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Bearing Habit of *Sapindus mukorossi* and the Relationship between the Shoot Characteristics of the Parent and Bearing Shoots and Yield

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Abstract: (1) Research Highlights: *Sapindus mukorossi* Gaertn has substantial economic and medicinal value as a high-quality raw material for energy, traditional Chinese medicine, and landscaping. However, few studies have focused on the bearing habit and shoot characteristics of *S. mukorossi*. (2) Background and Objectives: We aimed to investigate the bearing habit of "Yuanhua," a selective breeding variety of *S. mukorossi*, and to identify the relationships among shoot characteristics, fruiting, and yield. (3) Materials and Methods: Ten healthy *S. mukorossi* trees were randomly selected to investigate the number of current-year shoots and bearing shoots. Eight-hundred-fifty current-year shoots of "Yuanhua" *S. mukorossi* were selected to investigate the number and position of the bearing and vegetative shoots. A total of 210 parent shoots and 145 bearing shoots of "Yuanhua" *S. mukorossi* were selected to investigate the characteristics. A generalized linear mixed model and a zero-inflated model were used for the analysis. (4) Results: (i) "Yuanhua" *S. mukorossi* has two types of current-year new shoots. After the new shoots produce leaves, if the growth points at the top continue to produce inflorescences that grow, bloom, and bear fruits, the new shoots are classified as bearing shoots. When the top growth points do not grow and do not produce inflorescences, the new shoots are termed vegetative shoots. The bearing shoots and vegetative shoots sprouted on the *S. mukorossi* parent shoots and developed into parent shoots in the following year, either developing from the bearing shoots or the vegetative shoots. (ii) The yield was affected by parent shoot characteristics. The type, length, diameter, and slenderness of parent shoots had significant effects on the number of current-year bearing shoots; the top diameter of the parent shoots and the number of current-year vegetative shoots had significant effects on parent shoot yield. (iii) The type of parent shoots, the length, and the top diameter of the current-year bearing shoots had significant effects on the single yield of a bearing shoot. (5) Conclusions: Selecting parent shoots with more bearing shoots and more fruit production according to the type, length, and thickness is a more efficient method for production management.

Keywords: *Sapindus mukorossi*; parent shoot; type; characteristic; yield; bearing shoot

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Citation: Song, Y.; Wei, S.; Li, C.; Qin, C.; Jia, L.; Su, S. Bearing Habit of *Sapindus mukorossi* and the Relationship between the Shoot Characteristics of the Parent and Bearing Shoots and Yield. *Forests* **2023**, *14*, 730. https://doi.org/10.3390/f14040730

Academic Editor: José M. Climent Maldonado

Received: 7 February 2023
Revised: 24 March 2023
Accepted: 30 March 2023
Published: 3 April 2023

1. Introduction

Sapindus mukorossi, also known as ritha, soap nut tree, and washnut, is a deciduous tree belonging to the Sapindaceae family, and it is widely distributed south of the Huaihe River in China. It is a common garden tree in southern China; in addition, *S. mukorossi* has golden-yellow leaves in the fall and is a famous landscaping species [1] and has been recorded in early Chinese literature, such as "The Classic of Mountains and Seas" and "Compendium of Materia Medica." The *S. mukorossi* fruit rind contains up to 13.26% saponins [2]; therefore, it is commonly known as soap nut. Saponins are high-quality and pure natural detergents and are effective for heavy metal removal. In addition, saponins have a variety of physiological activities and curative effects on a variety of diseases. The roots, rind, seeds, and flowers of *S. mukorossi* are all medicinal materials and are used in traditional Chinese medicine [3]. The *S. mukorossi* seed kernel contains up to 44.69% oil [4], has good oxidative stability, and is a high-quality raw biomass material [5]. The oil residue can be made into protein cakes, and the seed shell can be made into activated carbon [6]. Moreover, *S. mukorossi* trees, which have a high comprehensive utilization rate, can easily form a complete industrial chain and are, therefore, an emerging new energy source.

Research on *S. mukorossi* is currently focused on germplasm resources, phenology, and industrial production. However, there is a lack of systematic research on the bearing habit, characteristics of the parent shoots (PSs), and their relationships with the current-year bearing shoots (BSs) and yield. Nevertheless, a variety of studies on other economic species have revealed that the branches provide nutrients for flowering and fruiting, the BSs are important determinants of the flowering density and fruit yield [7], and the growth status of the branches directly affects the quantity and quality of the fruits. For example, the type of the branch impacts the 13C absorption of the fruit [8]. Additionally, shorter and thinner bearing shoots lead to more female flowers [9], and the length of the PS has a significant effect on the number of flower buds and the yield of the hybrid hazelnut; the longer the PS, the higher the number of flower buds and yield [10]. Furthermore, the thickness of the PS affects the number of new shoots and flower bud differentiation [11]. However, in a study on apples [12], the short branch type was found to be favorable for fruit setting. Additionally, a study of *Torreya grandis* showed that the growing conditions and the thickness and length of the PSs were the key factors for increasing the yield [13]. Moreover, in walnut, there are significant positive correlations between the thickness of the PSs and BSs and the quantity of fruit [14]. Furthermore, the thicker the BS in highbush blueberries, the greater the yield [15]. Thus, PS characteristics have important effects on the BS and fruit set, and the BS characteristics have an important effect on the fruit set. Branches with such traits impact yield [16]. Therefore, a detailed understanding of the growth and development of the branches and fruiting properties is important for the rational cultivation and production of fruit trees, and there is a need for this research on *S. mukorossi*.

Consequently, to provide a theoretical basis for the pruning of *S. mukorossi* to improve its yield, the objectives of this study were (1) the investigation and analysis of the bearing characteristics of *S. mukorossi*, (2) the analysis of the characteristics of the PSs and their effects on the BSs and yield, and (3) the analysis of the characteristics of the BSs and their effect on the yield.

2. Materials and Methods

2.1. Experimental Site

The experimental site was located in the mountainous region of Jianning County, Sanming City, northwestern Fujian Province, China. The region is characterized by a subtropical oceanic monsoon climate, with four distinct seasons, abundant light [17], rainfall concentrated from May to September, an average annual precipitation of 1950 mm, and an average annual temperature of 17.0 °C [18]. Jianning County is the source of the Minjiang River, which has excellent water quality, a pleasant climate, and excellent air quality year-round. The test site had red soil, sufficient light, and good ventilation and drainage conditions. It is 301.4 m above sea level (26°51′59′′ N, 116°47′36′′ E) and has a slope of 23°.

The test forest was a 6-year-old asexual line of "Yuanhua," a selective breeding variety of *S. mukorossi*, that was planted at a density of 4 × 4 m. The plot was maintained using simple management measures with manual weeding once in May and August, the application of basic compound fertilizer once in May, and pest control once in April, June, and August of every year.

2.2. Determination of the Shoot and Bearing Characteristics

"Yuanhua" *S. mukorossi* trees with good growth status, similar growth potential, and good fruit setting were selected in consecutive years as the study subjects. To evaluate the bearing habit, the branch structure, fruiting parts, and fruit quantity were observed and recorded.

From 2016 to 2018, 10 healthy *S. mukorossi* trees were randomly selected at the test site to investigate the number of current-year new shoots (CNSs), vegetative shoots (VSs), and bearing shoots (BSs) for three consecutive years to analyze the proportion of BSs among the new shoots.

A total of 850 CNSs were selected in 2020, and the positions of the CNSs were marked numerically in ascending order from the top to the base of the PS (Figure 1), and the types of new shoots were recorded to analyze the proportion of BSs and VSs at each position on the PSs.

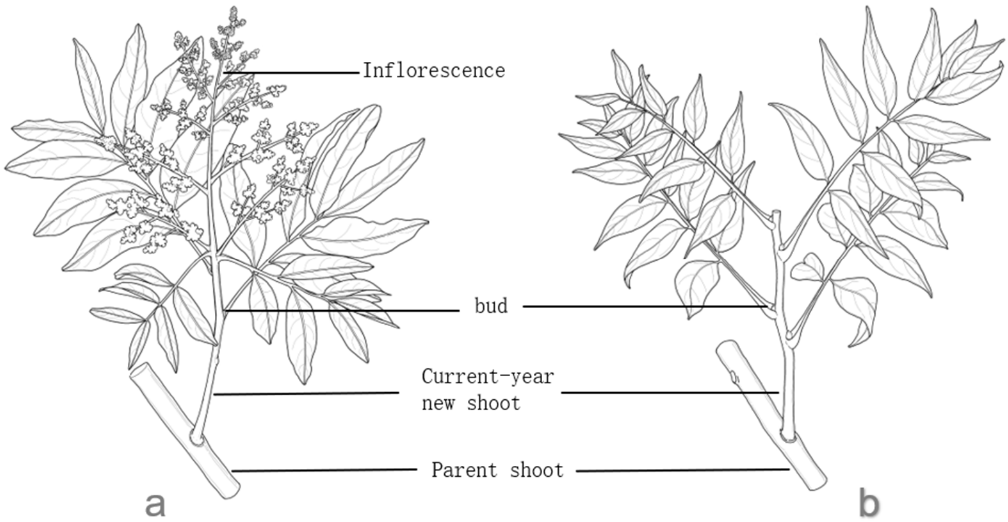

Figure 1. Schematic of the current-year new shoots on parent shoot. (**a**) bearing shoot of the current-year new shoot; (**b**) vegetative shoot of the current-year new shoot.

From 2020 to 2021, the "Yuanhua" *S. mukorossi* trees with good growth and similar growth potential were selected. Five PSs were randomly selected from each tree, with a total of 50 and 165 PSs and 100 and 45 BSs being selected in 2020 and 2021, respectively. The length, basal diameter, and top diameter of the PS; the position, number, and types (including the BS and VS) of the CNSs on the PSs; the total yield of a single PS; and the length, top diameter, basal diameter, number of leaves, and yield of the BS were measured. These characteristics were measured to analyze the distribution of the PS and BS characteristics, correlations among the characteristics of various PSs, zero-inflated model of the PS total yield, correlations between the BS and PS characteristics, and to create a generalized linear mixed model of the total yield of the BSs.

In addition, the lengths of the PSs and BSs were measured with a straightedge, while the basal and top diameters of the PSs and BSs were measured with a digital vernier caliper (DEGUQMNT MNT-150A, Shanghai, China).

The slenderness of the branch was calculated as follows: slenderness = (top diameter + base diameter)/length $\times$ 2. The internode of the BS was calculated as follows: internodal = length/number of leaves.

2.3. Statistical Analysis

The correlations among the characteristics, such as the type, length, top diameter, basal diameter, slenderness, number of BSs and VSs, and the total number of current-year PSs, were evaluated using the cor command in R. The correlations were analyzed for the types of PSs, length of the BSs, top diameter, basal diameter, slenderness, number of leaves, and internodal length. Then, plots were drawn using the corrplot package (version0.92) in R [19]. The type of PSs was designated as 0 (V) or 1 (F) for the statistical analyses.

Kernel density plots for the characteristics of the PSs and BSs were drawn using the ggplot2 (version3.4.0; New York, NY; USA) package in R (version 4.2.1) [20]. Then, using the glmmTMB (version1.1.4; Lyngby; Region Hovedstaden; Denmark) package [21], a zero-inflated model was fitted to the length, top diameter, basal diameter, slenderness, type, and yield of the PSs using the Poisson distribution, with the sampling year and sampling tree being selected as random variables to control for temporal and spatial variabilities. Additionally, the Akaike information criterion (AIC) values were used to select the best-fitting model. The plots were drawn using sjPlot (version2.8.12; Hamburg; Germany) [22].

Subsequently, the lme4 (version1.1-31; Madison; WI; USA) [23] and lmerTest (version3.1-3; Lyngby; Region Hovedstaden; Denmark) [24] packages were used to fit a generalized linear mixed model (GLMM) to the length of the BS, top diameter, basal diameter, number of leaves, internodal length, slenderness, and types of PSs using the Poisson distribution. To control for temporal and spatial variabilities, the sampling year and sampling tree were used as random variables, and an additional random variable with the same number of levels as those of the sample size was added to avoid overdispersion [25]. Lastly, lme4 was used to select the best model based on the AIC values, and the plots were drawn using sjPlot.

3. Results

3.1. Bearing Habits of Sapindus mukorossi

The asexual "Yuanhua" breed started to sprout in mid to late March, the inflorescences formed in late April, the full-blooming stage was in late May to early June, the stable fruiting period occurred after the first fruit setting in early July, and the maturity period was mid to late November, which was followed by the harvesting stage. "Yuanhua" *S. mukorossi* had panicles with both male and bisexual flowers, and the inflorescence was borne at the top of the shoot. Both the BSs and VSs of "Yuanhua" *S. mukorossi* became PSs in the following year, and both were able to sprout CNSs. Therefore, the PSs could be divided into two types, those that were BSs in the first year (hereinafter referred to as type F; Figure 2a) and those that were VSs in the first year (hereinafter referred to as type V; Figure 2b). Both types of PSs could sprout BSs and VSs. The buds on the PS sprouted and produced new shoots. After the new shoots produced leaves, the growth points at the top continued to produce inflorescences that grew, bloomed, and bore fruits, and the BS was formed, as shown in Figure 3. When the growth points at the top did not continue to grow after the new shoots produced leaves, but they fell off naturally, the VSs were formed, as shown in Figure 4.

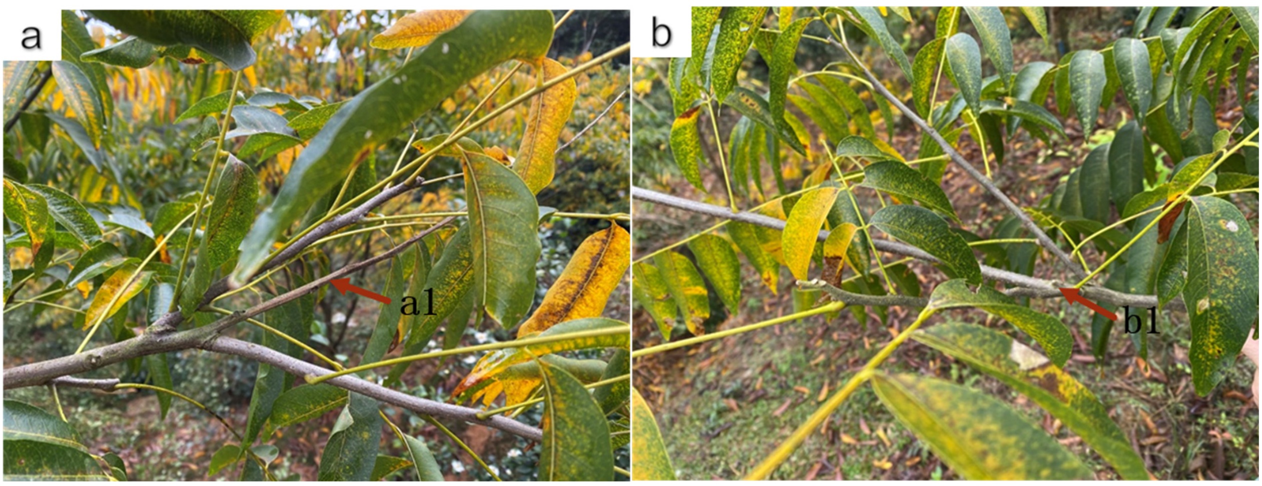

Figure 2. Types of *Sapindus mukorossi* parent shoots. (**a**) The parent shoots that developed from bearing shoots (type F), (**a1**) persistent infructescence of bearing shoot of previous year; (**b**) the parent shoots that developed from vegetative shoots (type V), (**b1**) top of vegetative shoot of previous year.

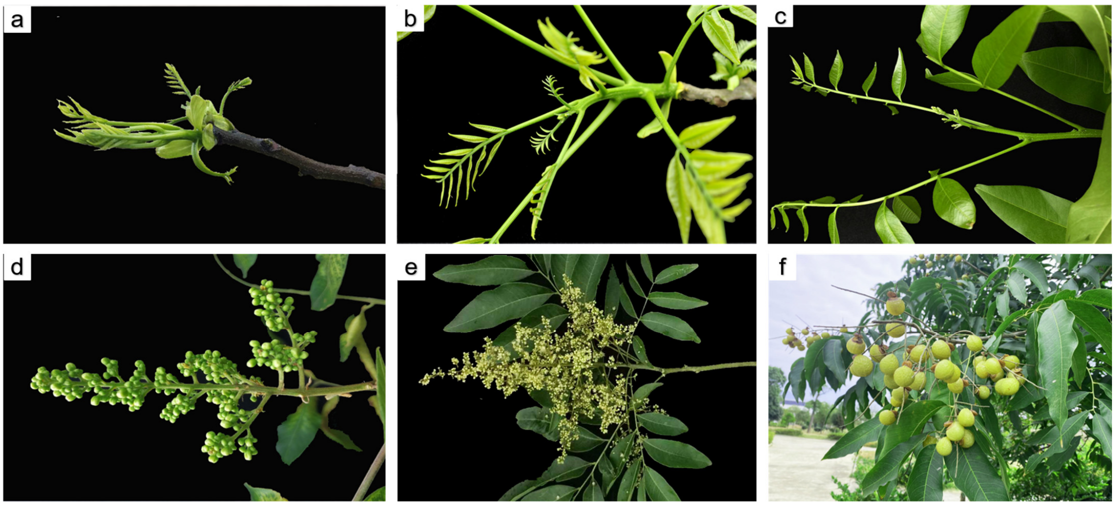

Figure 3. Developmental dynamics of bearing shoots. (**a**) bud sprouts and leaf-spreading stage; (**b**) new shoot continues to grow and develop, and the apical growth point continues to grow; (**c**) inflorescence sprouts on the top of new shoots; (**d**) inflorescence continues to grow and develop; (**e**) inflorescence flowering; (**f**) infructescence.

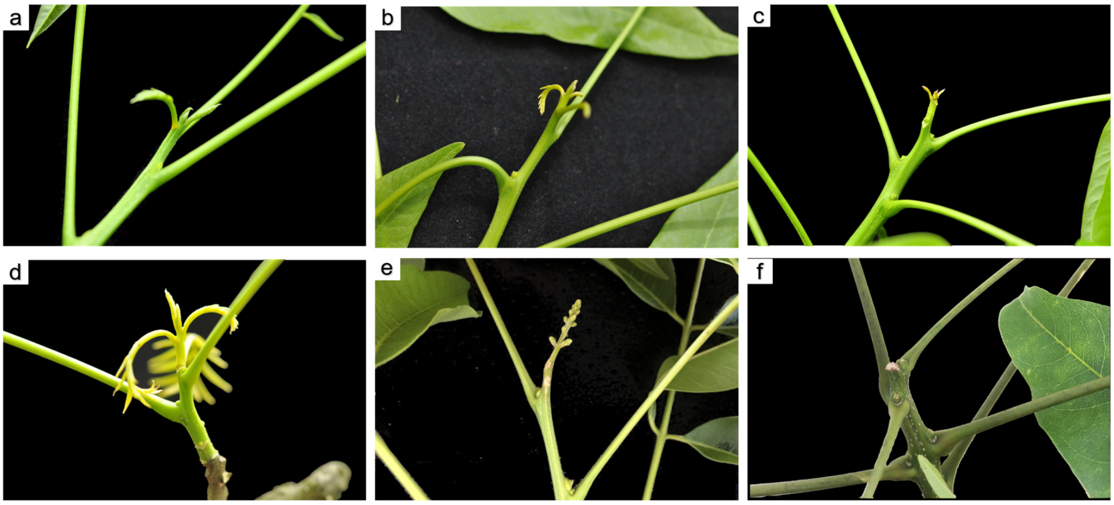

Figure 4. Developmental dynamics of vegetative shoots. (**a**) yellowing of the base of the undeveloped leaf blade at the top of the new shoot; (**b**) the top growth point of the new shoot stops growing completely, and all new leaf blades that are not fully developed turn yellow; (**c**) undeveloped new leaves of the new shoots fall off and an obvious abscission mark can be seen; (**d**) top of new shoot that has not grown into inflorescences falls off; (**e**) top of new shoot that has grown an inflorescence falls off; (**f**) vegetative shoot that developed completely.

The BSs and VSs from the CNSs varied in their number and position on each PS. Based on the analyses of 850 new shoots under natural conditions, all the buds on the PSs had the potential to sprout into new shoots, but the buds at positions 1–3, starting from the top of the PS, were more likely to sprout and form new shoots, accounting for 95.3% of the total shoots. Among these, the BSs that arose at positions one, two, and three accounted for 46%, 32%, and 16% of the BSs, respectively, and the VSs that arose at positions one, two, and three accounted for 37%, 41%, and 18% of the VSs, respectively. Moreover, each bud on the PS had the potential to form a BS or VS. An analysis of 10 healthy "Yuanhua" *S. mukorossi* trees in their natural growth state over three consecutive years from 2016 to 2018 revealed that the proportion of BSs among the new shoots varied substantially. The proportion of BSs ranged from 5% to 94% of the total shoots, as shown in Table 1.

Table 1. Proportion of BSs among the current-year new shoots for 10 *Sapindus mukorossi* trees from 2016 to 2018.

No.	2016	2017	2018
1	25%	58%	68%
2	30%	48%	84%
3	32%	39%	70%
4	45%	22%	25%
5	70%	78%	54%
6	82%	14%	76%
7	86%	7%	39%
8	94%	52%	48%
9	72%	5%	59%
10	91%	13%	73%

3.2. Distribution of the Characteristics of Parent and Bearing Shoots

The kernel density distributions of the characteristics of "Yuanhua" *S. mukorossi* PSs and BSs are shown in Figure 5. The length of the PSs ranged from 5.9 to 66.5 cm, with most shoots in the range of 33.5 to 52.5 cm. The top diameter of the PSs ranged from 5.02 to 21.6 mm, with the highest frequency in the range of 6.0 to 15.5 mm. Furthermore, the basal diameter of the PSs ranged from 5.77 to 23.13 mm, with the highest frequency in the range of 6.5 to 17.8 mm. The slenderness of the PSs ranged from 0.013 to 0.202, with the highest frequency in the range of 0.015 to 0.05.

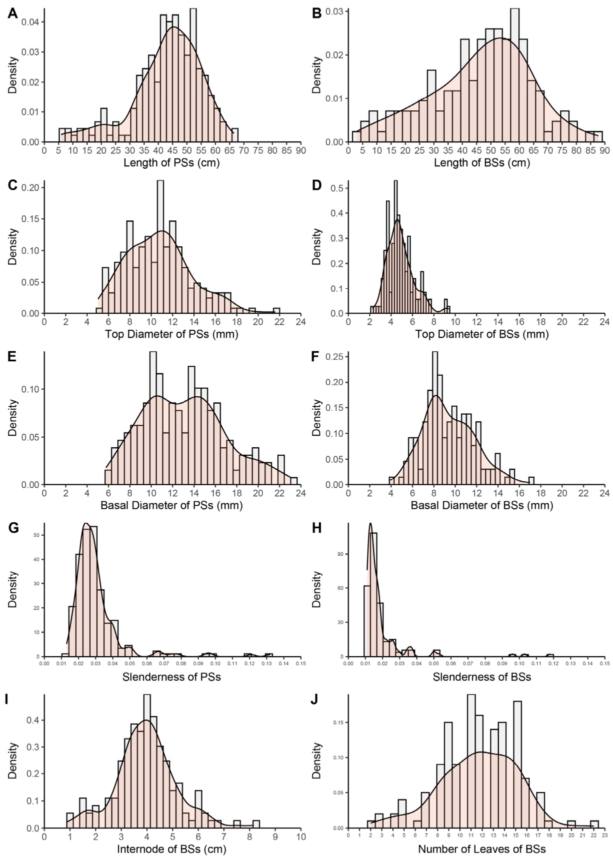

Figure 5. Exponential distribution of the trait values for the "Yuanhua" *Sapindus mukorossi* parent shoots (PSs) and bearing shoots (BSs). (**A**) the density of the length of PSs; (**B**) the density of the length of BSs; (**C**) the density of the top diameter of PSs; (**D**) the density of the top diameter of BSs; (**E**) the density of the basal diameter of PSs; (**F**) the density of the basal diameter of BSs; (**G**) the density of the slenderness of PSs; (**H**) the density of the slenderness of BSs; (**I**) the density of the internode of BSs; (**J**) the density of the number of leaves of BSs.

The length of BSs ranged from 3 to 87.7 cm, with the highest frequency in the range of 30.1 to 69 cm. Moreover, the top diameter of the BSs ranged from 2.25 to 9.4 mm, with the highest frequency in the range of 3.4 to 5.8 mm. The basal diameter of the BSs ranged from 3.92 to 16.99 mm, with the highest frequency in the range of 6.1 to 12.4 mm. Additionally, the slenderness of the BSs ranged from 0.011 to 0.118, with the highest frequency in the range of 0.01 to 0.024. Then, the number of leaves of the BSs ranged from 2 to 22, with the highest frequency in the range of 8 to 16, and the internodal length of the BSs ranged from 0.9 to 8.16 cm, with the highest frequency in the range of 2.8 to 5.2 cm.

3.3. Correlations between the Characteristics of the Parent Shoots

Figure 6 shows the Spearman correlation analysis of the characteristics of the PS indexes. The number of VSs showed a moderate negative correlation with the number of BSs with correlation coefficients of −0.64 ($p < 0.001$), and the number of VSs showed a low positive correlation with the number of CNSs, with correlation coefficients of 0.38 ($p < 0.001$). The number of BSs showed a low positive correlation with the length and the number of CNSs of PSs, with correlation coefficients of 0.38 and 0.43, respectively ($p < 0.001$), and the number of BSs showed a moderate positive correlation with the top and basal diameter of PSs, with correlation coefficients of 0.51 and 0.51, respectively ($p < 0.001$). The number of CNSs showed a low positive correlation with the length of PSs and the number of VSs and BSs with correlation coefficients of 0.46, 0.38 and 0.43, respectively ($p < 0.001$), and the number of CNSs showed a moderate positive correlation with the top and basal diameter of PSs with correlation coefficients of 0.55 and 0.50, respectively ($p < 0.001$). The top diameter of PSs showed a low positive correlation with the length and type of PSs with correlation coefficients of 0.44 and 0.31, respectively ($p < 0.001$). The top diameter of PSs showed a very high positive correlation with the basal diameter of PSs with correlation coefficients of 0.92 ($p < 0.001$). The basal diameter of PSs showed a moderate positive correlation with the length of PSs with correlation coefficients of 0.56 ($p < 0.001$).

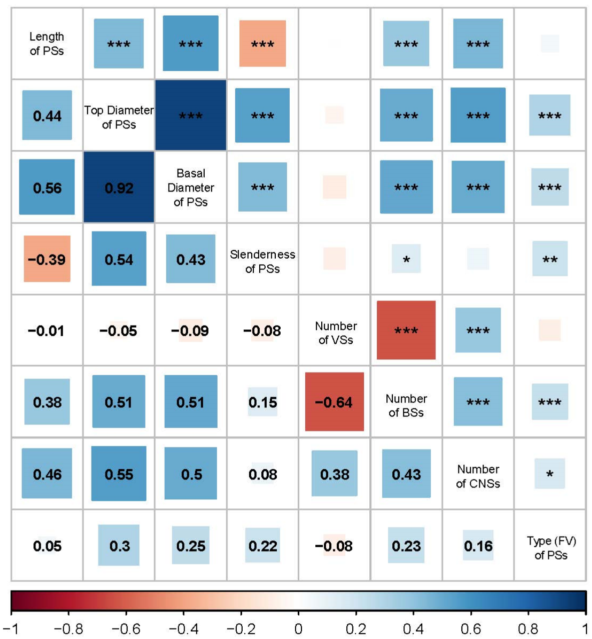

Figure 6. Correlations among the properties of the "Yuanhua" *Sapindus mukorossi* parent shoots. Note: Length of PS, length of the parent shoot; Top Diameter of PS, the diameter of the tip of the parent shoot; Basal Diameter of PS, the diameter of the base of the parent shoot; Slenderness of PS, the slenderness of the parent shoot; Number of VSs, the number of vegetative shoots on parent shoots; Number of BSs, the number of bearing shoots on parent shoots; Number of CNS, the total number of current-year shoots on parent shoots; Type (FV) of PS, the types of parent shoots. Asterisk in the figure are p-values and represent statistical significance (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$).

The total yield of a single PS was used as the dependent variable, and the length of the PS, top diameter of the PS, basal diameter of the PS, slenderness of the PS, type (F or V) of the PS, number of BSs, number of VSs, and the number of CNS were used as the independent variables; the sampling year and sampling tree were used as random factors. Using the zero-inflated GLMM for the analysis, the model was refined based on the AIC value, and the fixed factors of the model only included four variables: the type of PS, top diameter of PS, slenderness of PS, and the number of VSs. The incidence rate ratios (IRRs) of the total yield of a PS are shown in Figure 7 and Table 2. The V-type PS had a positive effect on the total yield of the PS (IRR = 1.12 [>1]), and it did not reach a significant level ($p = 0.105$); the top diameter of the PS had a positive effect on the total yield of the PS (IRR = 1.12), and it reached a significant level ($p < 0.001$); the slenderness of the PS had a slightly positive effect on the total yield of the PS (IRR = 1.01 [>1]), and it did not reach a significant level ($p = 0.124$); and the number of VSs had a slightly negative effect on the total yield of the PS (IRR = 0.93 [<1]), and it reached a significant level ($p = 0.046$). In contrast, the length of the PS, basal diameter of the PS, number of BSs, and the number of CNSs were not significantly related to the total yield of the PS.

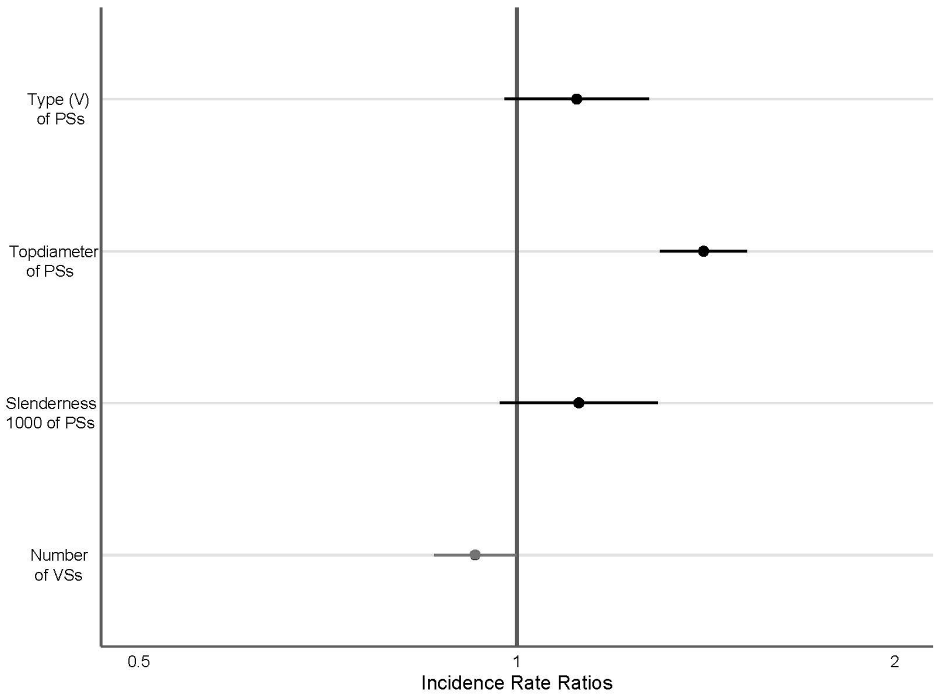

Figure 7. Zero-inflated model of the total yield of the parent shoots (PSs). Note: The higher the incidence rate ratio (>1), the more the yield is positively affected by this variable (black). The lower the incidence rate ratio (<1), the more the yield is negatively affected (gray). VS, vegetative shoots.

Table 2. Zero-inflated model of the total yield of the parent shoots (PSs).

Predictors	Estimate	SE	Incidence Rate Ratios	CI	*p*
Count Model					
(Intercept)	−0.318	0.565	0.73	0.24–2.20	0.573
Type (V) of the PS	0.110	0.068	1.12	0.98–1.27	0.105
Top diameter of the PS	0.113	0.013	1.12	1.09–1.15	<0.001
Slenderness 1000 of the PS	0.006	0.004	1.01	1.00–1.01	0.124
Number of VSs	−0.070	0.036	0.93	0.87–1.00	0.046
Zero-Inflated Model					
(Intercept)	0.091	0.186	1.01	0.76–1.58	0.625
Random Effects					
σ^2			1.95		

Note: SE, standard error; CI, confidence interval; *p*-value; VS, vegetative shoot.

3.4. Correlations between the Bearing Shoot Characteristics and the Parent Shoot Type

The correlations between the shoot length, top diameter, basal diameter, number of leaves, internodal length, slenderness, and type of PSs of the BSs of the "Yuanhua" *S. mukorossi* were analyzed, and the Spearman correlation analysis results are shown in Figure 8. The top diameter of BSs showed a low positive correlation with the length of BSs, with a correlation coefficient of 0.40 ($p < 0.001$); the top diameter of BSs showed a moderate positive correlation with the basal diameter of BSs, with a correlation coefficient of 0.53 ($p < 0.001$). The basal diameter of BSs showed a high positive correlation with the length of BSs, with a correlation coefficient of 0.78 ($p < 0.001$). The number of leaves of BSs showed a high positive correlation with the length and basal diameter of BSs, with correlation coefficients of 0.75 ($p < 0.001$) and 0.63 ($p < 0.001$), respectively. The number of leaves of BSs showed a low positive correlation with the top diameter of BSs, with correlation coefficients of 0.30 ($p < 0.001$), the number of leaves of BSs showed a moderate negative correlation with the slenderness of BSs, with a correlation coefficient of −0.53 ($p < 0.001$). The internode length of BSs showed a moderate positive correlation with the length of BSs, with correlation coefficients of 0.60 ($p < 0.001$); the internode length of BSs showed a low positive correlation with the basal diameter, with a correlation coefficient of 0.39 ($p < 0.001$), the internode length of BSs showed a moderate negative correlation, with correlation coefficients of −0.53 ($p < 0.001$).

Figure 8. Correlations between each trait for the bearing shoots (BS) and the type of parent shoots for "Yuanhua" *Sapindus mukorossi.* Note: Length of BS, the length of the BS; Top Diameter of BS, the diameter of the tip of the BS; Basal Diameter of BS, the diameter of the base of the BS; Number of Leaves of BS, the number of leaves of the BS; Internode of Number, the internodal length of the BS; Slenderness of BS, the slenderness of the BS; Type (FV) of PS, the type of parent shoot. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

The single yield of the BS was used as the dependent variable; the length, top diameter, basal diameter, number of leaves, internodal length, slenderness, and PS type (F or V) of the BS were used as the independent variables; and the sampling year and sampling tree were used as random factors. The GLMM was used for the analysis and refined based on the AIC values, and the fixed factors of the model were only the length, top diameter, internodal length, and PS type of the BS. The IRRs of the total yield of BSs are shown in Figure 9 and Table 3. The length of the BS had a positive effect on the total yield of the BS (IRR = 1.61 [>1]), and it reached a significant level ($p < 0.001$); the top diameter of the BS had a slightly positive effect on the total yield of the BS (IRR = 1.26 [>1]), and it reached a significant level ($p < 0.001$); the internodal length of the BS had a slightly negative effect on the total yield of the BS (IRR = 0.91 [<1]), and it did not reach a significant level ($p = 0.107$); the V-type of PS had a negative effect on the total yield of the PS (IRR = 0.77 [<1]), and it reached a significant level ($p = 0.037$). In contrast, the basal diameter, number of leaves, and slenderness of the BSs were not significantly related to the yield of the BS.

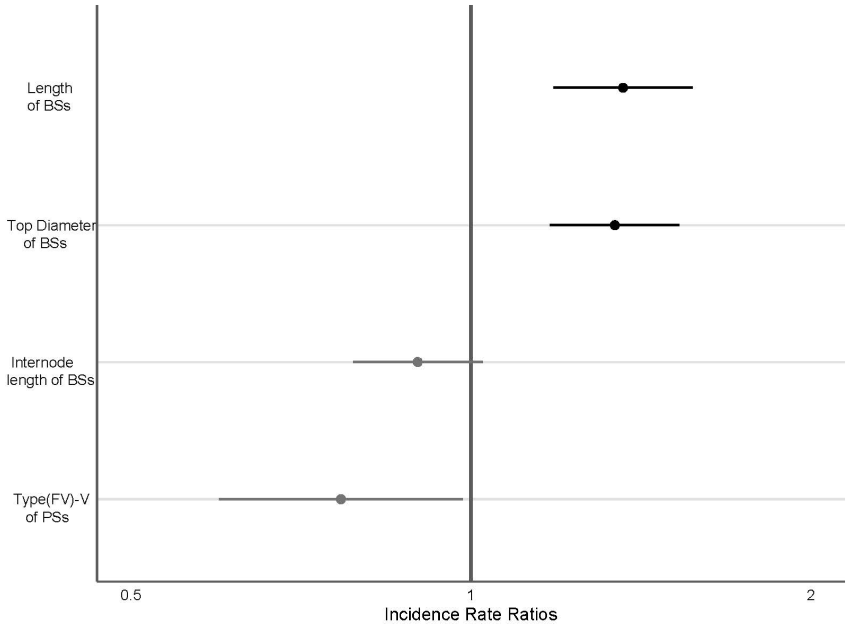

Figure 9. Generalized linear mixed model of the total yield of the bearing shoots (BSs). Note: The higher the incidence rate ratio (>1), the more the yield is positively affected by this variable (black). The lower the incidence rate ratio (<1), the more the yield is negatively affected (gray). Type (FV) of PS, the type of parent shoot.

Table 3. Generalized linear mixed model of the total yield of the bearing shoots (BS).

Predictors	Estimate	SE	Incidence Rate Ratios	CI	p
Intercept	0.477	0.392	1.61	0.75–3.48	0.224
Length of the BSs	0.018	0.004	1.02	1.00–1.03	<0.001
Top diameter of the BSs	0.231	0.053	1.26	1.14–1.40	<0.001
Internodal length of the BSs	−0.090	0.056	0.91	0.82–1.02	0.107
Type (FV) of PSs	−0.265	0.127	0.77	0.60–0.98	0.037
Random Effects					
σ^2			0.33		

$n = 145$; Marginal R^2/Conditional R^2 = 0.343/0.556. Note: SE, standard error; CI, confidence interval; p-value; PS, parent shoots; type (FV) of PSs, type of parent shoots including F and V.

4. Discussion

"Yuanhua" *S. mukorossi* has two types of CNSs, BSs and VSs. After the new shoots produce leaves, if the growth points at the top continue to produce inflorescences that grow, bloom, and bear fruits, the new shoots are classified as BSs. When the top growth points do not continue to grow and do not produce inflorescences, the new shoots are termed VSs. Therefore, the CNSs form both BSs and VSs, with varying numbers and positions on each PS. Under natural conditions, the proportion of "Yuanhua" *S. mukorossi* BSs reached 5%–94% of new shoots, showing the enormous potential of the species to form BSs. Therefore, various methods, including rational pruning and fertilization, could be used in production management to increase the proportion of BSs and improve the yield. The buds on the current-year shoots of "Yuanhua" *S. mukorossi*, including the BSs and VSs, sprouted in the following spring to form CNSs, while the current-year shoots developed into PSs. Under natural conditions, the first to third buds at the top of the PS were more likely to sprout, accounting for 95.3% of the total sprouting. Because of this sprouting, the shoots are unable to update, and this phenomenon leads to longer blind shoots, excessive nutrient consumption, uneven nutrient distribution, and a decrease in the number of vigorous branches year-to-year, leading to lower yields despite their continuous fruit sets. This issue can be resolved by removing the top dominance through scientific and reasonable pruning to promote the growth of young shoots [26], which affects the tree structure [27], canopy structure, light distribution [28], the relationship between nutritional and reproductive growth [29], and the nutrient distribution within the tree, thereby increasing fruit yield and quality. Shortcutting was found to break the top dominance and affect the branching capability of apples and walnuts [30,31]. Proper shortcutting can increase the number of BSs [32], and pruning can also promote the growth of new shoots and improve fruit quality [33]. Therefore, a reasonable pruning method could generate an effective shoot ratio for "Yuanhua" *S. mukorossi*, thereby forming a stable and healthy tree structure and a successive high-yield production pattern, which is an important aim for *S. mukorossi* cultivation and production. Consequently, this study provides a theoretical basis for the development of a reasonable and plastic pruning scheme.

The metrics which had significant effects on the number of current-year BSs included the type, length, diameter, and slenderness of the PSs. The correlation analysis showed that the characteristics of the PSs had significant effects on the development and yield of the "Yuanhua" *S. mukorossi* BSs. Studies on litchi [34] and hazelnut [10,35] have shown that the PSs have significant effects on yield. The length of the PSs had significant effects on the number of BSs and the total number of current-year shoots; in particular, the longer the PS, the higher the number of BSs and the total number of current-year shoots, which was similar to the results that were obtained for goji berry [10] and cherry [36]. The correlation analysis showed that the top diameter of the PSs was significantly and positively correlated with the yield, and the greater the top diameter, the higher the yield, which is consistent with the results of studies on *Acer truncatum* [37] and walnut [38]. Studies on sour cherries also showed that thicker PSs had more fruit sets [39]. In addition, Takishita et al. improved the quality of citrus by using the thickness of the PS as an indicator for managing fruit set [40], and Kelc, Štampar and Solar [14] concluded that the greater the diameter of the PSs, the larger their surface area and the better the accumulation of nutrients, which can provide more nutrients for fruit growth and development, thus promoting fruit setting and retention. The top diameter and basal diameter of the PSs had a positive effect on the number of BSs, and a study on Wenzhou honey tangerine showed that thicker PSs could produce more BSs that are conducive to fruit setting [41]. Moreover, Puntieri et al. [42] suggested that thicker branches have greater physical strength and conductivity, which could also explain this relationship.

The type of PSs had significant effects on the number and yield of BSs and the total number of current-year shoots. For the BS, there were more F-type PSs (derived from the BSs) than V-type PSs (derived from the VSs) and the total current-year shoots. This may be because the previous-year BSs received more nutrients and were stronger, which was conducive to the formation of BSs in the following year. The type of PSs also had a significant effect on the yield of the BSs. Parent shoots that were classified as F-type were beneficial for the yield of the BSs. The PS type affected the yield of the "Yuanhua" *S. mukorossi* by influencing the number and yield of the BSs, which is consistent with the results of studies on hazelnut [43] and *Carya cathayensis* [44]. Therefore, longer and stronger F-type BSs should be retained during pruning to obtain more BSs and a better yield in the second year.

The traits of the BSs had significant effects on the number of fruits. The shoot length, top diameter, basal diameter, number of leaves, and internodal length of the BSs had significant positive correlations with the yield. Similar findings were found for apple [45], olive [46], and walnut [47]. Moreover, in Juglandaceae, the longer and thicker the first-year shoots, the better their fruiting capacity [48], which is probably because vegetative growth within a certain limit can promote flowering and fruiting [49]. For "Yuanhua" *S. mukorossi*, the top diameters of the PSs and BSs had significant effects on the yield of the BSs. In addition, the type of PS had a significant effect on the yield of the BSs but not on the total yield of the PSs. This may be because this study focused on the morphological properties of the PS, while other factors, such as nutrient accumulation and hormone levels, also have important effects on the yield of the PSs. Thus, further research should focus on these additional factors.

This study revealed that the top diameter and type of parent shoots have important effects on yield and the number of bearing shoots. Therefore, when managing the cultivation of "Yuanhua" *S. mukorossi* in the test area, we can choose to leave shoots with a thick top diameter and appropriate F-type shoots and prune offshoots with a thin top diameter and some V-type shoots to increase bearing shoots and yield.

5. Conclusions

We investigated the bearing habits of "Yuanhua" *S. mukorossi* and analyzed the relationship between yield and the PS or BS characteristics. The results showed that: (1) "Yuanhua" *S. mukorossi* exhibited the following bearing habits according to the observation experiments: the "Yuanhua" *S. mukorossi* PSs had two shoot types, i.e., the current-year BSs and current-year VSs, which developed into PSs in the following year. The PSs could also be divided into those that developed from the BSs and those that developed from the VSs. (2) The yield was indicated to be affected by the characteristics of the PSs. The type, length, diameter, and slenderness of the PSs had significant effects on the number of the current-year BSs. Moreover, both the top diameter of the PSs and the number of current-year VSs had significant effects on the yield of the PSs. The total yield of a PS was higher when the top diameter was at least 9 mm. (3) The type of the PS and length and top diameter of the current-year BS had significant effects on the single yield of a BS. This study suggests that selecting PSs with more BSs and more production according to the type, length, and diameter is a more efficient and intuitive method for production management and facilitates efficient and simple management. In this study, the top diameter was an important factor affecting the yield of "Yuanhua" *S. mukorossi*. The type of parent shoots did not have a notable effect on the yield of fruiting mother branches but had a considerable effect on the yield of bearing shoots. This could be probably because the fruiting performance was influenced not only by the morphology of parent shoots but also by the nutritional status and environmental factors, which need to be further investigated.

Author Contributions: Conceptualization, Y.S.; methodology, Y.S.; formal analysis Y.S.; investigation, Y.S. and C.L.; resources, S.S. and L.J.; data curation, Y.S. and S.W.; writing—original draft preparation, Y.S. and S.W.; visualization, Y.S., S.W. and C.Q.; project funding acquisition, S.S. and L.J. All authors have read and agreed to the published version of the manuscript.

Funding: The research of this thesis is supported by the National Natural Science Foundation of China under Grant No. 32071793.

Data Availability Statement: The data are available upon request from lanxi0818@126.com.

Acknowledgments: The authors thank Shuijing Luo for helping with the experiment.

Conflicts of Interest: The authors declare no conflict of interest.

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