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Towards a Cleaner Production of an Underutilised Legume, Bambara Groundnut

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Abstract

Soilless cultivation systems such as aeroponics provide a more efficient, and clean food production of in areas where there is limited access to arable land for agricultural practices and drought-prone countries. The objective of this study was to evaluate the yield performance of seventy Bambara groundnut (BGN) landraces cultivated in aeroponics and compared with a traditional drip-irrigated hydroponic system with sawdust as a growing medium. The result showed that BGN landraces cultivated in aeroponics accumulated a high number of seeds, as compared to those landraces cultivated in hydroponics. However, BGN landraces cultivated in hydroponics recorded a high shoot dry weight and one hundred seed weight. The root length that could only be measured in BGN landraces cultivated in the aeroponics systems, showed that BGN root length can extend beyond one meter. Soilless cultivation systems with their high-water use efficiency have the potential of reducing production costs, thus making them accessible to farmers in countries where drought is a reality.

Keywords: *Aeroponics, Bambara groundnut, Climate smart farming, Hydroponics, Internet of things*

1. Introduction

The African agricultural sector faces many challenges (Muller *et al*., 2011; Middelberg, 2013), and for the sector to continue producing enough food for the growing population, it needs to undergo fundamental transformations (de Graaff, 2011; Collier and Dercon, 2014; Wiggins, 2014; Shimeles *et al*., 2018). In sub-Saharan Africa (SSA) alone, by 2022, there were approximately 123 million people already food insecure (Baptista *et al*., 2022). Owing to the lack of access to nutritious and healthy food, the SSA population is at risk of malnutrition and health-related complications (Binga *et al*., 2019). The African Union Agenda 2063 highlights the importance of healthy and well-nourished citizens and the use of modern agriculture to increase productivity and production (AUC & AUDA-NEPAD, 2022). Accordingly, to overcome food insecurity problems, SSA must explore the production of nutrition-dense food while conserving the environment (Ojiewo, *et al*. 2015). In line with sustainability transitions, climate-smart farming technologies have shown to increase crop productivity and food security, while reducing environmental impacts and saving natural resources (Branca et al.,2021). Despite the low adoption of climate-smart farming technologies in SSA (Makate *et al*., 2018; Ogunyiola *et al*., 2022), their implementation in certain regions has demonstrated a positive impact on crop production (Makate *et al*., 2019). Africa is disproportionately affected by the consequences of climate change, making it crucial for governments to prioritise the efficient use of available land and water resources (Kumssa and Jones, 2010; Tedesse, 2010). To achieve cleaner and more environmentally friendly agricultural practices, all stakeholders must adopt a mindset that prioritises minimising risks to the environment.

Several approaches can be pursued to achieve cleaner agricultural production. First, the utilisation of climate-smart farming technologies, such as aeroponics and hydroponics can significantly reduce the required space and water when compared to traditional farming methods (AlShrouf, 2017; Tunio *et al*., 2020; Mamatha and Kavitha *et al*., 2023). Second, the integration of monitoring and automation technologies through the Internet of Things (IoT) can serve as an innovative tool to promote cleaner agricultural production (Ragavi *et al*., 2019; Ahmed *et al*. 2022). Embracing these practices presents a promising path towards sustainable agriculture in Africa.

Aeroponics is an advanced agricultural technique that involves growing plants in a mist or air environment without using soil or traditional hydroponic growing medium (Christie *et al*., 2003; Mithunesh *et al*., 2015; Eldridge *et al*., 2020). In aeroponics, plant roots are suspended in air, and a fine mist of nutrient-rich water is frequently sprayed onto the roots (Gopinath *et al*., 2017; Lakhiar *et al*., 2019). This mist provides the necessary nutrients and moisture directly to the roots, allowing plants to thrive (El-Kazzaz and El-Kazzaz, 2017; Li *et al*., 2018). In this context, the primary objective of cleaner production is to minimise risks that could lead to adverse consequences in the future. In addition, this technology offers more opportunities to the agricultural industry, as it allows those directly involved in research to most plants from their aboveground parts (leaves) to their below-ground parts (roots) (Cai *et al*., 2023). The ability of researchers to study all parts of a plant is crucial for plant improvement studies.

In addition to the lag in the adoption of climate-smart technologies, SSA has also neglected its underutilised crop species, which have the potential to alleviate food insecurity on the continent (Massawe *et al*., 2015; Koch, *et al*., 20201). Neglected and underutilised crop species (NUCS) refer to a group of plant species that have been historically overlooked or underappreciated, despite their potential value in terms of food security, nutrition, and agricultural sustainability (Chivenge *et al*., 2015; Mabhaudhi *et al*., 2015). One such crop is the indigenous African legume Bambara groundnut (*Vigna subterranea* L. Verdc.). Bambara groundnut, a neglected and underutilised legume, is often referred to as a "complete food" due to its exceptional nutritional profile (Mazahib *et al*., 2013; Khan *et al*., 2021).

Bambara groundnut has evolved to thrive under conditions where other crops might struggle, making it a suitable candidate for cultivation in areas with limited access to nutrients and marginal soils. However, this also provides possibilities for exploring climate-smart technologies for the cultivation of this crop to improve its productivity. While the focus of research on aeroponic cultivation primarily targets commodity crops rather than underutilized crops, as awareness grows regarding the importance of consuming nutrient-rich food, there is now an increasing interest in exploring underutilised crops, such as Bambara groundnut. Therefore, this study evaluated the yield performance of seventy Bambara groundnut (BGN) landraces groundnut landraces cultivated in climate-smart technologies (aeroponics and drip irrigated hydroponics).

2. Methods

2.1 *Plant material study site description*

Bambara groundnut landraces (BGN) were sourced from subsistence farmers in Limpopo Province, South Africa (23.4013 °S, 29.4179 °E). The seeds were separated according to IPGRI Bambara groundnut descriptors, and successful separation seventy were chosen and used in this study. Before planting, the seeds were visually inspected to detect any abnormalities or defects that might limit seed germination and, subsequently, the overall performance of the plant. The study was performed at Welgevallen Experimental Farm, Stellenbosch University, in a tunnel (location:33°56'52.5″ "S, 18°52'19.9"″ E) over two trials. The recorded minimum and maximum temperatures of the tunnel ranged from 10-34ºC throughout the planting season. The data was collected using sensors, via the IoT system.

2.1.1. Aeroponics and Hydroponics system design

Seventy Bambara groundnuts were planted in two climate smart cultivation systems: aeroponics and drip irrigated hydroponics. The aeroponics system was composed of 30 units, and each unit was able to accommodate 12 plants. The system design was described by Mabitsela et al. (2023). The hydroponic systems followed a traditional drip irrigation method, with sawdust incorporated as the growing medium. The system consisted of 350, 10 L polyethylene planting bags. The nutrient solution supplied to the plants in both systems, was a modified Hoagland's solution prepared from (*Arachis hypogea* L) fertiliser recommendations.

2.1.2. Internet of things

To better understand the growth conditions in aeroponic systems. An IoT-based remote air and water temperature monitoring system was developed using DS18B20 temperature and humidity. The sensors were used to collect air and water temperature data every 5 minutes. The output was sent to a Telegram bot via cellular connectivity, which allowed real-time monitoring of the aeroponics system. The air and temperature data collected from the sensors were sent to a CSV file as numeric values, which enabled data visualisation. Bambara groundnut is said to thrive in harsh environmental conditions, and the use of IoT-based monitoring can be a tool to validate the information and understand how certain growth stages in a plant are affected at different temperatures.

For temperature and humidity control inside the tunnel, an extraction fan and evaporative cooling pads (wet wall) were simultaneously switched on to regulate the temperature inside the tunnel. The IoT solution was described by Mabitsela et al. (2023).

2.2 Data collection and analysis.

At the end of the trial, plants were removed from both the systems. In the aeroponics system the number of seeds were counted (NS), root length (RL), shoot dry (PBM), one hundred seed weight were determined (100SW). In the hydroponics system, all parameters were collected and recorded besides the root length (RL). Determining the root length and root dry weight in sawdust was not viable because of the decomposing nature of sawdust over time during the planting season.

The Shapiro-Wilk test was used to determine if the data set was normally distributed. The data was not normally distributed as such non-parametric tests were used. The Kruskal-Walli's test was used to determine the effect of the aeroponics and hydroponics systems on the measured parameters.

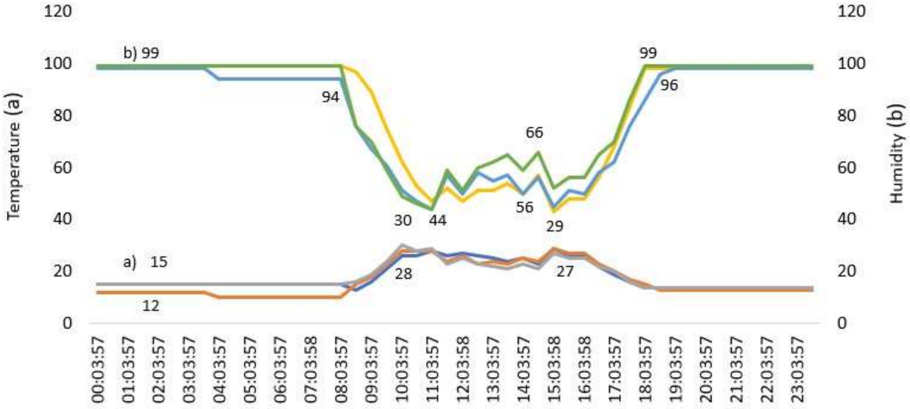

Fig. 1. Temperature (◦C) and humidity trends inside a tunnel. The data shown represent the tunnel conditions on May 23, 2023.

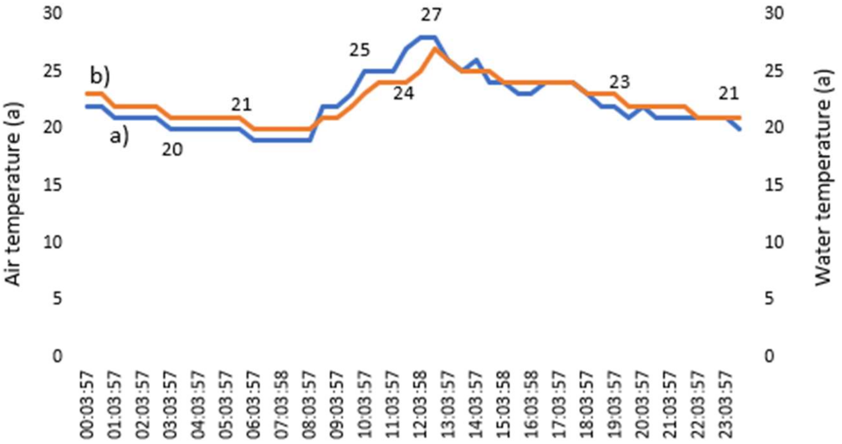

Fig. 2. Air and water temperature trends inside the aeroponics system. The data shown represent the tunnel conditions on May 23, 2023.

3. Results

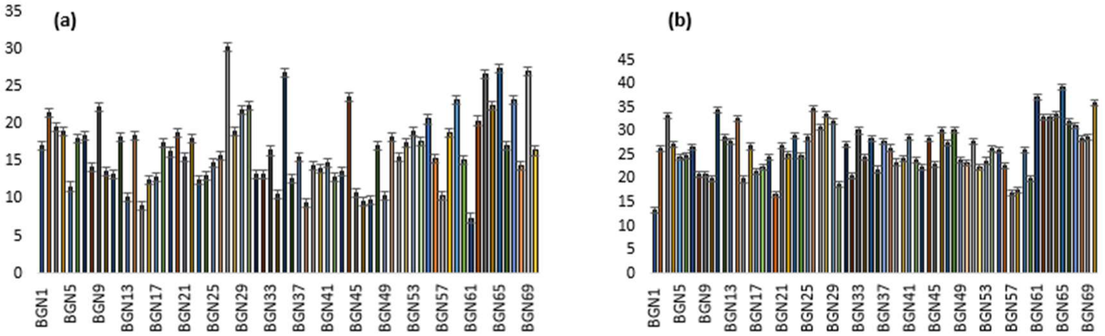

Fig.3. Mean shoot dry weight of 70 Bambara groundnut landraces cultivated in a) hydroponics b) aeroponics

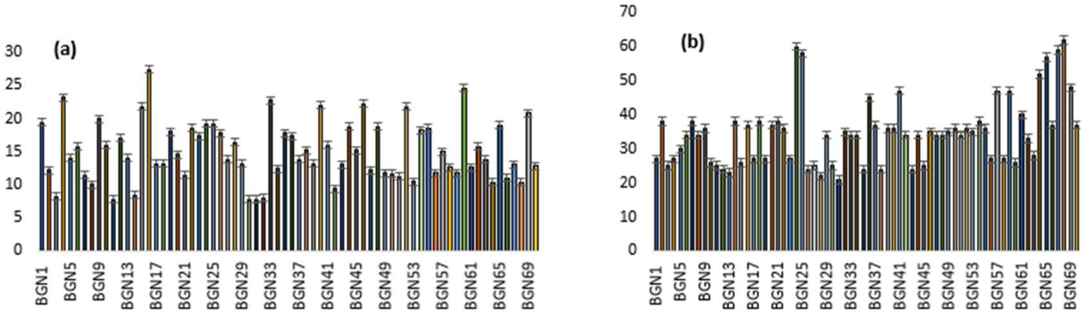

Fig.4. Mean number of seeds of 70 Bambara groundnut landraces cultivated in a) hydroponics b) aeroponics

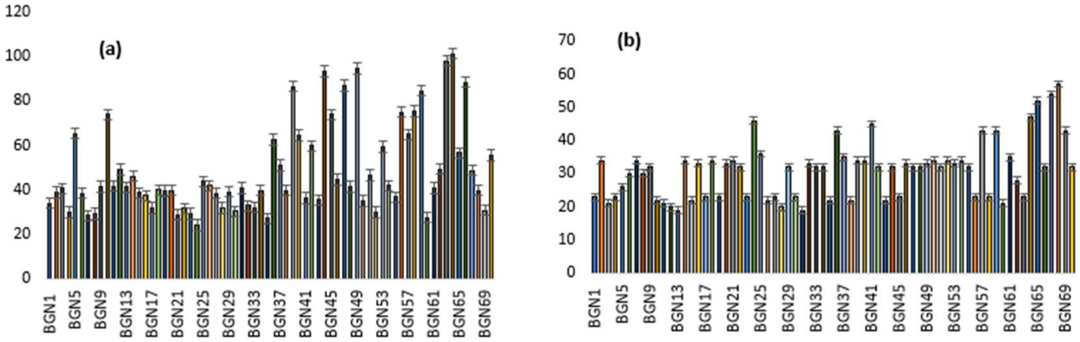

Fig.5. Mean 100 seed weight of 70 Bambara groundnut landraces cultivated in aeroponics (a) and sawdust media (b).

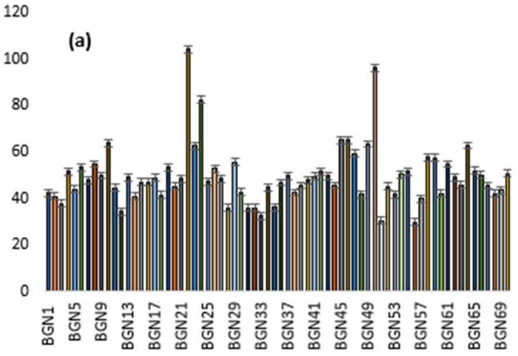

Fig.6. Mean root length of 70 Bambara groundnut landraces cultivated in aeroponics (a).

There was a significant difference ($p < 0.001$) in SDW between the BGN landraces grown in aeroponics and hydroponics. Shoot dry weight ranged from 30.2 g to 7.4 g in the sawdust media and from 39.2 g to 13.2 g in the aeroponics system (Fig.3a). In the hydroponics system, BGN 27 accounted for the highest SDW, while BGN 65 recorded the highest SDW in the aeroponics system (Fig.3 a & b). Significant differences ($p < 0.001$) were observed for NS in all BGN landraces. Bambara groundnut landrace 16 recorded the highest NS in the hydroponics system, while BGN 68 performed better than all other landraces in the aeroponics system (Fig.4 a & b). Interestingly, BGN 31 had the lowest NS in both systems (Fig.4 a & b). The hydroponics and aeroponics system both significantly ($p < 0.001$) influenced the 100SW, in all the BGN landraces. In the hydroponics system the 100SW ranged from 101,2g to 24.2 g while in the aeroponics system the 100SW ranged from 57 g to 19 g (Fig.5 a & b). In the hydroponics system, BGN 64 recorded the highest 100SW, whereas in the aeroponics system, the highest 100SW was recorded for BGN 68 (Fig.5 a & b). Root length varied significantly among all the BGN landraces ($p < 0.001$). Bambara groundnut landraces 22 (104.3 cm), 50 (96.4 cm), and 24 (82.7 cm) all recorded a root length of > 80 cm; BGN 56 had the lowest root length (29.9 cm, followed by BGN 51 (30.4 cm) and BGN 33 (32.6 cm) (Fig.6).

4. Discussion

During the life cycle of a crop, multiple factors can limit or enhance its growth and productivity. With the IoT-based solution, the environmental factors within the tunnel and aeroponics system were monitored or controlled. This was done to minimise any variability that might be influenced by external factors and for a more accurate comparison of yield parameters under the two soilless cultivation systems. The findings from this study showed that shoot dry weight in the aeroponics system was lower in some landraces than in those cultivated in the hydroponics system. Two scenarios are presented to explain the higher shoot development in hydroponics compared to the aeroponics system. First, sawdust, being the growth medium in the hydroponics system, provided the BGN landraces with uninterrupted moisture, were in the aeroponics system, and root proliferation in some BGN landraces could have restricted water and nutrient supply to their other landraces, thus compelling those landraces to increase their root surface area. The high variation in the root length of BGN landraces can be classified as an adaptive mechanism to restrict water and nutrient supply due to the misting intervals in the aeroponics system. Bambara groundnut landraces grown in aeroponics produced a high number of seeds than those grown in sawdust medium. The aeroponics system provided optimal aeration and a fresh mist of nutrients to the BGN landraces, which was a major factor in the BGN yield performance. In the hydroponics system, the physiochemical changes in the sawdust media over time might have restricted its yield performance in terms of the number of seeds per plant. It is interesting to note that the BGN landraces in the hydroponics recorded the highest one hundred seed weight compared to the aeroponics system. Because BGN is a *subterranean plant that* ripens its pods underground, the sawdust media in the hydroponics system provided an ideal darkened environment for their development. Unlike in the aeroponics system, sawdust was used as a "earthing up" material forty-five days after panting. High-yielding landraces, which also recorded a higher shoot dry weight in both systems, are desirable to farmers, as both the shoots and yield can be used. These landraces can be used as livestock feed and seeds for human consumption. In sub-Saharan Africa, BGN is used as an alternative feed for animals when farmers cannot afford the required feed. Even though there was a high variability within the landraces in the yield parameters, BGN 64, 65, 68, 50, and 22 performed better than all other landraces in the measured parameters when compared to BGN 31, which showed a negative response in both systems.

5. Conclusion

The findings from this study showed that the aeroponics system has a beneficial effect on the number of seeds, root length, and development, while the hydroponics system provided an ideal environment for shoot development. As such high yielding landraces in soilless systems were identified, showing that cleaner production of Bambara groundnut is possible. The different responses of all the landraces in the measured parameters in both systems showed the diversity in the adaptivity of the BGN in soilless cultivation systems.

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