Original Research Paper

Effect of Priming on the Phenology, Growth, and Yield of Bambara Groundnut (*Vigna subterranea* (L.) Verdcourt)

ABSTRACT

The Bambara Groundnut (Vigna subterranea (L.) Verdc) is the third most important legume among neglected crop species. It is cultivated for its numerous benefits. However, in the current context of decreasing rainfall, seed germination is often slow or even absent, leading to low yields. This study aims to evaluate the effect of seed priming on the phenological, growth, yield parameters, and yield components of Bambara groundnut cultivars under real field conditions during the 2023 rainy season. The experiment was conducted at the experimental station of the Faculty of Science and Technology, Abdou Moumouni University of Niamey. The experimental design used was a randomized block design with three replications. Three treatments were compared: (i) soaking seeds in tap water for 12 hours, (ii) soaking seeds in tap water for 24 hours, and (iii) a control group without soaking. The results showed a significant difference between treatments for the time to emergence (P = 0.016), flowering (P = 0.001), and the date of 50% flowering (P = 0.0013). No significant differences were observed among cultivars for these parameters. Priming did not considerably affect LAI (leaf area index) across cultivars and treatments. Regarding yield and yield components, soaking for 24 hours resulted in significantly higher values, except for dry biomass yield.

Keywords: Cultivation practice, germination, soaking, Bambara groundnut, Niger

(Arial, inclined, 10 font, justified)

1. INTRODUCTION

The Bambara groundnut (*Vigna subterranea (L.) Verdcourt), commonly known as the Bambara pea in Mali, is a food legume* whose cultivation is generally limited to sub-Saharan Africa [1].

The Bambara groundnut is a species native to Africa [2], cultivated for a long time, and classified as a neglected and underutilized crop [3]. It was domesticated in West Africa and ranks as the third most important food legume after groundnut and cowpea [4]. In 2020, Bambara groundnut was cultivated on 398,447 hectares globally, producing 259,313.22 tons annually, with an average yield of 650.8 kg/ha [5]. West Africa is the world's main production area for Bambara groundnut [6]. In 2021, annual production dropped to 239,607.10 tons, with a significantly low yield of 588.8 kg/ha [5]. In Niger, this crop is primarily grown by women, covering an area of 89,104 hectares in 2021 with a production of 52,211.04 tons.

Bambara groundnut is widely consumed across sub-Saharan Africa due to its numerous advantages [7]. Nutritionally, it is mainly grown for its seeds, which are rich in proteins, carbohydrates, and lipids. Studies [9,10] report that 100g of Bambara groundnut provides 387 kilocalories (kcal) of energy. The seeds contain an average of 63% carbohydrates, 19% proteins, and 6.5% lipids, making it a complete food that plays a significant role in nutritional balance [11]. Bambara groundnut is also rich in essential amino acids [12], making it an excellent crop choice for rural communities with limited access to animal protein [13]. Agronomically, it is one of the legumes cultivated for its tolerance to drought, salinity, and poor soil fertility [14]. Its ability to fix atmospheric nitrogen through symbiosis with Rhizobium bacteria enhances soil fertility [15]. Economically, Bambara groundnut seeds, whether fresh or dried, are sold in weekly markets or exported, providing a source of income and renewed interest for farmers in Niger [16].

Crop production and good agricultural yields are closely linked to seed germination, a critical stage in the plant life cycle [17]. However, germination is often slow, unreliable, and characterized by late and sparse emergence in low-rainfall regions. Factors such as pollutants and abiotic stressors [18] affect germination, making it uneven as seeds do not germinate uniformly or simultaneously. To address these challenges and improve plant development and yields, various techniques have been developed over the years [19]. Seed priming is one such method. Seed priming is a pre-germination treatment applied to seeds before sowing [20]. It involves soaking seeds in water or a solution to hydrate them sufficiently without allowing the radicle to emerge [21]. This method is especially effective for hard seeds, breaking dormancy and enabling faster, more uniform germination [22]. It ensures good seedling density and increased crop production [23].

Among the various seed priming methods, hydro-priming is the simplest and easiest to implement, involving water use to treat seeds [24]. Numerous studies have shown that pre-treating seeds, especially with water, improves germination, enhances growth, and results in higher yields for many cultivated species [25-27].

To our knowledge, no studies have been conducted in Niger on the effect of pre-soaking Bambara groundnut seeds in water. This study aims to evaluate the effect of pre-soaking seeds before sowing on the phenological parameters, growth, and yield of two local Bambara groundnut cultivars to improve agricultural production and yields.

2. MATERIALS AND METHODS

2.1 Study site description

The study was conducted at the experimental station of the Faculty of Science and Technology (FAST) at Abdou Moumouni University in Niamey as indicated in Figure 1. The climate of the study area is South-Sahelian, characterized by a short rainy season and high temperatures typical of semi-arid regions. The sandy-loam soil has a slightly acidic pH (pH = 6.5). Figure 2 presents the monthly distribution of rainfall and the maximum and minimum temperatures recorded in Niamey during the year 2023.

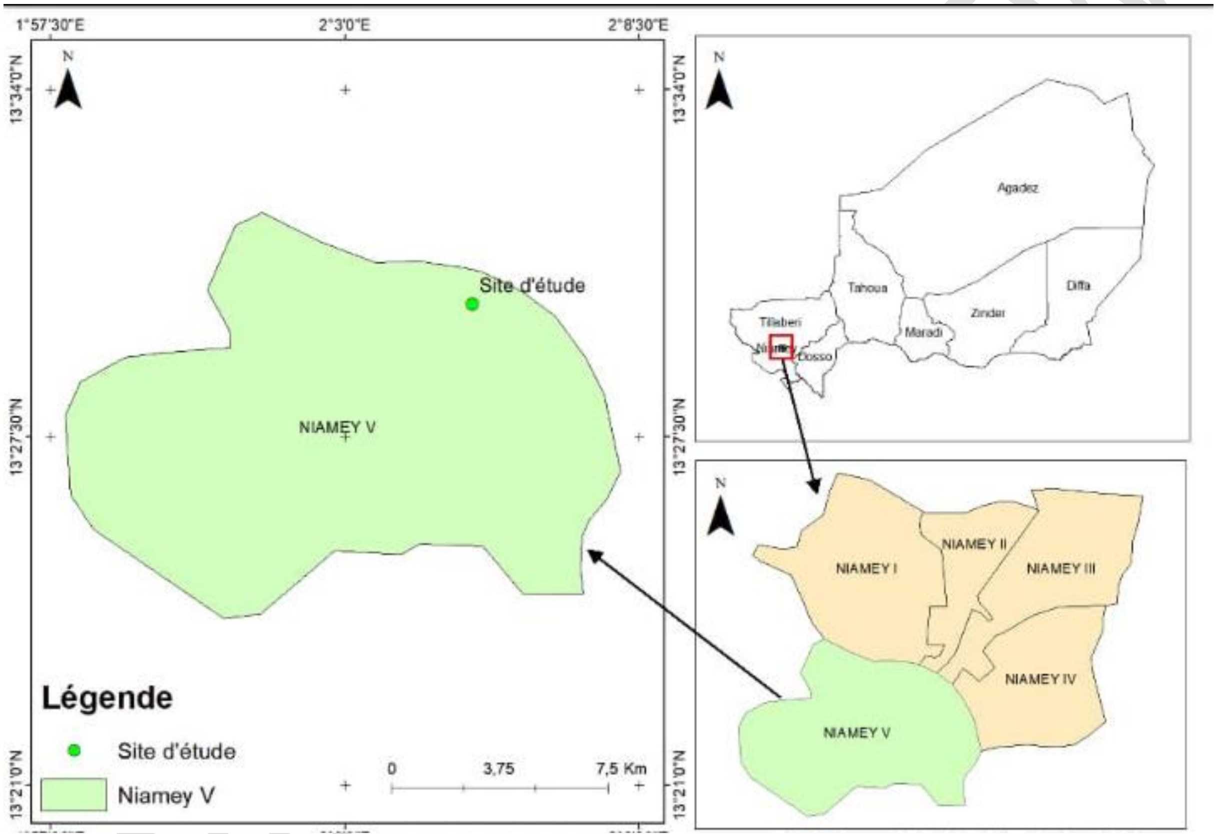

Fig. 1. Location of the Study Area

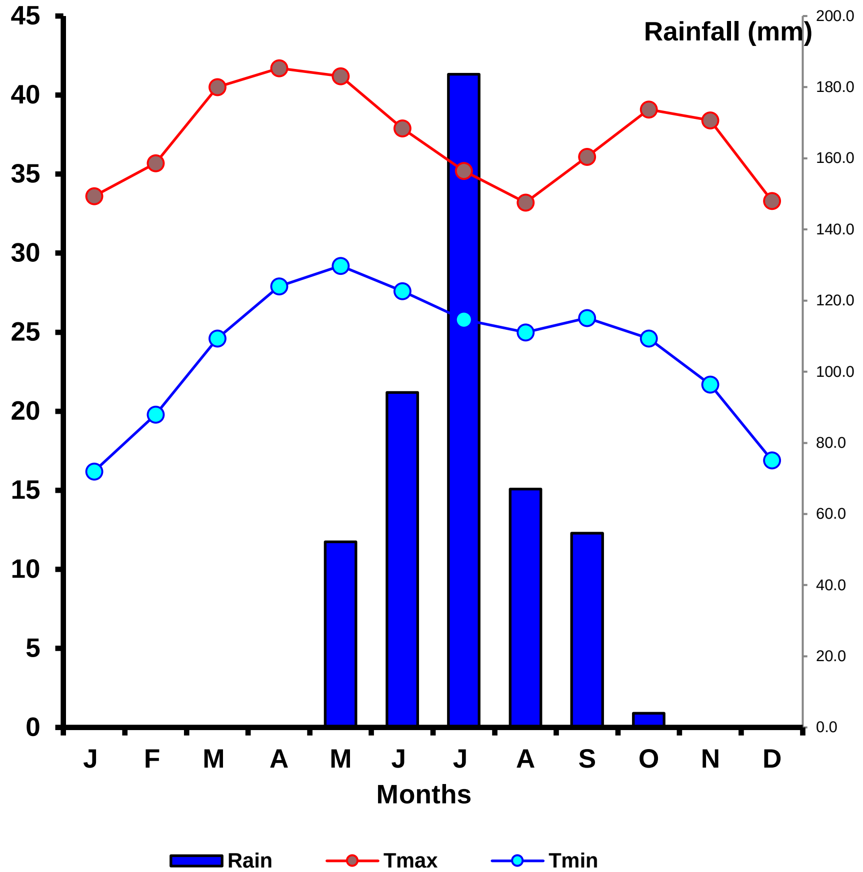

Fig. 2. monthly precipitation distribution and maximum and minimum temperatures

2.2. Plant Material

The plant material used in this study consists of two local cultivars of Bambara groundnut (*Vigna subterranea* (L.) Verdcourt), referred to as C1 and C2, both sourced from the Dosso region (Figure 1).

Cultivar C1: A local cultivar purchased from the market; Cultivar C2: An improved cultivar obtained from the ALHERI seed company. The characteristics of the seeds from these cultivars, as described by [16], are presented in Table 1 below.

Table 1. Characteristics of the Bambara groundnut cultivars C1 and C2.

	Cultivars	
Cultivars Characteristics	**C1 (Local)**	**C2 (Improved)**
Origin	Market purchase	Alheri seed Company
Seed Size	average size	average size
Seed Color	Yellow	Yellow
Germination Rate	Low	Very high
Organoleptic quality	Good taste, highly appreciated by consumers	Good taste, highly appreciated by consumers

A B

Fig. 3. Seeds of the two Bambara groundnut cultivars used in the study. A: C1; B: C2

2.3. Soaking seeds

After sorting the seeds, the two (2) Bambara groundnut cultivars, C1 and C2, underwent a pre-germination treatment before sowing. This treatment involved soaking the seeds in tap water in containers for 12 hours and 24 hours of imbibition. The seeds that were not soaked in water were considered as the control group. After soaking, the seeds were spread out on sacks and air-dried for eight (8) hours.

Conduct of the experiment

The experimental design is a randomized complete block with three replications. The treatments consisted of factorial combinations of three priming options: control, 12 hour and 24 hours. The elementary plots have an area of 6 m^2 (2.5 m × 2.4 m) and are spaced 1 m apart, and 2 m apart repetitions.

Before sowing, the field was plowed to a depth of 15 cm using a plow. Sowing was carried out on July 9, 2023, with three (3) seeds per hole. After germination, the plants were thinned to one plant per hole 18 days after sowing. A dose of 3 g of NPK per hole, in the form of a microdose, was applied as a basal fertilizer at the time of sowing. Maintenance operations included manual weeding of weeds in the plots to allow for the growth of the plants. No phytosanitary treatments were applied.

2.4. Measured parameters

The following phenological parameters were measured: germination delay (DLj), which corresponds to the number of days between sowing and the first germination; first flowering date (DFj), which corresponds to the time between sowing and the appearance of the first flowers; 50% flowering date (Flo_50J), which represents the number of days between sowing and the flowering of half the plants; and pod formation start date (DFGj). These parameters were measured in all plots of the different treatments. To evaluate growth parameters such as leaf area index (LAI), four (4) cuts were made:

(i) the first cut was made on the 25th day after sowing at the vegetative stage;

(ii) the second cut was made on the 44th day after sowing, corresponding to the flowering start date;

(iii) the third cut was made on the 66th day after sowing, corresponding to the start of pod filling;

(iv) the fourth cut was made at physiological maturity.

The LAI was calculated by the ratio of the fresh leaf area to the soil surface covered by the plants. At harvest, the yield parameters and yield components were measured: stover yield, pod yield, seed yield, hundred-seed weight, and the harvest index. The harvest index for seeds was calculated by the formula:

$$HI = 1.65 \times \frac{\text{pod weight}}{(\text{pod weight} \times 1.65 + \text{stover weight})}$$

The correction factor of 1.65 was used to adjust for the differences in the energy requirements of peanuts to produce the dry matter of the pods compared to the vegetative part of the plant [28].

2.5. Data Analysis

The data collected during the experiment was entered into Excel 2016 for analysis, and tables and graphs were created using the same software. The Image J software (Version 1.34s) was used to calculate the leaf area. After checking the normality of the data using the Ryan Joiner test, an Analysis of Variance (ANOVA) was performed to compare the means of the various treatments for the different parameters. This was done using R software (version 4.3.2). For parameters that did not follow a normal distribution, a non-parametric Kruskal-Wallis test was applied at a 5% significance level. Additionally, the degree of association between the different parameters was assessed using the Pearson correlation coefficient at the 5% significance level.

3. RESULTS

3.1. Effect of Priming on the Phenology of Bambara Groundnut

The results of the variance analysis of the effects of hydro-priming on phenological traits are presented in Table 2. These findings reveal a significant difference at the 5% threshold for the onset of germination (DLj), the date of first flowering (DFj), and the date of 50% flowering (Flo_50J) ($p < 0.05$). However, no significant difference was observed for the onset of pod formation (DFGj) ($p > 0.05$).

On average, the time to germination onset (DLj) for the 12-hour treatment (3.67 DAS) was shorter than that for the 24-hour treatment (4.33 DAS) and the control treatment (4.83 DAS). The dates of first flowering (DFj) and 50% flowering (Flo_50J) were also earlier for the 12-hour treatment, at 27.17 DAS and 29.17 DAS, respectively. Conversely, the DFj and Flo_50J were almost similar for the 24-hour treatment and the untreated control.

At the cultivar level, significant differences were found between cultivars C1 and C2 for germination onset (DLj) and 50% flowering (Flo_50J) ($p < 0.05$). However, no significant differences were observed for the date of first flowering (DFj) and the onset of pod formation (DFGj) ($p > 0.05$). On average, cultivar C2 exhibited a shorter germination onset period (4.00 DAS) compared to cultivar C1 (4.83 DAS). Similarly, the time to 50% flowering for cultivar C2 (31.83 DAS) was shorter than that of cultivar C1 (35 DAS).

Table 2. Comparison of Mean Phenological Parameters of Bambara Groundnut Cultivars

Variables		**Parameters**			
		DLj (JAS)	**DFj (JAS)**	**Flo_50J(JAS)**	**DFGj (JAS)**
Treatment	**T12H**	3,67±0,52b	27,17±0,41b	29,17±0,41b	43,83±2,40a
	T24H	4,33±0,52ab	31,83±3,19a	35,83±2,79a	45,83±2,40a
	Tm	4,83±0,83a	31,00±3,19a	31,00±3,23a	46,50 ±2,15a
	P-value	**0.016**	**0.001**	**0.001**	**0.085**
Cultivars	**C1**	4.83±0.83a	31,75±3,86a	35±3.90a	45.75±2.30a
	C2	4.00±0.60b	28,75±1.86a	31,83±2.69b	45.59±2.67 a
	P-value	**0.015**	0.072	**0.032**	0.871

In the same column, figures followed by the same letter are not significantly different (mean ± standard deviation). T12H: Soaking in water for 12 hours; T24H: Soaking in water for 24 hours; Tm: Untreated control; C1: Cultivar 1; C2: Cultivar 2; DLj: Germination onset; DFj: Date of first flowering; Flo_50j: Date of 50% flowering; DFGj: Date of onset of pod formation

3.2. Leaf Area Index (LAI)

The analysis of Figure 4 shows no significant differences between treatments for cuts 1 (P = 0,11) and 4 (P = 0.07). However, for cuts 2 and 3, the germination pre-treatments significantly increased the Leaf Area Index (LAI) compared to the control, with $P =$ 0.024 P=0.024 for both cuts. LAI values exhibit an upward trend, peaking at cut 3, which corresponds to the pod-filling phase, where the highest values are recorded.

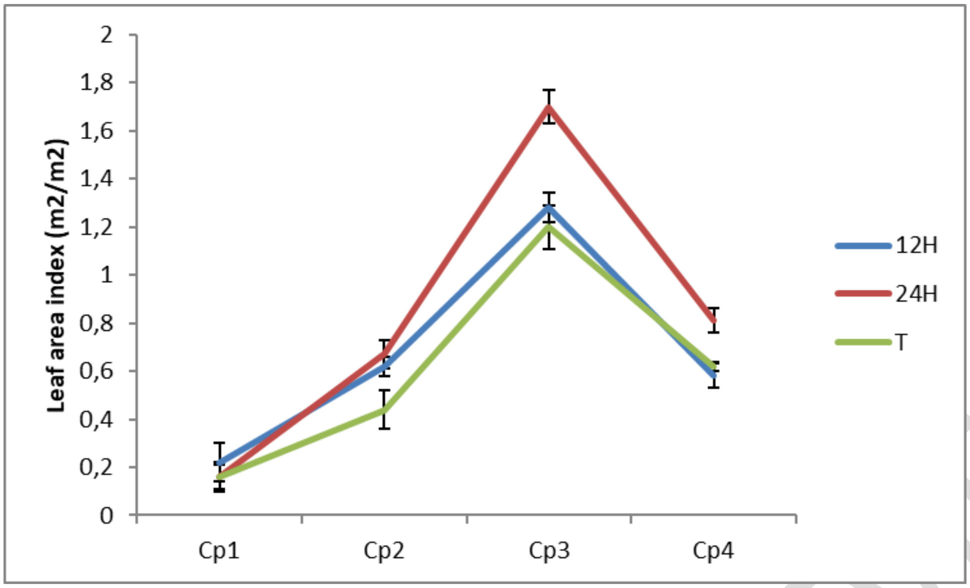

Fig. 4. LAI According to Cuts at Different Development Stages of the Plants.
Vertical bars represent the standard error of mean values. T12H: Soaking in water for 12 hours; T24H: Soaking in water for 24 hours T: Control (untreated) cp1: Cut 1; cp2: Cut 2; cp3: Cut 3; cp4: Cut 4

3.3. Effect of Priming on Yield and Yield Components

The study of the effect of seed pre-germination treatments on yield parameters yielded the results summarized in Table 3. Variance analysis results revealed a significant difference at the 5% threshold between treatments for pod yield (Rdt G), seed yield (Rdt Gr), dry weight of 100 seeds (P sec C Gr), and pod harvest index (HI) (P = 0.02). However, the pre-treatment had no significant effect on dry biomass yield (P = 0.73). The mean values for pod yield and seed yield were significantly higher for the 24-hour treatment (11,405.07 kg/ha and 7,642.84 kg/ha, respectively) compared to other treatments. Furthermore, the dry weight of 100 seeds and the harvest index were also improved by the 24-hour treatment, at 51.59 g and 72.09%, respectively. In contrast, the dry weight of 100 seeds and the harvest index for the 12-hour treatment and the untreated control were statistically similar. At the cultivar level, no significant effect was found between the two cultivars for any of the yield parameters studied.

Table 3. Effect of Seed Priming on Yield and Yield Components of Bambara Groundnut Cultivars

Variables		Parameters				
		Dry Biomass (Kg/ha)	Pod yiel (Kg/ha)	Seed yield (Kg/ha)	100 seeds weight (g)	HI (%)
Treatment	**12H**	7930.14±1523,55a	8509.09±1092,91 b	5384.58±610,40 b	44.00±4,52 b	64.04±4,31 b
	24H	7222.08±709,53 a	11405.07±1448,90 a	7642.84±722,48 a	51.59±3,94 a	72.09±3,68 a
	T	8018.76±2641,11 a	7978.57±1760,96 b	5066.77±1008,70 b	44.82±4,21 b	62.70±5,49 b
	p-value	0.737	**0.0008**	**0.0002**	**0.007**	**0.002**
Cultivars	**C1**	7102.40±1303.52a	8579.58±2394.47a	5720.69±1457.42a	47.92±5.41a	65.99±4.68a
	C2	8492.48±2397.87a	9356.07±1719.94a	5859.79±1349.92a	44.70±4.43a	64.76±7.43a
	p-value	0.09156	0.3715	0.8106	0.1258	0.6322

Following the same column, numbers followed by the same letter are not significantly different (mean ± standard deviation). HI: Harvest index

3.4. Correlation Between Variables

The correlation matrix was developed to determine the relationships between the different traits studied. Analysis of the correlation results (Table 4) shows that the 50% flowering date is positively and highly significantly correlated with the first flowering date (r = 0.94). The results also indicate that the dry weight of 100 seeds has a positive and highly significant correlation with the first flowering date (r = 0.57) and the 50% flowering date (r = 0.61).

Pod yield (RdtG) is highly significantly and positively correlated with the dry weight of 100 seeds (r = 0.74). Similarly, grain yield is highly significantly and positively correlated with the dry weight of 100 seeds (r = 0.80) and pod yield (r = 0.90). Lastly, the harvest index (HI) is significantly and positively correlated with the dry weight of 100 seeds (r = 0.46) and pod yield (r = 0.50).

A highly significant positive correlation also exists between the harvest index and grain yield (r = 0.52); however, the harvest index is negatively and highly significantly correlated with haulm yield.

Table 4. Correlation Between Variables

Caracters	DFj	Flo_50j	DFGj	PSecCGr	RdtF	RdtG	RdtGr	HI
DFj	1	**0.94*** **	0.10	**0.57** **	-0.03	0.28	0.30	0.22
Flo_50j		1	0.13	**0.61** **	-0.06	0.32	0.36	0.27
DFGj			1	0.09	-0.23	-0.20	-0.09	0.06
PSecCGr				1	0.11	**0.74*** **	**0.80*** **	**0.46* **
RdtF					1	0.31	0.19	**-0.65*** **
RdtG						1	**0.90*** **	**0.50* **
RdtGr							1	**0.52** **
IR								1

* significant ** : very significant *** : highly significant DFj: start of flowering; Flo_50j: 50% flowering date; DFGj: start of pod formation; PSecCGr: 100 seeds weight; RdtF: dry biomass yield; RdtG: pod yield: RdtGr: seed yield; HI: harvest index

4. DISCUSSION

4.1. Phenology

The results of this study showed a significant difference ($p < 0.05$) in the germination initiation time of *Vigna subterranea* seeds between treatments and cultivars. Soaking seeds in water for 12 hours reduced the germination time to an average of 3 days compared to 4 days for the 24-hour treatment and 4.84 days for the untreated seeds (Table 2). The germination time was shorter for Cultivar 2 compared to Cultivar 1. Soaking seeds for 12 hours improved germination by reducing the emergence time, making 12 hours the optimal soaking duration for these *Vigna subterranea* cultivars. Our results demonstrate that pre-soaking seeds in tap water accelerates germination and reduces the germination time. Similar observations were made in studies on *Vigna subterranea* by [29–31], who also found that hydro-priming improved germination by reducing emergence time. Hydro-priming is an effective method to shorten germination time and enhance seed germination rates.

The reduction in germination time observed with hydro-priming can be attributed to water softening the seed coat and allowing moisture to penetrate seed tissues. This hydration triggers metabolic reactions in the embryo, accelerating germination speed and reducing the time to germination [32, 33]. In this study, 12 hours of hydro-priming was most effective in improving the germination potential of *Vigna subterranea*. Other studies align with these findings. [34, 35] observed that a 12-hour pre-treatment is optimal for improving germination and germination rates in some cultivated species. In contrast, [36] reported that soaking seeds for 24 hours improved the germination of *Vigna subterranea* varieties in Botswana. Additionally, [37] found that a 48-hour soak enhanced germination in *Vigna subterranea*.

The variability in hydro-priming durations could be due to differences in cultivars used or variations in drying conditions before sowing. However, [38] cautioned that prolonged soaking may decrease seed viability, as excessive water can cause seed damage, promote parasite attacks, or lead to seed rot. Similarly, [39] reported that prolonged flooding significantly reduces the germination rate of *Vigna subterranea*. Differences in germination between local cultivars of the same species may also result from significant genetic variation or environmental factors influencing the germination process [40].

The dates of the first flowering and 50% flowering were significantly affected ($p < 0.05$) by the pre-treatment of *Vigna subterranea* seeds. Seeds soaked for 12 hours reached the first flowering date and 50% flowering date (27 and 29 days after sowing, respectively) earlier than seeds soaked for 24 hours or untreated seeds. No significant difference was observed between cultivars for the first flowering date. However, there was a significant difference in the 50% flowering date. Cultivar 2 was the earliest to reach 50% flowering, while Cultivar 1 was the latest. The earlier flowering observed in plants soaked for 12 hours may be explained by their faster germination, allowing them to flower earlier. These results align with findings by [41], who observed that seed priming reduced the flowering period in chickpea plants.

4.2. Effect of Priming on Growth Parameters, Yield, and Yield Component

The growth analysis of the two *Vigna subterranea* cultivars revealed low Leaf Area Index (LAI) values during the vegetative stage, which increased significantly at the beginning of flowering and during the pod-filling phase. During these stages, leaf area expansion supports higher photosynthetic activity, leading to greater accumulation of reserves in seeds and, consequently, better seed yields at harvest.

Pre-sowing hydration had no significant effect on dry biomass production across treatments compared to the control (Table 5). This suggests that seed soaking did not enhance dry matter production in *Vigna subterranea* cultivars. These findings align with those of [42], who reported that 24-hour hydro-priming of *Vigna subterranea* seeds did not significantly affect dry matter production compared to 12-hour priming and control treatments.

Pod yield, seed yield, 100-seed weight, and harvest index were significantly influenced by pre-treatment (Table 5). The highest values were obtained with the 24-hour treatment. These results corroborate those of [42], who observed increased seed yields in *Vigna subterranea* following 24-hour hydro-priming. Similarly, [43] reported that soaking *Vigna subterranea* seeds for 24 hours improved pod yields in their study on the effects of different pre-treatments and spacing on growth and production of four local varieties in Indonesia

The correlation matrix for quantitative traits revealed very strong positive and negative correlations. A highly significant positive correlation (r = +0.94) was observed between the first flowering date and the 50% flowering date. This indicates that earlier flowering leads to a quicker attainment of 50% flowering. These findings align with [44], who found strong correlations between the first flowering date and the 50% flowering date in their agro-morphological characterization of *Vigna subterranea* accessions in Burkina Faso. Highly significant positive correlations were observed between pod yield, seed yield, and harvest index. This suggests that increasing pod and seed yields also increases the harvest index. Conversely, a strong and significant negative correlation (r = -0.65) was found between haulm yield and the harvest index, indicating that higher haulm yields are generally associated with a lower harvest index. These correlations explain the superior performance of the 24-hour treatment in terms of seed and pod yields compared to the 12-hour treatment and control (Table 3).

5. CONCLUSION

The results showed that soaking seeds for 12 hours improved parameters such as germination time, flowering duration, and the time to 50% flowering, except for the time to pod formation, in local Vigna subterranea cultivars. Pre-soaking in water had limited significant influence on growth parameters. Hydro-priming for 24 hours increased pod yield, seed yield, 100-seed weight, and harvest index but did not enhance dry biomass production in any of the local cultivars. These findings highlight the importance of seed priming as an effective strategy to improve germination, a critical step in the plant development cycle, especially as an adaptation strategy to climatic variability.

REFFERENCES

1. Chantal M, Djakissam W, Jeremie V, Fatime A, Robert N, Augustin G, ... & Leonard NT. Pratiques paysannes de production durable des graines de Voandzou [Vigna subterranea (L.) Verdc.] pour la sécurité alimentaire dans le Cameroun septentrional. *European Scientific Journal*. 2018 ; *14*(18), 424-441.
2. Baina D J, Mourtala IZM, Abdou MM, & Yerima A RIB. Étude de la Variabilité agro morphologique de 81 accessions de Voandzou [Vigna subterranea (L.) Verdc] au Niger. Journal of Applied Biosciences. 2023 ;183, 19181-19196.
3. Ouoba A, Ouedraogo M, Sawadogo M, & Nadembega S. Aperçu de la culture du voandzou (Vigna subterranea (L.) Verdcourt) au Burkina Faso: enjeux et perspectives d'amélioration de sa productivité. International Journal of Biological and Chemical Sciences. 2016 ; 10(2), 652-665.
4. Touré Y, Koné M, Silué S, & Kouadio YJ. Prospection, collecte et caractérisation agromorphologique des morphotypes de voandzou [Vigna subterranea (L.) Verdc.(Fabaceae)] de la zone savanicole en Côte d'Ivoire. European scientific journal. 2013 ; 9(24).
5. FAO. World Food and Agriculture – Statistical Yearbook 2023. Rome. https://doi.org/10.4060/cc8166en .2023.
6. Khan MMH, Rafii MY, Ramlee SI, Jusoh M, & Al-Mamun M. Bambara groundnut (Vigna subterranea L. Verdc): A crop for the new millennium, its genetic diversity, and improvements to mitigate future food and nutritional challenges. Sustainability. 2021; 13(10), 5530.
7. Mbaiogaou A, Hema A, Ouedraogo M, Palé E, Naitormbaide M, Mahamout Y, & Nacro M. Etude comparative des teneurs en polyphénols et en antioxydants totaux d'extraits de graines de 44 variétés de voandzou (Vigna subterranea (L.) Verdcourt). International Journal of Biological and Chemical Sciences. 2013 ; 7(2), 861-871.
8. Ouédraogo OG. Plantes médicinales et pratiques médicales traditionnelles au Burkina Faso ; cas du plateau central. Thèse de Doctorat, Faculté des Sciences et Techniques de l'université de Ouagadougou, Burkina-Faso. 1996 ; 168p
9. Wassouo F., Madi A, Sobda G, Koubala BB, & Mvondoawono JP. Diversités agro morphologiques de trente-six accessions de voandzou [Vigna subterranea (L.) Verdcourt]

cultivées dans la région de l'Extrême-Nord Cameroun. Journal of Applied Biosciences. 2019 ; 140, 14227-14234.
10. Adji FA, Chantal M, Djakissam W, & Tinkeu LN. Formulation d'un aliment de complément à base du voandzou (Vigna subterranea (L.) Vercourt (1980) pour relever la dénutrition dans l'Extrême-Nord du Cameroun. Journal of Applied Biosciences. 2018 ; 123, 12379-12387.
11. Bamshaiye OM, Adegbola J A, & Bamishaiye EI. Bambara groundnut: an under-utilized nut in Africa. Advances in agricultural biotechnology.2011; 1(1), 60-72.
12. Stephens JM. Bambara Groundnut--Voandzeia Subterranea L. Thouars. University of Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, EDIS; 1994.
13. Khan MMH, Rafii MY, Ramlee S I, Jusoh M, & Al Mamun M. Path-coefficient and correlation analysis in Bambara groundnut (Vigna subterranea [L.] Verdc.) accessions over environments. Scientific reports. 2022; 12(1), 245.
14. Andriamananjara A. Système de culture a rotation voandzou – riz pluvial (oryza sativa) sur les hautes terres de Madagascar. Rôle du voandzou (Vigna subterranea) sur la biodisponibilité du phosphore dans les ferralsols. Thèse de Doctorat, Ecole Supérieure des Sciences Agronomiques, Université d'Antananarivo, Madagascar. 2011 ; 186p.
15. Agboka K, Tchegueni M, Tounou AK, & Aziadekey GM. Diversity and production constraints of Bambara groundnut (Vigna subterranea L.) in dry savanna of Togo. International Journal of Development Research. 2018; 8(08), 22371-22378.
16. Issa AH, Bakasso Y, Mayaki ZA, Doumma A, & Boucar I M. Participatory analysis of the diversity of morphotypes and local knowledge of the culture of Bambara groundnut (Vigna Subterranea L.) at Niger. International Journal of Innovation and Applied Studies. 2014; 9(4), 1915.
17. Khalida LAABAS AB. Influence de différents traitements de prégermination des graines de quinoa (Chenopodium quinoa Willd.) Sur les performances germinatives et la tolérance au stress hydrique.Mémoire de Master de l'université Mohamed Khider de Biskra, Algérie, 55p
18. Pawar VA, & Laware SL. Seed priming a critical review. Int. J. Sci. Res. Biol. Sci. 2018; 5(5), 94-101.

19. Basra SMA, Pannu IA, & Afzal IRFAN. Evaluation of seedling vigor of hydro and matriprimed wheat (Triticum aestivum L.) seeds. Int. J. Agric. Biol. 2003; 5(2), 121-123.
20. Boucelha L and Djebbar R. Synthèse sur le Priming des Graines. Université des Science et de Technologie Houari Boumediene, Algérie. 2019 ; 6p.
21. Gaudreault M. Amorçage et séparation des graines d'épinette noire (Picea mariana (Mill.) BSP) : amélioration de la germination des lots de semences forestières. Université du Québec à Chicoutimi. 2005 ; 109 p.
22. Memento de l'Agronome. Ministère de la coopération et du développement Paris (France). 1991 ;1635 p/tabl.
23. Samake O, Traore K, Bengaly A, Yens A, Traore B, & Cisse F. Effets de différentes modalités de trempage de semences sur le rendement du maïs dans l'agriculture de décrue à Yélimané en zone sahélienne du Mali: Effects of different methods of seed priming on maize yield in flood recession agriculture in Yélimané in the Sahelian zone of Mali. International Journal of Biological and Chemical Sciences. 2022 ;16(6), 2549-2559.
24. El-Sanatawy AM, El-Kholy AS, Ali MM, Awad MF, & Mansour E. Maize seedling establishment, grain yield and crop water productivity response to seed priming and irrigation management in a Mediterranean arid environment. Agronomy. 2021; 11(4), 756.
25. Ghassemi-Golezani K, Chadordooz-Jeddi A, Nasrullahzadeh S, & Moghaddam M. Influence of hydro-priming duration on field performance of pinto bean (Phaseolus vulgaris L.) cultivars. African Journal of Agricultural Research. 2010; 5(9), 893-897.
26. Mahmoodi TM, Ghassemi-Golezani KAZ E M, Habibi DAVOOD, Paknezhad FARZAD, & Ardekani MR. Effect of hydro-priming duration on seedling vigour and field establishment of maize (Zea mays L.). Research on Crops. 2011; 12(2), 341-345.
27. Damalas CA, Koutroubas SD, & Fotiadis S. Hydro-priming effects on seed germination and field performance of faba bean in spring sowing. Agriculture. 2019; 9(9), 201.
28. Duncan W, McCloud D, MacGraw R, Boote K. Physiological aspects of peanut yield improvement. Crop Science. 1978; 18(6):1015-1020.
29. Modi AT. Pre-germination hydration affects seed performance in bambara groundnut. Scientific Research and Essays. 2013; 8(21), 940-945.

30. Al Shareef I, Sparkes D, & Azam-Ali S. Temperature and drought stress effects on growth and development of bambara groundnut (*Vigna subterranea* L.). Experimental Agriculture. 2014; 50(1), 72-89.
31. Mutetwa M, Mafukidze BP, Makaure BT, Mubaiwa TC, Dendera O, Tovigepi E, ... & Chaibva P. Priming seeds with potassium nitrate is associated with modulation of seed germination and seedling growth ecology of *cucumis metuliferus*. EUREKA: Life Sciences; 2023; (4), 23-35.
32. Ouattara N, Kouassi BAT, Soro D, & Soro D. Effet des Prétraitements sur la Dormance des Semences de *Acacia auriculaeformis* A. Cunn ex. Benth (Fabaceae). European Scientific Journal, ESJ. 2019 ; 15(18), 202.
33. Kouadio K, Sanogo S, Kouassi EK, & Doffou CS. Effet des durées de conservation et du traitement à l'eau sur la germination des graines de Tieghemella heckelii Pierre ex A. Chev. (Sapotaceae) en Côte d'Ivoire. International Journal of Biological and Chemical Sciences. 2020 ; 14(8), 2880-2892.
34. Bokobana A, Gnofam N, Koffi ZK, Assih A, Akantetou K P, Bassarou A, & Koffi T. Seed hydropriming to alleviate drought stress in germination of two cotton (*Gossypium hirsutum* L.) varieties. Research Square. 2023; DOI : http//doi.org10.21203/rs.3rs-3328668/V1
35. Bayala R, Diedhiou I, Siene LAC, Yao KAG, & Sagna CVN. Test de Germination des Graines de Ricin (Ricinus communis L.) Sous Différentes Contrainte Abiotiques. ESI Preprints. 2024 ; 20(3).
36. Legwaila GM, Karikari SK, Mogamisi K, & Mathowa T. Response of three Bambara groundnut landraces to pre-sowing hydration in Botswana.Agric. Biol. J.N Am. 2013; 4430-434
37. Berchie JN, Adu-Dapaah H, Sarkodie-Addo J, Asare E, Agyemang A, Addy S, & Donkoh J. Effect of seed priming on seedling emergence and establishment of four bambara groundnut (*Vigna subterranea* L. Verdc.) landraces. Journal of Agronomy. 2010; Vol. 9, No. 4, 180-183 ref. 15.
38. Kareem I, Ismai MR, Puteh AB, Kareem SA, Adekola OF, Faseyi, AF, Baba HS, Yusuf SY, Okebiorun, SE, Nageri OH, Lawal MT, Lawal QO, Musa AI, Oyewole AM. Improvement of rice seed germination and seedling growth using seed priming. Anchor University Journal of Science and Technology. 2021; 2(1), 1-8.

39. Sesay A. Influence of flooding on Bambara groundnut (vigna subterranean L.) germination; effect of temperature, duration and timing. African journal of agricultural research. 2009; vol. 4 (2). Pp. 100-106.
40. Maatougui A, & BAKALI AH. Effet des prétraitements et de la saison sur la germination des caryopses de Stipa tenacissima L. dans la région orientale du Maroc. African and Mediterranean Agricultural Journal-Al Awamia. 2020 ; (128), 76-92.
41. Zare I, Mohammadi G, Sohrabi Y, Kahrizi D, Khah EM, & Yari K. Effect of different hydropriming times on the quantitative and qualitative characteristics of chickpea (Cicer arietinum L.). African Journal of Biotechnology. 2011; 10(66), 14844-14850.
42. Ogbuehi HC, Amadi CA, and Ashilonu P. Effect of seed hydropriming on dry matter production and yield of bambara groundnut (*vigna subterranean* (l.) verdc.) landrace. Global Journal of Biology, Agriculture and Health Sciences. 2013; 2(3), pp.150-153
43. Suryati H, Ilyas S, Qadir A, & Budhianto B. Effects of invigoration and spacing on growth and seed production of four bambara groundnut (*Vigna subterranea* (L) Verdc) Landraces. Agriculture and food Science. 2019; 14(1), 16-25.
44. Kambou DJ, Nandkangre H, Ouoba A, Konate MNG, Sawadogo N, Ouedraogo M, & Sawadogo M. Agro-morphological characterization of Bambara nut accessions [*Vigna subterranean* (L) Verdcourt] from Burkina Faso. Journal of Applied Biosciences. 2020; 153(1), 15727-15744