2; the remaining were empty seeds. The filled seeds were bigger in the carpels on the side nearest the fruit stalk than in the carpels located on the farther side. The latter also contained more empty seeds.

For the Sukajadi trees studied, all fruit trait parameters, except the numbers of filled seed, showed no significant difference among trees. In contrast, all parameters significantly differed among the Padasari trees studied (Table 3). In addition, variations among some of the fruit trait parameters differed markedly among the sub-branches of a particular tree, but none of the parameters differed among the sub-branches of other trees.

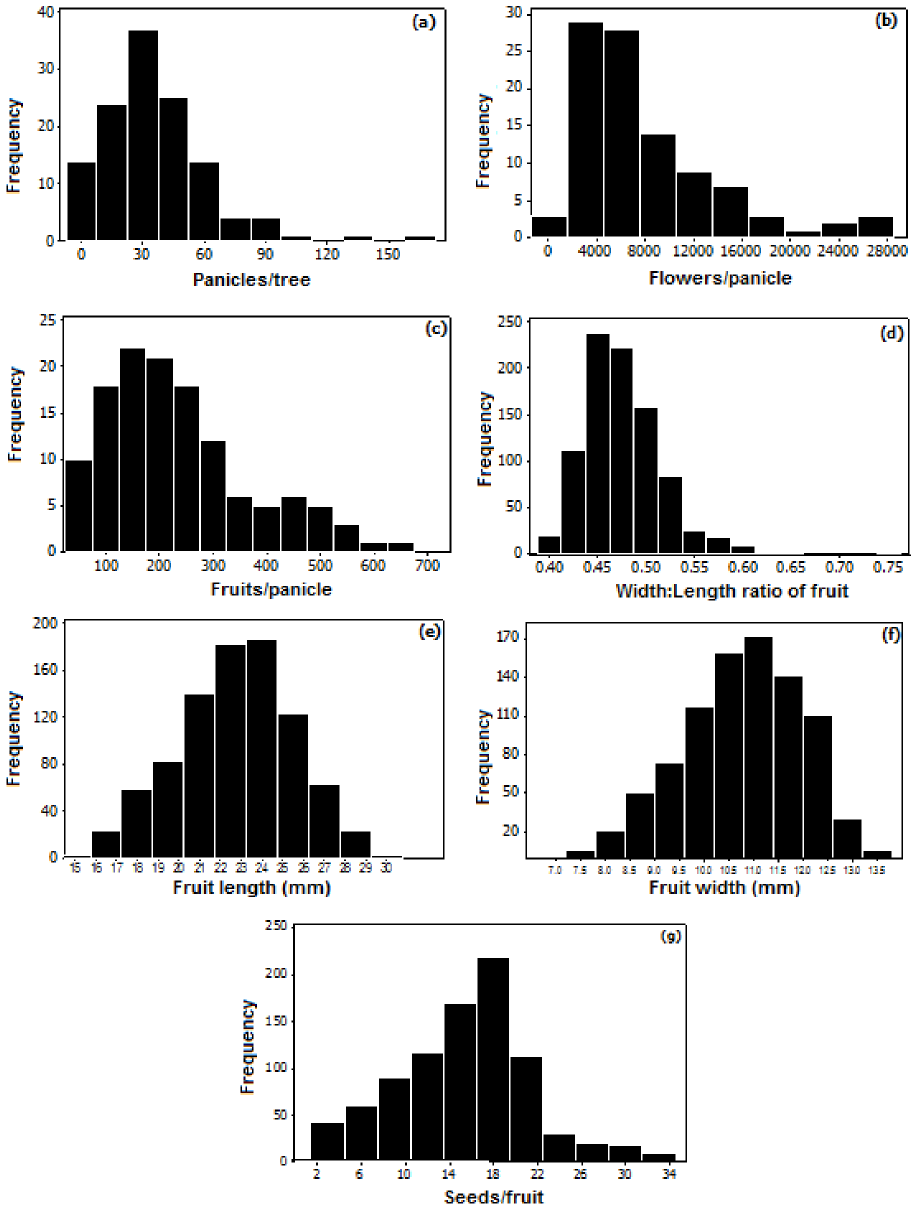


Figure 2: Frequency distributions of (a) number of panicles/tree, (b) number of flowers/panicle, (c) number of fruits/panicle, (d) fruit width/length ratios, (e) fruit lengths, (f) fruit widths, and (g) number of seeds/fruit.

Table 3: Analysis of variance results for fruit and seed characteristics among trees and branches.

Charateristic	*p* value				
	Among 4 trees		Among sub-branches		
	Sukajadi	Padasari	Tree 1	Tree 2	Tree 3
Fruit length	0.142^{ns}	0.0000**	0.002**	0.013*	0.258^{ns}
Fruit width	0.259^{ns}	0.0043**	0.410^{ns}	0.027*	0.241^{ns}
Fruit width:length ratio	0.076^{ns}	0.0002**	0.000**	0.008**	0.526^{ns}
Seed number	0.003**	0.0000**	0.004**	0.009**	0.914^{ns}
Ovule number	0.180^{ns}	0.0006**	0.216^{ns}	0.740^{ns}	0.962^{ns}
Seed set	0.051^{ns}	0.0000**	0.003**	0.040*	0.817^{ns}

Notes: ns = not significantly different, * = significantly different at 0.05, ** = significantly different at 0.01 confidence level.

Correlation Between Fruit Size and Number of Filled Seeds

As shown in Figure 3, the relationship between fruit size and number of seeds adheres to the following quadratic regression equation: $\log_{10}$ fruit length = 1.220 + 0.01596 seeds content – 0.000407 seeds content^2, with R^2 = 31.1% and p<0.001. On the other hand, the correlation between fruit width and number of filled seeds is described by the following equation: $\log_{10}$ fruit width = 0.8668 + 0.01980 seeds content – 0.000518 seeds content^2, with R^2 = 52.8% and p<0.001. Correlations were higher for fruit width than for fruit length, indicating that the number of seeds has a stronger effect on fruit width than fruit length. In addition, as shown in the accompanying graph, the correlation between increasing fruit size and increasing number of seeds held only until the number of seeds reaches 20 seeds/fruit. For larger number of seeds per fruit, fruit sizes tended to decrease.

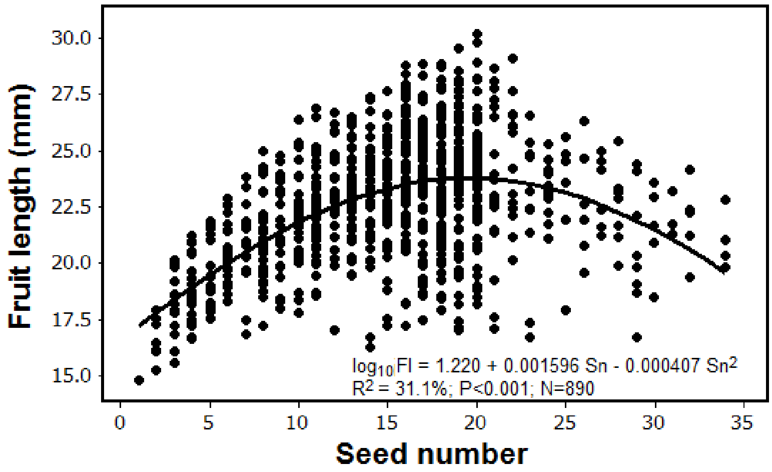
Relationships Between Dendrometric Variables and Production Variables

The number of panicles per tree positively and significantly correlated with DBH (p<0.05), crown width (p<0.01), and number of sub-branches per tree (p<0.05) (Table 4). The remaining dendrometric variables, i.e., total height, crown length, and crown base height, showed weak correlations with the number of panicles (Fig. 4). Variations in numbers of fruits/panicle did not correlate with all dendrometric variables considered herein, except crown length and crown base height (Fig. 5). The number per panicle was positively correlated with crown length and negatively correlated with crown base height.

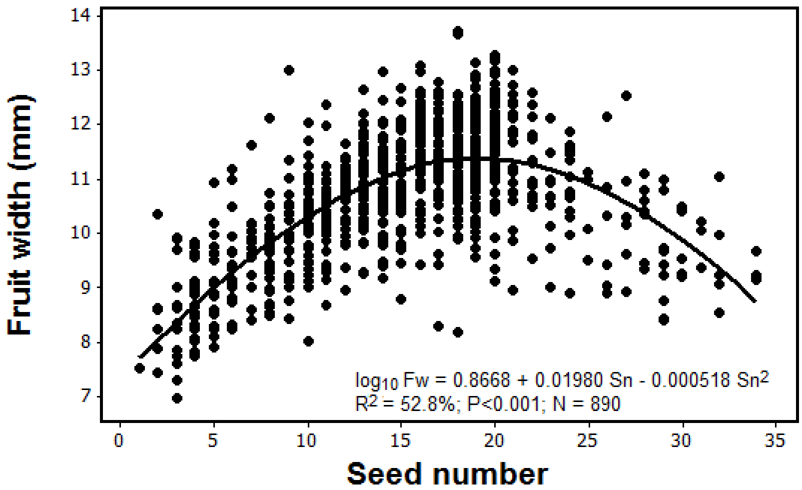
Table 4: Pearson correlations between surian (*T. sinensis*) production and dendrometric variables.

		DBH	Total height	Crown length	Crown base height	Branches number	Crown width
Panicles number (n = 34)	Koef.	0.427*	0.174	0.096	0.108	0.433*	0.576**
	P	0.012	0.325	0.589	0.545	0.011	0.000
Flowers number (n = 26)	Koef.	0.001	–0.012	–0.027	–0.037	–0.037	–0.064
	P	0.995	0.955	0.897	0.856	0.859	0.755
Fruits number (n = 30)	Koef.	–0.123	–0.168	0.448*	–0.520**	–0.187	0.154
	P	0.519	0.374	0.013	0.003	0.322	0.417
Seeds number (n = 28)	Koef.	–0.066	–0.157	–0.282	0.058	–0.217	–0.001
	P	0.739	0.425	0.146	0.769	0.266	0.997
Ovules number (n = 28)	Koef.	–0.031	–0.018	0.303	–0.293	–0.013	–0.197
	P	0.875	0.928	0.117	0.131	0.949	0.316
Seed set (n = 28)	Koef.	–0.058	–0.152	0.366	0.141	–0.212	0.066
	P	0.769	0.441	0.055	0.475	0.279	0.740
Fruit length (n = 28)	Koef.	–0.042	–0.14	0.063	–0.224	–0.039	0.010
	P	0.824	0.451	0.735	0.226	0.835	0.956
Fruit width (n = 28)	Koef.	0.025	–0.167	–0.099	–0.08	–0.076	0.146
	P	0.895	0.37	0.598	0.667	0.685	0.432
Fruit width:length ratio (n = 28)	Koef.	–0.044	–0.2	–0.184	–0.043	–0.266	0.106
	P	0.814	0.28	0.321	0.818	0.148	0.570

Note: * = Correlation significant at confidence level α = 0.05.



(a)



(b)

Figure 3: Scatter graphs and quadratic regression curves of 890 surian fruit samples from the Padasari and Sukajadi Villages, correlating the number of seeds/fruit with (a) fruit length and (b) fruit width.

Note: SN = seed number; Fw = fruit width; Fl = flower length.

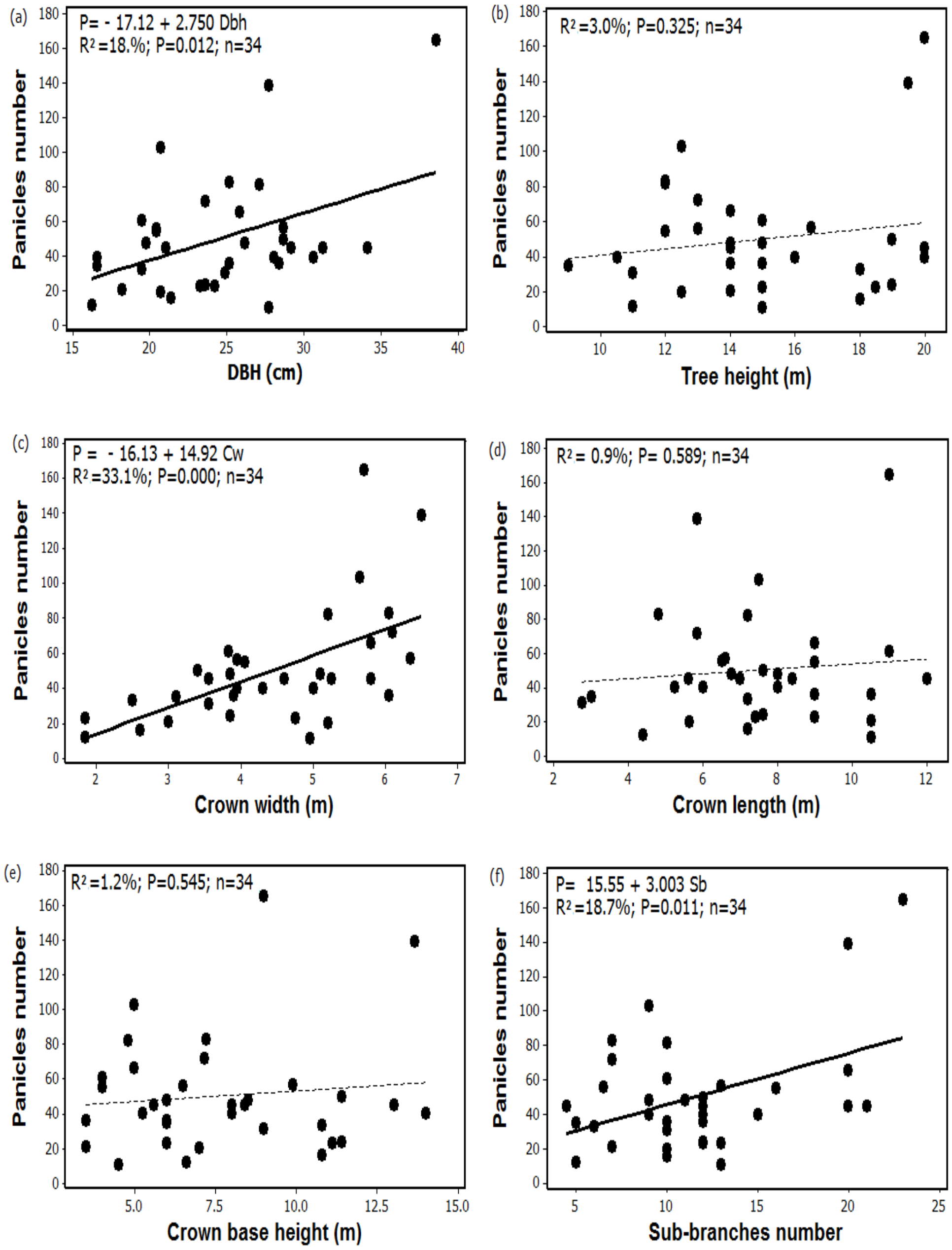


Figure 4: The relationship between surian tree characteristics and the number of panicles per tree.

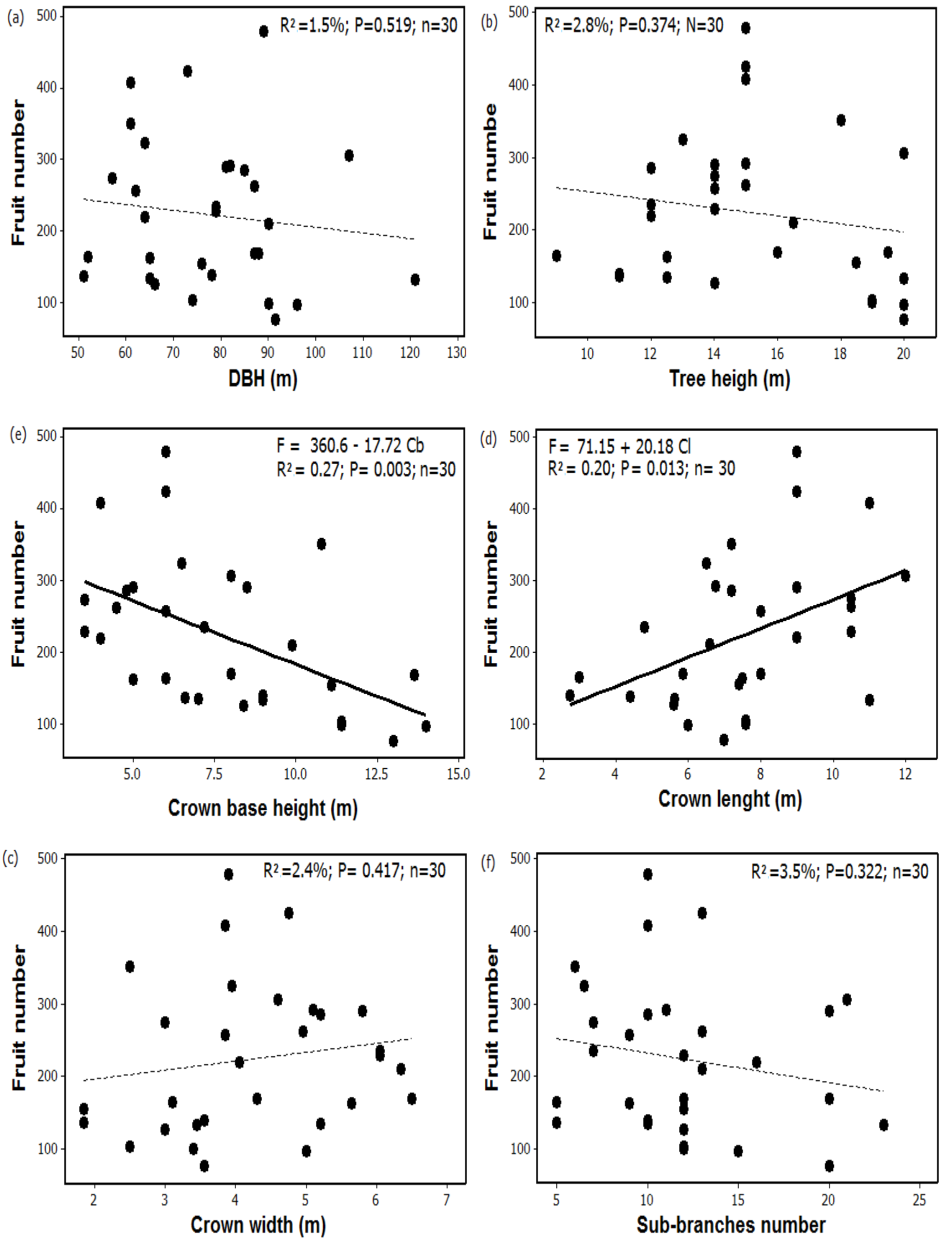


Figure 5: The relationship between surian tree characteristics and the number of fruit per panicle.

DISCUSSION

The number of flowers vary greatly, from 951 to 27,315 flowers per panicle, indicating that internal or environmental factors can considerably affect surian flower production. Therefore, understanding the factors that affect flower production is crucial to improving the productivity of a surian seed source. In the present study, we found that some fruits containing 1–5 filled seeds could grow and mature. This indicates that surian flowers do not require many fertilised ovules to produce mature fruits. As opposed to the types of pollinators that bring abundant pollen but visit fewer flowers, it appears that flower-visiting insects, such as small insects, that carry less pollen, have high populations, and visit a multitude of flowers, were more beneficial with regard to surian seed sets that produce large numbers of small flowers.

The results herein showed that fruit sizes increased with increasing number of seeds; however, for numbers greater than 20 seeds per fruit, greater seed numbers correlated with smaller fruits. It is suspected that the resources required for seed settings were limited, such that, as fertilised ovules exceeded capacity, available resources were used to set higher numbers of smaller seeds. The results also showed that the largest and most common fruits contained ± 20 seeds. This indicates that the optimal capacity for surian fruit development is ± 20 filled seeds per fruit. Surian fruit containing greater than 20 filled seeds also demonstrated lower seed quality, in agreement with previous studies of other species that showed positive correlations between seed size and seed or seedling quality. For example, in *Prosopis cineraria* (Manga & Sen 1995) and *Acacia crassicarpa* (Yuniarti *et al*. 2013), smaller and lighter seeds have lower seed viability compared to heavier and larger seeds. Seed size is also positively correlated with the growth and survival of seedlings of *Quercus rubra* (Aizen & Woodcock 1996). Furthermore, smaller fruits raise the risk of producing poor-quality seeds because fruit size can affect seed quality. Khan *et al.* (1999) showed that seeds collected from smaller *Mesua ferrea* fruit have lighter seeds and lower germination rates and require longer times to germinate than seeds obtained from large fruits. In addition, seeds collected from fruits containing many seeds exhibited lower vigour and survival rates than seeds collected from fruits containing fewer seeds (Khan *et al*. 1999).

Seed sets obtained from 890 sample fruits from both villages ranged from 2.6% to 91.9% with an average value of 39.7±16.0%. This average level is low because, approximately 50% seed set (for which the number of seeds is approximately 20 seeds/fruit) is the most optimal as well as the most common. It should certainly be possible to increase the average seed set level to 50%. According to a study by Ishida *et al*. (2003), inbreeding depression as a result of self-pollination is one of the causes of low seed set. This may be the case with surian, as surian flowers are small and strongly scented, indicating that the pollinators of surian flowers are small insects (Hua & Edmonds 2008; Kettle *et al*. 2011). Small pollinators with narrow flight ranges (Kettle *et al*. 2011) may increase the likelihood of self-pollination. The present study showed that some trees that grow alone produce fertile fruit, suggesting that surian trees may self-pollinate. When nutrients are limited, self-pollination increases embryo abortion rates (Nuortila 2007). Therefore, with regard to managing surian seed sources, spacing becomes very important in order to ensure facile pollinator movement among trees. Seed set levels can also be influenced by photosynthate availability. According to Goldsworthy (1992), photosynthate availability is vital to seed formation. Low photosynthate availability, due to a reduced quantity of leaves, reduces seed production. This indicates that seed set levels may be increased via crown volume enlargement and improved sunlight intensity, both of which can be obtained by improved soil fertility and plant spacing.

In the present study, fruit sizes and seed productions significantly differed between trees (Table 3), suggesting that differences in conditions among trees and their interaction with the local environment affect fruit and seed production. In addition, some production parameters differed among sub-branches on a particular tree, while these parameters did not differ significantly for other trees (Table 3). This suggests that the reproductive success of surian trees were sensitive to differences in local environmental conditions. For a given tree, the position of the panicle and the wind direction, both of which affect flowers' access to pollinators and sunlight, and their interaction with plants, branches, or panicles nearby may play significant roles in seed production and fruit production. Differences in production among parts of a given tree and the benefits of north-east orientation of the tree crown have also been reported in *Vitellaria paradoxa* (Lamien *et al*. 2007).

The dendrometric variables considered herein did not correlate with the number of flowers per panicle, probably due the effects of soil nutrients (Kelly *et al*. 2007) or climate on flowering (Sakai *et al*. 2006). Nonetheless, these dendrometric variables affected the number of fruits per panicle, consistent with studies conducted by Tabla and Bullock (2006), which revealed a significant relationship between tree size and fruit production of a particular tropical tree. In the present study, the number of fruits per panicle decreased with increasing canopy base height and total tree height. This is likely caused by low incidences of flower visits by insect pollinators due to increased distances between the pollinators' nests/habitats and the flowers requiring pollination (Boreux *et al*. 2013), which indicates that herbaceous plants or the forest floor are the habitat of the insect pollinators. Indeed, Bawa *et al.* (1989) reported that plants on tropical forest floors experience the highest diversity of pollinators. It can, therefore, be surmised that small pollinators of surian that inhabit the forest floor prefer to visit flowers located in a low canopy. However, data related to surian pollinator movements were not obtained in this study.

Crown length and crown base height significantly correlated with the number of fruit per panicle but did not significantly correlate with the number of seeds per fruit. It is possible that this occurred because the fruit set, which is determined by pollination, is influenced by pollinator visits, while the number of seeds, which is determined by the success of fertilisation, is influenced by the availability of compatible pollen stuck to the surface of each stigma. The canopy length and canopy base height influence the availability of pollinators more substantially than the availability of compatible pollen. The availability of compatible pollen is determined by outcrossing, which is influenced by the existence and condition of other surian trees in the surrounding areas.

CONCLUSION

In summary, productions of surian fruit and seeds vary greatly, and these variations differed significantly among trees as well as their branches, a phenomenon that is thought to be influenced by differences in a narrow range of local environmental factors. Dendrometric factors also affected the characteristics of fruit production. Stem diameter, crown width, and the number of sub-branches positively affected the production of panicles per plant. The lower the base of the crown and the greater the distance between the crown base to the total tree height, the higher should be the surian fruit set. With regard to managing seed sources, interactions of surian trees with other trees as well as with the forest floor environment are very important considerations. Therefore, more research is required to improve our understanding of the influences of soil, tree structure, and species composition and interactions on surian reproduction.

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