agronomy

Article

Seed Viability, Seedling Growth and Yield in White Guinea Yam

Prince E. Norman [1,2,3,*], Agyemang Danquah [2], Asrat Asfaw [3], Pangirayi B. Tongoona [2], Eric Y. Danquah [2] and Robert Asiedu [3]

1 Sierra Leone Agricultural Research Institute, Tower Hill, Freetown PMB 1313, Sierra Leone
2 West Africa Centre for Crop Improvement, College of Basic and Applied Sciences, University of Ghana, PMB LG 30 Legon, Accra, Ghana; adanquah@wacci.ug.edu.gh (A.D.); tongoona@ukzn.ac.za (P.B.T.); edanquah@wacci.ug.edu.gh (E.Y.D.)
3 International Institute of Tropical Agriculture, Ibadan PMB 5320, Nigeria; a.amele@cgiar.org (A.A.); r.asiedu@cgiar.org (R.A.)
* Correspondence: pnorman@wacci.ug.edu.gh; Tel.: +232-76-618-454

Abstract: The yam is an economic tuber crop utilized for food, feed, and various industrial applications. Botanical seed viability, seedling growth, and development are among factors that influence plant population dynamics, development, structure, and sustainability. However, little is known about seed viability, growth, and yield potential of seed-progenies developed using different mating designs. This study assessed seed germination, seedling growth, and yield traits in seed-progenies developed using North Carolina I (NC-1) and polycross mating designs. For this, seed germination and seedling nursery trials established using seed-progenies from different yam crosses were used. Results revealed that days to first seed germination (DAYFG), days to 50% germination (DAYSG), coefficient of velocity of germination, seed emergence speed (SES), germination index, final germination percent, and seedling vigor index significantly ($p < 0.05$) varied within and among NC-1 and PC-derived families. The mean days to first seed germination (DFSG) and DAYSG seed-progenies of NC-1 were significantly lower than the polycross progenies. Moreover, the seedling-progenies from the polycross produced a higher number of stems and more elongate tubers than those originated from the NC-1 mating. Progenies of family TDr1687 from a polycross mating were among the families that had the highest stem number (2.2), longest tuber (7.5 cm), and widest tuber (2.8 cm). The inter-family means of both NC-1 and polycross had a non-significant variation for mean tuber weight per plant. Our results suggest the relevance of seed germination and seedling attributes for selection of superior progenies at the early generation stage trials in yam breeding.

Keywords: *Dioscorea rotundata*; hybrid progeny; seed viability; seedling traits; mating systems

Citation: Norman, P.E.; Danquah, A.; Asfaw, A.; Tongoona, P.B.; Danquah, E.Y.; Asiedu, R. Seed Viability, Seedling Growth and Yield in White Guinea Yam. *Agronomy* **2021**, *11*, 2. https://dx.doi.org/10.3390/agronomy11010002

Received: 16 November 2020
Accepted: 18 December 2020
Published: 22 December 2020

1. Introduction

The white Guinea yam (*Dioscorea rotundata* Poir) is a valued African food crop grown for its starchy tubers. The crop is mostly produced and consumed in West Africa, where it also plays significant roles in people's social and cultural lives [1]. Fresh and processed white Guinea yam products possess tremendous potential as a source of income and food for over 300 million people in Africa [2]. The fresh tubers also serve as raw materials for various industrial applications. Despite its importance, there is a lack of information on seed viability, growth and yield of first filial generation white yam developed from mating designs.

Yam breeding utilizes various mating designs for botanical seed production. The botanical seed production, dispersal, viability, seedling growth and developmental phases are key factors that influence the plant population dynamics, development, structure and sustainability [3,4]. Botanical seed viability is the degree of germination ability of botanical seeds. The germination ability determines the pathway of germinated and growing progeny from their parents. Botanical seed germination is critical in determining plant population size and distribution in communities [5].

The assessment of seed germination and its impact on plant growth and development has attracted human interest since the dawn of agriculture (about 10,000 BC) for the discovery of genotypes or species with physiological and multiplicity potentials [6]. The time, rate, homogeneity, and synchrony of seed germination are important attributes that inform the dynamics of various progenies' seedling growth processes [6]. Seed germination, seedling growth and development traits are critically important to physiologists, seed technologists, ecologists, geneticists, and breeders due to the possibility of predicting the extent of species success based on harvested and germinated seeds, establishment and survival. The theoretical capacity of seeds that express their vital functions and physiological potential has been particularly attributed to viability and seedling vigor [6]. Good seed viability and seedling vigor are among important indices for increased crop productivity [7]. Low seed viability and seedling vigor affect percent germination of seeds, duration of germination, uniformity of growing seedlings, yield, market quality, and other related attributes [7]. In yam breeding, many national programs often use an open pollination by insects to generate sufficient botanic seeds and select superior progenies with desired traits to release as new varieties [8].

Yam breeding and genetics research are often constrained by low seed viability and seedling establishment of the progenies from crosses, as well as irregular, low or non-flowering genotypes, lack of synchronization of flowering and low fruit set [9,10]. Seeds generated from natural and controlled crosses exhibit varying degrees of viability and seedling vigor due to dormancy, poor embryo and endosperm development [10,11]. Moreover, botanical seeds of yam from different cross combinations possess their peculiar differences in viability, establishment, survival, yield potential, and other attributes [12]. These attributes determine the adaptability and selection of crops in test environments [13]. Notwithstanding, no comparative studies on different mating designs have been conducted to assess their effect on seed germination, seedling growth and seed-tuber yield attributes. Such knowledge is needed to develop and utilize efficient seedling management technique that enhances seed germination and higher seedling vigor index [14,15]. The objective of this study was to assess botanical seed viability, seedling growth and tuber yield potential of progenies developed using North Carolina I and polycross mating designs.

2. Materials and Methods

2.1. Experimental Location

This study was conducted at the glasshouse (pre-nursery) and screen-house (nursery) facilities of the yam improvement program, International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, during the 2017/2018 cropping season.

2.2. Experimental Materials, Layout, Design and Management

The experimental materials were botanical seeds generated using North Carolina I (NC-I) and polycross mating designs. The crossing blocks of both mating designs were established at the International Institute of Tropical Agriculture, Ibadan, Nigeria. A total of 12 clones of *D. rotundata* comprising nine females and three males with desired complementary traits for the fresh tuber yield, tuber dry matter, tuber shape, earliness and tolerance to yam mosaic virus were used [8]. The mating schemes targeted crossing three female parents to a male parent (3:1), producing nine cross combinations. For the polycross block, staggered planting (at 10-day intervals) was done to facilitate synchronization of flowering among the parents. However, successful cross of eight and nine families were generated with the polycross block and NC-1 design hand pollination scheme, respectively. Female parent, TDr08-21-3 (Ekpe II), did not produce viable seeds in the polycross block. The botanical seeds from the 17 families were collected from trilobated fruits of the maternal parents in late February 2017 at the crop's physiological maturity.

Prior to the establishment of the pre-nursery and nursery experiments, cocopeat and topsoil substrate samples were collected and analyzed for nutrient composition at IITA soil analytical lab using standard procedures described by the International Soil Reference and

Information Center (ISRIC) and the FAO [16]. The chemical properties of the two growth media are shown in Table 1.

Table 1. Chemical attributes of the cocopeat and topsoil growth media.

			Macronutrients				
Medium	**pH (H_2O)1:1**	**%OC**	**N (%)**	**P (%)**	**K (%)**	**Mg (%)**	**Ca (%)**
Cocopeat	4.61	1.401	0.133	0.057	0.380	0.199	1.618
Topsoil	6.08	1.489	0.078	0.0004	0.007	0.019	0.050
			Micronutrients				
			Na (%)	Zn (%)	Cu (%)	Mn (%)	Fe (%)
Cocopeat			0.339	0.008	0.002	0.019	0.006
Topsoil			0.003	0.001	0.002	0.043	0.015

OC = organic carbon, N = nitrogen, P = phosphorus, K = potassium, Mg = magnesium, Ca = calcium, Na = sodium, Zn = zinc, Cu = cupper, Mn = manganese, Fe = iron.

The pre-nursery experiment was laid out in a completely randomized design with two replicates. The cocopeat medium was put in perforated polyethylene seedling trays and slightly soaked. About 300 botanical seeds per family were sown in holes created in the growing medium in early March 2017. The trays were well labeled at planting and irrigated every other day until four weeks after sowing (WAS). The growing seedlings were irrigated to field capacity every other day for four WAS. They were also fumigated with cypermethrin at the rate of 15 mL per 1 L water at six WAS before transplanting in the seedling nursery at eight WAS.

The nursery experiment was laid out in a randomized complete block design with five replications. About 100 seedlings per family were transplanted to polythene bag (pot) in early June, with 20 seedlings planted per replication. The interspatial and intra-spatial block spaces were 0.5 m apart. Each polythene bag (pot) was filled with sterilized topsoil and irrigated to field capacity before transplanting. The seedlings were transplanted in holes created in the crest of the sterilized topsoil and irrigated to field capacity every three days until six months after transplanting (MAT).

2.3. Data Collection

A total of 11 parameters were assessed, with seven traits studied at the pre-nursery and four parameters at the nursery trial stages. Data collected during pre-nursery included days to first seed germination (DAYFG), days to 50% seed germination (DAYSG), final germination percent (FGP) and other derived attributes such as coefficient of velocity of germination (CVG), seed emergence speed (SES), germination index (GI) and seedling vigor index (SVI). The germination parameters were assessed daily from sowing by counting using germ count pins and continued until the germination ceased. Weekly germination counts were done from three to eight WAS.

The coefficient of the velocity of germination was estimated as

$$CVG = \frac{(N_1 + N_2 + \ldots\ldots.. + N_x)}{(T_1 N_1 + T_2 N_2 + \ldots\ldots.. + T_x N_x)} \times 100$$

where $N_1, N_2, \ldots., N_x$ are numbers of seedlings counted on the first day, the second day, up to the last day (x); and $T_1, T_2, \ldots., T_x$ are numbers of days after sowing seeds or from seedling corresponding to N.

The seed emergence speed (SES) was estimated as described by Islam et al. [17]

$$\text{SES} = \frac{(\text{No. of germinated seeds at 35 days after sowing})}{(\text{No. of germinated seeds at 49 days after sowing})} \times 100$$

The germination index (GI) was estimated using a similar description in the association of official seed analysis [18] as:

$$\mathrm{GI} = \frac{(\text{No. of germinated seeds})}{(\text{Days of first count})} + \frac{(\text{No. of germinated seeds})}{(\text{Days of second count})} + \ldots + \frac{(\text{No. of germinated seeds})}{(\text{Days of last count})}$$

Seedling vigor index (SVI) was estimated as described by Hossain et al. [19] as germination percent $\times$ seedling height.

The data collected during nursery included stem number per plant, length of tubers per plant, tubers' width per plant, and weight of tubers per plant. The stem number per plant was collected at five MAT, and the tuber traits were done at harvest (6 MAT).

2.4. Data Analysis

The phenotypic traits of yam families grown at the pre-nursery and nursery were analyzed in GenStat version 16 statistical package. The least significant difference (LSD) was used to compare treatment means at the $\alpha = 0.05$ level of significance. The residuals of data for the parameters were first checked for normality and homogeneity using the Shapiro–Wilk test and Bartlett's test to ensure that data were normally distributed.

3. Results

3.1. Seed Germination and Related Attributes

Mean days to first seed germination (DFSG), days to 50% germination (DAYSG), coefficient of the velocity of germination (CVG), seed emergence speed (SES), germination index (GI), final germination percent (FGP) and seedling vigor index (SVI) were significantly high ($p < 0.05$) and varied within and among families developed using NC-1 and polycross designs (Table 2). Generally, the mean DFSG and DAYSG of NC-1-derived progenies were significantly lower than that of the polycross-derived progenies.

Mean percent of seed germination significantly ($p < 0.05$) increased with time in both the within and between NC-1 and polycross-derived-progeny families (Table 3). The mean percent germination across the sampling regimes was significantly ($p < 0.05$) higher in the NC-1 relative to the polycross-derived progeny-families. The mean percent germination at 49 days after sowing ranged from the highest of 87.72 in family TDr1679 to the lowest, 27.02 in family TDr1677. The mean percent germination at 49 days after sowing ranged from the highest of 87.72 in family TDr1679 to the lowest, 0.762 in family TDr1689. Families with the highest and lowest percent germination values at 49 DAS were also among families with the highest and lowest percent germination at 21 to 42 DAS (Table 3).

3.2. Seedling Growth, Tuber Yield and Related Attribute Assessments

Table 4 presents differences in mean stem number per plant, and mean tuber length and width per plant within and between NC-1 and polycross-derived-families. The polycross-derived families generally produced a higher number of stems and more elongate tubers relative to those produced by NC-1. In contrast, NC-1-derived progeny-families had wider tubers (2.6 cm) than the polycross (2.2 cm). Polycross-derived-family TDr1687 (half-sib progenies of clone TDr8902475) was among seed-progenies that had the highest stem number (2.2), longest tuber (7.5 cm) and widest tuber (2.8 cm). Mean seed-tuber weight per plant did not show significant difference between the NC-1 and polycross derived progenies. However, within the NC-1 and polycross derived progenies, the difference for seed-tuber weight per plant was significant for some families. For instance, family TDr1687 (half-sib progenies from an open-pollinated female parent TDr8902475) produced a mean seed-tuber yield of 47.4 g.plant^{-1}, which significantly out-yielded seed-progeny from other families evaluated. The lowest mean seed-tuber weight per plant 14.2 g.plant^{-1} was recorded from family TDr1688 (half-sib progenies from an open pollinated female parent TDr9700632).

Table 2. Variation in seed germination attributes of white Guinea yam seed-families (crosses) generated using North Carolina 1 (NC-1) and polycross (PC) designs.

Family	DFSG	DAYSG	CVG	SES	GI	FGP	SVI
North Carolina 1							
TDr1676	20.5	39.0	2.33	39.7	5.2	81.45	332.0
TDr1677	23.5	74.0	2.30	32.3	0.9	30.16	76.0
TDr1678	26.0	72.0	2.30	26.4	0.8	31.36	87.0
TDr1679	17.5	30.0	2.49	80.4	72.3	88.00	628.0
TDr1680	18.5	33.0	2.47	91.6	17.5	81.37	358.0
TDr1681	23.5	36.0	2.33	55.7	4.0	90.79	304.0
TDr1682	22.0	36.0	2.42	69.5	12.5	73.80	368.0
TDr1683	22.0	42.0	2.36	46.8	6.8	73.05	391.0
TDr1684	18.5	34.0	2.42	61.3	15.2	84.8	689.0
Mean	21.3	44.0	2.38	56.0	15.0	70.5	359.0
$LSD_{(0.05)}$	2.50	4.13	0.03	2.98	0.77	5.19	140.5
Polycross							
TDr1685	19.0	36.0	2.35	53.2	12.2	82.4	438.0
TDr1686	26.5	71.0	2.26	22.9	2.1	40.4	92.0
TDr1687	22.0	69.0	2.28	28.3	4.9	45.0	160.0
TDr1688	19.5	32.0	2.44	69.4	6.2	72.8	378.0
TDr1689	20.5	32.0	2.44	72.3	17.1	91.0	646.0
TDr1690	30.5	43.0	2.27	38.9	1.2	70.5	240.0
TDr1691	25.0	54.0	2.23	18.2	1.1	33.2	72.0
TDr1692	23.0	43.0	2.31	36.0	8.2	63.0	317.0
Mean	23.3	47.5	2.32	42.4	6.6	62.3	292.9
$LSD_{(0.05)}$	3.46	2.82	0.02	6.99	0.37	5.92	95.30
Between NC-1&PC $LSD_{(0.05)}$	0.98	1.18	0.01	1.72	0.20	1.82	40.05
Within all families $LSD_{(0.05)}$	2.85	3.44	0.02	5.00	0.59	5.31	116.57
CV(%)	6.1	3.5	0.5	4.8	2.5	3.8	16.8

DFSG = days to first seed germination, DAYSG = days to 50% germination, CVG = coefficient of velocity of germination, SES = seed emergence speed, GI = germination index, FGP = final germination percent, SVI = seedling vigor index, CV=coefficient of variation, LSD= least significant difference.

Table 3. Mean percent germination of yam botanical (true) seeds across families and sampling regimes.

Family	Sampling Regime				
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS
North Carolina 1					
TDr1676	1.61	8.06	30.24	58.87	76.21
TDr1677	0.00	3.20	8.74	19.05	27.02
TDr1678	0.00	4.25	7.64	16.98	28.85
TDr1679	2.98	40.95	70.48	84.54	87.72
TDr1680	1.51	28.04	70.68	76.99	77.16
TDr1681	0.00	4.58	48.06	81.67	86.32
TDr1682	0.00	21.20	48.20	61.00	69.40
TDr1683	0.00	13.65	32.87	65.25	70.47
TDr1684	1.60	26.40	51.40	78.40	83.80
Mean	0.86	16.70	40.92	60.31	67.44
Within NC-1 family $LSD_{(0.05)}$	0.69	3.92	6.02	8.49	9.44
Polycross					
TDr1685	0.40	9.20	42.80	70.20	80.40

Table 3. *Cont.*

Family	Sampling Regime				
	21 DAS	28 DAS	35 DAS	42 DAS	49 DAS
TDr1686	0.00	2.06	7.53	20.89	32.86
TDr1687	0.20	2.80	11.40	29.40	40.20
TDr1688	1.38	25.00	50.74	71.44	73.30
TDr1689	1.00	29.20	65.60	84.20	90.80
TDr1690	0.00	0.00	25.83	49.17	68.12
TDr1691	0.00	0.83	4.20	13.02	23.10
TDr1692	0.00	6.20	22.40	48.80	62.20
Mean	0.37	9.41	28.81	48.40	58.90
Within PC family $LSD_{(0.05)}$	0.71	1.64	4.95	11.54	16.40
Between NC-1 and PC $LSD_{(0.05)}$	0.23	1.02	1.83	3.29	4.31
Between all families $LSD_{(0.05)}$	0.65	2.85	2.43	9.26	12.12
CV(%)	48.7	10.2	6.9	8.3	9.1

DAS = days after sowing, NC-1 = North Carolina design 1 and PC = polycross design.

Table 4. Mean seedling traits of first filial generation yam populations developed using North Carolina 1 and polycross designs.

Family	Pedigree	SN	TL (cm)	TW (cm)	TWT (g)
	North Carolina 1				
TDr1676	TDr9700793 × TDr9902789	1.8	6.0	2.6	28.8
TDr1677	TDr8902157 × TDr9902789	2.2	6.4	2.7	27.4
TDr1678	TDr8902475 × TDr9902789	2.2	6.9	2.8	33.8
TDr1679	TDr9700632 × TDr9902607	2.0	6.6	2.8	31.5
TDr1680	TDr9700205 × TDr9902607	1.6	5.3	2.0	19.2
TDr1681	TDr08-21-3 × TDr9902607	2.3	5.5	2.5	25.9
TDr1682	TDr9519158 × TDr9501932	1.9	5.9	2.3	23.9
TDr1683	TDr9518988 × TDr9501932	1.5	4.9	1.9	15.1
TDr1684	Ojuiyawo × TDr9501932	1.6	6.1	2.3	24.0
Mean		1.7	6.0	2.6	25.7
$LSD_{(0.05)}$		0.46	1.22	0.3	8.3
	Polycross				
TDr1685	TDr9700793	1.6	6.6	2.5	29.7
TDr1686	TDr8902157	2.0	6.3	2.4	28.5
TDr1687	TDr8902475	2.2	7.5	2.8	47.4
TDr1688	TDr9700632	1.9	4.8	1.9	14.2
TDr1689	TDr9700205	1.7	5.4	2.8	16.2
TDr1690	TDr08-21-3	1.8	5.3	2.0	17.2
TDr1691	TDr9519158	1.8	5.6	2.2	20.0
TDr1692	TDr9518988	1.8	5.6	2.1	19.5
Mean		2.0	6.2	2.2	26.7
Within PC family $LSD_{(0.05)}$		0.24	0.78	0.26	7.56
Between NC-1 and PC $LSD_{(0.05)}$		0.06	0.19	0.06	1.81
Between all families $LSD_{(0.05)}$		0.28	0.90	0.31	8.58
CV(%)		44.4	43.4	36.9	96.6

NC-1 = North Carolina design 1 and PC = polycross, SN = stem number per plant, TL = tuber length, TW = tuber width, and TWT = tuber weight per plant.

4. Discussion

High rate of seed germination is an important factor in the process of yam breeding. The rate of seed germination varies among cross-seeds of different clones. For instance, family TDr1679 took the lowest duration to germinate, highest germination index, and was among the families that exhibited the highest coefficient of the velocity of germination, seed emergence speed, final germination percent and seedling vigor index. Seed germination and seedling emergence are the most important and vulnerable phases of a crop cycle. Duration to emergence and percent emergence may influence crop yield by altering plant population density, spatial arrangement, and effective crop growth duration. The coefficient of the velocity of germination (CVG) indicates the rapidity of seed germination where the highest number of seeds germinate in shortest possible time [20]. Families with high seedling vigor index are indicative of consistent growth of emergent seedlings and optimal emergence. Moreover, families with low seedling vigor index lacked optimal emergence and uniform growth of emergent seedlings. The delayed and poor germination of the botanical yam seeds of some families were possibly attributable to dormancy caused by genetic factors [17,21]. Knowledge of existing variations in the degree of seed viability and dormancy permits selection for either dormancy or non-dormancy [22]. This information also helps in devising robust, practical strategies that overcome dormancy. Seed dormancy has been overcome in many crops using physical and chemical seed-treatment techniques with resultant early and increased germination and seedling vigor [17,23]. Moreover, Feike et al. [21] and Islam et al. [17] have demonstrated that water soaking of seeds prior to sowing greatly enhances germination and seedling vigor. Improvement of viability, vigor and related seedling growth traits would probably enhance the identification of superior progenies at the early-stage yam breeding trials. Finch-Savage and Bassel [24] suggested that improvement of seed vigor would enhance the crop establishment for better yield in the agricultural industry and the seed/breeding companies [24]. Besides the agronomic seed treatments, genetic studies to identify loci controlling seed weight, size and seedling traits are also critically important for combating poor seed germination in yam compared to other crops such as tomato, where similar studies have been done. Botanical seeds of yam vary in size [8]. Understanding the genetic basis underlying variability in seed weight, size, and seedling traits will contribute to the yam's breeding efforts. Many researchers have demonstrated that higher seedling survival and competitiveness depend on seed traits such as quality, size and weight [7,25–27]. The reserved food energy and nutrients accrued in seeds during the seed filling phase are released to the viable embryo during germination. This suggests the significance of the seed filling phase in addressing the nutrient and energy gap needed in combating early germination of seeds and establishment of cotyledons prior to initiation of their photosynthetic potentials [28].

The significant within and between NC-1 and PC derived family variations for the measured traits indicate inherent genetic differences in the yam seed-progenies for germination and seedling attributes. The highest and lowest mean seed-tuber weights per plant were obtained from a polycross-derived family TDr1687 and TDr1688, respectively. The wider variability for seed-tuber weights in the polycross-derived family was expected as the progenies were half-sibs from a wider gene pool of putative male parents (three males) relative to the full-sib progenies from the bi-parental cross in the NC-1 design. The wide variability of tuber size among families could be attributed to the differences in the effective individual plant growth periods after emergence. The higher coefficient of variation of the seedling traits measured in the nursery (screen-house stage) indicates a higher level of dispersion around the mean. Our findings concur with the results of Cornet et al. [29], who reported a high coefficient of variation of 42–71% for fresh tuber yield caused by uneven emergence in *D. alata* and *D. rotundata*.

5. Conclusions

The slow rate of germination decreased the effective growth and development duration of the seedling progenies in yam. The use of appropriate physical or chemical treatment techniques should be exploited to break dormancies that could contribute to increased and consistent seed germination, good seedling growth and development traits in yam population improvement. The polycross-derived progenies possess higher phenotypic plasticity with a higher potential of creating more useful variability in seedling traits.

Our results suggest the relevance of seed germination and seedling attributes for selection of superior progenies at early generation yam breeding populations.

Author Contributions: P.E.N. and A.A. designed the experiment. P.E.N., A.A., A.D., P.B.T., E.Y.D. and R.A. supervised the work. P.E.N. and A.A. performed the data analysis and drafted the manuscript. All the authors contributed to writing the article, read and approved its submission. All authors have read and agreed to the published version of the manuscript.

Funding: The work was financially supported by Bill and Melinda Gates Foundation (BMGF) through the AfricaYam project (OPP1052998) to IITA and the International Development Research Center (IDRC) under the IDRC/CORAF-WECARD/IITA sub-grant agreement for developing capacity for Agricultural Research in Sub-Saharan Africa (PJ-2126) to PEN (Ph.D. student) at the West African Center for Crop Improvement (WACCI), University of Ghana.

Acknowledgments: The authors are grateful to IITA for the glasshouse and screenhouse facilities provided for the study. The technical support from the entire yam breeding team, IITA, Ibadan, Nigeria, is also duly acknowledged.

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

References

1. Obidiegwu, J.E.; Akpabio, E.M. The geography of yam cultivation in southern Nigeria: Exploring its social meanings and cultural functions. *J. Ethn. Foods* **2017**, *4*, 28–35. [CrossRef]
2. Alabi, T.R.; Adebola, P.O.; Asfaw, A.; De Koeyer, D.; Lopez-Montes, A.; Asiedu, R. Spatial multivariate cluster analysis for defining target population of environments in West Africa for yam breeding. *Intern. J. Appl. Geo. Res.* **2019**, *10*, 1–30. [CrossRef]
3. Baeten, L.; Jacquemyn, H.; van Calster, H.; van Beek, E.; Devlaeminck, R.; Verheyen, K.; Hermy, M. Low recruitment across life stages partly accounts for the slow colonization of forest herbs. *J. Ecol.* **2009**, *97*, 109–117. [CrossRef]
4. Chen, F.Q.; Xie, Z.Q. Reproductive allocation, seed dispersal and germination of *Myricaria laxiflora*, an endangered species in the three Gorges Reservoir Area. *Plant. Ecol.* **2007**, *191*, 67–75. [CrossRef]
5. Chen, F.; Liu, L.; Chen, F.; Jia, G. The ecological characteristics of seed germination and seedling establishment of *Manglietia patungensis*: Implication for species conservation. *Am. J. Plant. Sci.* **2012**, *3*, 1455–1461. [CrossRef]
6. Marcos-Filho, J. Seed vigor testing: An overview of the past, present and future perspective. *Sci. Agric.* **2015**, *72*, 363–374. [CrossRef]
7. Khan, N.; Kazmi, R.H.; Willems, L.A.J.; van Heusden, A.W.; Ligterink, W.; Hilhorst, H.W.M. Exploring the natural variation for seedling traits and their link with seed dimensions in tomato. *PLoS ONE* **2012**, *7*, e43991. [CrossRef]
8. Norman, P.E.; Asfaw, A.; Tongoona, P.B.; Danquah, A.; Danquah, E.Y.; Koeyer, D.D.; Asiedu, R. Can parentage analysis facilitate breeding activities in root and tuber crops? *Agric. J.* **2018**, *8*, 95. [CrossRef]
9. Akoroda, M.O. Sexual seed production in white yam. *Seed Sci. Technol.* **1985**, *13*, 571–581.
10. Aighewi, B.A.; Asiedu, R.; Maroya, N.; Balogun, M. Improved propagation methods to raise the productivity of yam (*Dioscorea rotundata* Poir.). *Food Secur.* **2015**, *7*, 823–834. [CrossRef]
11. Sadik, S.; Okereke, O.U. Flowering, pollen grain germination, fruiting, germination and seedling development of yam (*Dioscorea rotundata* Poir.). *Ann. Bot.* **1975**, *39*, 597–604. [CrossRef]
12. Lebot, V. Tropical root and tuber crops cassava, sweet potato, yams and aroids. In *Crop Production Science in Horticulture*; Series 17; CABI Publishing: Wallingford, UK, 2009; 432p.
13. Orkwor, G.C.; Asiedu, R.; Ekanayake, I.J. (Eds.) *Food Yams: Advances in Research*; International Institute of Tropical Agriculture (IITA): Ibadan, Nigeria; Nigeria and National Root Crops Research Institute (NRCRI): Umudike, Abia State, 1998; p. 249.
14. Powell, A.A.; Thornton, J.M.; Mitchell, J.A. Vigour differences in brassica seed and their significance to emergence and seedling variability. *J. Agric. Sci.* **1991**, *116*, 369–373. [CrossRef]
15. Demir, I.; Ermis, S.; Mavi, K.; Matthews, S. Mean germination time of pepper seed lots (*Capsicum annuum* L.) predicts size and uniformity of seedlings in germination tests and transplant modules. *Seed Sci. Technol.* **2008**, *36*, 21–30. [CrossRef]
16. International Soil Reference and Information Centre and the Food and Agriculture Organization (ISRIC/FAO). *Procedures for Soil Analysis. Technical Paper 9*, 6th ed.; Van Reeuwljk, L.P., Ed.; FAO: Wangeningen, The Netherlands, 2002; p. 118.
17. Islam, A.K.M.A.; Anuar, N.; Yaakob, Z. Effects of genotypes and pre-sowing treatments onseed germination behavior of Jatropha. *Asian J. Plant. Sci.* **2009**, *8*, 433–439. [CrossRef]
18. AOSA. *Seed Vigor Testing Handbook: Contribution No. 32 to Handbook on Seed Testing*; Association of Official Seed Analysis: Springfield, IL, USA, 1983; pp. 1–93.
19. Hossain, M.A.; Arefin, M.K.; Khan, B.M.; Rahman, M.A. Effects of seed treatments on germination and seedling growth attributes of Horitaki (*Terminalia chebula* Retz.) in the nursery. *Res. J. Agric. Biol. Sci.* **2006**, *1*, 135–141.
20. Jones, K.W.; Sanders, D. The influence of soaking pepper seed in water or potassium salt solutions on germination at three temperatures. *J. Seed Technol.* **1987**, *11*, 97–102.

21. Feike, T.; Weis, K.; Claupein, W.; Mueller, J. Propagation of physic nut (Jatropha curcas) on Leyte Island, Philippines. In *Proceedings of the Conference on International Agricultural Research and Development, New Delhi, India, 9–11 October 2007*; University of Kassel-Wittzenhauzen and University of Gottingen: Gottingen, Germany, 2007; 6p. Available online: http://www.tropentag.de/2007/abstracts/full/284.pdf (accessed on 2 March 2009).
22. Burson, B.L.; Tischler, C.R.; Ocumpaugh, W.R. Breeding for reduced post-harvest seed dormancy in switchgrass: Registration of TEM-LoDorm switchgrass germplasm. *J. Plant. Regist.* **2009**, *3*, 99–103. [CrossRef]
23. Sadhu, R.N.; Kaul, V. Seed coat dormancy in Robinia pseudo-acacia. *India For.* **1989**, *115*, 483–487.
24. Finch-Savage, W.E.; Bassel, G. Seed vigour and crop establishment: Extending performance beyond adaptation. *J. Exp. Bot.* **2016**, *67*, 567–591. [CrossRef]
25. Wood, D.; Morris, W. Ecological constraints to seedling establishment on the pumice plains, Mount St. Helens, Washington. *Am. J. Bot.* **1990**, *77*, 1411–1418. [CrossRef]
26. Zhang, J.; Maun, M. Establishment and growth of *Panicum virgatum* L. seedlings on a Lake Erie sand dune. *Bull. Torrey Bot. Club* **1991**, *118*, 141–153. [CrossRef]
27. Moegenburg, S. Sabal palmetto seed size: Causes of variation, choices of predators, and consequences for seedlings. *Oecologia* **1996**, *106*, 539–543. [CrossRef] [PubMed]
28. Castro, J.; Hodar, J.; Gomez, J. Seed size. In *Handbook of Seed Science and Technology*; CRC Press: Boca Raton, FL, USA, 2006; p. 397.
29. Cornet, D.; Sierre, J.; Tournebize, R.; Nez, B. Yams (*Dioscorea* Spp.) Plant Size Hierarchy and Yield Variability: Emergence Time is Critical. *Eur. J. Agron.* **2014**, *55*, 100–107. [CrossRef]