seeds

MDPI

Article

Variability in Fruit Morphology and Germination Capacity of the Tropical Medicinal Species *Securidaca longipedunculata* Fres.

Edith M. S. Daboué [1,2,*], Ali Béné [3], Kangbéni Dimobe [4], Djibril S. Dayamba [3], Aboubacar B. Zouré [2], Bassiaka Ouattara [5], Prospère Sabo [2], Sévérin Tuina [2], Oblé Neya [3], Barbara Vinceti [6] and Amadé Ouédraogo [2]

1 Centre National de Semences Forestières (CNSF), Ouagadougou P.O. Box 2682, Burkina Faso
2 Laboratoire de Biologie et Ecologie Végétales (LaBEV), Université Joseph KI-ZERBO, Ouagadougou P.O. Box 7021, Burkina Faso; zo_abouba@yahoo.fr (A.B.Z.); prosperesabo90@yahoo.fr (P.S.); severintuina1@gmail.com (S.T.); amadeouedraogo@gmail.com (A.O.)
3 Institut de l'Environnement et de Recherches Agricoles (INERA), Centre National de la Recherche Scientifique et Technologique (CNRST), Ouagadougou P.O. Box 7047, Burkina Faso; bene_ali@yahoo.fr (A.B.); djibril.dayamba@yahoo.fr (D.S.D.); neyaoble@hotmail.com (O.N.)
4 Département des Eaux, Forêts et Environnement, Institut des Sciences de l'Environnement et du Développement Rural (ISEDR), Université Daniel Ouezzin Coulibaly, Dédougou P.O. Box 176, Burkina Faso; kangbenidimobe@gmail.com
5 Institut Supérieur du Développement Durable (ISDD), Université Yembila Abdoulaye Toguyeni, Fada N'Gourma P.O. Box 7030, Burkina Faso; bass.ouatt@gmail.com
6 Alliance Bioversity-CIAT, 00153 Rome, Italy; b.vinceti@cgiar.org
* Correspondence: edaboue@gmail.com; Tel.: +226-63-26-35-67

Abstract: *Securidaca longipedunculata* Fresen, a medicinal tree indigenous to tropical Africa, faces threats due to root overharvesting and limited occurrence. This study assessed the extent of variation in the morphological traits and germination of seeds collected from populations located across the Sudano-Sahelian and Sudanian climatic zones in Burkina Faso. A total of 1600 mature fruits across the two climatic zones were characterized in their morphology. Seed germination tests were conducted with material collected across climatic zones, using six physical and chemical pre-treatments and two substrates. Descriptive statistics and analyses of variance were used to process the data generated. The morphological data showed significant variations in fruit and nut traits across the populations sampled, which may reflect a significant underlying genetic diversity, as expected in wild plants. Samples from the Sudano-Sahelian zone exhibited larger fruits (11.87 ± 1.38 mm) containing heavier (0.12 ± 0.04 g) and larger (5.64 ± 1.02 mm) nuts. Seeds sown on river sand exhibited the highest mean germination percentage (35.24 ± 17.73%) and germination speed (0.40 ± 0.36 seedlings per day). Seed wing and coat removal resulted in the highest mean germination percentages (respectively, 36.5 ± 19% and 35.5 ± 16%). These results suggest the existence of some barriers to germination in *S. longipedunculata* seeds. For seedling production, preferably heavier fruits should be collected and sowing carried out on river sand after wing or coat removal.

Keywords: medicinal plant; fruits traits; germination; Sub-Saharan Africa; threats; Burkina Faso

check for updates

Citation: Daboué, E.M.S.; Béné, A.; Dimobe, K.; Dayamba, D.S.; Zouré, A.B.; Ouattara, B.; Sabo, P.; Tuina, S.; Neya, O.; Vinceti, B.; et al. Variability in Fruit Morphology and Germination Capacity of the Tropical Medicinal Species *Securidaca longipedunculata* Fres. *Seeds* **2024**, *3*, 639–655. https://doi.org/10.3390/seeds3040042

Academic Editor: Alba Cuena Lombraña

Received: 5 August 2024
Revised: 11 November 2024
Accepted: 14 November 2024
Published: 19 November 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Forests are sources of a diverse range of services and goods for mankind. This is particularly true in the tropics, where both rural and urban populations depend to a considerable extent on forest resources for food, medicine, firewood, building materials, fodder and income [1]. In terms of health benefits derived from forests and trees, research has documented more than 5400 plant species with medicinal use across the African continent [2]. The demand for medicinal plants is currently increasing in both developed and developing countries for various reasons, including the growing recognition that natural products have fewer or even no side effects, their accessibility and affordable costs and their use in various domains, such as pharmacy, cosmetology, perfumes and

food industry, among others [3]. The rising demand of plant-based drugs is creating heavy pressures on some important medicinal plant populations in the wild due to their overharvesting [4]. In addition to anthropogenic pressures, a substantial loss in species habitats has been observed in recent decades in Sub-Saharan Africa, in some specific geographies, due to harsh climatic conditions [5].

This situation is affecting African countries in particular, as reflected in the annual rate of net forest loss globally, in the decade 2010–2020, estimated at 3.9 million hectares, surpassing that of South America, the previous leader [6]. Indeed, the wild populations of many high-value medicinal plant species have been declining over the years. Several important plant species have become scarce (e.g., *Pterocarpus erinaceus* Poir., *Afzelia africana* Smith ex Pers., *Bombax costatum* Pellegr. & Vuill.) in areas where they were previously abundant. Due to unregulated exploitation, some plant species may become threatened with extinction [3]. This calls for urgent action to protect, sustainably manage and, possibly, cultivate native plant species [7].

Among the species of greatest concern in Sub-Saharan Africa is *Securidaca longipedunculata* Fresen, commonly called "the violet tree". Indeed, this upright shrub or small tree, which belongs to the Polygalaceae family [8], has properties for treating almost every conceivable ailment, and is particularly known to have antivenin [9], antimicrobial and anti-inflammatory [10,11], psychoactive and neuropsychiatric effects [12]. The plant is reported to have therapeutic effects against various diseases and conditions such as malaria, rheumatism, asthma, tuberculosis, cancer, venereal diseases, and diabetes. It is also used to manage blood pressure and as an abortifacient [13,14]. Additionally, the plant has been noted for its cosmetics properties [15], its repellent activities against snakes [16], and its beneficial effects in managing opportunistic diseases associated with HIV/AIDS [17]. Despite its recognized values in Sub-Saharan Africa in general, and particularly in Burkina Faso, the long-term conservation of the species is a challenge due to its unsustainable management practises, such as debarking, pruning, grooving and cutting. The fact that roots are the most frequently collected organ causes major threats to the species. A significant reduction in species distribution areas has been already observed [18]. In this context, the propagation of the species through seeds could be an option to sustain the resource base. Indeed, the regular propagation of native tropical tree species is important for successful reforestation programmes, but the lack of knowledge on their seed physiology is a major obstacle for the sustainable management and successful implementation of these programmes [19]. The natural regeneration of *S. longipedunculata* is limited due to factors such as low seed germination rates, poor recruitment rates, slow seedling growth and planting difficulties caused by easily broken taproots [20]. Indeed, experiments on the species have shown that, under field conditions, untreated seeds monitored for a full year did not germinate and presented signs of rot and sand inside the coat; under greenhouse conditions, untreated seeds showed a low germination rate (26%) and slow growth, with an average height of 11 cm after 70 days of monitoring [21]. Planting the species on farmland could potentially increase the occurrence of *S. longipedunculata*; however, this could be constrained by limited knowledge regarding its germination ecology.

Seed dormancy is the failure of an intact viable seed to complete germination under favourable environmental conditions including water, temperature, light and aeration [22,23]. Dormancy is an adaptive trait that prevents germination in unfavourable conditions, improving seedling survival. It is influenced by factors like temperature, light and moisture. Dormancy is naturally broken by processes such as stratification (cold and warm exposure) or scarification (seed coat damage) [24]. Artificial methods, including mechanical scarification, chemical treatments, and temperature control, mimic these processes to promote large-scale germination for agriculture and restoration. These strategies are key to managing germination in species like *S. longipedunculata*, especially when natural regeneration is limited by environmental or human factors.

Previous studies had hypothesized that *S. longipedunculata* seeds exhibit physical dormancy [21]. This observation has guided our decision to treat the whole fruit as the seed

in our experiments, allowing us to explore the importance of the wing in *S. longipedunculata* seed germination.

In addition, fruits' and seeds' morphological characteristics most likely affect germination [25], and these factors are in turn dependent on provenance/climatic zones [26]. However, there is limited research on the association between the morphological characteristics of fruits and seeds, and their impact on enhancing seed germination in *S. longipedunculata*. To fill this gap, this study investigated (i) the morphological variability of fruits of *S. longipedunculata* across different climatic zones in Burkina Faso, and (ii) the conditions (seed provenance, substrate, pre-sowing treatment) that improve seed germination for this species. Of the three climatic zones in Burkina Faso (Sudanian, Sudano-Sahelian, and Sahelian), the Sahelian zone was excluded as the target species does not occur there. The chosen locations represent distinct climatic conditions and habitat types within the Sudanian and Sudano-Sahelian zones, reflecting the species' natural distribution range.

2. Materials and Methods

2.1. Study Area

A total of four sampling sites were selected, with two in each of the climatic regions targeted (Figure 1) to capture the potential variability in fruit morphology and germination performance. In the Sudano-Sahelian zone, the Bissiga and Tiakane sites were retained. The rainy season in this zone lasts 4–5 months with a mean annual rainfall of 600–900 mm, temperatures range from 20 to 30 °C and soils are of a brown mineral type. Orodara and Peni were the sites in the Sudanian zone; the rainy season lasts for 5 to 6 months with a mean annual rainfall of 900 to 1100 mm; mean annual temperatures range from 20 °C to 25 °C; and soils are completely weathered, ferrallitic, deep and homogeneous [27].

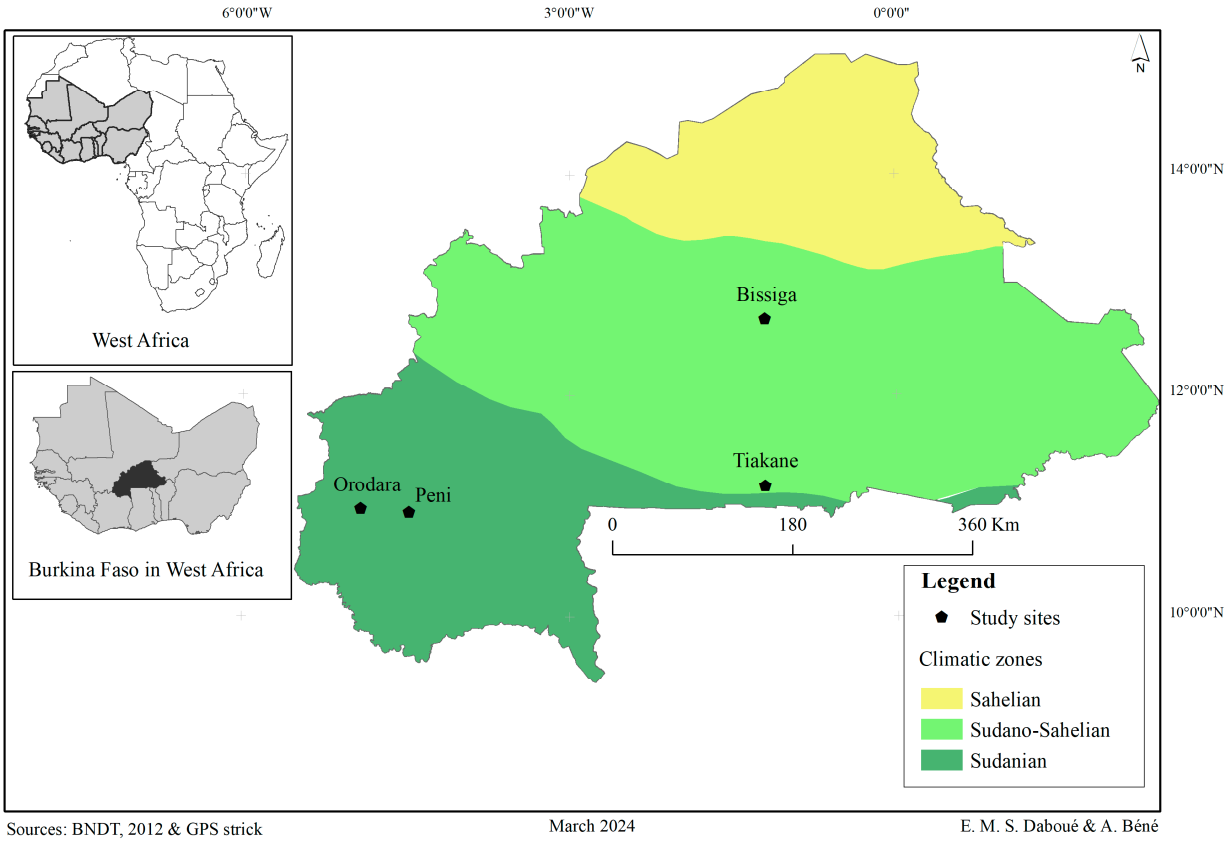


Figure 1. Location of the different sampling sites of *Securidaca longipedunculata* in Burkina Faso across two different climatic zones (map on right hand side). The upper quadrant on the left shows the location of the West African region and the lower quadrant shows the position of Burkina Faso within the West African region.

2.2. Fruit Collection and Seed Processing

Fruits were collected from 31 January to 2 February 2017. During this period, a dry, dusty and relatively cool trade wind named Harmattan blew southwestwards from the Sahara into the Gulf of Guinea. Temperatures varied between 15 and 33 °C with an average of 25 °C. At each site (Bissiga, Orodara, Peni and Tiakane), 30 healthy fruiting trees were randomly selected in natural stands, using a minimum of 50 m of distance between targeted trees. Each sampled tree was visually assessed to ensure the sampling would focus exclusively on healthy individuals. Ripe fruits were collected from all accessible branches of each sampled tree to avoid inducing effects on the traits studied due to the specific position of the fruit on its maternal parents [28]. At each site, fruits from all the trees were combined into a single batch for analysis. For each batch, the processing consisted in winnowing and sorting impurities, such as remaining leaves and branch pieces, poorly formed fruits, etc.

2.3. Evaluation of Fruit Morphological Traits

The fruits were spread on jute bags throughout the duration of the experiments, which were conducted under laboratory conditions (30–35 °C during the day and 20–25 °C during the night, where relative humidity (RH) ranged between 40 and 45%). For biometric and quantitative morphological measurements, four replicates of 100 fruits for each site were sampled randomly and numbered from 1 to 100. The fruit of *S. longipedunculata* is a samara with a long peduncle, a wing with parallel venation apically (Figure 2A), a proximal locule position with respect to the wing and a small wing on the upper surface of the nut [29]. Each fruit contains one nut. Each fruit was measured as well as its nut. The morphometric parameters considered were weight, length and width. The length and width of fruits (Figure 2A) and that of the nut (seed) it contained (Figure 2B) were measured using an electronic calliper with a precision of 0.01 mm, while the weight of the fruits and nuts was measured using an electronic balance (Kett Electronic Laboratory, FD-240-2, Tokyo, Japan) with a precision of 0.001 g.

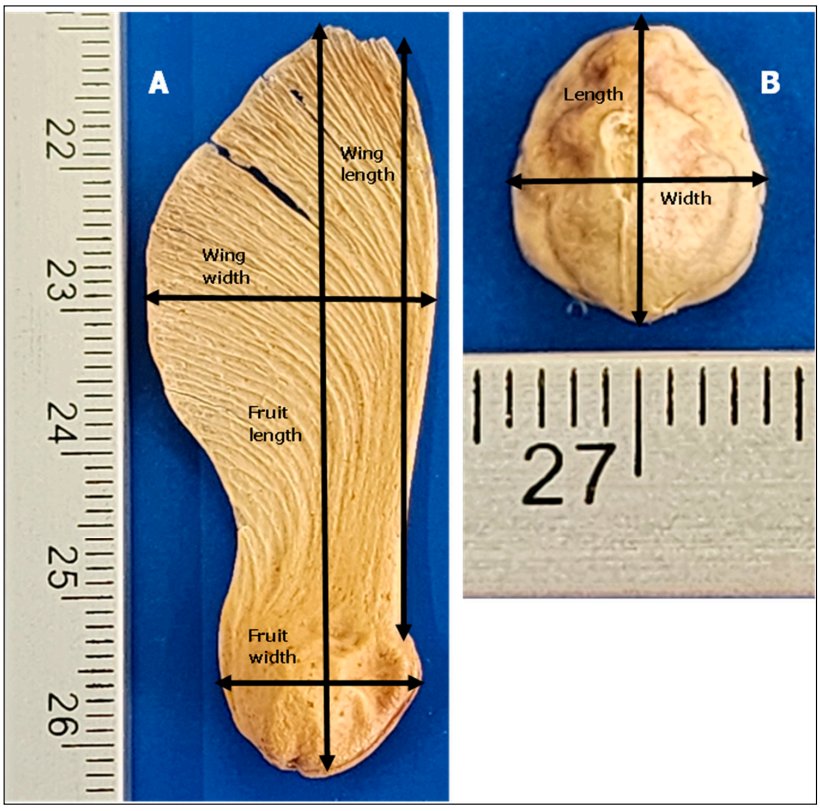


Figure 2. Photograph of *Securidaca longipedunculata* fruit (**A**) and nut (**B**) measurement.

2.4. Seed Initial Moisture Content (iMC) Assessment

For the germination capacity assessment, the whole fruit was considered as the seeding material.

Seed maturation is a process characterized as an organized sequence of several physiological events culminating in physiological maturity [30]. Physiological maturity is defined as the stage in which the seed reaches the maximum dry weight [31]. Therefore, we assessed the drying level of the seeds by measuring their initial moisture content (iMC), which provided crucial information on their water content and drying state. Initial moisture (iMC) was assessed for seed from each collecting site according to International Seed Testing Association (ISTA) rules [32] using four replicates of five seeds per site. The seeds were weighted and dried in an oven (Binder E28, WTB binder GmbH, Tuttlingen, Germany) at 103 °C for 17 h. The moisture contents (MC) are expressed on a fresh weight basis using the following formula:

$$MC(\%) = \frac{W_{0\ m} - W_{1\ m}}{W_{0\ m}} \times 100$$

where W_{0m} is the mean weight of fresh seeds, and W_{1m} the mean weight of dried seeds.

2.5. Pre-Sowing Treatments

Six different pre-sowing treatments, including the control, were tested on the seeds of each provenance (Table 1).

Table 1. Description of the pre-sowing treatments applied to *Securidaca longipedunculata* seeds before sowing.

Pre-Sowing Code	Treatment	Method
Control	Control	Fruits were sown intact
Water	Tap water soaking 48 h	Fruits were soaked in tap water for 48 h before sowing
SeedWingR	Wing removal	The wing of the fruit was removed entirely with scissors before sowing
SeedCoatR	Coat removal	The pericarp of the fruit was removed entirely
Acid1	Sulphuric acid soaking 1 min	Fruits were covered with sulphuric acid at 97% concentration, stirred for 1 min, then washed and soaked in tap water for 24 h before sowing
Acid2	Sulphuric acid soaking 3 min	Fruits were covered with sulphuric acid at 97% concentration, stirred for 3 min, then washed and soaked in tap water for 24 h before sowing

For each collecting site and for each treatment, four replicates of 25 seeds were used for germination tests. The so-treated seeds were sown on two different substrates: river sand, previously sterilized in an oven at 200 °C for three hours, and a mixture of three volumes of soil + one volume of sand + one volume of cattle manure, all collected locally. On each substrate, pre-treated seeds were sown in transparent plastic boxes. Germination boxes were filled with the substrate at 1/3 and then watered with 90 mL of distilled water. After mixing, seed beds were printed with a wooden board. Sowing consisted in placing the seeds in the seedbed and then covering them with a thin layer of sterilized dry sand. After sowing, the boxes were covered and placed on a table at ambient temperature in the laboratory (30–35 °C during the day and 20–25 °C during the night), where the relative humidity (RH) ranged between 40 and 45%. The germinating seeds were exposed to laboratory lighting consisting of neon lamps. ISTA rules prescribe that the substrate must at all times contain sufficient moisture to meet the requirements of germination [33].

Therefore, the germinating seeds were watered with 50 mL of distilled water every two days after checking germination, using a squirt bottle.

Germination, determined based on the emergence of the radicle [24], was recorded every two days according to ISTA rules [32]. At the end of each test, all non-germinated seeds were systematically dissected to determine the count of hard, empty and insects or worm-infested seeds. According to ISTA rules [32], a hard seed at the end of a test is considered a viable seed that did not germinate because of the short duration of the test. Empty and infested seeds are seeds that would never germinate regardless of the conditions in which they were handled. Thus, empty and infested seeds were therefore removed from the total number of seeds sown before calculating the final germination percentage "*G* (%)".

For each germination assay conducted, we measured the incubation period starting from the moment water was first applied to the seeds, initiating the biochemical processes of germination, called "imbibition start". We specifically recorded the first visible sign of germination, defined as the day of the protrusion of the seed coat by the emerging radicle, referred to as "radicle emergence" [34]. According to ISTA rules, the mean duration of a germination test is 28 days. However, given the extent and irregularity of the germination, we extended the monitoring period to 103 days. Given the extensive variability in germination timing and duration observed, we also computed two additional parameters to provide a comprehensive analysis of germination dynamics:

- "Germination end", defined as the day the last seeds were observed to germinate;
- "Germination duration", which qualifies the total number of days from the first to the last germination event.

2.6. Statistical Analysis

Seed weight and size are two crucial physical parameters determining seed quality, since they greatly influence germination capacity and seedling growth [35]. In this experiment, we investigated how "seed weight"—measured here as the weight of the nut within the fruit—can be predicted from the fruit's "weight", "length" and "width". This was achieved by applying a standard multiple linear regression analysis.

Descriptive statistics for each morphological parameter of the fruits were obtained, followed by a one-way analysis of variance (ANOVA), used to test differences between sites regarding morphological parameters. When a significant difference was found, a two-by-two comparison of the sites was carried out using Tukey tests. ANOVA was employed to identify which specific fruit characteristics were most affected by differences between sites. Subsequently, a multivariate analysis of variance (MANOVA) was applied to evaluate the joint effect of the geographical collection sites on multiple interrelated traits, providing a comprehensive analysis of how these traits vary collectively across different environments. A total of 1221 samples were included in this analysis, using Pillai's trace as the test statistic.

Germination percentage "*G* (%)" was calculated using the following formula:

$$G(\%) = \frac{Total\ number\ of germinated\ seeds}{Total\ number\ of\ seeds\ sown - (empty + infested\ seeds)} \times 100$$

For statistical analysis, germination percentages were previously subjected to an angular (arcsine square root) transformation prior to the analysis, using the following formula:

$$\theta = Arcsin\ \sqrt{p}$$

where θ is the improved value, and p the gross germination frequency.

This transformation was employed to stabilize the variance and normalize the distribution of the percentage data, as percentage values are bounded between 0 and 100%, often violating the assumptions of normality and homogeneity of variance required for parametric tests such as ANOVA.

Thus, all the frequencies equal to 0 and 1 have been improved by using, respectively, the following formulas: $(1/4\ n)$ and $[1 - (1/4\ n)]$, where n is the total number of observations.

In addition, Germination speed, "***S***", defined as the number of germinated seeds per day, was calculated according to Maguire [36] as follows:

$$S = \sum_{i=1}^{n} \frac{G_i}{D_i}$$

where G_i = the number of germinated seeds in the day and D_i = the number of days after sowing.

A one-way ANOVA was then applied to test the differences between the treatments and sites. Box plots were generated to visualize and explore variations in seed germination across climatic zones and collection sites. All the analyses were realized at a 5% level of significance and performed with the R statistical software package, version 4.2.1.

3. Results

3.1. Fruit and Nut Morphological Traits

Across all sites sampled, descriptive statistics showed that *S. longipedunculata* fruit measured on average 42.62 ± 5.55 mm in length, 11.53 ± 1.44 mm in width and had an average weight of 0.33 ± 0.07 g. The average length of the wing was 29.05 ± 5.23 mm, its width was 13.07 ± 2.67 mm and its average weight was 0.04 ± 0.01 g. Regarding the nut inside the fruit, its average weight was 0.12 ± 0.04 g and it measured 7.25 ± 1.13 mm in length, and 5.39 ± 1.02 mm in width.

A MANOVA analysis, conducted with 1221 samples, revealed a statistically significant influence of sampling locations on fruit morphology (Pillai's trace = 0.5922, F-statistic = 99.775, df = 9, 3651, $p < 0.001$; Table 2). This evidence suggests considerable variability in fruit morphology traits across different sites, emphasizing the role of environmental factors in determining phenotypic characteristics.

Table 2. Results of a multivariate analysis of variance (MANOVA) to assess the impact of sampling location on *S. longipedunculata* fruit morphology. Code Signification: *** Very highly significant difference at 5% level ($p < 0.001$).

Source	Df	Pillai	Approx F	Num Df	Den Df	Pr (>F)
Collecting sites	3	0.5922	99.775	9	3651	$<2.2 \times 10^{-16}$ ***
Residuals	1217					

Variation in fruits and nut morphological traits was observed between climatic zones (Figure 3).

The ANOVA also revealed variations in fruit and nut characteristics ($p = 0.000$) across collecting sites. Fruits collected in Orodara (Sudanian zone) were heavier (0.34 ± 0.97 g) with medium-sized and lighter wings compared to those of the other sites. On the other hand, fruits collected in Peni (Sudanian zone) were longer (48.66 ± 6.28 mm) and larger (12.42 ± 1.98 mm) with heavy (0.05 ± 0.02 g), long (33.66 ± 5.33 mm) and large (15.91 ± 2.89 mm) wings. Nuts excised from fruits collected in Bissiga (Sudano-Sahelian zone) turned out to be heavier (0.13 ± 0.03 g), longer (7.59 ± 1.36 mm) and larger (5.90 ± 1.18 mm) (Figure 4).

Pearson's correlation analysis indicated a strong association between fruit weight and nut weight (r = 0.66), while association with fruit length (r = 0.17) and fruit width (r = 0.23) were comparatively weaker (Table 3). The significance value obtained was 0.000, meaning a p value lower than 0.0005, thus indicating a statistically significant correlation. Regression analysis demonstrated that "fruit weight" accounted for 24.60% of the variance in "nut weight", with a beta coefficient of 0.709 and a significance level of 0.000 < 0.05. The partial correlation coefficient was 0.496.

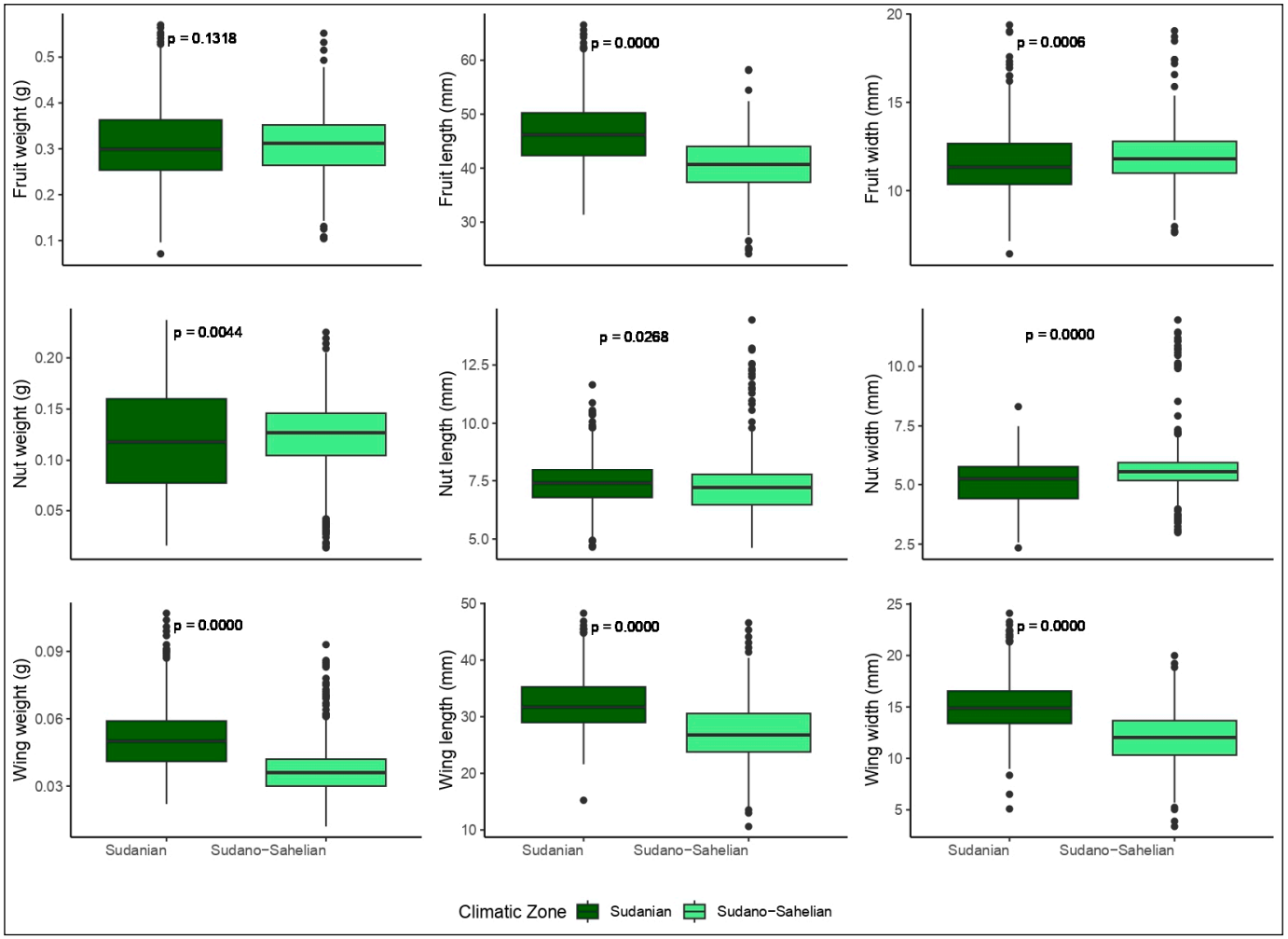


Figure 3. Variation in Securidaca *longipedunculata* fruit, nut and wing morphological traits across climatic zones. Number of samples by climatic zone: Sudano-Sahelian = 797, Sudanian = 795 (total = 1592).

Table 3. Pearson's correlation coefficients for fruit, nut and wing traits.

Variables	Nut Weight	Fruit Weight	Fruit Length	Fruit Width	Nut Length	Nut Width	Wing Weight	Wing Length	Wing Width
Nut weight	1								
Fruit weight	0.66	1							
Fruit length	0.167	0.478	1						
Fruit width	0.233	0.41	0.259	1					
Nut length	0.446	0.389	0.289	0.272	1				
Nut width	0.549	0.342	0.011	0.276	0.477	1			
Wing weight	0.076	0.514	0.709	0.131	0.119	−0.045	1		
Wing length	0.126	0.357	0.881	0.149	0.263	0.088	0.626	1	
Wing width	0.139	0.404	0.584	0.182	0.175	−0.044	0.578	0.529	1

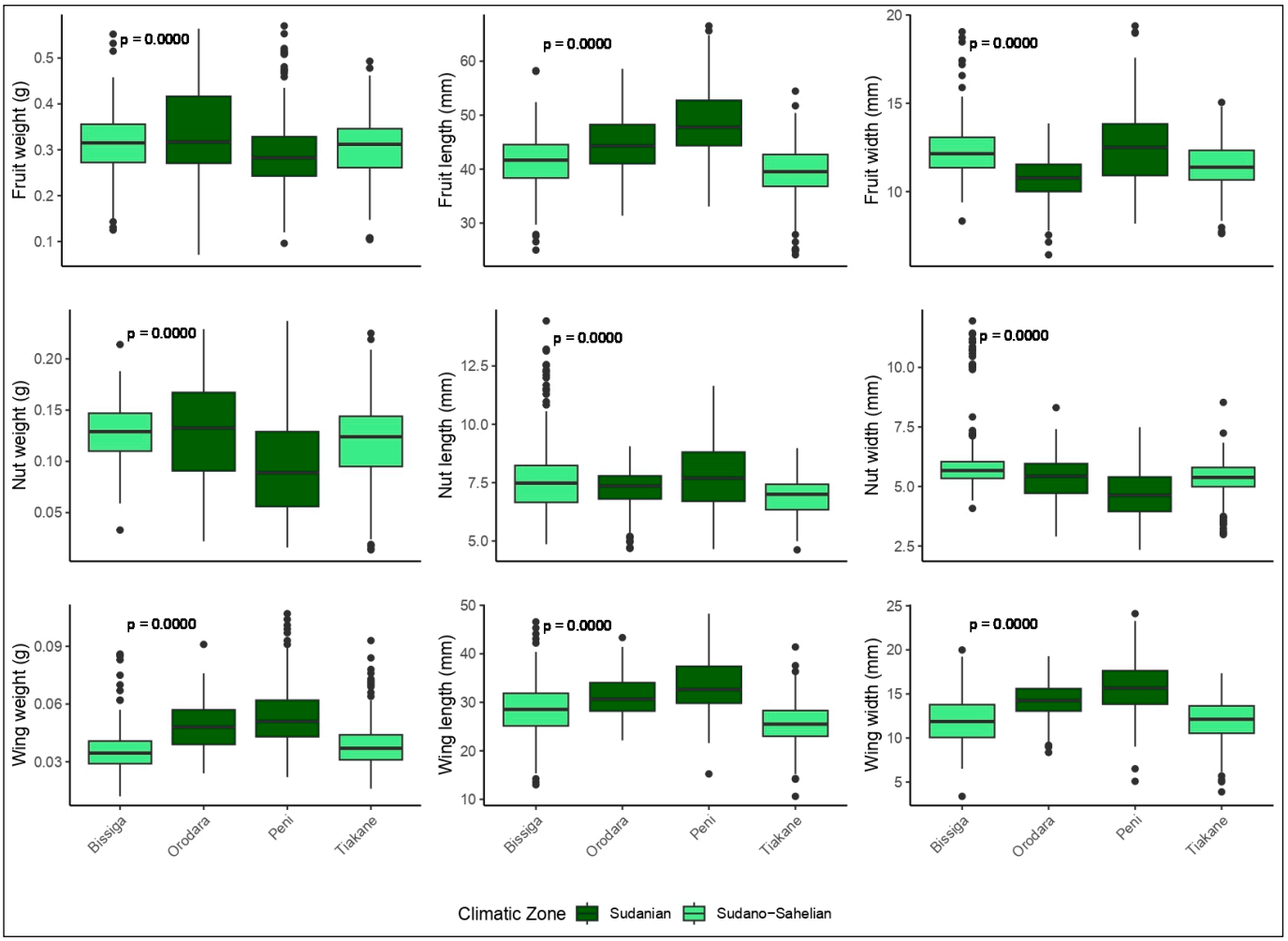


Figure 4. Variation in Securidaca *longipedunculata* fruits, nuts and wings morphological traits across the four collecting sites, two per each climatic zone. Number of samples per collecting site: Peni = 400, Tiakane = 399, Bissiga = 398, Orodara = 395 (total = 1592).

3.2. Seeds Germination Traits

The initial moisture content was 6.39% and 6.29%, respectively, for seed collected in Bissiga and Tiakane (Sudano-Sahelian zone), and 3.63% and 4.26%, respectively, for those collected in Orodara and Peni (Sudanian zone). Such iMC values (3 to 6%) show that the "seeds" of the two climatic zones were quite dry at harvest, suggesting that they have reached their maximum dry weight and were thus physiologically mature.

The type of substrate significantly affected all germination parameters (p = 0.000 ***) except duration (p = 0.13). On river sand, the seeds started germinating 23 ± 10 days after sowing and stopped 47 ± 21 days after sowing, with a mean germination period of 23 ± 17 days. Germination on the composite substrate started later (36 ± 12 days after sowing) and ended 64 ± 28 days after sowing, with a slightly longer mean duration (28 ± 21 days) (Figures 5 and 6). Seeds sown on river sand had the highest mean germination percentage (35.24 ± 17.73%) and speed (0.40 ± 0.36 seed per day), while those sown on the composite substrates germinated at a speed of 0.14 ± 0.09 seed per day and reached a percentage of 26.69 ± 14.46% (Figures 5 and 6).

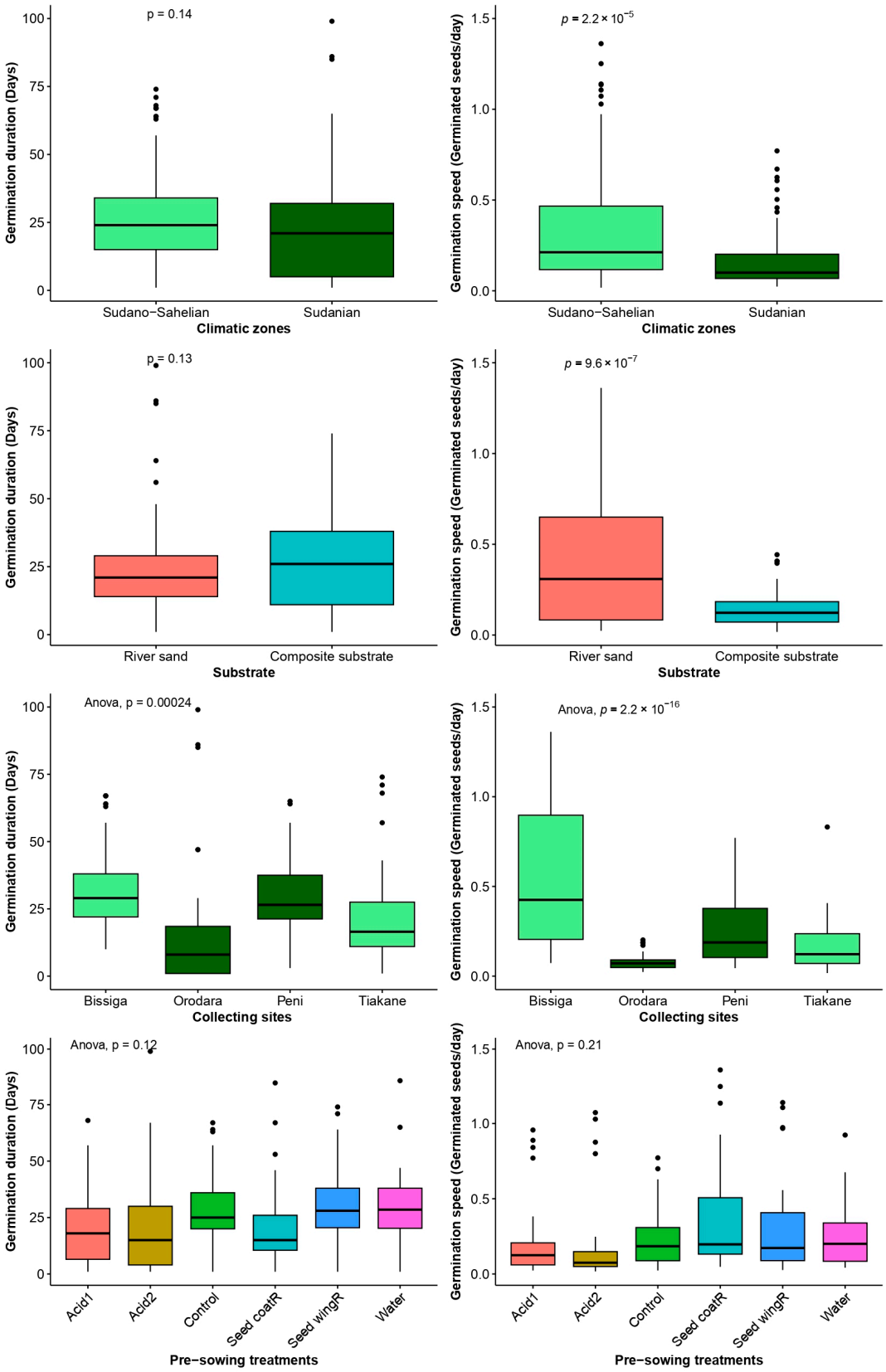


Figure 5. Variation in Securidaca *longipedunculata* seed germination duration and speed across climatic zones and collecting sites under different pre-sowing and substrate conditions. Acid1 = acid soaking 1 mn (n = 31); Acid2 = acid soaking 3 mn (n = 27); Seed coatR = seed coat removal (n = 31); Seed wingR = seed wing removal (n = 31); Water48 = water soaking 48 h (n = 30); control (n = 29).

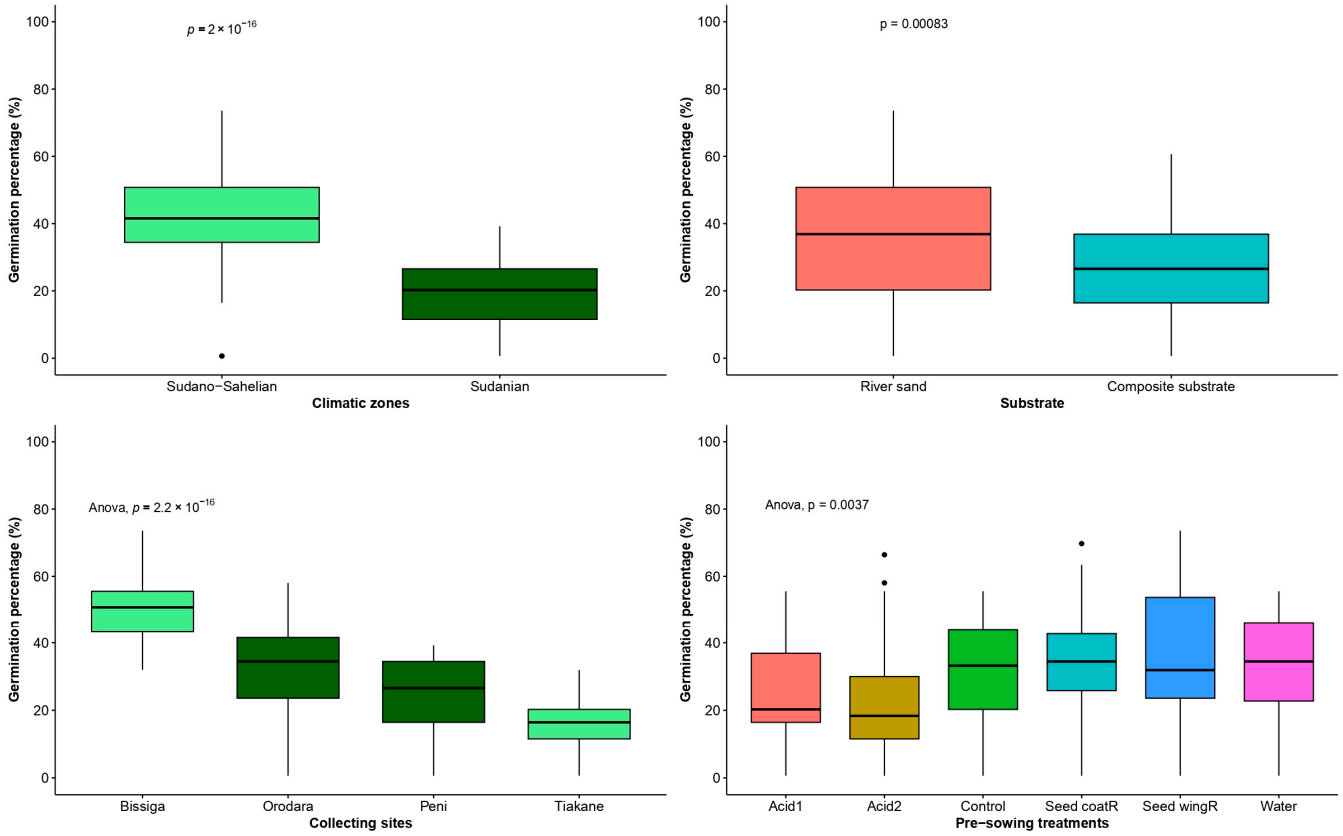


Figure 6. Variation in Securidaca *longipedunculata* seed germination percentage across climatic zones and collecting sites under different pre-sowing and substrate conditions Acid1 = acid soaking 1 mn (n = 32); Acid2 = acid soaking 3 mn (n = 32); Seed coatR = seed coat removal (n = 32); Seed wingR = seed wing removal (n = 32); Water = water soaking 48 h (n = 32); control (n = 32).

Unlike the substrate, pre-sowing treatment positively affected only the germination percentage (p = 0.004). For the six (06) pre-treatments tested, including the control, the seeds started germinating 26–34 days after sowing and stopped after 48–59 days, with a mean germination duration of 20–29 days (Figure 7). Seed wing and seed coat removal produced the highest mean germination percentages with, respectively, 36.5 ± 19% and 35.5 ± 16% (Figure 6) compared to the untreated samples, which germinated at 31.62 ± 15.80%.

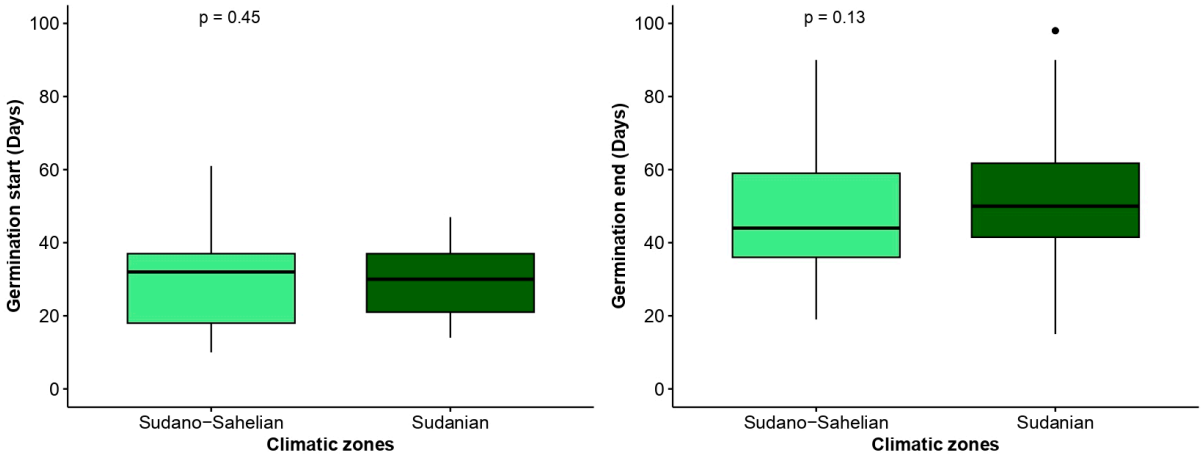


Figure 7. *Cont.*

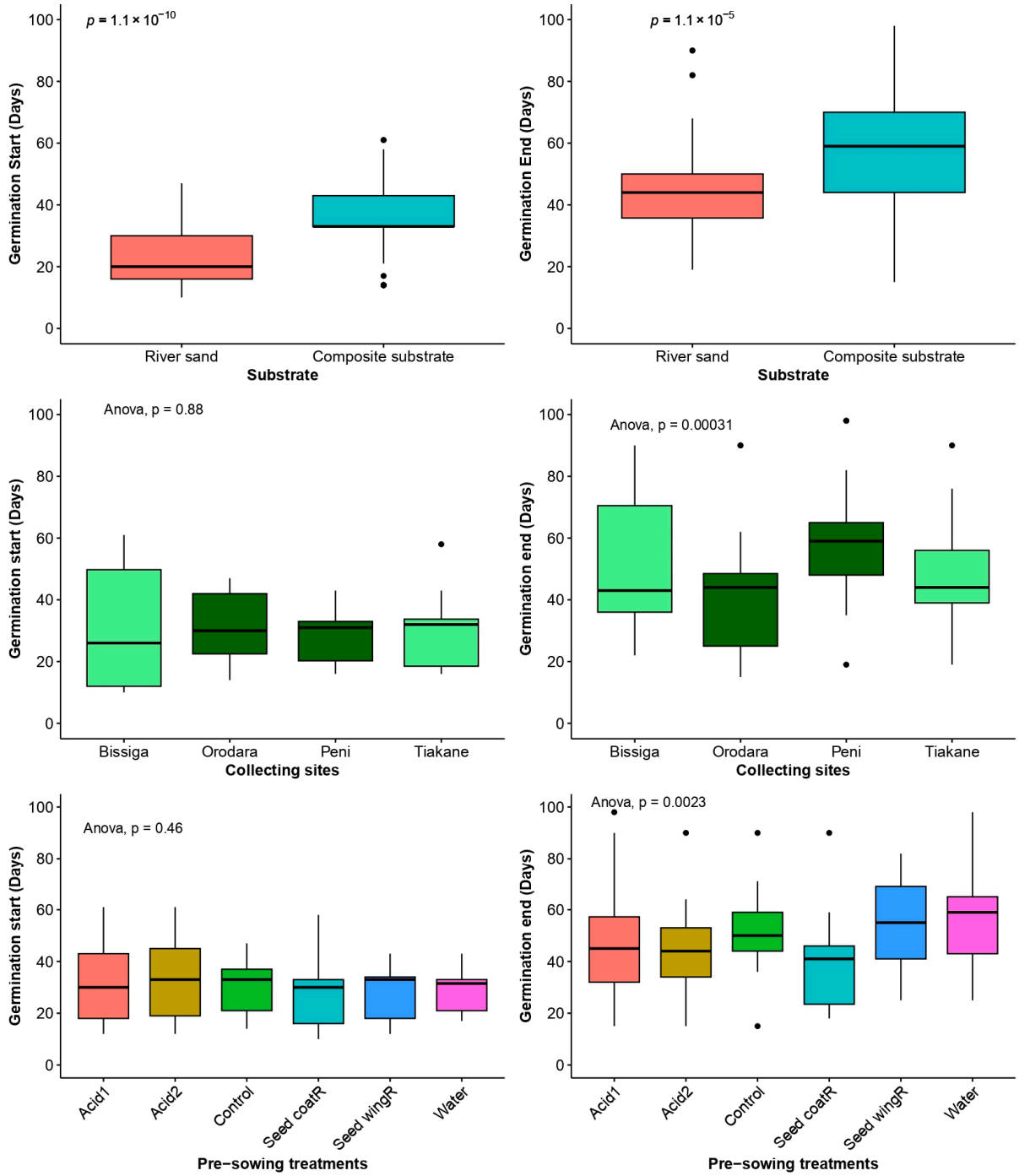


Figure 7. Variation in Securidaca *longipedunculata* seed germination start and end across climatic zones and collecting sites under different pre-sowing and substrate conditions. Acid1 = acid soaking 1 mn (n = 31); Acid2 = acid soaking 3 mn (n = 27); Seed coatR = seed coat removal (n = 31); Seed wingR = seed wing removal (n = 31); Water = water soaking 48 h (n = 30); control (n = 29).

4. Discussion

4.1. Variation in Securidaca longipedunculata Fruit Physical Traits and Germination Following Climatic Zones

The morphometric traits of fruits and seeds are of practical importance for domestication programmes, and seed selection must be considered in relation to improving forest management [37]. The current study revealed that the fruit of *S. longipedunculata*, a one-winged samara 42.62 ± 5.55 mm long, had a wing measuring 29.05 ± 5.23 mm in length

and a mean weight of 0.04 ± 0.01 g. The nut inside the fruit had an average weight of 0.12 ± 0.04 g, measuring 7.25 ± 1.13 mm in length and 5.39 ± 1.02 mm in width. These mean values were aligned with those described in some flora [8]. Our results suggest an inter-climatic zone and inter-site variations in fruit and nut traits, with larger fruits and heavier nuts collected in the Sudano-Sahelian zone. Differences in fruit and seed characteristics based on agroecological zones and provenances have been reported for other species by several authors. For example, differences in seeds traits within 19 accessions of *Jatropha curcas* L. originating from two different agro-ecological zones in Senegal (West Africa), were reported [38]. Similarly, variations in fruit and seed characteristics among populations of *Parkia biglobosa* (Jacq.) R.Br. ex G.Don in Nigeria [39] and *P. erinaceus* in Côte d'Ivoire [40] were found. The patterns of morphological variation in the fruit and seed of *S. longipedunculata* from this study relate to environmental or climatic factors and reflect adaptation to different environmental conditions. The morphological variation observed in distant populations across Burkina Faso could also be supported by underlying patterns of genetic variation [41,42]. Understanding the relative role of environmental and genetic factors in shaping the variation observed would require further investigation.

Pearson's correlation analysis revealed that among the nine (09) variables measured, "fruit weight" is the most positively correlated with "nut weight" (coef. = 0.660), with "fruit weight" explaining most of the variation in "nut weight" across the sampled individuals (bêta = 0.709). This means that the heavier the fruit of *S. longipedunculata*, the heavier the nut it contains.

The best germination traits and germination patterns were observed in seeds collected in the Sudano-Sahelian zone. In this climatic zone, seeds collected in Bissiga exhibited the best germination traits and trends, regardless of the treatment applied. This result could be associated with the fruit's size and the nut's weight. Indeed, fruits from the Sudano-Sahelian zone were larger (11.87 ± 1.38 mm) and contained heavier (0.123 ± 0.04 g) and larger (5.64 ± 1.02 mm) nuts on average. Among the two sites of this climatic zone, nuts from Bissiga were the heaviest (0.128 ± 0.025 g), longest (7.593 ± 1.359 mm) and largest (5.904 ± 1.183 mm), and had also the highest germination percentage. It is known that seed size, and especially its weight, is a factor which significantly influences its germination capacity. Similar results were observed in germinating seeds of two close relative species (*Acer negundo* L. and *Acer ginnala* Maxim.) of *S. longipedunculata* [43]. This previous study also found that the germination percentage of the seeds of the two species varied considerably with their weight and recommended using the seed size of *A. negundo* and *A. ginnala* as an effective predictor of their ability to germinate. A similar relationship was also highlighted with seeds of *Acer pseudoplatanus* L. [44] and *Acer rubrum* L. [45]. Regarding tropical species, investigation of *Gmelina arborea* Roxb. Ex Sm. seeds in Ethiopia [46], and those on *P. erinaceus* in Côte d'Ivoire [47], also revealed the best germination performances of large-sized seeds. Such evidence could be associated with the availability of nutrient reserves as reported for *Opilia amentacea* Roxb. [48]. Indeed, in general, large and heavy seeds germinate better with vigorous seedlings because of their important nutrient reserves [49,50], particularly reserves of starch and other nutrients that are critical in affecting the size of embryos, the vigour of seeds and expression in terms of seed germination and plant growth [35,51].

4.2. Effect of Pre-Sowing Treatments and Substrate on Germination

The highest germination percentages were recorded in both climatic zones in seeds which had wings or coats removed before sowing. Removing this barrier by cutting the wing or simply opening the fruit facilitates water penetration and thus accelerates the catabolic reactions that precede and initiate germination. Based on this assumption, to trigger the germination of *S. longipedunculata*, seed wing or seed coat removal is recommended, confirming findings from previous studies [21] focused on the identification of optimal pre-sowing treatments to break *S. longipedunculata*'s dormancy.

The substrate also affected seed germination. Similar studies revealed a significant effect of the substrate on the germination of other species such as *J. curcas* and *Zanthoxylum zanthoxyloides* (Lam.) Zepern. & Timler [52,53] but no specific test on *S. longipedunculata* has been conducted in this respect. For the populations of both climatic zones examined, the best germination results were observed in seeds sown on river sand. Indeed, sand is light and very porous; this makes it easier for germinating seeds to find a way out of the top part of the substrate under which they were sown. With a 1.5 to 2 cm layer of sand in the germination box, there is a larger stock of water available for seeds to fully imbibe and initiate germination. In addition, if materials such as sugars, amino acids and germination inhibitors leach from seeds, they will be more diluted in sand because of the greater volume of water and dilution of leachates that help to reduce the chances of seeds being attacked by fungi or germination being reduced by inhibitors [54]. Regarding the composite substrate, it tends to be heavy and compact because of the characteristics of the soil and the manure. These two components contain fine particles which, when moistened, can produce a cement-like layer around sand grains. Such a texture may delay the emergence of the radicle compared to seeds sown on sand. Pre-sowing treatment improved germination percentages across climatic zones, collecting sites and substrates. While this improvement suggests an initial barrier to germination, it does not conclusively indicate physical dormancy in seeds of *S. longipedunculata*.

4.3. Suggestions for the Development of a Germination Protocol for Securidaca longipedunculata

Based on the observations from this study, we can conclude that, for the seedling production of *S. longipedunculata*, heavier fruits should be collected, whatever the location of the collection site, to ensure a higher success rate of planting initiatives, such as reforestation programmes. Morphological characteristics can be used as proxy indicators of germination success. The experiments presented in this study indicated a significant positive correlation between "fruit weight" and "nut weight" and, deductively, a positive relation between these two parameters and germination success. In addition, the variable "nut weight" was found to be negatively correlated with "wing length", thus this last parameter is likely to be negatively correlated with germination capacity. The emerging recommendation is that the collection of light fruit with extremely long wings should be avoided to the greatest extent possible during seed harvesting to increase chances of successful seed germination. Regarding geographic variation, this study revealed that fruits sampled from the Sudano-Sahelian zone, specifically those collected in Bissiga, presented both the largest size and best performance in germination, regardless of the pre-sowing treatment adopted. Such results could suggest superior characteristics of seeds collected from this particular ecoregion. However, further investigation could help to identify the possible factors behind the patterns found.

5. Conclusions

These initial findings provide critical guidance for a systematic sampling strategy geared towards the identification of source populations of *S. longipedunculata* seed with ideal traits for the production of planting material. Indeed, the results from the current study on *S. longipedunculata* are of immediate practical use and relevance to support the domestication of this species and forest landscape restoration efforts. Indeed, morphological data revealed a variation in fruit and nut traits that depended on climatic zones and inter-site environmental difference, with heavier fruits and nuts found in the Sudano-Sahelian zone. The morphological traits examined can aid the selection of the best planting material, with greater chances of successful germination. In particular, fruit weight was found to be positively correlated with nut weight, influencing germination success. Pre-sowing treatments, especially removing wings or coats, improved germination by facilitating water absorption, and sand proved to be the best substrate for germination due to its porosity. For successful reforestation, seeds should be selected based on their size and weight, avoiding lighter fruits with long wings.

Author Contributions: E.M.S.D., A.B. and O.N. conceived the research idea and designed the protocol. S.T. and E.M.S.D. collected the data and proceed to their computing. Data clearance and pre-analysis were carried out by E.M.S.D., A.B. and A.B.Z.; then, in association with P.S. and K.D., they performed the statistical analysis. The first author drafted the manuscript. All of the authors discussed the results and commented on the manuscript. Finally, the manuscript was reviewed by O.N., D.S.D., B.O., B.V. and A.O. All authors have read and agreed to the published version of the manuscript.

Funding: This work was partly supported by the CGIAR Trust Fund through the NATURE+ Initiative.

Data Availability Statement: The data will be available on reasonable request.

Acknowledgments: This work was carried out as part of the first author's Ph.D. research project. The authors are grateful to Mamadou Tou, Aramatou Dao, and Ramata Meda/Konaté for their support in material collection in field and seed processing.

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

References

1. Sinare, H.; Gordon, L.J.; Kautsky, E.E. Assessment of ecosystem services and benefits in village landscapes—A case study from Burkina Faso. *Ecosyst. Serv.* **2016**, *21*, 141–152. [CrossRef]
2. Neuwinger, H.D. African traditional medicine. In *A dictionary of Plant Use and Applications*; Medpharm Scientific Publisher: Stuttgart, Germany, 2000; 589p.
3. Ghorbanpour, M.; Hadian, J.; Nikabadi, S.; Varma, A. Importance of medicinal and aromatic plants in Human life. In *Medicinal Plants and Environmental Challenges*; Ghorbanpour, M., Varma, A., Eds.; Springer: Cham, Switzerland, 2017; pp. 1–29.
4. Lone, S.A.; Yadav, A.S.; Bajaj, A.; ASharma, K.; Badkhane, Y.; Raghuwanshi, D.K. Conservation strategies for threatened medicinal plant—*Barleria prionitis* L.—using in vitro and ex vitro propagation techniques. *Arch. Phytopathol. Plant Prot.* **2012**, *45*, 1–14. [CrossRef]
5. Dimobe, K.; Ouédraogo, A.; Soma, S.; Goetze, D.; Porembski, S.; Thiombiano, A. Identification of driving factors of land degradation and deforestation in the Wildlife Reserve of Bontioli (Burkina Faso, West Africa). *Glob. Ecol. Conserv.* **2015**, *4*, 559–571. [CrossRef]
6. FAO. *Evaluation des Ressources Forestières Mondiales 2020: Rapport Principal*; FAO: Rome, Italy, 2021; 170p. [CrossRef]
7. Máthé, A.; Neffati, M.; Najjaa, H. Introduction to medicinal and aromatic plants in Africa. In *Medicinal and Aromatic Plants of the World—Africa*; Neffati, M., Najjaa, H., Máthé, Á., Eds.; Springer Science + Business Media B.V.: Dordrecht, The Netherlands, 2017; Volume 3.
8. Arbonnier, M. *Trees, Shrubs and Lianas of West African Dry Zones*, 4th ed.; Versaille Cedex: Versailles, France, 2019; 776p.
9. Sanusi, J.; Shehu, K.; Jibia, A.B.; Mohammed, I.; Liadi, S. Anti-snake venom potential of Securidaca longepedunculata leaf and root bark on spitting cobra (*Naja nigricollis* Hallowel) in envenomed wister rats. *J. Pharm. Biol. Sci.* **2014**, *9*, 92–96. Available online: www.iosrjournals.org (accessed on 22 April 2021). [CrossRef]
10. Adejuwon, A.; Tsygankova, V.A.; Adeosun, A.M.; Falase, A.O.; Obayemi, O.S.; Amusa, F.I. Phytochemical screening and antimicrobial efficacy of the root bark of Securidaca longipedunculata extracts. *Am. J. Res. Med. Sci.* **2019**, *5*, 7–13. [CrossRef]
11. Datagni, G.; Mouzou, A.P.; Metowogo, K.; Afanyibo, Y.G.; Sadji, A.; Eklu-Gadegbeku, K. In vitro anti-inflammatory and antimicrobial activity of Securidaca longepedunculata and Annona senegalensis hydro-alcoholic extract. *J. Drug Deliv. Ther.* **2021**, *11*, 63–70. [CrossRef]
12. Kinda, P.T.; Zerbo, P.; Guenn, S.; Compaore, M.; Ciobica, A.; Kiendrebeogo, M. Medicinal Plants Used for Neuropsychiatric Disorders Treatment in the Hauts Bassins Region of Burkina Faso. *Medicines* **2017**, *4*, 32. [CrossRef]
13. Keshebo, D.L.; Choudhury, M.K.; Dekebo, A.H. Investigation on toxicity, hypoglycemic effect of the root bark of Securidaca longepedunculata Fresen (Polygalaceae) and determination of heavy metals in it. *Ann. Biol. Res.* **2014**, *5*, 15–19.
14. Fatokun, O.T.; Wojuola, T.E.; Esievo, K.B.; Kunle, O.F. Medicinal plants used in the management of asthma: A Review. *Eur. J. Pharm. Med. Res.* **2016**, *3*, 82–92.
15. Agu, M.O.; Jatau, D.F.; Hotton, J.A. Analytical investigation of foam formation and emulsifying power of Sanya (*Securidaca longepedunculata*) roots and comparison with some commercial/synthetic surfactants. *Int. J. Eng. Sci.* **2013**, *2*, 8–15.
16. Wanzala, W.; Hassanali, A.; Mukabana, W.R.; Takken, W. Repellent activities of essential oils of some plants used traditionally to control the brown ear tick, Rhipicephalus appendiculatus. *J. Parasitol. Res.* **2014**, *2014*, 1–10. [CrossRef] [PubMed]
17. Anywar, G.; Kakudidi, E.; Byamukama, R.; Mukonzo, J.; Schubert, A.; Oryem-Origa, H.; Jassoy, C. A review of the toxicity and phytochemistry of medicinal plant species used by herbalists in treating people living with HIV/AIDS in Uganda. *Front. Pharmacol.* **2021**, *12*, 1–10. [CrossRef] [PubMed]
18. Thiombiano, A.; Schmidt, M.; Dressler, S.; Ouédraogo, A.; Hahn, K.; Zizka, G. *Catalogue des Plantes Vasculaires du Burkina Faso*; Boisiera: Geneve, Switzerland, 2012; 391p.
19. Neya, O.; Hoekstra, F.A.; Golovina, E.A. Mechanism of endocarp-imposed constraints of germination of Lannea microcarpa seeds. *Seed Sci. Res.* **2008**, *18*, 13–24. [CrossRef]

20. Mbuya, L.P.; Msanga, C.K.; Ruffo, C.K.; Birnie, A.; Tengas, B. *Useful Trees and Shrubs for Tanzania: Identification, Propagation and Management for Agricultural and Pastoral Communities*; Swedish International Development Authority (SIDA): Nairobi, Kenya, 1994; 542p.
21. Tiawoun, M.A.P.; Tshisikhawe, M.P.; Ligavha-Mbelengwa, M.H. Seed germination and seedling establishment of Securidaca longepedunculata (polygalaceae). *Pakistan J. Bot.* **2017**, *49*, 1009–1016.
22. Vleeshouwers, L.M.; Bouwmeester, H.J.; Karssen, C.M. Redefining Seed Dormancy: An Attempt to Integrate Physiology and Ecology. *J. Ecol.* **1995**, *83*, 1031–1037. [CrossRef]
23. Bewley, J.D. Seed Germination and Dormancy. *Plant Cell.* **1997**, *9*, 1055–1066. [CrossRef]
24. Bewley, J.D.; Bradford, K.J.; Hilhorst, H.M.W.; Nonogaki, H. *SEEDS: Physiology of Development, Germination and Dormancy*, 3rd ed.; Springer: New York, NY, USA, 2013; 392p. [CrossRef]
25. Hudson, A.R.; Ayre, D.J.; Ooi, M.K.J. Physical dormancy in a changing climate. *Seed Sci. Res.* **2015**, *25*, 66–81. [CrossRef]
26. Cochrane, A.; Yates, C.J.; Hoyle, G.L.; Nicotra, A.B. Will among-population variation in seed traits improve the chance of species persistence under climate change? *Glob. Ecol. Biogeogr.* **2015**, *24*, 12–24. [CrossRef]
27. Dipama, J.M. The biophysical environment: Climate. In *Biodiversity Atlas of West Africa*; Thiombiano, A., Kampmann, D., Eds.; BIOTA: Ouagadougou, Burkina Faso; Frankfurt/Main, Germany, 2010; Volume II, pp. 122–124.
28. Gutterman, Y. Maternal effects on seeds during development. In *Seeds: The Ecology of Regeneration in Plant Communities*, 2nd ed.; Fenner, M., Ed.; CAB International: Wallingford, UK; Negev, Israël, 2000; pp. 59–84.
29. Johnson, C.T. Taxonomy of the African species of Securidaca (polygalaceae). *S. Afr. J. Bot.* **1987**, *53*, 5–11. [CrossRef]
30. Bareke, T. The link between agricultural production and population dynamics in Ethiopia: A review. *Adv. Plants Agric. Res.* **2018**, *8*, 336–346. [CrossRef]
31. Shaw, R.H.; Loomis, W.E. Bases for the prediction of corn yields. *Methods* **1949**, *7*, 225–244. [CrossRef] [PubMed]
32. The International Seed testing Association (ISTA). *International Rules for Seed Testing 2015: Introduction to the ISTA Rules Chapters 1–19*; ISTA: Bassersdorf, Switzerland, 2015; 276p.
33. The International Seed Testing Association (ISTA). *ISTA Handbook on Seedling Evaluation*, 4th ed.; ISTA: Bassersdorf, Switzerland, 2018; 221p. Available online: www.seedtest.org (accessed on 10 October 2024).
34. Al-Mudaris, M.A. Notes on various parameters recording the speed of seed germination. *J. Agric. Trop. Subtrop.* **1998**, *99*, 147–154.
35. Patel, J.B.; Bhatiya, V.J.; Babariya, C.A.; Sondarva, J. Effect of seed size on seedling vigour, plant growth, seed yield and its parameters: A review. *Res. Environ. Life Sci.* **2016**, *9*, 859–864. Available online: https://pdfs.semanticscholar.org/2985/20c8443c465b12e1d41fe2372b4d834c1c65.pdf (accessed on 17 November 2018).
36. Maguire, J.D. Speed of germination- aid in selection and evaluation for seedling emergence and vigor. *Crop Sci.* **1962**, *2*, 176–177. [CrossRef]
37. Lankoandé, B.; Ouédraogo, A.; Kouyaté, A.M.; Boussim, I.J.; Lykke, A.M. Production and morphological traits of Lophira lanceolata fruits in natural stands. *For. Trees Livelihoods* **2020**, *29*, 176–186. [CrossRef]
38. Ouattara, B.; Diédhiou, L.; Ndir, K.N.; Agbangba, E.C.; Cisse, N.; Diouf, D.; Akpo, E.L.; Zongo, J.D. Variation in seed traits and distribution of *Jatropha curcas* L. in Senegal. *Int. J. Curr. Res.* **2013**, *5*, 17–21.
39. Olorunmaiye, K.S.; Fatoba, P.O.; Adeyemi, O.C.; Olorunmaiye, P.M. Fruit and seed characteristics among selected Parkia biglobosa (JACQ) G. Don. Population. *Agric. Biol. J. North Am.* **2011**, *2*, 244–249. [CrossRef]
40. Goba, K.A.E.; Kouonon, L.C.; Koffi, K.G.; Bony, B.S.; Diomandé, I.; Sié, R.S. Morphological diversity within Pterocarpus erinaceus Poir. (Fabaceae), an Overexploited Species in the Savannahs of Côte d'Ivoire. *Am. J. Plant Sci.* **2019**, *10*, 1675–1688. [CrossRef]
41. Padonou, E.A.; Kassa, B.; Assogbadjo, A.E.; Fandohan, B.; Chakeredza, S.; Glèlè Kakaï, R.; Sinsin, B. Natural variation in fruit characteristics and seed germination of Jatropha curcas in Benin, West Africa. *J. Hortic. Sci. Biotechnol.* **2014**, *89*, 69–73. [CrossRef]
42. Elmagboul, H.; Mahgoup, S.; Eldoma, A. Variation in seed morphometric characteristics and germination of Acacia tortilis Subspecies Raddiana and Subspecies Spirocarpa Among Three Provenances in Sudan. *Glob. J. Bio-Sci. Bio-Technol.* **2014**, *3*, 191–196.
43. Kiseleva, O.A.; Loretts, O.G.; Veselkin, D.V. Seed size and cold stratification affect Acer negundo and Acer ginnala seeds germination. *Agron. Res.* **2020**, *2*, 461–471. [CrossRef]
44. Kostić, S.; Čukanović, J.; Ljubojević, M.; Mladenović, E.; Mrđan, S.; Svilokos, N. Germination and relations between seed quality characteristics for Acer pseudoplatanus and Acer pseudoplatanus 'Atropurpureum'. *Contemp. Agric.* **2017**, *66*, 51–55. [CrossRef]
45. Goszka, A.R.; Snell, R.S. Seed quality and seed quantity in red maple depends on weather and individual tree characteristics. *Ecol. Evol.* **2020**, *10*, 13109–13121. [CrossRef] [PubMed]
46. Owoh, P.W.; Offiong, M.O.; Udofia, S.I.; Ekanem, V.U. Effects of seed size on germination and early morphological and physiological characteristics of Gmelina arborea, Roxb. *African Res. Rev.* **2011**, *5*, 422–433. [CrossRef]
47. Adji, B.I.; Akaffou, D.S.; De Reffye, P.; Sabatier, S. Maternal environment and seed size are important for successful germination and seedling establishment of Pterocarpus erinaceus (Fabaceae). *J. For. Res.* **2021**, *33*, 977–990. [CrossRef]
48. Daboue, E.M.S.; Neya, O.; Nandziga, E.B.; Ouedraogo, A.; Ouedraogo, M.; Pasquini, S. Morphometric characteristics and desiccation response of Opilia amentacea seeds from Burkina Faso. *Seed Sci. Technol.* **2017**, *45*, 354–367. [CrossRef]
49. Leishman, M.R.; Wright, I.J.; Moles, A.T.; Westoby, M. The evolutionary ecology of seed size. In *Seeds: The Ecology of Regeneration in Plant Communities*, 2nd ed.; Fenner, M., Ed.; CAB International: Wallingford, UK, 2000; pp. 31–57.

50. Westoby, M.; Falster, D.S.; Moles, A.T.; Vesk, P.A.; Wright, I.J. Plant ecological strategies: Some leading dimensions of variation between species. *Annu. Rev. Ecol. Syst.* **2002**, *33*, 125–159. [CrossRef]
51. Adebisi, M.A.; Kehinde, T.O.; Salau, A.W.; Okesola, L.A.; Porbeni, J.B.O.; Esuruoso, A.O.; Oyekale, K.O. Influence of different seed size fractions on seed germination, seedling emergence and seed yield characters in tropical soybean (*Glycine max* L. Merrill). *Int. J. Agric. Res.* **2013**, *8*, 26–33. [CrossRef]
52. Rodríguez, O.A.V.; Vázquez, A.P.; Martínez, A.J. Effects of seed weight and substrate on germination and growth of non-toxic Jatropha curcas L. seedlings. *Annu. Res. Rev. Biol.* **2014**, *4*, 4232–4245. [CrossRef]
53. Daboue, E.M.S.; Neya, O.; Bene, A.; Pasquini, S. Effects of substrate and pre-sowing treatment on Fagara (*Zanthoxylum zanthoxyloides* (Lam.) Watermann) seeds germination. *Sci. Tech. Sci. Nat. Appliquées* **2020**, *39*, 89–107.
54. Baskin, C.C.; Baskin, J.M. *Seeds: Ecology, Biogeography and Evolution of Dormancy and Germination*, 2nd ed.; Elsevier/AP: San Diego, CA, USA, 2014; 1586p.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.