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Variation in seed and seedling traits of the different ethno-varieties of jackfruit, a potential fruit tree species for food security

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A B S T R A C T

A key component of the performance of plant seeds is the germination capability as well as seedling survival and vigor. Seed traits from five jackfruit ethno-varieties (infra-specific diversity as understood and managed by farmers) were assessed. A greenhouse experiment was conducted to determine the survival of seeds, emergence and germination rate. Seeds from different ethno-varieties differed in their length (F (4,145) = 6.31, $p < 0.001$). The difference was highest between seeds from white, orange or yellow ethno-varieties. The width also slightly differed among ethno-varieties (F (4,145) = 3.29, $p < 0.05$). The average fresh and dry weights tended to be higher in seeds from the soft ethno-variety than the rest of the ethno-varieties. Differences in the survival of seeds and germination rate were also exhibited among ethno-varieties, where the white ethno-variety showed the highest pre-emergence mortality but at the same time the least germination time. Over the six-week period of germination, the soft ethno-variety exhibited the highest root:shoot ratio but also grew faster than all other ethno-varieties. There is potential evidence of phylogenetic constraints on seed size, germination and seedling vigor. Optimum growth for most of the traits was achieved between 6 and 7 weeks after sowing, which can guide on the time seedlings should be left in the pots before being transferred to the field. Further progeny tests should be undertaken on these provenances in the field over a longer period so as to obtain better distinction of the growth traits among the ethno-varieties.

Introduction

Seeds are central to crop production, food security as well as plant restoration and sustainability, and successful seed germination and vigor of seedlings are desirable traits. However, several factors affect successful establishment of seedlings, and these include seed traits, the environment and the interactions (Khan et al., 2012; Upadhaya et al., 2007; Xu et al., 2014). Among the traits of importance, seed mass and external morphological traits like shape have been shown to have an effect on germination and ultimately, emergence, seedling establishment, persistence of plants and even the reproductive ability of adult plants (Barak et al., 2018; Jiménez-Alfaro et al., 2016; Wang et al., 2016). Moreover, these aspects are influenced both by genetics and environmental conditions during seed development, as well as subsequent harvesting methods, handling, and storage (Khan et al., 2012; Singh et al., 2006). The phylogenetic signal is likely to cause a variation in seed traits and germination among families or populations (Moya et al., 2017; Xu et al., 2014). This variation has consequences for agricultural production systems, affecting the uniformity of the crop and subsequent management cost, yield and marketing quality. Therefore, improved understanding of seed and germination traits and their effects on plant germination, emergence, and establishment may help make crop production outcomes more predictable (Brudvig et al., 2017).

Jackfruit (*Artocarpus heterophyllus* Lam.) has potential to reduce food and nutrition insecurity for both rural and urban communities in various parts of the world (Borines et al., 2014; Swami et al., 2012). Studies have shown that jackfruit is rich in both macro and micronutrients including carbohydrates, proteins, vitamins as well as minerals that could be a valuable part of food (Nantongo et al., 2021; Ranasinghe et al., 2019; Swami et al., 2012). Other parts of jackfruit trees including fruits, leaves, and bark have also been extensively used in traditional medicine due to their anti-carcinogenic, antimicrobial, antifungal, anti-inflammatory, wound healing, and hypoglycemic effects (Hari et al., 2014; Ranasinghe et al., 2019; Vazhacharickal et al., 2015).

In Uganda, there is a deliberate effort to increase jackfruit production through establishment of orchards. Currently, the trees are commonly found as scattered agroforestry trees managed by small-holder farmers, propagated through seed (Balamaze et al., 2019). Farmers possess 2–7 jackfruit trees on their farms and a large proportion of the planting is not deliberate (Balamaze et al., 2019). Even where there is deliberate effort to plant jackfruit, planting is often done by transplanting already germinated seedlings within the area. Non-deliberate planting is however, met by germination constraints, where the ethno-varieties that easily germinate, emerge and establish are more likely to be found on farms. This not only threatens the diversity of the difficult-to-germinate ethno-varieties, but it also impedes the potential nutritional benefits that

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could be derived from the diversity of the jackfruits. Although closely-related individuals should share similar germination times, studies have also indicated the existence of phylogenetic constraints on seed traits as well as seed germination within a genus or family (Barak et al., 2018; Daws et al., 2002; Parker et al., 2006). Whether this is present in jackfruit still needs to be confirmed. Therefore, the objectives of the study were to; 1) examine the intraspecific differences in seed and seedling traits of Jackfruit ethno-varieties and 2) to assess the potential of separating the ethno-varieties of jackfruit based on phenotypic traits of seedlings. The prefix 'ethno' refers to traditional knowledge and cognition available in a given culture (Sturtevant, 1964). The concept of 'ethno-variety' can therefore be defined as the infra-specific diversity, especially in crop plants, as understood and managed by farmers (Rivera et al., 2006). In this paper therefore, a grouping of jackfruit tree phenotypes identified by farmers under a single name within a particular ethnic group is referred to as an 'ethno-variety'. By understanding the variability in seeds and seedlings, it is possible to develop strategies to increase production of preferred ethno-varieties for both small-holder farmers and jackfruit orchards. This is very vital especially following studies that have highlighted little success with vegetative propagation of jackfruit, which has been attributed to the high sap in the plant (Khatun et al., 2008).

Materials and methods

Seed sampling

Sampling was done based on the existing ethno-varieties (white, yellow, orange, red and soft) in the Eastern agroecological zone of Uganda. The number of sampled trees per ethno-variety ranged from 9 to 12 depending on the availability of reproductively mature individuals at the time of seed collection. Two fully ripened fruits from each tree were harvested and seeds extracted. To ensure maximum unrelatedness, the selected seed trees were between 100 m and > 1 km apart from each other. A minimum of 100 seeds were extracted from each fruit and the seeds from the trees belonging to the same ethno-variety were mixed to form a composite sample. Seeds were stored in cool boxes according to ethno-variety and then transported to the laboratory at the National Forestry Resources Research Institute (NaFORRI) in Mukono, Uganda.

Assessment of seed traits

A total of 150 random seeds were assessed for length and width above the seed coat. Three random batches of 10 seeds per ethno-variety were also weighed when fresh (to get the fresh weight) and then dried in the oven at 70 °C for 24 h (Mabel Queiroz de Oliveira et al., 2022) and then reweighed to get the dry weight.

Seed germination test

The germination experiment was conducted in a greenhouse at NaFORRI. The mean reduction in solar irradiance in the greenhouse in relation to outdoor conditions on sunny days was about 60%. The pot size was 6 inches x 9 inches using top forest soil. The seeds were kept in cool boxes before sowing. Sowing was done eight days after seed collection by inserting one seed into the soil, up to a depth of 5 cm below the surface. The pots were drenched with a fungicide (the tradename is Ridomil) on sowing. Daily watering was done immediately after sowing until the end of the experiment. A total of 108 seeds for each ethno-variety were sown in a randomised complete block design of nine line plots containing 12 pots each. The line plots were randomly placed in three blocks, three lines per block. Observations were done weekly for a period of 6 weeks. Assessment of germination and seedling growth began three weeks after sowing to allow for complete germination (Warrier et al., 2009). This was done by destructive sampling of 2 pots of each ethno-variety (18 plants per ethno-variety). Assessment was done for germination, root and shoot length, root collar diameter and leaf number. The seeds whose cotyledons had emerged were considered as germinated. The chronology of the activities of the experiment are highlighted in the supplementary Table 1.

Data analysis

The mean values and the associated standard error as well as the Pearson's phenotypic correlations between all evaluated traits were estimated using MS Excel. To detect the differences among the different ethno-varieties, one-way analysis of variance (ANOVA) for each trait was done in R computing version 3.6.0 (R Core Team, 2021). Where a significant difference between groups was detected, the least significant difference between the groups was calculated. Significant differences between means were considered at $p < 0.05$, with Bonferroni adjustment for multiple testing. To test whether the ethno-varieties could be distinguished using the seedling traits, a multivariate principal component analysis (PCA) was done in R using the FactoMineR function (Lê et al., 2008). To identify the significance of the separation along the principal components, ANOVA was applied to the loadings of the first three principal components. Differences between groups were tested as mentioned above. For simplicity in this paper, the seeds will be referred to according to ethno-variety, for example those from the white ethno-variety will be referred to as white seeds and so on.

Results

Variation in seed characteristics

Seeds from different ethno-varieties differed in their length ($F(4145) = 6.31$, $p < 0.001$). The difference was strongest between the white and orange or yellow seeds, where the mean length of white seeds ($\bar{x} = 2.35$ cm) was significantly smaller than the mean of the orange ($\bar{x} = 2.72$ cm, diff = 0.37 cm, $p < 0.001$) and yellow ($\bar{x} = 2.67$ cm, diff = 0.33 cm, $p < 0.01$) seeds. The red seeds ($\bar{x} = 2.45$ cm) were also smaller than the orange seeds (diff = 0.27 cm, $p < 0.05$). There were also some marginal differences between the yellow and red seeds (yellow > red, diff =0.23 cm, $p = 0.07$) as well as the white and soft seeds (soft > white, diff = 0.23 cm, $p = 0.07$). The width also slightly differed among the ethno-varieties ($F(4145) = 3.29$, $p < 0.05$), where white seeds tended to be narrower than the orange and soft seeds (Supplementary Table 2).

Combining both length and width showed that white seeds were significantly smaller than orange seeds (diff = 0.69 units, $p = 0.001$) or soft seeds (diff = 0.59 units, $p < 0.007$). The red seeds were also smaller than orange seeds (diff = 0.55, $p < 0.01$) (Supplementary Table 2). The average fresh and dry weights were higher in seeds from the soft and yellow ethno-varieties compared to the rest of the seeds (Fig. 1; Supplementary Table 2).

Germination rates

At the first week of measurement (4th week since sowing), irrespective of ethno-variety, there was 64% survival of seeds. Differences were however, exhibited by ethno-varieties in the survival of seeds and germination rate (Fig. 2). The white ethno-variety showed the highest pre-emergence mortality but at the same time the least germination time. The orange and soft seeds seem to require the most time for germination since they had the highest number of ungerminated seeds by the time of initial assessment. The orange seeds further exhibited the least pre-emergence mortality by the time of initial assessment (Fig. 2). The red seeds showed the highest germination rate by the assessment time.

Root:shoot (RS) ratio

Whole-plant growth rate was measured as the root:shoot ratio,

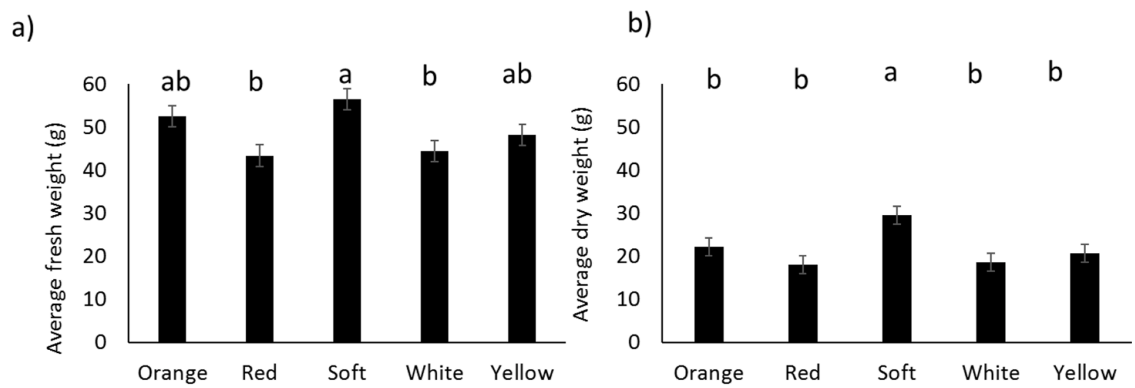

Fig. 1. (a) Average fresh weight, (b) average dry weight of a batch of 10 seeds of the different ethno-varieties of jackfruit.

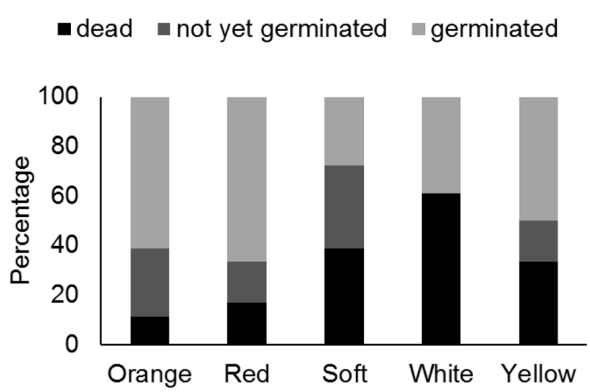

Fig. 2. Survival and germination of the seeds from different varieties assessed 3 weeks after sowing.

indicating how the seedlings partition the photosynthate. Overall, the RS ratio was higher at 5 weeks after planting (Fig. 3). Over the six-week period of the experiment, the soft ethno-variety exhibited the highest RS ratio. However, different ethno-varieties followed different trajectories, where RS of the soft and orange ethno-varieties was highest in the 2nd week while the RS ratio of the yellow ethno-variety was highest in the 3rd week while for the red, maximum RS ratio was highest in week 4 (Fig. 3).

Optimum growth for most of the traits in the different ethno-varieties was achieved between 6 and 7 weeks after sowing. Overall, the soft ethno-variety that had the highest RS ratio grew faster than all other ethno-varieties. However, there was variation in the trajectory of individual traits for the different ethno-varieties (Fig. 4). For example, differences in radicle length (4, 56, $F = 2.85$, $p < 0.05$) and root collar diameter (4, 46, $F = 3.54$, $p < 0.01$) among ethno-varieties were detected at the 2nd and 4th week of measurement, respectively. The ethno-varieties also differed in the number of lateral roots (4.47, $F = 3.13$, $p < 0.05$), where the soft ethno-variety tended to have the highest number of leaves while the orange ethno-variety had the least number of roots.

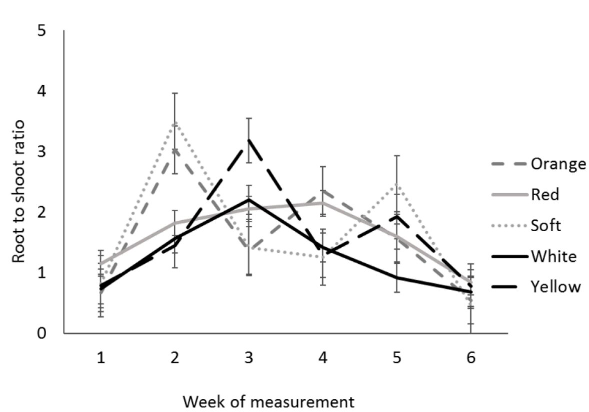

Fig. 3. Progress of root:shoot ratio of the different ethno-varieties of jackfruit.

Correlation among traits

There was a positive correlation between most of the seedling traits Table 1). However, a negative correlation was detected between number of roots and the length of lateral roots at week 3 suggesting a possible trade-off. This trade-off was not detected at any other weeks of measurement (data not shown).

Separation of seedlings in space

To understand whether the seedlings could be separated in space based on all the seedling measurements taken over the 6-weeks period, the first principal component separated the seedlings of the red ethno-variety from other ethno-varieties ($F = 5.17$, $p < 0.001$) suggesting that these seedlings potentially differ in the overall mean of the measured traits compared to other seedlings (Fig. 5). The red ethno-varieties tended to have the least value of the assessed seed traits.

Discussion

Variability in seed behavior and germination is observed across multiple scales including among populations and individuals and is a consequence of a combination of biotic and abiotic factors. In this study, there was significant variation in seed traits, where seeds from the white ethno-variety were the smallest. Seed mortality for this ethno-variety was also higher than the other seed types, although all surviving seeds had all germinated at the time of measurement. The size of the white seeds possibly contributed to both their mortality and quick germination. With regard to their mortality, it is possible that these seeds received excess water than is required during nursery management since they are smaller. Studies have shown that seed germination of species vary significantly in response to various water regimes (Daws et al., 2008; Gorai et al., 2009; Maraghni et al., 2010). Understanding the optimal watering requirements for the seeds from different ethno-varieties would, therefore, be interesting. Mortality could also be that these smaller seeds lose their viability more quickly or are more prone to pre-sowing fungal infections than the others. Warrier et al. (2009) and Merlin and Palanisamy (2000) indicated that viability may be reduced in jackfruit seeds at 8 −14 days of storing under dry conditions of storage with free air circulation. However, how long the seeds lose viability under cool storage and how this varies among ethno-varieties is not well documented. Future studies should consider

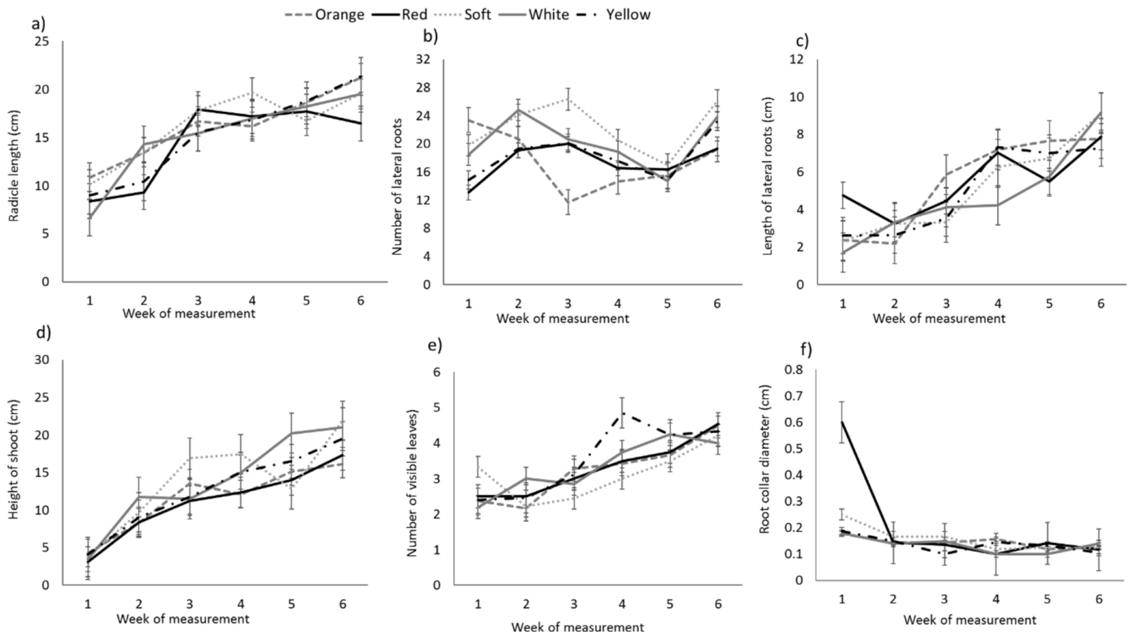

Fig. 4. The change in growth parameters of the 5 traits assessed over the 6 - weeks period. Measurements commenced 3 weeks after sowing.

Table 1
Correlation among seedling traits assessed in the 3rd week of measurement.

	Radicle length (cm)	Length of lateral roots (cm)	Number of roots	Root collar Diameter (cm)	Total height of shoot (cm)
Length of lateral roots (cm)	0.21				
Number of roots	0.54	−0.23			
Root collar Diameter (cm)	−0.04	0.19	0.06		
Total height of shoot (cm)	0.38	0.15	0.27	0.15	
Number of visible leaves	0.12	0.04	0.00	−0.01	0.47

testing the viability of the seeds progressively from the time of harvesting under different storage conditions. Seed decay can also be driven by the depth of the burial of the seeds, where germination of smaller seeds is reduced with increased burial depth, and in contrast large seeds have greater and more rapid emergence from deeper depths (Benard and Toft 2007; Chauhan et al., 2006; Maraghni et al., 2010). In this current study, the depth of sowing was not measured but the results suggest that the burial depth of white seeds should possibly be smaller than for seeds from other ethno-varieties, and this could be an aspect of investigation. These results are also consistent with other studies that have indicated that small seeds tend to have greater germination percentage within a population (Benard and Toft, 2007; Fang et al., 2017; Saeed and Shaukat 2000; Upadhaya et al., 2007). The comparative size of the seeds of the white ethno-variety is also consistent with early successional habitats, which implies that these seeds need more light to germinate compared to the others. Hence, the 60% light of the greenhouse may not have been favourable, causing more mortality. Likewise, the seeds form the soft ethno-variety that had the highest fresh and dry weight also exhibited the least rate of germination at the start of measurement.

The soft seeds, which tended to have the highest fresh and dry weight also had a tendency to exhibit the highest overall R:S ratio throughout the experiment. The red seeds that also tended to have low seed weight and size were significantly spatially separated from the rest, suggesting that overall, seedling properties from the red seeds were different in size (smaller) than the others. Seed mass is an important trait since it directly relates to the amount of nutritional reserves that can be allocated to initial seedling development (Kołodziejek, 2017). Hence, it has been indicated that when compared to lighter seeds, heavier seeds often have a higher germination percentage and produce more vigorous seedlings (Parker et al., 2006; Upadhaya et al., 2007), which are more likely to cope with limitations imposed by growth-constraining resources in the environment and may ultimately influence the rate of plant growth. In this case, the seedlings from the soft seeds could easily cope with environmental stresses such as those likely to be imposed by climate change.

Overall, the germination behavior of seeds from the white and soft ethno-varieties represents an evolutionary trade-off, the former seeds have greater competitive advantage, especially in early successional habitats, while the latter will survive better where later growth is faced with more competition (Ginwal and Gera, 2000; Houssard and Escarré, 1991). In Acacias for example, the rate of seed germination was found to positively correlate with growth in the field seedlings (Ginwal and Gera, 2000). We also noted during the field survey as we collected the seeds that the soft ethno-varieties tended to have the biggest fruits compared to other ethno-varieties. These differences can be exploited to breed for tailored end-uses. However, for production planning it should also be noted that seed size can trade-off with seed number in the fruit, an aspect that may need to be examined in the jackfruit. We also acknowledg that although developmental morphology is inherent, its expression will vary in response to growing conditions. In the nursery environment, root:shoot ratio could possibly vary with growing media, nutrient supplementation or watering regimes (Abera et al., 2018; Kołodziejek, 2017). In the field, plants distribute higher proportions of biomass into leaves and stems in nutrient-rich environments where above-ground competition for light is strong, whereas in nutrient-poor environments, where below-ground competition prevails, they allocate a higher proportion to roots (Yan et al., 2016). Therefore, seedlings need to be monitored in the field as sometimes environmental traits that are suitable for seed germination may not be ideal for seedling or adult plant development, which generates a seed-seedling conflict (Veloso et al., 2017).

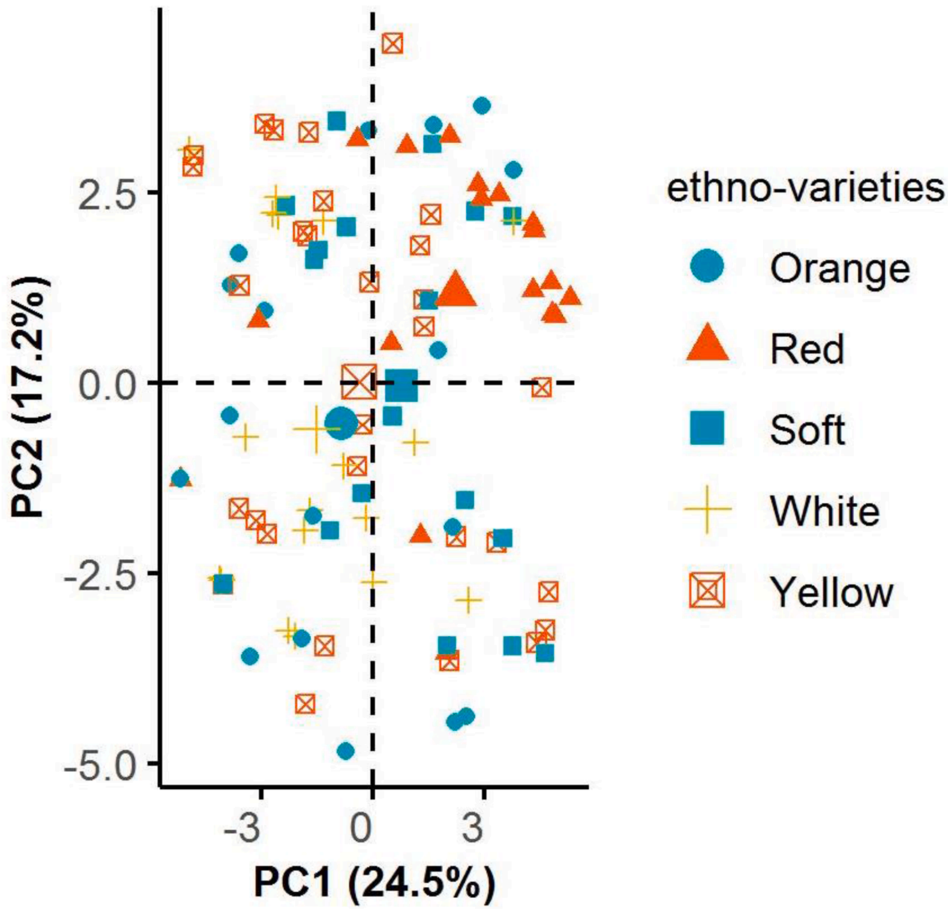

Fig. 5. The principal component analysis (PCA) plot showing the separation of space of seedlings from different ethno-varieties based on the traits assessed over 6 weeks.

Conclusion

Optimum growth for most of the traits was achieved between the 3rd and 4th week of measurement (6–7 weeks after sowing), which can guide on the time the seedlings should be left in the pots before being transferred to the field. There is some evidence of phylogenetic constraints on seed and seedling traits. However, since the period of this study was short (2.5 months), further progeny tests should be undertaken on these provenances in the field over a longer period so as to obtain more information on the traits. We also noted that by the 4th week of measurement, the roots were beginning to outgrow the size of the pots, indicating that future experiments need to use larger pots. Seeds also need to be tested for viability before the start of experiments.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.tfp.2022.100303.

References

Abera, B., Derero, A., Waktole, S., Yilma, G., 2018. Effect of pot size and growing media on seedling vigour of four indigenous tree species under semi-arid climatic conditions. For. Trees Livelihoods 27, 61–67.
Balamaze, J., Muyonga, J., Byaruhanga, Y., 2019. Production and utilization of jackfruit (Artocarpus heterophyllus) in Uganda. Afr. J. Food Agric. Nutr. Dev. 19, 14289–14302.
Barak, R.S., Lichtenberger, T.M., Wellman-Houde, A., Kramer, A.T., Larkin, D.J., 2018. Cracking the case: seed traits and phylogeny predict time to germination in prairie restoration species. Ecol. Evol. 8, 5551–5562.
Benard, R.B., Toft, C.A., 2007. Effect of seed size on seedling performance in a long-lived desert perennial shrub (Ericameria nauseosa: asteraceae). Int. J. Plant Sci. 168, 1027–1033.
Borines, L.M., Palermo, V.G., Guadalquiver, G.A., Dwyer, C., Drenth, A., Daniel, R., Guest, D.I., 2014. Jackfruit decline caused by Phytophthora palmivora (Butler). Australas. Plant Pathol. 43, 123–129.
Brudvig, L.A., Barak, R.S., et al., 2017. Interpreting variation to advance predictive restoration science. J. Appl. Ecol. 54, 1018–1027.
Chauhan, B.S., Gill, G., Preston, C., 2006. Factors affecting seed germination of annual sowthistle (Sonchus oleraceus) in southern Australia. Weed Sci. 54, 854–860.
Daws, M., Burslem, D.F.R.P., Crabtree, L.M., Kirkman, P., Mullins, C., Dalling, J.W., 2002. Differences in seed germination responses may promote coexistence of four sympatric Piper species. Funct. Ecol. 16, 258–267.
Daws, M.I., Crabtree, L.M., Dalling, J.W., Mullins, C.E., Burslem, D.F., 2008. Germination responses to water potential in neotropical pioneers suggest large-seeded species take more risks. Ann. Bot. 102, 945–951.
Fang, X.W., Zhang, J.J., Xu, D.H., Pang, J., Gao, T.P., Zhang, C.H., Li, F.M., Turner, N.C., 2017. Seed germination of Caragana species from different regions is strongly driven by environmental cues and not phylogenetic signals. Sci. Rep. 7, 11248.

Ginwal, H., Gera, M., 2000. Genetic variation in seed germination and growth performance of 12 Acacia nilotica provenances in India. J. Trop. For. Sci. 12, 286–297.
Gorai, M., Tlig, T., Neffati, M., 2009. Influence of water stress on seed germination characteristics in invasive Diplotaxis harra (Forssk.) Boiss (Brassicaceae) in arid zone of Tunisia. J. Phytol. 1, 249–254.
Hari, A., Revikumar, K., Divya, D., 2014. Artocarpus: a review of its phytochemistry and pharmacology. J. Pharma Search 9, 7–12.
Houssard, C., Escarré, J., 1991. The effects of seed weight on growth and competitive ability of Rumex acetosella from two successional old-fields. Oecologia 86, 236–242.
Jiménez-Alfaro, B., Silveira, F.A., Fidelis, A., Poschlod, P., Commander, L.E., 2016. Seed germination traits can contribute better to plant community ecology. J. Veg. Sci. 27, 637–645.
Khan, N., Kazmi, R.H., Willems, L.A., Van Heusden, A.W., Ligterink, W., Hilhorst, H.W., 2012. Exploring the natural variation for seedling traits and their link with seed dimensions in tomato. PLoS One 7 (8), e43991.
Khatun, M., Islam, M., Haque, T., Khan, N., 2008. Propagation of jackfruit by modified cleft grafting as influenced by time of operation. Progress. Agric. 19, 67–74.
Kołodziejek, J., 2017. Effect of seed position and soil nutrients on seed mass, germination and seedling growth in Peucedanum oreoselinum (Apiaceae). Sci. Rep. 7, 1959.
Lê, S., Josse, J., Husson, F., 2008. FactoMineR: an R package for multivariate analysis. J. Stat. Softw. 25, 1–18.
Mabel Queiroz de Oliveira, T., da Silva Junior, A.F., Farias, V.S.D.O., Alves de Medeiros, R., Nascimento Lima, A.R., 2022. Description of drying of jackfruit seed through diffusive models. J. Food Process. Preserv. 46, e16389.
Maraghni, M., Gorai, M., Neffati, M., 2010. Seed germination at different temperatures and water stress levels, and seedling emergence from different depths of Ziziphus lotus. S. Afr. J. Bot. 76, 453–459.
Merlin, J., Palanisamy, V., 2000. Seed viability and storability of jackfruit (Artocarpus heterophyllus L). Seed Res. 28, 166–170.
Moya, R.S., Meza, S.E., Díaz, C.M., Ariza, A.C., Calderón, S.D., Peña-Rojas, K., 2017. Variability in seed germination and seedling growth at the intra-and inter-provenance levels of Nothofagus glauca (Lophozonia glauca), an endemic species of Central Chile. N Z J For. Sci. 47, 1–9.
Nantongo, J.S., Odoi, J.B., Agaba, H., Gwali, S., 2021. Nutritional prospects of Artocarpus heterophyllus and its potential for improving dietary diversity in Uganda. BMC Res. Notes 15, 1–6.
Parker, W.C., Noland, T.L., Morneault, A.E., 2006. The effects of seed mass on germination, seedling emergence, and early seedling growth of Eastern white pine (Pinus strobus L.). New For. 32, 33–49.
R Core Team, 2021. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/.
Ranasinghe, R.A.S.N., Maduwanthi, S.D.T., Marapana, R.A.U.J., 2019. Nutritional and health benefits of jackfruit (Artocarpus heterophyllus Lam.): a review. Int. J. Food Sci. 2019, 4327183.
Rivera, D., Obón, C., Heinrich, M., Inocencio, C., Verde, A., Fajardo, J., 2006. Gathered Mediterranean food plants: ethnobotanical investigations and historical development. Eds. In: Heinrich, M., Müller, W.E., Karger, C.G. (Eds.), Local Mediterranean Food Plants and Nutraceuticals. Karger, pp. 18–74.
Saeed, S., Shaukat, S.S., 2000. Effect of seed size on germination, emergence, growth and seedling survival of Senna occidentalis Link. Pak. J. Biol. Sci. 3, 292–295.
Singh, B., Bhatt, B., Prasad, P., 2006. Variation in seed and seedling traits of Celtis australis, a multipurpose tree, in Central Himalaya, India. Agrofor. Syst. 67, 115–122.
Sturtevant, W.C., 1964. Studies in ethno-science. Part Three: anthropological approaches. Am. Anthropol. 66 (3), 99–131.
Swami, S.B., Thakor, N., Haldankar, P., Kalse, S., 2012. Jackfruit and its many functional components as related to human health: a review. Compr. Rev. Food Sci. Food Saf. 11, 565–576.
Upadhaya, K., Pandey, H.N., LAW, P., 2007. The effect of seed mass on germination, seedling survival and growth in Prunus jenkinsii Hook. f. & Thoms. Turk. J. Bot. 31, 31–36.
Vazhacharickal, P.J., Sajeshkumar, N., et al., 2015. Chemistry and medicinal properties of jackfruit (Artocarpus heterophyllus): a review on current status of knowledge. Int. J. Innov. Res. Rev. 3, 83–95.
Veloso, A.C., Silva, P.S., Siqueira, W.K., Duarte, K.L., Gomes, I.L., Santos, H.T., Fagundes, M., 2017. Intraspecific variation in seed size and light intensity affect seed germination and initial seedling growth of a tropical shrub. Acta Bot. Bras. 31, 736–741.
Wang, Z., Wang, L., Liu, Z., Li, Y., Liu, Q., Liu, B., 2016. Phylogeny, seed trait, and ecological correlates of seed germination at the community level in a degraded sandy grassland. Front. Plant Sci. 7, 1532.
Warrier, R.R., Singh, B.G., Anandalakshmi, R., Sivakumar, V., Geetha, S., Kumar, A., Hegde, M.T., 2009. Standardization of storage conditions to prolong viability of seeds of Artocarpus heterophyllus Lam-a tropical fruit tree. ARPN J. Agric. Biol. Sci. 4, 6–9.
Xu, J., Li, W., Zhang, C., Liu, W., Du, G., 2014. Variation in seed germination of 134 common species on the eastern Tibetan Plateau: phylogenetic, life history and environmental correlates. PLoS One 9, e98601.
Yan, B., Ji, Z., Fan, B., Wang, X., He, G., Shi, L., Liu, G., 2016. Plants adapted to nutrient limitation allocate less biomass into stems in an arid-hot grassland. New Phytol. 211, 1232–1240.