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Effect of Phosphorus Fertilizer Rates and Seed Priming Treatments on Seed Quality of Bambara Groundnut

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Abstract
Bambara groundnut (BG) is one of the neglected and underutilized African legumes. Not many studies have examined the seed quality response of BG landraces grown by Ugandan farmers to seed quality enhancement treatments and application of phosphorus. This study was aimed at determining the effect of applying different rates of phosphorus on seed yield and seed quality of BG, and the effect of hydropriming and halopriming with potassium nitrate on its seed quality. Field experiment was set at Zonal Agricultural Research and Development Institute, Ngetta in Uganda using RCBD with a 3x4 factorial treatment structure (3 BG landraces and 4 phosphorus rates). A standard germination test was conducted on seeds harvested from this experiment. Landrace with the poorest germination was subjected to seed priming treatments, and a standard germination test done. Phosphorus application did not significantly affect seed yield ($p>0.05$) of landraces but significantly affected their germination capacity and seed vigour ($p<0.05$). The effect of seed priming treatments on germination capacity and vigour of AbiBam 001 landrace was not significant ($p>0.05$). Among the landraces evaluated, only AbiBam 001 landrace responded positively to phosphorus application with respect to seed yield and seed quality. Seed priming treatments did not improve germination capacity and vigour in AbiBam 001 landrace. Phosphorus use efficiency of Bambara groundnut landraces should be investigated to explain their responses to application of phosphorus.

Keywords: Bambara groundnut, Phosphorus fertilizer rates, Seed priming, Seed yield, Seed quality.

Effet des taux d'engrais au phosphore et des traitements d'amorçage des semences sur la qualité des semences de l'arachide Bambara

Résumé
L'arachide bambara (BG) est l'une des légumineuses africaines négligées et sous-utilisées. Peu d'études ont examiné la réponse de la qualité des semences des variétés BG cultivées par les agriculteurs ougandais. Cette étude visait à déterminer l'effet de l'application de différents taux d'engrais au phosphore sur le rendement des semences et la qualité des semences de BG, ainsi que l'effet de l'hydroprimination et de l'haloprimition avec du nitrate de potassium sur la qualité des semences. Une expérience sur le terrain a été réalisée au Zonal Agricultural Research and Development Institute de Ngetta, en Ouganda, à l'aide de RCBD avec 3 variétés locales de BG et 4

taux d'engrais au phosphore. Un test de germination standard a été effectué sur des graines récoltées à partir de cette expérience. Landrace avec la germination la plus faible a été soumis à des traitements d'amorçage des semences, et un test de germination standard a été effectué. Les taux d'engrais au phosphore n'ont pas eu d'effet significative sur le rendement des semences (p>0,05) des varietés locales, mais ont eu un effet significative sur leur capacitéde de germination et leur vigueu (p 0,05). L'effet des traitements d'amorçage des graines sur la capacité de germination et la vigueur de la variété autochtone AbiBam 001 n'était pas significatif (p >0,05). On a conclu que seule la variété AbiBam 001 affichait une tendance positive en matière de rendement et de qualité des semences avec l'application de taux de phosphore variables. Les traitements d'amorçage des semences n'ont pas amélioré la qualité des semences dans la variété AbiBam 001.

Mots clés: Arachide bambara, taux d'engrais au phosphore, amorçage des semences,

Introduction

Bambara groundnut (*Vigna subterranea* L. Verdc.) is one of the neglected and underutilized African legumes (Harouna *et al.* 2018), yet it is considered the third most important food legume in Africa after cowpea and groundnut (Dansi *et al.* 2016; Odongo et al. 2015). It is an annual plant with a creeping stem and grows to a height of approximately 30-35 cm (Bamshaiye *et al.* 2011). The seed coat colour variegates from black, cream, brown or red and may be streaked with several colours (Jideani & Diedericks, 2014). Some studies have reported that Bambara groundnut performs better than other legumes in poor soils (Alhassan & Egbe, 2013; Anchirinah et al. 2001), but application of phosphorus fertilizer improves its growth, development and yield (Hasan et al. 2019; Temegne *et al.* 2019). Phosphorus is a component of energy storage and transfer compounds which are important in photosynthesis (Hammond & White, 2008). Phosphorus plays a role in cell division and development of meristematic tissues (Weil & Brady, 2017). Phosphorus is also required for seed development (Moon *et al.* 2018). Therefore, enrichment of soil by application of phosphorus fertilizer could improve seed quality. Seed quality is also improved by subjecting seeds to priming treatments such as hydropriming and halopriming with potassium nitrate (Das & Mohanty, 2018; Anisa *et al.* 2017; Tizazu et al. 2019). Hydropriming promotes seed germination by enhancing physiological and biochemical processes and improving antioxidant enzyme systems (Kamithi *et al.* 2016; Essou *et al.* 2016). Hydropriming also antagonizes the functions of Trypsin-like proteolytic enzymes inhibitors present in some seeds (Ashraf & Foolad, 2005). Hydropriming has been reported to improve germination capacity in tomato, groundnut and sesame (Camu, 2017; Das & Mohanty, 2018; Tizazu et al. 2019). On the other hand, seed priming with potassium nitrate also improves seed germination by osmotic activity of potassium ions (K^+) that helps in cell water standing, and acting as cofactor for some metabolic enzymes, and nitrate ions which acts as a substrate for amino acid and protein synthesis (Taiz & Zeiger, 2010). Studies on tomato, Cleome and onion seeds showed improved germination capacity by priming with potassium nitrate (Kumar & Kumar, 2018; Anisa et al. 2017; Essou et al. 2017). Although some previous studies demonstrated improved seed yield of Bambara groundnut with application of different phosphorus rates, not much has been reported on the seed quality response of this crop with application of phosphorus. Besides, no previous study has examined the seed quality responses of Ugandan landraces to hydropriming and halopriming with potassium nitrate. This study was therefore aimed at determining the effect of applying different rates of phosphorus on seed yield and seed quality of Bambara groundnut, and determining the effect of hydropriming and halopriming with potassium nitrate solution on seed quality of Bambara groundnut, with emphasis on landraces grown by Ugandan farmers.

Materials and Methods

Phosphorus studies

Site description: Field experiment was conducted at Zonal Agricultural Research and Development Institute (ZARDI) in Ngetta, Northern Uganda. Ngetta ZARDI is located in Northern Agro Ecological Zone in Lira district, few kilometres along Lira-Kitgum Road. It lies between 2˚17'N and 32˚55'E with an altitude of 1,100m above sea level. Ngetta ZARDI receives average annual rainfall of about 1,197mm, with temperature range of 15°C to 32.5°C (UBOS, 2009).

Plant materials: Three Bambara groundnut landraces used in the field experiment were obtained from Abi ZARDI located in Arua district, North Western Uganda. These landraces are AbiBam 001, AbiBam 003 and TVSU 759, and are commonly grown by Ugandan farmers.

Study design

Field experiment was laid out in a Randomized Complete Block Design (RCBD) with a 3x4 factorial treatment structure, that is three Bambara groundnut landraces (AbiBam 001, AbiBam 003 and TVSU 759), and four phosphorus rates (0 $kgPha^{-1}$, 50 $kgPha^{-1}$, 75 $kgPha^{-1}$ and 100 $kgPha^{-1}$), in three replications. Each plot was measuring 1m x 1m with a spacing of 1m between blocks and 0.5m between plots and 1m on either side of outside blocks, covering a total area of $140m^2$. Treatments were randomly allocated in the field. Triple supper phosphate (TSP) was used as phosphorus source. Phosphorus rate per plant was calculated and TSP weighed accordingly ie 1.4g TSP/plant, 2.1g TSP/plant and 2.8g TSP/plant corresponding to 50 $kgPha^{-1}$, 75 $kgPha^{-1}$ and 100 $kgPha^{-1}$ respectively, and applied during sowing. Seeds were sown singly per hill at a spacing of 50cm x 20cm, giving plant population of 18 plants per plot.

Land preparation, agronomic and post-harvest handling practices: Land was ploughed twice using a tractor and harrowed once to make a fine tilth for planting. Planting was done on 16th August, 2019 at the spacing stated above. Weeding was manually done by hoeing four times. Earthing up was done just before flowering and no other fertilizer or nutrient source was applied except the experimental phosphorus which was applied at sowing. Harvesting was done on 04th January, 2020 (139 days after sowing) by digging out the pods with a hand hoe. Pods were sun dried on gunny bags for five days and later shelled by gently and carefully cracking with a stone. Seed harvested from each plot was weighed and seed yield calculated using the formula

$$\text{Seed yield (t/ha)} = \frac{\text{Seed yield per plot } (g) \times 10{,}000 \text{ m2}}{\text{Plot size (m2)} \times 1{,}000{,}000\text{g}}$$

Standard germination test: A standard germination test was conducted with the seeds harvested from the field experiment, in a completely randomized design using 25 seeds in three replications. Seeds were counted on aluminium foil and sterilized with 1% sodium hypochlorite solution for about 3 minutes to remove any surface contamination, and rinsed with distilled water. Seeds were sown on sterilized sand in plastic germination trays and moistened with distilled water. The trays were transferred to an incubator set at alternating temperature of 20°C/30°C in 16hrs darkness and 8hrs light for 14 days. The number of seeds germinated were recorded daily. Final germination percentage (FGP) was calculated on the 14th day using the formula according to Damalas *et al.* (2019) as:

$$FGP = \frac{Ng}{Nt} \times 100 \qquad 1$$

Where:

Ng is the number of germinated seeds.
Nt is the total number of seeds sown.

Germination velocity index was calculated according to Maguire (1962) as:

$$GVI = \frac{G1}{N1} + \frac{G2}{N2} + \cdots + \frac{Gn}{Nn} \qquad 2$$

Where:

$G1, G2 \ldots \ldots \ldots Gn$ are number of seeds germinated on 1st, 2nd and last count.
$N1, N2 \ldots \ldots \ldots Nn$ are number of days at 1st, 2nd and last count from the sowing day.

Seedling vigour index II (SVI-II) was calculated according to Abdul-Baki & Anderson (1973) as:

$$SVI\text{-}II = FGP \; \frac{Seedling}{dry\ weight} \qquad 3$$

Hydropriming and halopriming with potassium nitrate.

Plant material: Landrace that showed the lowest germination capacity from the control field experiment (AbiBam 001 at 0 $kgPha^{-1}$, 18.67%) was selected for hydropriming and halopriming with potassium nitrate solution. Seeds were stored in a deep freezer at -5°C for two months at the seed physiology laboratory, University of Eldoret before subjecting to hydropriming and halopriming with potassium nitrate solution.

Seed priming procedure: Seeds were removed from the deep freezer and left in ambient air for 24 hours before carrying out seed quality enhancement treatments. Hydropriming was done by soaking 100 seeds in 100ml distilled water followed by incubation at 25°C for 6, 12, 18 and 24 hours, and air drying for one hour. Seed priming with potassium nitrate was done by soaking 100 seeds in 100ml of 0.5, 1, 2 and 3% potassium nitrate solution for 2 hours, followed by air drying for 1 hour. Unprimed seeds were used as control.

Standard germination test: A standard germination test was performed on the primed and nonprimed seeds in a Completely Randomized Design (CRD) using the procedure described previously under the phosphorus study. Final germination percentage, GVI and SVI-II were calculated using the formulas in equation 1, 2 and 3 respectively.

Data collection and analysis*:* Field data was collected on seed yield and 1000 seed weight, while laboratory data was collected on FGP, GVI and SVI-II. Analysis of variance was performed in GenStat® 14th Edition and significant means separated using least significant difference (LSD) at 5% significance level.

Results

Chemical soil characteristics of study site

The results of soil analysis showed that the soil was slightly acidic, with a higher amount

Table 1: Some soil chemical properties of the study site

Organic Carbon (%)	Available phosphorus (%)	Soil PH
2.2	1.36	6.01

of organic carbon and available phosphorus.

Seed yield. Landraces did not differ significantly with respect to seed yield (p = 0.332). Application

of phosphorus did not significantly affect seed yield of landraces (p = 0.780). The interaction of landraces and phosphorus rates was not significant (p = 0.323). AbiBam 001 landrace attained highest seed yield (2.94t/ha) at 100 kgPha^{-1}, AbiBam 003 landrace registered its highest seed yield (2.41t/ha) at 50 kgPha^{-1}, while TVSU 759 landrace recorded highest seed yield (2.58t/ha) at 0 kgPha^{-1} (Table 2).

1000 seed weight. Landraces exhibited a significant difference in relation to thousand seed weight (p = 0.031). However, thousand seed weight of landraces was not affected by phosphorus application (p = 0.696). Interaction of landraces and phosphorus rates was not significant (p = 0.772). The highest and lowest thousand seed weight was attained in AbiBam 003 (511.43g) at 50 kgPha^{-1} and TVSU 759 (403.50g) at 75 kgPha^{-1} respectively (Table 3).

Germination capacity. Landraces significantly differed in their germin-ation capacity (p<0.001). Germination capacity of landraces was also significantly affected by application of phosphorus fertilizer (p< 0.001). The interaction of landraces and phosphorus rates was also significant (p<.001). The highest and lowest germination capacities were attained with AbiBam 003 landrace (90.67%) at 0 kgPha^{-1} and AbiBam 001 landrace (14.67%) at 50 kgPha^{-1} (Figure 1).

Seed vigour. Landraces showed a significant difference in their GVI (p<.001). Application of phosphorus was also shown to significantly affect GVI of landraces (p<.001). The interaction of landraces and phosphorus rates was also significant (p<.001). The highest GVI (2.89) was recorded with TVSU 759 at 75 kgPha^{-1} whereas the same parameter was lowest in AbiBam 001 (0.47) at 50 kgPha^{-1} (Figure 2). Similarly, landraces also significantly differed with respect to SVI-II

Table 2: Seed yield of Bambara groundnut landraces at different phosphorus rates

Phosphorus rate (KgPha^{-1})	Landrace		
	AbiBam 001	AbiBam 002	TVSU 759
0	2.01± 0.73	2.38±0.46	2.58±0.30
50	2.22±0.66	2.41±0.72	1.89±0.04
75	2.46±1.01	1.82±0.24	1.63±0.25
100	2.94±1.65	1.57±0.38	1.87±0.31
MEAN	2.41	33.9	
CV (%)	33.9	1.23	
LSD (p≤0.05) Landrace	NS		
LSD (p≤0.05) P rate	NS		
LSD (p≤0.05) Landrace X P rate	NS		

Table 3: Table 3: 1000 seed weight of Bambara groundnut landraces at varying phosphorus

Phosphorus rate (KgPha^{-1})	Landrace		
	AbiBam 001	AbiBam 002	TVSU 759
0	464.63±54.43	500.93±47.23	462.23±10.70
50	470.0±32.90	511.43±84.11	450.93±54.71
75	491.33±40.57	466.67±25.46	403.50±27.17
100	471.0±68.34	489.73±14.17	436.60±19.86
MEAN	474.24	492.19	438.32
LSD ($p \leq 0.05$) Landrace	39.80		
LSD ($p \leq 0.05$) P rate	NS		
LSD ($p \leq 0.05$) Landrace X P rate	NS		
CV (%)	10.0		

($p<.001$). Seedling vigour index II of landraces was significantly affected by application of phosphorus ($p<.001$). The interaction of landraces and phosphorus rates was significant ($p<.001$). Seedling vigour index II was highest in AbiBam 003 landrace (383.11) at 0 kgPha^{-1} and lowest in AbiBam 001 landrace (37.55) at 50 kgPha^{-1}(Figure 2).

Germination capacity. Landraces significantly differed in their germination capacity ($p<0.001$). Germination capacity of landraces was also significantly affected by application of phosphorus fertilizer ($p<0.001$). The interaction of landraces and phosphorus rates was also significant ($p<.001$). The highest and lowest germination capacities were attained with AbiBam 003 landrace (90.67%) at 0 kgPha^{-1} and AbiBam 001 landrace (14.67%) at 50 kgPha^{-1} (Figure 1).

Seed vigour. Landraces showed a significant difference in their GVI ($p<.001$). Application of phosphorus was also shown to significantly affect GVI of landraces ($p<.001$). The interaction of landraces and phosphorus rates was also significant ($p<.001$). The highest GVI (2.89) was recorded with TVSU 759 at 75 kgPha^{-1} whereas the same parameter was lowest in AbiBam 001 (0.47) at 50 kgPha^{-1} (Figure 2). Similarly, landraces also significantly differed with respect to SVI-II ($p<.001$). Seedling vigour index II of landraces was significantly affected by application of phosphorus ($p<.001$). The interaction of landraces and phosphorus rates was significant ($p<.001$). Seedling vigour index II was highest in AbiBam 003 landrace (383.11) at 0 kgPha^{-1} and lowest in AbiBam 001 landrace (37.55) at 50 kgPha^{-1}(Figure 2).

Effect of hydropriming on seed germination and vigour

Treatments did not show any significant difference in relation to germination capacity ($p = 0.279$). Nonprimed seeds (control) had the highest germination capacity (90.67%) while seeds primed for 18 hours (80.0%) and 24 hours (80.0%) had the lowest germination

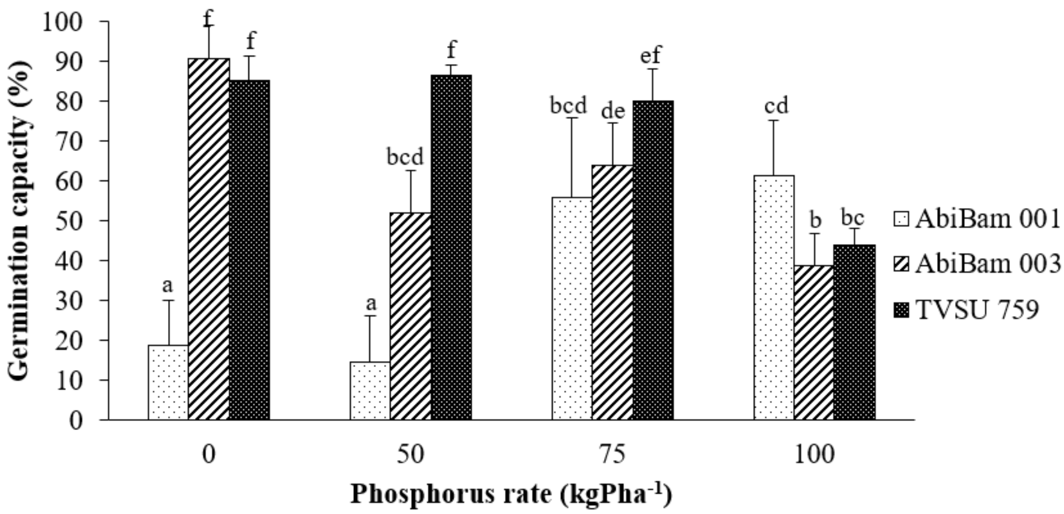

Figure 1: Germination capacity of Bambara groundnut landraces at varying phosphorus rates

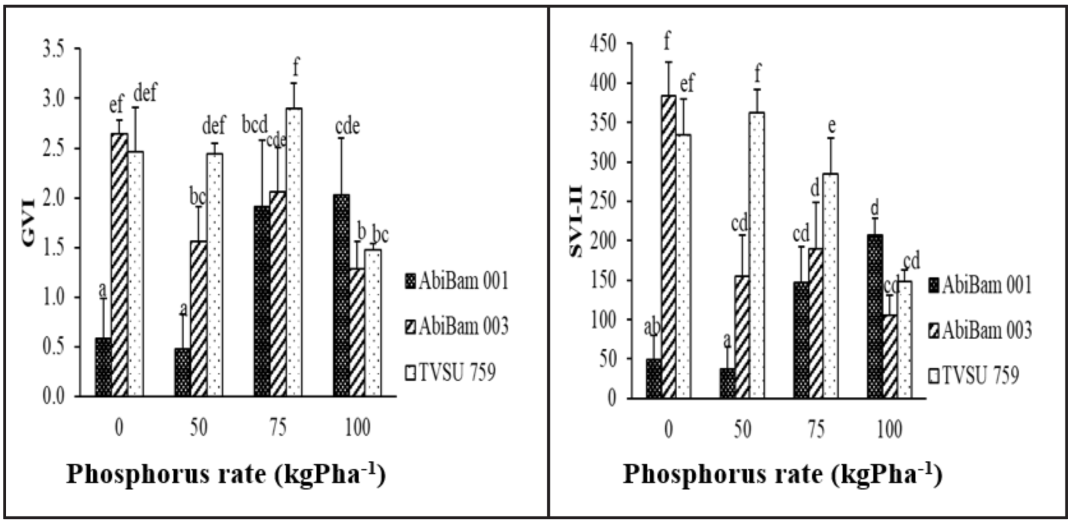

Figure 2: Seed vigour of Bambara groundnut landraces at varying phosphorus rates

capacity. However, germination commenced on the 3rd day for seeds hydroprimed for 18 and 24 hours, while there was a delay in germination of control treatment up to the 5th incubation day (Figure 3). Similarly, there was no significant difference among treatments with respect to GVI (p = 0.881) and SVI-II (p = 0.813). The highest (4.063) and lowest (3.795) GVI were attained with 12hours and 24 hours hydropriming periods respectively (Table 4). On the other hand, SVI-II was highest in 6 hours hydropriming period (358.93) and lowest in 18 hours hydropriming period (320.93) (Table 4).

Effect of potassium nitrate on seed germination and vigour

There was no significant difference among treatments with respect to germination capacity (*p* = 0.640). The highest (92.0%) and lowest (82.67%) germination capacity were attained with 3% and 0.5% potassium nitrate concentrations respectively (Figure 4). Similarly, treatments did not differ in relation to SVI-II and GVI (*p* >0.05). Control treatment had the highest SVI-II (328.7) while the same parameter was lowest in 3% potassium nitrate concentration (260.1) (Table 4). The lowest (3.86) and highest (4.05) GVI were recorded with 0.5 and 3% potassium nitrate concentrations respectively (Table 4).

Discussion

Seed yield. The effect of phosphorus fertilizer application on seed yield of landraces was not significant. This result is contrary to the studies that reported a significant effect of phosphorus fertilizer application on seed

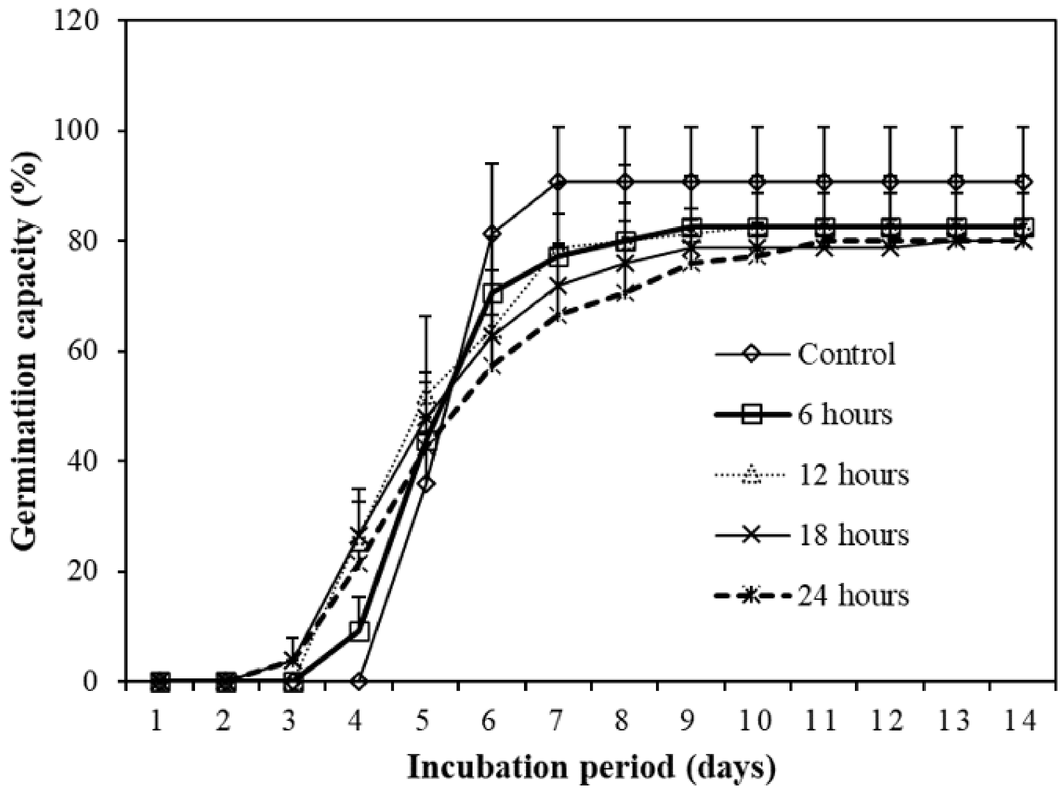

Figure 3: Daily cumulative germination capacity of AbiBam 001 landrace at different hydropriming durations

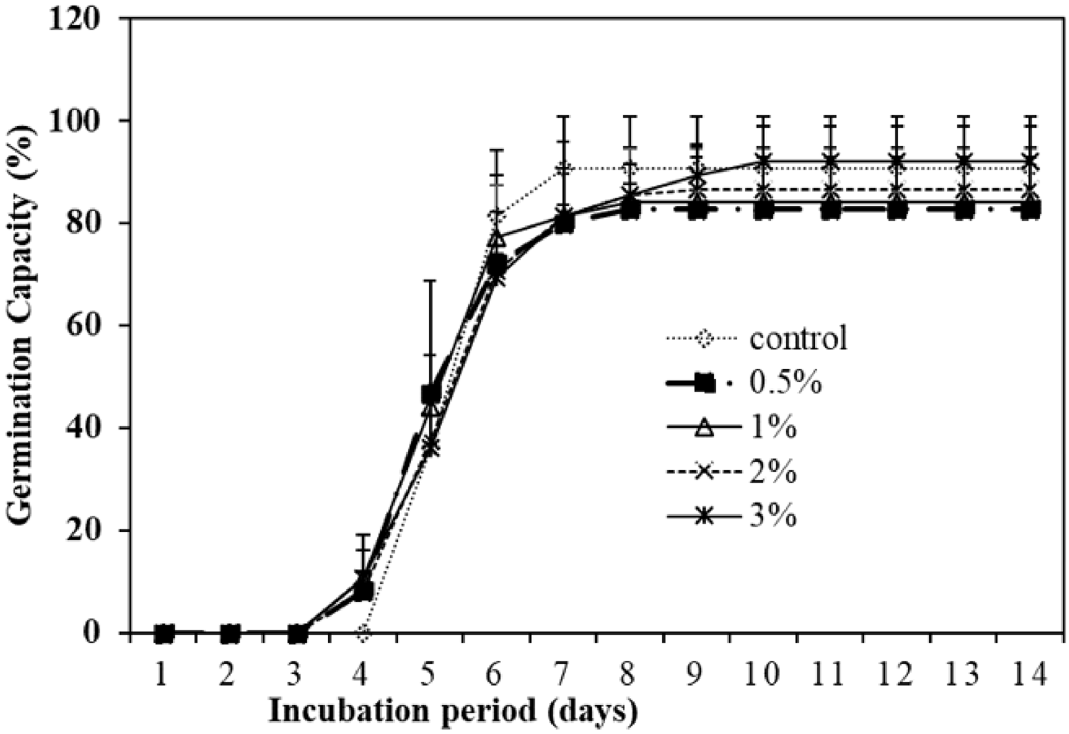

Figure 4: Daily cumulative germination capacity of AbiBam 001 landrace at different potassium nitrate concentrations

Table 4: Effect of Hydropriming and potassium nitrate solution on seed vigour of AbiBam 001 landrace

	Hydropriming			**Potassium Nitrate**	
	GVI	SVI-II		GVI	SVI-II
Control	4.022±0.58a	328.67±40.02a	Control	4.02±0.58a	328.7±40.02a
6 hours	3.829±0.32a	358.93±65.83a	0.5%	3.86±0.80a	280.5±43.45a
12 hours	4.063±0.44a	351.07±26.23a	1%	3.95±0.52a	271.9±37.56a
18 hours	3.986±0.22a	320.93±44.23a	2%	3.90±0.33a	290.4±55.33a
24 hours	3.795±0.27a	333.87±33.57a	3%	4.05±0.06a	260.1±12.27a
CV (%)	9.9	13.0		13.2	14.1
LSD	0.707	80.2		0.949	73.3

yield of Bambara groundnut (Temegne *et al.* 2019; Hasan et al. 2019). However, this present study is in agreement with Effa *et al.* (2016) who reported that application of phosphorus fertilizer did not significantly affect seed yield of Bambara groundnut. Seed yield of AbiBam 001 landrace increased with increasing phosphorus rate whereas that of AbiBam 003 and TVSU 759 landraces was opposite to this trend. The result observed in AbiBam 001 landrace affirms with Temegne *et al.* (2019) and Hasan *et al.* (2019) who observed increasing seed yield in Bambara groundnut with increasing phosphorus application rate. However, the trend ascertained in AbiBam 003 and TVSU 759 disagrees with the same studies (Temegne *et al.* 2019; Hasan et al. 2019), but corroborates with Effa *et al.* (2016) who observed decreasing seed yield in Bambara groundnut with increasing phosphorus application rate. Bambara groundnut landraces with varying seed coat colours, that is white seed coat, light red seed coat and white seed coat with grey eyes were evaluated by Temegne et al. (2019) while Hasan *et al.* (2019) used Malaysian landraces. This present study evaluated three landraces, that is AbiBam 001 (mottled), AbiBam 003 (Black) and TVSU 759 (mixture). The different seed types in TVSU 759 landrace could have varied individual responses to added phosphorus resulting in a negative trend exhibited. The results of soil analysis showed that the soil was slightly acidic with PH of 6.01, and high available phosphorus (Table 1). This soil PH is within the recommended range, that is 5.0 to 6.5 for Bambara groundnut production (FAO, 2007), but the high available soil phosphorus could have caused little or no response by other landraces (AbiBam 003 and TVSU 759) to added phosphorus. However, AbiBam 001 landrace responded positively to application of phosphorus, hence there could be some uniqueness in its genotype and physiology. The seed yield trends observed in these three Bambara groundnut landraces could probably be due to differences in their phosphorus use efficiency. Crop species exhibit both intra and inter species differences in phosphorus use efficiency (Marcante *et al.* 2016; Zhou et al. 2016). This is ascribed to differences in both genotypic and root morphological traits (Shanka *et al.* 2018; Mourice & Tryphone, 2012; Fageria *et al.* 2010), which influence phosphorus absorption from the soil (Lynch, 1995), and its translocation and use in seed formation (Shen *et al.* 2011). A study reported that phosphorus efficient common bean cultivars had higher seed yield at all phosphorus levels in comparison to inefficient cultivars (Shanka *et al.* 2018). However, phosphorus use efficiency was not determined for landraces evaluated in this present study.

1000 seed weight. Phosphorus fertilizer application did not significantly affect thousand seed weight of landraces. This is inconsistent with the recent studies that reported a significant increase in thousand seed weight of Bambara groundnut landraces (white seed coat, black seed coat and light red seed coat) with application of different phosphorus fertilizer rates (Wamba *et al.* 2012). Thousand seed weight of landraces exhibited a similar trend with their seed yield. This could be attributed to differences in phosphorus use efficiency of these landraces as mentioned earlier, and also due to genotypic and physiological factors (Deivasigamani & Swaminathan, 2018). Thousand seed weight helps in determining the average seed weight of a seed lot, which is a measure of seed quality, and is related to quantity of stored reserves (Afshari et al. 2011; Cao *et al.* 2011). Plants raised from heavier seeds are likely to have higher vigour than those raised from lighter seeds of the same maturity stage, possibly due to more stored reserves in heavier seeds (Erdal *et al.* 2017).

Germination capacity. Phosphorus application significantly affected germination capacity of Bambara groundnut landraces. Germination capacity of AbiBam 001 landrace had an increasing trend with increase in phosphorus rate, while an opposite trend was observed with AbiBam 003 and TVSU 759 landraces (Figure 1). The observation in AbiBam 001 landrace agrees with other studies that reported improved germination capacity in French bean, gaillardia and cotton seeds, with application of phosphorus fertilizer (Moon et al. 2018; Kakon et al. 2015; Sawan *et al.* 2011). Phosphorus application increases the chlorophyll concentration in plant leaves which improves their photosynthetic capacity (Sawan *et al.* 2011). This implies that more assimilates are made available to the plant, which upon translocation and accumulation in the seed during seed filling, would improve seed quality particularly seed germination and vigour (Paneru *et al.* 2017). However, another study revealed that seeds obtained from phosphorus fertilized soybean plants had lower germination capacity than those obtained from plants that did not receive phosphorus fertilizer (Krueger *et al.* 2013), which is a similar observation in AbiBam 003 landrace. The germination pattern of these landraces could be attributed to their genotypes and embryo maturity at harvesting. Bambara groundnut has an indeterminate growth habit, and flowering and podding continues until maturity of the plant as long as environmental conditions are favourable (Singh & Basu, 2005; Collinson *et al.* 1996). This flowering behaviour is also influenced by day length especially in photoperiod sensitive landraces (Berchie *et al.* 2013). This observable flowering pattern in Bambara groundnut would also suggest that pods and seeds from the same plant can be at different maturity stages even when the plant shows signs of physiological maturity, hence affecting germination capacity.

Seed vigour. Application of phosphorus significantly affected seed vigour of Bambara groundnut landraces. The seed vigour of AbiBam 001 landrace showed an increasing trend with increase in phosphorus rate for both GVI and SVI-II (Figure 2). This finding agrees with some studies which have shown that application of phosphorus fertilizer improved seed vigour in both cotton and French bean (Kakon *et al.* 2015; Sawan *et al.* 2011). Phosphorus plays a role in metabolism of nucleic acids, proteins and other growth substances in the seed hence improving seed vigour (Welch & Shuman, 1995; Wiatrak *et al*. 2005). Seed proteins content also improves with application of phosphorus (Kakon *et al.* 2015). This implies that upon hydrolysis of these proteins, amino acids and other metabolic substances are channelled to the growing points of the seed during germination thus improving seed vigour. Phosphorus is also an important component of energy compounds such as ATP, which is very important in the process of photosynthesis, seed formation and maturation (Hammond & White, 2008). Posphorus is also essential for the general health and vigour of plants (Moon *et al.* 2018), hence the observed improved seed vigour in AbiBam 001 landrace. AbiBam 003 and TVSU 759 landraces demonstrated decreasing trends in their seed vigour with increase in phosphorus rate. This is consistent with a study which demonstrated that application of phosphorus fertilizer negatively affected seed vigour of soybean (Krueger et al. 2013).

Effect of hydropriming on seed germination and vigour. Hydropriming did not improve seed germination (Figure 3). This finding disagrees with the observation that hydropriming improves percentage emergence in Bambara groundnut (Ogbuehi *et al.* 2013; Berchie *et al.* 2010). However, Mabhaudhi and Modi (2011) reported that hydropriming had a negative effect on final germination of maize seeds. In addition, Ochuodho (2005) observed that seed pre-hydration did not improve germination in *Cleome gynandra* seeds. Germination commenced earlier in all hydropriming durations than the control, this agrees with Berchie *et al.* (2010) who reported that Bambara groundnut seeds hydroprimed for 24 and 48 hours emerged earlier than nonprimed seeds under field conditions. Hydropriming has been shown to improve seed germination in crop species such as groundnut (Das & Mohanty, 2018), sesame (Tizazu *et al.* 2019), bitter gourd (Tania *et al.* 2019), *Aegle marmelos* (Singh, 2017), but some studies also reported that germination decreases with increased priming duration (Kumarimanimuthu & Kalaimathi, 2019; Ogbuehi *et al.* 2013; Dastanpoor *et al.* 2013). Very low percentage emergence (5.7%) and no emergence at all was observed with 48hours, and 72 hours hydropriming durations respectively in comparison with the control (35.7%) in groundnut seeds (Kumarimanimuthu & Kalaimathi, 2019). Similarly, a low percentage emergence (5.9%) with 36 hours hydropriming duration and no field emergence at all with 48 hours hydropriming period was also observed in Bambara groundnut (Ogbuehi *et al.* 2013).

Bambara groundnut landrace (AbiBam 001) used in this study is dark coloured, and it has been reported that dark coloured Bambara groundnut landraces have rapid water imbibition (Mandizvo & Odindo, 2019). Therefore, rapid water imbibition during hydropriming might have caused imbibition injury to the seed cells, hence killing the cells and resulting in unsuccessful germination of some seeds (Mabhaudhi & Modi, 2011; Finch-Savage *et al.* 2004). Hydropriming did not improve seed vigour, this disagrees with other studies that reported improved seed vigour in faba beans (Damalas *et al.* 2019), and Aegle *marmelos* seeds (Sigh, 2017). This observation could be explained by the fact that longer hydropriming periods caused excessive water to be imbibed by the seed, which might have resulted to imbibition injury to seed cells due to a reduction of oxygen to the seed embryo hence lowering seed vigour (Ogbuehi *et al.* 2013).

Effect of halopriming with potassium nitrate on seed germination and vigour.

Halopriming with potassium nitrate solution did not improve germination capacity. This result contradicts the observation that halopriming with potassium nitrate improves seed germination (Anisa *et al.* 2017; El-Baki *et al.* 2018; Essou *et al.* 2017). Halopriming with potassium nitrate solution has been reported to improve seed germination in other crops such as soybean (Ahmadvand *et al.* 2012), faba bean (El-Baki *et al.* 2018), rice (Anisa *et al.* 2017), sorghum (Shehzad *et al.* 2012), *Cleome gynandra* (Essou *et al.* 2017), *Gerbera jamesonii* and *Zinnia elegans* (Ahmad *et al.* 2017). All these studies primed seeds with potassium nitrate solution for more than ten hours, hence the longer priming periods could have caused the difference with this present study which primed seeds with potassium nitrate solution for two hours. Potassium nitrate influences seed water imbibition, and time taken to reach phase I and II of imbibition increases with increasing concentration (Anisa *et al.* 2017). This could possibly explain why the control (non primed seeds) attained maximum germination earlier than all potassium nitrate concentrations (Figure 4), and had higher GVI than most of the potassium nitrate concentrations (Table 4). Although priming with potassium nitrate did not improve germination capacity of Bambara groundnut, germination showed an increasing trend with increase in the concentration of potassium nitrate from 0.5 to 3%. On the other hand, increasing the concentration of potassium nitrate resulted in a decrease in SVI-II (Table 4). This is in agreement with Nego et al. (2015) who had a similar observation when onion seeds were primed with different concentrations of potassium nitrate solution. This decrease could be attributed to the salinity effect of potassium nitrate that could have imposed a negative effect on seedling growth (Nego *et al.* 2015).

Conclusion and Recommendations

Application of phosphorus fertilizer did not significantly affect seed yield but significantly affected seed quality of Bambara groundnut landraces. Among the landraces evaluated, only AbiBam 001 landrace responded positively to phosphorus application with respect to seed yield and seed quality. Seed priming treatments did not improve germination capacity and vigour in AbiBam 001 landrace. Genetic attributes and phosphorus use efficiency of Bambara groundnut landraces should be investigated to explain their responses to application of phosphorus. Hydropriming and halopriming with potassium nitrate should be done with other Bambara groundnut landraces, and a longer priming duration should be investigated for potassium nitrate solution.

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