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Effects of Storage and Priming on Seed Emergence in Soil and Embryo Culture of *Musa acuminata* Calcutta 4

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

Aims: Effects of 3 storage durations, 3 hydro priming protocols and 6 chemical priming protocols on emergence in soil (*in vivo*) and embryo culture (*in vitro*) of *Musa acuminata* Calcutta 4 were investigated.
Study Design: The experimental design was a completely randomised with three replicates. Analysis of variance was used (P=.05) to test treatment effects in a Completely Randomised design. Mean comparison was by LSD.
Place and Duration of Study: This study was carried out for a period of 10 months at the International Institute of Tropical Agriculture High Rainfall Station, Onne, in Rivers State, Nigeria.
Methodology: Seed pre-sowing treatments consisted of 3 storage protocols, 3 hydro priming and 6 chemical treatment protocols. After which treated seeds were divided into two sets. One set was sown directly in soil and the other set subjected to embryo culture technique.

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Results: Seeds sown in soil immediately they were extracted had significantly higher emergence than stored seeds. Emergence declined by 20% and 23% after 2 weeks and 4 weeks of storage respectively. For embryo culture, seeds stored for 2 weeks had significantly higher germination (40%) than seeds that were not stored or seeds stored for 4 weeks (38%). Emergence *in vivo* was significantly higher for seeds that were not hydro primed than for seeds hydro primed for 4 days or 8 days. Emergence declined by 33% and 38% in seeds hydro primed for 4 days and 8 days respectively. Hydro priming for embryo culture for 4 days increased germination significantly by 60% compared to those without hydro priming. All the chemicals reduced emergence in both soil and *in vitro* procedures except that of Copper oxychloride in embryo culture which increased germination by 18%, compared to the control achieving 47% germination.

Conclusion: Higher germination was recorded with *in vitro* than *in vivo* procedures irrespective of the treatments applied. Perhaps inherent factors in the seed coat and possible interactions in soil may account for the poor emergence exhibited *in vivo* and will require further investigation.

Keywords: Musa acuminate Hydro-priming chemical-priming; in vivo; in vitro.

1. INTRODUCTION

Seed production is required in plantain and banana (*Musa* spp.) mainly for breeding purposes. At maturity, *Musa* seeds are black or dark brown stony bodies. The seed has a rough seed coat [1]. It contains an embryo, which is embedded in a copious endosperm and chalazal mass [2]. Seeds vary in size (about 4-6 mm), colour (brown or black) and shape (angular or globose). Seed shape varies due to compression between neighbouring seeds [1]. The structure of the *Musa* seed is complex, hence making germination very difficult [1,3,4]. It was found that seed viability was also affected by moisture content, oxygen and temperature [5]. The presence of a semi-permeable inner membranous seed coat restricts the movement of moisture and oxygen into the embryo. In addition, while a hard seed coat provides effective protection during maturation, dispersal and dormancy, it hampers germination because the embryo requires extra energy to rupture the seed coat.

Seed set in *Musa* spp. varies greatly among seed-fertile cultivars. This limitation in variable seed set is further compounded by an extremely low rate, slow and non-uniform emergence in soil thus making creation of new cultivars and other breeding activities of plantains and bananas difficult [1,6]. In fact seed emergence especially of hybrid seeds in soil is reported to be less than 1% [7]. While seeds of *Musa balbisiana* (with the B genome) readily germinate in culture and soil [8], seeds of *M. acuminata* (with the A genome) and most interspecific hybrids have poor germination and are not viable especially if the fingers are left to over ripen (blackened or rotten) before extraction [8]. However, a major source of pollen in plantain & banana breeding is the wild diploid accession, *Musa acuminata* Calcutta 4, which though agronomically poor, produces abundant and viable pollen [9]. It is resistant to black Sigatoka disease, but produces non-parthenocarpic fruits due to the presence of two complementary recessive genes for parthenocarpy [10]. It is important in germplasm enhancement because it serves as a source of plantain alleles and resistance to black Sigatoka disease [11].

The parental differences between seeds from *M. balbisiana* and other accessions could be histological, physiological or genetic in nature. Another study have identified single sequence repeats (SSRs) that could help in understanding the divergence between *M. acuminata* and *M. balbisiana* [12]. For example, in *Vicia spp*., germination ability has been linked to permeability of the seed coat, a condition that was found to be controlled by a two-gene system [13]. Similarly seed coat permeability in cotton *Gossypium hirsutum* L. was found to be controlled by a single gene [14].

Due to their triploid nature, plantains and bananas are almost completely female sterile, resulting in low seed set upon pollination and poor seed quality. If seeds from Tetraploid (4x) and Diploid (2x) crosses can be made to germinate at relatively high frequency when planted in soil, they can be grown in environments other than those under which they were produced provided that an efficient method for seed germination is available. Perhaps seeds obtained from the 4x - 2x crosses, if treated with some chemicals and sown in the soil could have relatively high emergence.

In order to increase germination, seeds are scarified by physical or chemical means to permit imbibition and improve the rate of germination or shorten the time required for germination [15]. Unfortunately, some pre-sowing treatments such as chipping of testa, scorching and the application of temperature shocks are usually deleterious and often lethal to *Musa* seeds [16]. Other methods used to overcome dormancy in *Musa* seeds include treatment with different concentrations of potassium hydroxide, sulphuric acid and carbon dioxide [17]. The use of potassium hydroxide has also been found to improve germination and emergence of several other crop species [18]. This was demonstrated in oat (*Avena fatua* L.) as dormancy was broken and germination was significantly enhanced. Other studies have pointed out that seed germination and seedling vigour can be improved as a result of various hydro priming protocols [19,20,21,22,23,24].

Since emergence of plantain and banana seeds in soil is abysmally low, hybrid seed propagation in *Musa* is usually difficult [4,7]. Therefore, the regeneration of hybrid seedlings has relied more on *in vitro* culture of excised embryos [25], a technical and relatively more expensive procedure than planting in soil. Improving *Musa* seed emergence in the soil being the natural medium of plant growth (designated as *in vivo*) could accelerate hybrid development, selection, and evaluation of several cultivars in *Musa* breeding efforts that meet the production and consumption requirements of target populations as advocated [26]. In addition enhanced seed germination would encourage seed storage in gene banks [4] for germplasm preservation. Moreover, it would facilitate the production of large number of segregating planting materials and decentralize hybrid distribution for research and production under various agro-ecologies at a relatively low cost.

The main objective of this study was to investigate how to enhance emergence of *Musa acuminata* Calcutta 4 (AA genome) seeds when planted in soil (*in vivo*) and by embryo culture technique (*in vitro*). Specifically:

I. whether varying storage durations will affect emergence of seeds planted in soil (in vivo) and embryo culture (*in vitro*) differently;
II. determine how hydro priming protocols will affect emergence of seeds planted in soil (*in vivo*) and embryo culture (*in vitro*); and
III. find out how chemical priming with various chemicals will affect emergence of seeds planted in soil (*in vivo*) and embryo culture (*in vitro*).

2. MATERIALS AND METHODS

2.1 Experimental Site and Planting Material

This study was carried out at the International Institute of Tropical Agriculture (IITA) High Rainfall Station, Onne (4°51'N, 7° 03'E, 10 m above sea level), in Rivers State, south-eastern Nigeria. The rainfall pattern is monomodal, distributed over a 10 month period from February through December, with an annual average of 2400 mm. Relative humidity remains high all year round with mean values of 78% in February, increasing to 89% in the months of July and September. The mean annual minimum and maximum temperatures are 25^0C and 27^0C, respectively, while solar radiation/sunshine lasts an average of 4 hours daily [27].

Seeds of the wild banana *M. acuminata,* Calcutta 4 (diploid AA) which is resistant to black Sigatoka disease were used to evaluate the effect of different seed treatments on direct seed emergence in soil (*in vivo*) and on embryo culture (*in vitro*). Bunches were harvested when the fruits of the proximal nodal cluster (first hand) had reached physiological maturity. Harvested bunches were ripened with ethylene for 4 days, after which the seeds were extracted mechanically, washed and air-dried.

2.2 Treatments and Experimental Details

Seed pre-sowing treatments consisted of 3 storage protocols, 3 hydro priming and 6 chemical treatment protocols. Seed pre-sowing treatments consisted of the under listed protocols, after which treated seeds were divided into 2 sets. One set was sown directly in soil (*in vivo*) and the other set subjected to embryo culture technique (*in vitro*) after embryo rescue. Each set of treatments was replicated 3 times, in a completely randomized design.

Treatment protocols

1. Three storage protocols of seed in transparent air-tight plastic jars at ambient temperature for 0 (sowing immediately on extraction), 2 weeks and 4 weeks after extraction of seeds;
2. Three hydro priming protocols, i.e., soaking of seeds in water for 0 (no soaking in water

before sowing), 4 days and 8 days before sowing. Seeds were soaked in water with 2 drops of Tween 80 (Sorbitan), agitated initially and allowed to stand for 24 hrs, with changes of solution (at 24 hrs intervals) for the different soaking durations.

3. Six chemical treatment protocols, with copper-oxychloride (0.052 M), 25% sulphuric acid (0.23 M), silver nitrate (0.06 M) plus streptomycin sulphate (0.0002 M), hydrogen peroxide (0.1 M), potassium nitrate (0.01 M) and water (control). Seeds were soaked in chemical solution with 2 drops of Tween 80 (Sorbitan), agitated initially and allowed to stand for 24 hrs.

2.3 Crop Conduction

2.3.1 Planting in soil – (*in vivo*)

On completion of treatment protocols, seeds were immediately washed with tap water and sown at a rate of 11 seeds per pot, in perforated plastic pots (16 cm x 13 cm x 4.9 cm), three-quarters filled with soil (soil, dried palm fibre and dried poultry manure in a 7:3:1 ratio). Watering of sown seeds was carried out as required. Germination was considered to have occurred when the plumule emerged about 1cm above the soil level.

2.3.2 Embryo culture – (*in vitro*)

Treated seeds were subjected to *in vitro* culture [28]. Seeds were surface sterilized (with 70% methylated spirit for 2 minutes) and transferred to a 1% solution of silver nitrate plus Tween 80 for 20 minutes and rinsed in sterilized distilled water. Embryos were excised from seeds using forceps and a scalpel under a stereoscopic microscope in a laminar flow cabinet. The excised embryos were inoculated in culture tubes, each containing 20 ml of modified MS (Murashige and Skoog) medium [29]. The medium was half the standard concentration of MS, supplemented with 3% sucrose, 2 mg 1-1 glycerine, 0.5 mg 1-1 nicotinic acid, 0.5 mg 1-1 pyridoxine, 0.4 mg 1-1 thiamine and 20 mg 1-1 ascorbic acid. Gelrite (Sigma, USA) was used to solidify the medium. Cultures were incubated under continuous light at a temperature of 10^0C and examined daily. Germination was recorded when shoots emerged to about 1 cm above the medium.

2.4 Data Collection and Statistical Analyses

The number of emerged seed in both *in vivo* and *in vitro* procedures was recorded weekly until no further emergence occurred. The experimental design was a completely randomised design with treatments replicated 3 times. Analysis of variance was used to test treatment effects. All data were analysed using the GLM procedure of Statistical Analyses Software and any effects found to be significant have been tested at a significance level of 5% while means were compared using the LSD test at $P \geq 0.05$. Graphs of means with associated standard errors were drawn to show treatment effects.

3. RESULTS AND DISCUSSION

3.1 Seed Storage Duration

Best emergence of 31% (*in vivo*) was achieved when seeds were not stored. Seeds sown in soil (*in vivo*) that were not stored had significantly higher emergence compared to seeds that were stored for 2 weeks or 4 weeks (Fig. 1). Emergence declined by 20% and 23% after 2 weeks and 4 weeks of storage respectively. However, seeds stored for 2 weeks did not significantly differ in emergence from those stored for 4 weeks. For embryo culture (*in vitro)*, seeds stored for 2 weeks had 42% germination; significantly higher germination than seeds that were not stored or seeds that were stored for 4 weeks (Fig. 1). Germination increased by 40% at 2 weeks of storage but declined by 38% beyond 2 weeks at 4 weeks of storage. There was no significant difference in germination between seeds that were not stored and those that were stored for 4 weeks. On the average germination in embryo culture *(in vitro)* was 29% higher than emergence in soil (*in vivo)* and was significantly better. Planting immediately after seed extraction was best for soil *(in vivo*) and planting at 2 weeks of storage was best for embryo culture (*in vitro*). This was significantly better and 36% higher than the best soil (*in vivo*) emergence.

Emergence in soil (*in vivo*) was significantly higher in seeds that were not stored than for seeds stored for 2 weeks or 4 weeks (Fig. 1). Storage of seeds of pearl millet (*Pennisetum glaucum*, Slapf & Habbnd) for 10 days reduced soil germination, and declined further after 14 days of storage [30]. A major limitation of stored seeds may result from the seed coat. The seed coat contains ferulic acid and polyphenolic compounds that affect soil germination by restricting the embryo development [1]. Germination in soil (*in vivo*) was reported to be

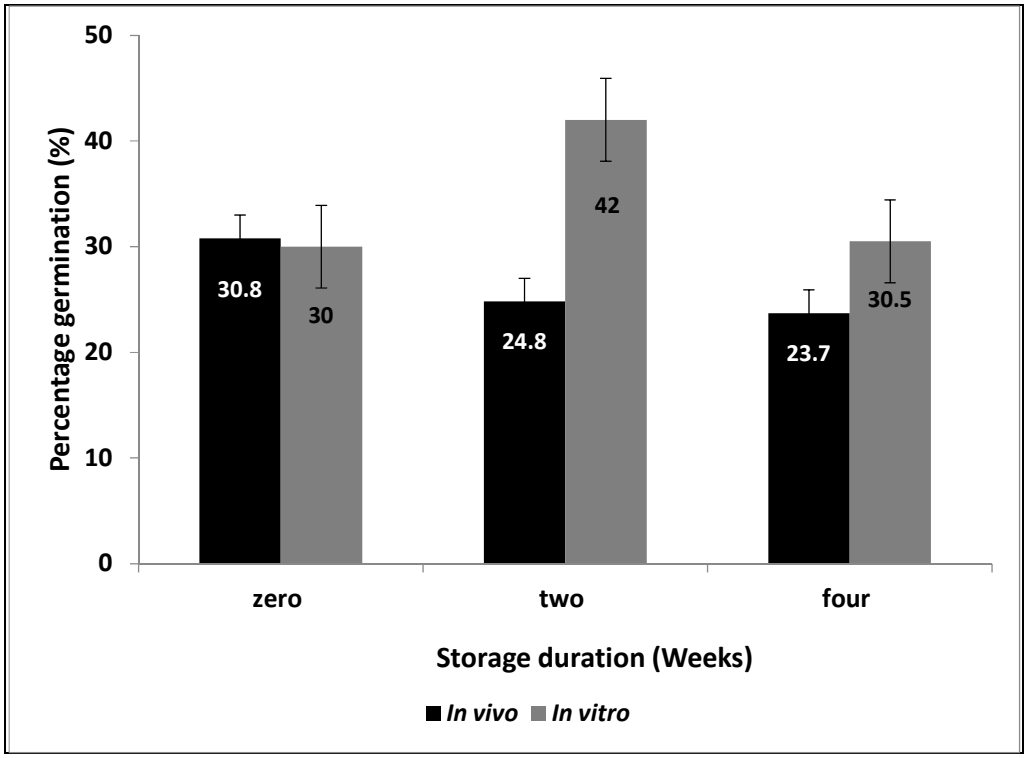

Fig. 1. Effect of storage duration on *in vivo* and *in vitro* percentage germination of *Musa acuminata* Calcutta 4

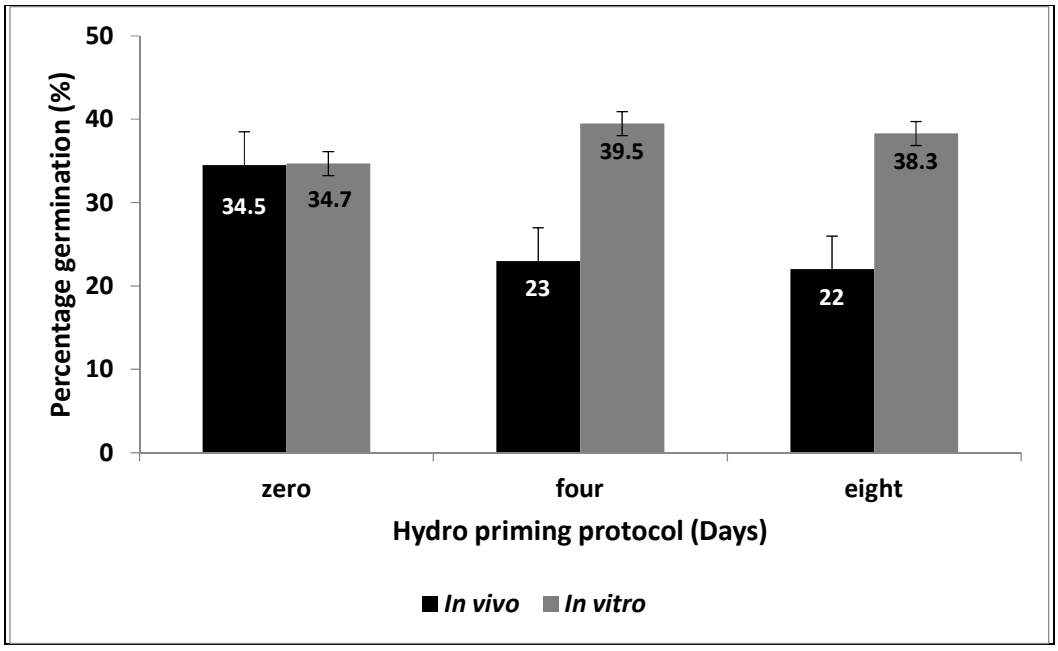

Fig. 2. Effect of hydro-priming on *in vivo* and *in vitro* germination of *Musa acuminata* Calcutta 4

as erratic as <5%-23% over 20 days [31]. In this study, *in vivo* emergence ranged from 24%-31% for storage duration. For embryo culture (*in vitro*) germination was significantly higher in seeds

stored for 2 weeks, and declined thereafter. Perhaps lower moisture content could have played a role in the higher level of emergence observed after 2 weeks of storage and the decline beyond 2 weeks to 4 weeks [31]. While storage for 2 weeks increased *in vitro* germination, it reduced the rate of *in vivo* emergence, although the data suggests that the seeds in both instances retained viability for as long as 4 weeks. For best results, seeds to be planted in soil (*in vivo*) should be planted as soon as they are excised from the fruits while seeds for embryo culture (*in vitro*) should be stored for 2 weeks before use.

3.2 Hydro Priming Protocol

When seeds were sown in soil (in vivo), emergence was significantly higher for seeds that were not hydro primed than for seeds that were hydro primed for 4 days or 8 days (Fig. 2). Emergence declined by 33% and 38% in seeds hydro primed for 4 days and 8 days respectively. Emergence of seeds that were hydro primed for 4 days did not significantly differ from those that were hydro primed for 8 days. In embryo culture (in vitro) germination of those not hydro primed was significantly lower than those hydro primed for 4 days and 8 days (Fig. 2). Hydro priming for 4 days increased germination significantly by 60% compared to those without hydro priming but reduced germination by 3% when hydro primed for 8 days compared to that hydro primed for 4 days. There was no significant difference in germination between seeds hydro primed for 4 days and that hydro primed for 8 days (Fig. 2). Comparing both procedures, again on the average, germination in embryo culture (in vitro) was 29% higher than in soil (in vivo) and was significantly better. Planting without hydro priming was best for soil *(in vivo*). Planting after 4 days hydro priming was best for embryo culture (*in vitro*) resulting in a 15% higher germination than the best soil (*in vivo*) emergence.

Seeds that were not hydro primed gave significantly higher *in vivo* emergence compared to seeds hydro primed for 4 days and 8 days (Fig. 2). Sowing of hydro primed seeds in the soil led to decline in the rate of emergence. It is likely that hydro priming reduced the protection level provided by the seed coat under normal circumstances. Hence, the seeds became exposed to microbial attack and other detrimental soil factors [31] or the moisture content of the seeds could have exceeded the optimum required for germination over the 4 days - 8 days period [31].

In embryo culture (*in vitro*) seeds hydro primed for 4 days gave significantly higher germination than seeds hydro primed for 8 days. Hydro priming for 5 days was reported to have increased *in vitro* germination in *M. balbisiana* more than hydro priming for 3 days and 9 days [32]. They found germination after hydro priming for 5 days was 94% (*in vitro*) within 7 days compared to 50% after 54 days for greenhouse-sown seeds (*in vivo*). Similarly, in this study, hydro priming only increased *in vitro* but not *in vivo* emergence. Hydro priming is also thought to increase free-radical scavenging enzyme activity, counteracting the effects of lipid peroxidation and reducing leakage of metabolites [33, 34,35]. It is likely that by the fourth day of soaking, the embryos could have become metabolically active for rapid germination under aseptic conditions. The reasons for the difficulty in achieving high emergence of *Musa* under natural conditions (*in vivo*) need to be further investigated.

3.3 Chemical Priming Protocol

Emergence of seeds primed with sulphuric acid was significantly lower than those of seeds primed with other chemicals or the control in both *in vivo* and *in vitro* procedures (Fig. 3). Other than this, for soil, (*in vivo*) there was no significant difference in emergence of seeds primed with other chemicals and the control (water). In fact, all the chemicals reduced emergence by 6% (KNO_3), 8% (CuOCl), 11% ($AgNO_3$ + Streptomycin), 21% (H_2O_2) and significantly by as much as 63% (H_2SO_4) compared to the control. However, in embryo culture (*in vitro*), copper oxychloride increased germination by 18% compared to the control achieving 47% germination. All other chemicals reduced germination by 11% ($AgNO_3$ + Streptomycin), 21% (KNO_3), 23% (H_2O_2) and significantly by 50% (H_2SO_4) compared to the control. Emergence in all chemical priming treatments was lower for *in vivo* than for *in vitro* procedures. The best *in vitro* germination was with copper oxychloride priming which was significantly better and 46% higher than the best *in vivo* emergence, the control -priming with water (32% germination).

Chemical priming of seeds did not improve germination of *M. acuminata* Calcutta 4, although their efficacy has been reported in several other crop species [36]. This study has shown that sulphuric acid priming at the concentration used, significantly reduced both *in vivo* and *in vitro* germinations (Fig. 3). Emergence *in vivo* did not significantly differ between chemically primed

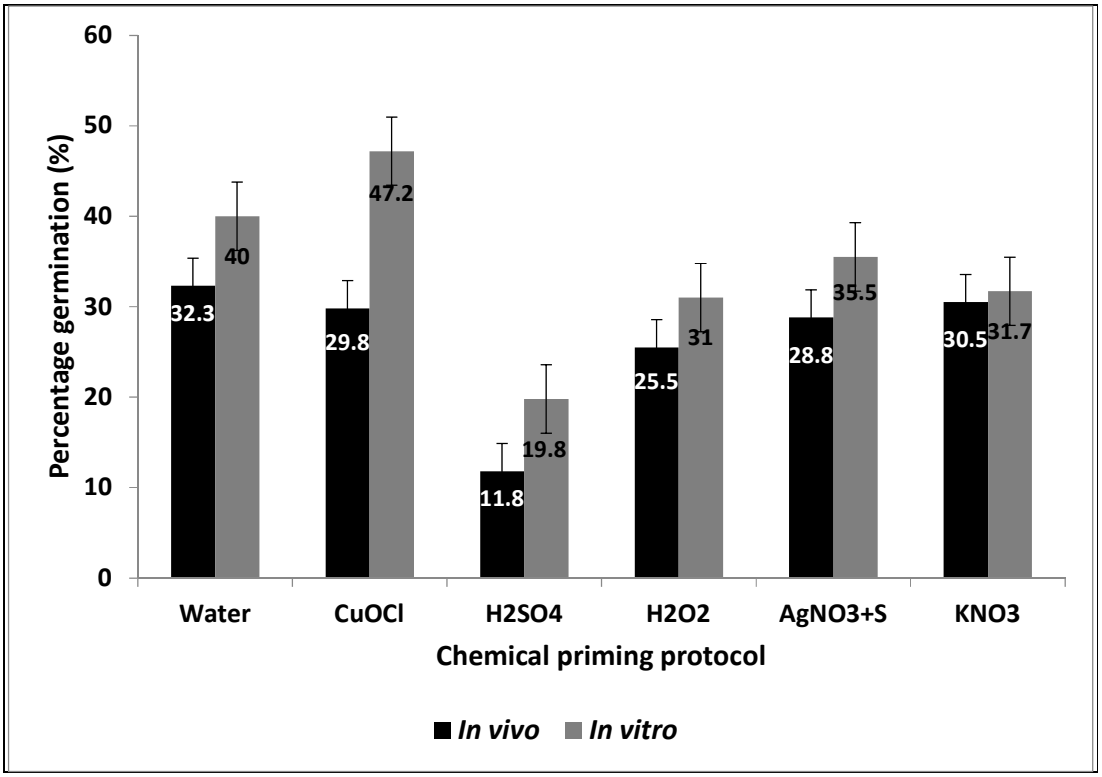

Fig. 3. Effect of chemical priming on *in vivo* and *in vitro* germination of *Musa acuminata* Calcutta 4

seeds and the control. This suggests that the chemical priming at the concentrations used, did not improve *in vivo* emergence. However, significantly higher germination was reported with application of copper oxychloride in hybrid plantain seeds when applied at low concentrations as a fungicide to soil [6] rather than as a seed primer. This perhaps indicates that soil treatment rather than seed treatment could be an avenue for further exploration. They also identified the average weather conditions such as air, temperature and sunshine at the time of seed treatment as a significant factor influencing the germination of the seeds.

For *in vitro* germination, priming with copper oxychloride produced a significantly higher germination than other chemicals implicating perhaps its anti-fungal properties relative to the other chemicals in embryo culture.

Consistently higher germination was recorded with *in vitro* than *in vivo* procedures irrespective of the treatments applied. Almost all studies conducted have reported the same trend [32,37,38,39].

4. CONCLUSION

Consistently higher germination was recorded with *in vitro* than *in vivo* procedures irrespective of the treatments applied. Perhaps inherent factors in the seed coat and possible interactions in soil may account for the poor emergence exhibited *in vivo* and will require further investigation. In this study, sowing seeds extracted immediately without hydro priming was best for (*in vivo*), while for embryo culture (*in vitro*), storage for 2 weeks and hydro priming for 4 days or priming with copper oxychloride gave the best results.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Graven P, De Koster CG, Boon JJ, Bouman F. Structure and macromolecular composition of seed coat of the *Musaceae*. Annals of Botany. 1996;77:105-122.
2. Cronquist A. An integrated system of classification of flowering plants. Columbia University Press, New York; 1981.
3. Kiew R. Notes on the natural history of the Johore banana, *Musa gracilis* Holtum. Malayan Nature Journal. 1987;41:239-248.
4. Chin, HF Germination and storage of bananas seeds. In: Frison EA. Horry JP. DE Waele D. (eds) New frontiers in resistance breeding for nematode, fusarium and Sigatoka. INIBAP. Proceedings of workshop held in Kuala Lumpur, Malaysia. 1995;218-227.
5. Owen EB. The storage of seeds for maintenance of viability. Commonwealth Agricultural Bureaux. Field Crops Bulletin. 1956;43:81.
6. Dumpe BD, Wokoma ECW. Factors influencing germination of hybrid plantain seeds in soil. Plant Foods for Human Nutrition. 2003;58:1–11.
7. Ortiz R, Vuylsteke D. Factors influencing seed set in triploid *Musa* spp. L. and production of euploid hybrids. Annals of Botany. 1995;75:151-155.
8. Simmonds NW. The germination of banana seeds. Tropical Agriculture Trinidad. 1952;29:2-16.
9. Swennen R, Vuylsteke D. Breeding black Sigatoka resistant plantains with a wild banana. Tropical Agriculture Trinidad. 1993;70(1):74-77.
10. Simmonds NW. Segregations in some diploid bananas. Journal of Genetics. 1953;51:458-469.
11. Vuylsteke D, Ortiz R. Plantain-derived diploid hybrids (TMP2x) with black Sigatoka resistance. American Journal of Horticultural Science. 1995;30:147-149.
12. Ravishankar KV, Sampangi-Ramaiah MH, Ajitha R, Khadke GN, Chellama V. Insights into *Musa balbisiana* and *Musa acuminata* species divergence and development of genic microsatellites by transcriptomics approach. Plant Gene. 2015;4:78-82.
13. Donnelly ED, Watson JE, McGuire JA. Inheritance of hard seed in Vicia. Journal of Hereditary. 1972;63:361-365.
14. Lee JA. Inheritance of hard seed in cotton. Crop Science. 1975;15:149-152.
15. Lopez JH, Aviles RB. The pre-treatment of seeds of four Chilean prosopis to improve their germination response. Seed Science and Technology. 1988;16:239-246.
16. Simmonds NW. The evolution of the bananas. Longmans, London; 1962.
17. Simmonds NW. Experiments on the germination of banana seeds. Tropical Agriculture, Trinidad. 1959;36(4):259-273.
18. Gao YP, Zheng GH, Gusta LV. Potassium hydroxide improves seed germination and emergence in five native plant species. American Journal of Horticultural Science. 1998;32(2):274-276.
19. McDonald MB. Seed priming. In: Black m, Bewley JD. (eds). Seed technology and its biological basis. Sheffield Academic Press, England. 2000;287–325.
20. Halmer P. Methods to improve seed performance in the field. In: Benech-arnold RL. Sanchez R. (eds). Handbook of seed physiology. Food Product Press, New York. 2004;125–156.
21. Ghassemi-Golezani K, Sheikhzadeh-Mosaddegh P, Valizadeh M. Effects of hydro-priming duration and limited irrigation on field performance of Chickpea. Res. J. Seed Sci. 2008;1:34-40.
22. Ghassemi-Golezani K, Chadordooz-Jeddi A, Nasrullahzadeh S, Moghaddam M. Effects of hydro-priming duration on seedling vigor and grain yield of pinto bean (*Phaseolus vulgaris* L.) cultivars. Not. Bot. Hor. Agro. Cluj Nap. 2010;38:109–113.
23. Ghassemi-Golezani K, Hossseinzadeh-Mahootchy A, Zehtab-Salmasi S, Tourchi M. Improving field performance of aged chickpea seeds by hydro-priming under water stress. Int. J. Plant Animal Environ. Sci. 2012;2:168–176.
24. Ghassemi-Golezani K, Hosseinzadeh-Mahootchy A. Influence of hydro-priming on reserve utilization of differentially aged chickpea seeds. Seed Technology. 2013;l35(1):117-124.
25. Vuylsteke D, Swennen R, De Langhe E. Tissue culture technology for the improvement of African plantains. In: Fullerton RA, stover RH. (eds). Sigatoka leaf spot diseases of bananas INIBAP Proceedings, San José, Costa Rica. 1990;316-337.
26. Coffman WR, Smith ME. Role of public, Industry and International Research Centre. Breeding programs in developing germplasm for sustainable agriculture. In: Sleeper, da, barker, tc. bramel-cox, pj.

(eds) plant breeding and sustainable agriculture, considerations for objectives and methods. CSSA Special Publication. 1991;18:1-9.

27. Ortiz R, Austin PD, Vuylsteke D. IITA high rainfall station African humid forest. American Journal of Horticultural Science. 1997;32:969-972.
28. Vuylsteke D, Swennen R, De Langhe E. Tissue culture technology for the improvement of African plantains. In: Fullerton ra, stover rh (eds). Sigatoka leaf spot diseases of bananas. INIBAP Proceedings, San José, Costa Rica. 1990;16-337.
29. Vuylsteke D. Shoot-tip culture for the production, conservation and exchange of *Musa* germplasm. Practical manuals for handling crop germplasm in vitro 2. International Board for Plant Genetic Resources, Rome. 1989;56.
30. Singh J, Govila OP, Agrawal PK. Preliminary results from a study of seed germinability of pearl millet (*Pennisetum typhoides* L.) F_1 hybrids and their parents during accelerated ageing test. Seed Science and Technology. 1988;16:685-692.
31. Vineesh PS, Skaria R, Mukunthakumar S, Padmesh P, Decruse SW. Seed germination and cryostorage of *Musa acuminata* subsp. Burmannica from Western Ghats. South African Journal of Botany. 2015;100:158–163.
32. Afele JC, De Langhe E. Increasing in vitro germination of *Musa balbisiana* seed. Plant Cell, Tissue and Organ Culture. Kluwer Academic Publishers, Netherlands. 1991;27:33-36.
33. McDonald MB. Seed deterioration: Physiology, repair and assessment. Seed Sci. Technol. 1999;27:177–237.
34. Hsu CC, Chen CL, Chen JJ, Sung JM. Accelerated aging-enhanced lipid peroxidation in bitter gourd seeds and effects of priming and hot water soaking treatments. Sci. Hortic. 2003;98:201–212.
35. Wang HY, Chen CL, Sung JM. Both warm water soaking and solid priming treatments enhance anti-oxidation of bitter gourd seeds germinated at sub-optimal temperature. Seed Sci. Technol. 2003;31(1):47–56. DOI:https://doi.org/10.15258/sst.2003.31.1.06
36. Copeland LO, McDonald MB. Principles of seed science and technology. 3rd edition. Macmillan, New York. 1995;409.
37. Chin HF. Germination and storage of banana seeds. In: Frison AE, Horry JP, De Waele D. (eds). New frontiers in resistance breeding for nematodes, fusarium and Sigatoka. INIBAP, Montpellier, France. 1996;218-227.
38. Uma S, Lakshmi S, Saraswathi MS, Akbar A, Mustaffa MM. Embryo rescue and plant regeneration in banana (*Musa* spp.). Plant Cell Tissue Organ Cult. 2011;105–111.
39. Uma S, Lakshmi S, Saraswathi MS, Akbar A, Mustaffa MM. Plant regeneration through somatic embryogenesis from immature and mature zygotic embryos of *Musa acuminata* ssp. Burmannica. In Vitro Cell Dev. Biol. Plant. 2012;48:539–545.

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