VARIATIONS AMONG TEN YAM (*Dioscorea spp.)* GENOTYPES IN GROWTH AND TUBER YIELD AT DIFFERENT NITROGEN LEVELS

BY

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CERTIFICATION

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DEDICATION

This project is dedicated to the God of the Universe for charting the course of my life and for his innumerable blessings, and to my Parents, Mr. O. O. Agbozuadu and Mrs. Bosede Magaret Agbozuadu, for their guidance.

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ABSTRACT

Yam is an essential food crop with high economic importance in Nigeria and West Africa. However, yam production has declined greatly because farmers lack knowledge of yam nutrient requirements for optimal yield. Semi-Autotrophic Hydroponics (SAH), a licensed propagation technique, enables year-round yam cultivation under controlled conditions and has been successfully adopted at the International Institute of Tropical Agriculture (IITA). Although previous studies have investigated adequate nutrient application and timing in yam, the overall scope of research remains limited. This limitation is partly attributable to the different sources of nutrients and genotypic variation in response to nutrient application by yam accessions. Also, no information exists on yam nutrient studies using the SAH technique. This study was therefore conducted to evaluate the variability in the response of yam to different nitrogen levels.

Ten *Dioscorea rotundata* accessions (DRS002, DRS027, DRS044, DRS074, DRS104, R-031, TDr93-31, TDr8902665, Meccakusa, TDr9519177) were screened under four nutrient regimes within a Semi- Autotrophic Hydroponics setup. A Randomized Complete Block Design (RCBD) with ten replicates per treatment was used. The nutrient regimes used were ALL-N (15.08 g N, 21.06 g K, 2.80 g P, 10.74 g Ca, 4.28 g Na, 3.25 g Mg, and 2 g Fe), Half-N (7.55 g N, 31.64 g K, 2.80 g P, 5.37 g Ca, 4.28 g Na, 3.25 g Mg, and 2 g Fe), - N (0 g N, 21.11 g of K, 2.80 g P, 10.8g Ca, 21.55 g Na, 3.25 g Mg, and 2 g Fe), and Water (as control).

Growth and yield parameters, including number of leaves (NL), leaf chlorophyll content (SPAD), leaf fresh weight (LFW), shoot fresh and dry weights (SFW, SDW), tuber fresh and dry weights (TFW, TDW), were recorded at 50 and 150 days after treatment (DAT). Amongst the accessions, TDr8902665 demonstrated significantly superior growth and yield ($p > 0.001$) under Half-N and ALL-N conditions compared to - N and Control treatments, with the highest TDW (0.69 g) recorded under the Half-N regime.

These results indicate that Half-N concentrations can sustain comparable performance to full nutrient levels in certain yam genotypes under SAH. TDr8902665 is recommended for breeding programs and commercial propagation targeting improved nutrient efficiency under semi-autotrophic hydroponic systems**.**

Keywords: Semi-Autotrophic Hydroponics, genetic gain, nitrogen, screening, breeding

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CHAPTER 1

INTRODUCTION

Yam is a tropical root crop cultivated predominantly for its edible starchy tubers, which are consumed as staple foods in West Africa, South America, the Caribbean, Asia, and Oceania (FAO, 2021). There are over 600 species of yams, of which six are socially and economically cultivated for food, income, and medicine (IITA, 2009). Approximately 50 other species are consumed as food in times of scarcity and as wild-harvested staples (Padhan and Panda, 2020; Elliott *et al*., 2016), and a few are grown on a small scale as medicinal plants.

Yam performance is affected by the agronomic quality of the soil. Unlike other root and tuber crops such as potatoes and cassava, which survive in marginal soils, yam require pulverized and well-drained, nutrient-rich soil with high soil organic matter content, which aids tuber penetration and development. Yam is grown in tropical areas and mostly produced in the savannah region of West Africa, where the climatic condition is classified into rainy and dry seasons. Yam requires an even rainfall distribution during its active growth period for vine and leaf development, tuber maturation, and bulking (Adifon *et al*., 2020). An annual rainfall of 1000–1200 mm, particularly when spread over 6-7 months cropping season, is adequate for vegetative growth and tuber development (Andres *et al*., 2017; Gweyi- Onyango *et al.,* 2021). Plant growth could be stalled during long periods of drought (Asiedu, 2003). In regions experiencing irregular rainfall, supplemental irrigation may be necessary to maintain soil moisture and avoid yield reduction, as water stress has been shown to induce leaf yellowing, senescence, and early leaf drop, reducing the crop's photosynthetic capacity and leaf area index (Agre et al., 2022a).

Yam production is majorly concentrated in Africa as it accounts for 98 percent of global production, with West Africa contributing 95 percent between 2020 and 2022 (FA0, 2024). Within the same period, Nigeria contributed 71 percent, Ghana 11 percent, Côte d'Ivoire 9 percent, Benin 4 percent, and Togo 1 percent to Africa's yam production. In

2023, the total area of land harvested in Nigeria was about 7.5 million hectares with a total production of about 61.9 million tonnes (FAOSTAT, 2024).

Despite the importance of yam in Africa and other parts of the world, with Nigeria being the largest producer (Yaw et al., 2024) there has been a decline or stagnation in yam production with some farmers getting 10 tonnes per hectare compared to a potential yield of 50 tonnes per hectare (Neina, 2021). According to Kalu (2023), farmers were interviewed across the farming belts of Nigeria, and it was identified that pest and disease attacks, climate change, high cost of seed yams, insecurity, lack of improved seeds, low sprouts, low yields, and high labour cost were the major causes of this decline. However, the three most prevalent problems faced by farmers in the South-South region of Nigeria are pest and disease attacks (50%), high cost of farm inputs (18.8%), and low soil fertility (17.5%). Yam yield in Nigeria declined from 9.4 tons per hectare in 1988 to an estimated value of 8.2 tons per hectare in 2023 (FAOSTAT, 2024). Scarcity of quality seed yams may ultimately lead to a further reduction in yam production.

Yam is traditionally grown as the first crop after clearing in many parts of West Africa due to its high nutrient demand (Danquah et al., 2022a). Yam has been reported to respond to fertilizer application under various agronomic conditions (Hgaza *et al.,* 2010a). Studies have shown that the most critical yield-limiting factor in yam production is nitrogen availability (Hgaza et al., 2012b; Cornet et al., 2022). Yam is particularly sensitive to soil nutrient status, and its productivity is closely tied to nitrogen uptake during early growth stages (Oberson et al., 2020). Nitrogen is an essential nutrient not only for plants but also for the environment. Yet, yam production in West Africa often occurs on nutrient-depleted soils due to shortened fallow periods and continuous cropping systems, reducing natural nitrogen replenishment (Pouya et al., 2022; Danquah et al., 2022a). Multiple recent studies (2021-2023) across diverse agroecological zones in West Africa involving soil fertility management confirm a strong positive correlation between fallow duration and yam tuber yield (Pouya *et al.,* 2023; Danquah *et al.,* 2022b). This relationship holds due to the important role fallow plays in the restoration of soil structure, nitrogen cycling, and beneficial microorganisms (Heller *et al.,* 2022; Maliki *et al.,* 2022). However, the interaction between fallow history, cover crop species, soil type, and fertilizer application introduces significant variation in yam response to nitrogen, emphasizing the need for site-specific and genotype-specific recommendations (Agre *et al.,* 2022b)

Moreover, while nitrogen is widely acknowledged as a critical macronutrient for yam, there remains no clear consensus on the optimal nitrogen requirements for different yam species. Empirical studies have shown that yam response to nitrogen varies significantly across genotypes, soil types, and environmental conditions, leading to conflicting fertilizer recommendations (Oberson et al., 2020; Tokpa et al., 2020; Cornet et al., 2022). The discrepancies underscore the importance of quantifying nutrient use efficiency (NUE) across yam genotypes, which could inform precision nutrient management and breeding programs. A good knowledge of the nitrogen requirement of plants, especially under controlled propagation systems, where nutrient delivery can be precisely managed, is key to improving yam yield. Therefore, it is important to develop efficient phenotyping protocols for yam nutrient use efficiency.

In response to the persistent limitations in yam seed systems, particularly the low multiplication rate, high susceptibility to diseases, and reliance on bulky tuber propagation, numerous innovative propagation technologies have been developed. These include tissue culture, vine cutting, aeroponics, temporary immersion bioreactors (TIBs), minisett techniques, and, more recently, Semi-Autotrophic Hydroponics (SAH). These methods have been tested and documented by research institutions such as the International Institute of Tropical Agriculture (IITA) in Ibadan, Nigeria (Aighewi et al., 2015a; Balogun et al., 2021).

Among these tissue culture techniques have gained significant attention for their potential to generate disease-free planting materials, conserve genetic resources, and accelerate multiplication under controlled environments (Agrodemy website: Yam Minisett: A Guide with Tissue Culture Micropropagation 2023 – Agrodemy Technologies and services; Balogun, 2014; Aighewi et al., 2021a). This method of propagation provides effective solutions to several limitations of conventional propagation methods, particularly by enabling the production of disease-free planting materials, ensuring year-round availability of high-quality seed yams, and facilitating the conservation of valuable genetic resources. Recent studies have validated the use of tissue culture, including meristem culture and micropropagation, as scalable options to reduce the transmission of pathogens, enhance multiplication rates, and maintain genetic stability in elite yam genotypes (Uyoh et al., 2022; Ossai et al., 2024; Deubel, 2023). Although tissue culture systems are effective, they are often costly and technically demanding, especially for decentralized or rural propagation centers. In contrast, SAH systems, which allow yam propagation in semi-controlled, nutrient-enriched environments without soil, offer a cost-effective and scalable alternative (Cornet et al., 2022; Maroya et al., 2020). SAH combines the efficiency of hydroponics with reduced input costs, enabling continuous monitoring of nutrient uptake and facilitating genotype screening.

Despite their potential, most propagation techniques, including SAH, have not been optimized for specific nutrient regimes, particularly for nitrogen, which has been consistently identified as the most limiting nutrient in yam production (Hgaza et al., 2012b; Oberson et al., 2020). Moreover, the response of yam genotypes to different nitrogen levels under SAH remains poorly characterized, resulting in a knowledge gap that limits the effective deployment of this technique for seed system development and breeding support. Addressing this gap is essential for improving Nitrogen Use Efficiency (NUE), shortening the yam breeding cycle, and developing a standardized, genotype-responsive SAH protocol.

Furthermore, integrating nutrient screening within SAH platforms allows researchers to select high-performing genotypes under low-input conditions, making it highly relevant for resource-constrained farmers. By establishing nutrient-efficient genotypes and optimized in vitro nutrient regimes, this study aims to support seed yam innovation and breeding programs with broader implications for food security and sustainable intensification in yam-based systems across West Africa.

The objectives of this study were therefore to:

i. investigate the effect of different nitrogen levels on the growth and yield of yam using the Semi-Autotrophic Hydroponics technique, thereby defining optimal nutrient regimes for in-vitro propagation.

ii. assess genotypic variation in nitrogen use efficiency, with the goal of identifying nutrient-efficient yam genotypes.
iii. establish a stable seed system that shortens the breeding cycle of yam using Semi-Autotrophic Hydroponics protocols.

CHAPTER 2

LITERATURE REVIEW

2.1. Origin and distribution of yam

Yam is a common name for various species belonging to the family Dioscoreaceae and genus *Dioscorea* with varying origins and distributions in the tropic, sub-tropic, and temperate regions (Darkwa *et al*., 2020). There are over 600 species of yam with only six species that are of economic importance as foods. These include *D. rotundata* (white yam), *D. alata* (water yam), *D. cayenensis* (yellow yam), *D. esculenta* (lesser yam), *D. dumeterum* (bitter yam), and *D. bulbifera* (aerial yam). The white yam, water yam, and yellow yam are the most important together making up about 90% of the world's food yam production.

Yam species have different sources of origin. White yam is closely related to *y*ellow yam, another domesticated yam widely consumed in West Africa. They were both derived from the wild progenitor *Dioscorea praehensilis (*Scarcelli *et al*., 2019). *Dioscorea alata* (purple yam or "ube") was first cultivated somewhere in Southeast Asia. It has the largest distribution worldwide as it is grown in Asia, the Pacific islands, Africa, and the West Indies (Mignouna, 2003). Water yam has also become an invasive species in some southern states of the United States of America. Meanwhile, aerial yams are found both in Africa and Asia. All edible yams are cultivated for their tuber except *D. bulbifera* which are produced for their bulbils or aerial growing tubers. Although *D. bulbifera* produces underground tubers, the bubils are the more important food products (Ambayeba, 2018). *Dioscorea dumetorum* is like *D. hispida*, it is popular in some parts of West Africa and *D. esculenta* is of Asian origin. However, most of these species are spread across continents and can be found in many parts of the world.

Yams were successfully grown in Europe to mitigate the effects of the potato famine in 1840’s. Although yam is cultivated in Asia and America, more than 96% of the world’s yam is grown in Africa, and its high starch content makes it an important food crop (FAO, 2016). History has it that yams were taken to America by pre-colonial Portuguese and Spanish on the borders of Brazil and Guyana. They were later dispersed throughout the Caribbean. Yams are produced mainly in West and Central Africa, New Guinea, Islands of the pacific, and some parts of South-East Asia (Dumont and Vernier, 2000).

2.2 Botany of Yam

Yams are monocotyledonous herbaceous climbing plants that coil readily around a stake. They are perennial crops that can grow and produce over several years through their root system but are grown as annual crops within a single growing season (Dumet *et al*., 2008). It takes about six to eight months to complete its growth cycle comprising five distinct stages which vary according to species, genotypes, and environmental conditions. These stages are tuber sprouting, foliage development, tuber bulking, foliage senescence, and dormancy. Tuber sprouting can take up to six weeks. It normally begins during storage, in the absence of light, soil and water (Frederik *et al*., 2013).

Yams are large plants, with their twining vines growing as long as 10 to 20 m (33-39. ft). The direction of twining may vary with species. The three most important edible yam species, *D. rotundata, D. alata,* and *D. cayenensis* are characterized by vines that twine to the right, in a clockwise direction (Bhattacharjee *et al*., 2011). Yam vines can grow up to several meters long if a rigid support is provided and their length varies among species. Yam leaves grow on long petioles and could be simple, cordate, or acuminate but are usually lobed or palmate in some species. *Dioscorea rotundata* bears simple cordate leaves which have an opposite arrangement (Okonkwo, 1985). The tip of the leaf is usually green (Rodriguez and Montero, 2007) except in young leaves of *D. alata* cultivars in which anthocyanin pigment may mask the green color of the leaves (O'Sullivan 2010). The petiole is long with a swollen base and *D. rotundata* is capable of twisting in such a way that it exposes its lamina to a maximal amount of sunlight.

2.3 Propagation Methods of Yam

Traditionally, seed yams are used for propagation. A portion of seed yam from the previous harvest is reserved for planting in the next season (Nweke *et al*., 2011); otherwise, tuber setts could be used as practiced in West Africa. The most important traditional method of propagation in the yam belt of West Africa is 'milking' whereby a plant is harvested twice. The first harvest is done carefully 4 to 5 months after shoot emergence while the shoot is still green. The multiplication ratio is 1:4 to 1:6 (Aighewi, 2015b). The minisetts technique is a modern method of yam propagation developed by the National Root Crops Research Institute (NRCRI), Umudike, Nigeria (IITA, 1985). This technique makes use of healthy seed yams cut into discs of about 2 cm, which are further cut into segments and then treated with wood ash or fungicides and insecticides and spread out to dry for 1-2 days before planting. Minisetts are usually 20–25 g in size and are used to produce planting material or seed yams, which are in turn used for ware yam production (Pelemo, 2012). The multiplication ratio of the minisetts technique is 1:30. The vine cutting technique is fast replacing seed yam production and has a higher multiplication ratio (1:300) when compared to methods such as milking and minisetts techniques, thereby reducing the cost of the planting material (IITA, 2014., Aighewi *et al.*, 2021b). The vine-cutting technique is advantageous because it makes year-round production of yams possible. Other techniques for propagating yam include the use of botanical seeds for seed yam propagation, plant tissue culture, aeroponics system, Temporary immersion bioreactor system, semi-autotrophic Hydroponics, etc.

2.4 Semi-Autotrophic Hydroponics Technique for Yam Propagation

Semi-autotrophic hydroponics (SAH) is a licensed technology targeted at the high ratio propagation of true-to-type virus-free plants of tissue culture origin. It is a low-cost and easy-to-adapt technique that is suitable for commercial seed production and enhanced multiplication in breeding programme. This technology has been used for seed production in clonal crops, such as potato, cassava (Legg *et al.*, 2022), and recently, yam (IITA, 2018). Semi-autotrophic hydroponics facility for yam started in Ibadan in April 2017 to expand the scope of technologies targeted at overcoming seed yam production challenges (IITA, 2018).

This technology produces plants at an efficient rate to meet the seed needs of yam growers. Semi-Autotrophic Hydroponics is useful for arrays of activities within the research communities. These uses include, but are not limited to, high ratio propagation of virus-free yam seedlings for seed yam tuber production and reintroduction into tissue culture, shortening of breeding cycle and scale testing scheme to accelerate yam breeding gain, acclimatization of in vitro plantlets for onward transplanting into the field, efficient viral and microbial inoculation, viral indexing, and adequate symptom expression and data capture.

Plants, like other living organisms, require nutrients for growth and survival. These nutrient forms have been grouped into plant hormones and macro and micronutrients. Nutrient supply in vivo depends on soil type and use, as well as some edaphic factors, while for in vitro propagation, growth factors, including nutrient supply, can be manipulated to suit the aim. Nutrients significantly influence the growth rate and physiological development of tissue culture plantlets, with mineral elements like nitrogen, phosphorus, potassium, and micronutrients being essential for proper morphogenesis, shoot elongation, and root development in vitro (Arteta et al., 2022; Munthali et al., 2022). Moreover, plant species and even genotypes within the same species display distinct responses to nutrient availability, with significant variation in sensitivity to nutrient deficiencies and ion concentrations (Kumar et al., 2023; Manokari et al., 2022).

Over the years, the semi-autotrophic hydroponics technique on seed yam propagation has been very productive and economically beneficial. The performance in terms of the growth and development of yams using this technique has been attributed to several factors, including the variety and its adaptation in vivo.

2.5 Yam Genetic Resources

The largest world collection of yams is maintained by the International Institute of Tropical Agriculture (IITA), Ibadan, which accounts for over 3,000 accessions mainly of West African origin. The collection comprised eight species: *D. rotundata* (67%), *D. alata* (25%), *D. cayenensis* (2%), *D. bulbifera* (2%), *D. dumetorum* (1.6%), *D. mangenotiana* (0.25%), *D. esculenta* (0.7%), and *D. praehensilis* (0.3%). The passport data and characterization information on these accessions are maintained in databases accessible at *http://genebank.iita. org/*. On request, these germplasm accessions are distributed following Standard Material Transfer Agreements (SMTA). As with many other crops, the request for gene bank accessions has been low for use in national and international yam improvement programmes. Of a total of 3170 accessions maintained at IITA as of 2012, only 1077 accessions had been distributed over the preceding decade (Lopez et al., 2012).

2.6 Importance and Uses of Yam

Yam is among the most important root crops worldwide, alongside other root and tuber crops such as cassava (*Manihot esculenta*), potato (*Solanum tuberosum*), and sweet potato (*Ipomoea batatas Lam*). These crops rank among the top ten foods grown in developing countries. (Scott *et al*., 2000). Yam is a major food security crop for millions of resource-poor farmers in West Africa (Matsumoto *et al*., 2021). Yam falls into a wide range of root and tuber crops, which contributes to food diversification and plays an important role in the annual food cycle by acting as a safety net in sustaining food availability to households across Africa, even at times of general scarcity.

Yams contain riboflavin, thiamin, pantothenic acid, folic acid, and niacin. *Dioscorea alata* is rich in vitamins, minerals, fibers, and carbohydrates (Baah *et al*., 2009). Yams are used in Japanese, Korean, and Chinese medicine because they contain allantoin, which accelerates the healing process when applied as a poultice to abscesses and boils (Wang *et al.,* 2023). Yam contains diosgenin, which is a hormone that is believed to affect hormonal patterns by producing steroids, such as progesterone and estrogen. It helps reduce the symptoms of menopause in women (Mustapha *et al.,* 2018).

Yam can be boiled, fried, roasted, grilled, sliced, mashed, chipped, and flaked. Fresh tubers can be peeled, chipped, dried, milled into flour, and pounded into paste with hot water that is eaten with soup (Condé *et al.,* 2024). However, it is most popularly eaten as pounded yam in its growing belt in West Africa. Yam could also be used as feed for livestock, especially the peels. Yam is used in fertility and marriage ceremonies, and an annual festival is held to celebrate its harvest (Condé *et al.,* 2024).

2.7 Constraints to Yam Production

Studies by Ayanwuyi *et al*. (2011a) and Kleih *et al*. (2012) showed that low soil fertility, lack of improved yam varieties, poor road networks, high cost of labour, and lack of finance to carry out necessary farming activities are constraints to productivity. Yam cultivation, like many other crops in Nigeria, requires a significant amount of labour. The demand and cost of labour have been major constraints in the production of yams. Smallholder farmers' production is hampered by the high cost of labour (Ayanwuyi *et al*., 2011b; Migap and Audu, 2012). Labour accounts for a substantial share of the yam production costs, with planting alone contributing more than half the costs of total variable expenses in some regions (Ariyo and Adebayo, 2020). In a bid to cut labour costs, most family members practically perform all production and marketing activities themselves (Ike and Inoni, 2006). Okeoghene *et al.* (2013) confirmed that over 65% of smallholder farmers used family labour in Delta State, Nigeria. A study by the Food and

Agriculture Organization (FAOSTAT, 2022) on the decline in yam yield in Nigeria found that the average yield dropped from 9.4 tonnes per hectare in 1988 to 7.94 tonnes per hectare in 2020, resulting in an annual loss of between 10% and 20% over the period. The country recorded its highest yam loss in 2006 with over 3.7 million metric tons (Verter and Bečvářová, 2015). Inadequate preservation, storage, and processing facilities, marketing, and market access to yam products are responsible for yam waste and loss in the country. This partly dissuades rural farmers from fully participating in their cultivation (Verter and Bečvářová, 2015). Pest-related issues such as parasitic nematodes, insects such as leaf and tuber beetles, fungi such as leaf spot, tuber rot, and other viruses such as Yam mosaic virus (Aighewi *et al.,* 2025) have also been identified as major constraints to yam production.

In developing countries like Nigeria, Ghana, Cote d'Ivoire, Benin, and Togo, insufficient farm inputs and lack of modern technologies also act as constraints to yam production (Verter and Bečvářová, 2015). As a result, the majority of smallholder farmers still use traditional farming methods, such as hand hoes, axes, wood, and cutlasses, as opposed to machines and tractors for farm-related activities. In addition, there is the problem of insufficient chemical and fertilizer applications and the resulting decline in soil fertility, which has affected output in recent times (Verter and Bečvářová, 2015). Financial resources are another major constraint to production, as farmers are poor and suffer from limited access to credit facilities. This impedes productivity and output (Izekor and Olumese, 2010). The lack of adequate provision for agricultural loans from financial institutions to farmers has constrained sustainable yam cultivation in Nigeria. This can be attributed to factors such as the risk involved in yam production, the difficulty in estimating returns on investment, and the inability of many yam producers to provide the required collateral securities (Migap and Audu, 2012). The lack of political will by the government regarding policies related to yam production in the country also constrains yam production in Nigeria.

2.8 Soil Fertility

Yam performed better in deep, well-drained loamy soils. They are nutrient-demanding plants, explaining why after the land is left to fallow, yams are cultivated first in a rotation system. Low soil resulted in a low yield of 8 tonnes per hectare, where its potential yield was estimated at approximately 30 tonnes per hectare (Andres *et al*., 2017). Farmers' inability to purchase fertilizers due to limited financial resources and lack of access has worsened the situation, compelling them to integrate soil fertility management practices. These include crop rotation or intercropping, conservation tillage, maintenance of organic matter content through direct applications of manures or compost, and soil cover maintenance before planting to enhance soil fertility and structure in yam-based cropping systems. (Andres *et al*., 2017)

2.9 Soil Nutrient Management

Several soil nutrient management technologies that enhance crop productivity have been developed, tested, and promoted in Africa’s low-input farming systems (Kihara *et al*., 2020). However, little information is available on yams’ input intensification technologies (Enesi *et al*., 2017). Intensification of yam production through soil amendments, improved cultivars, and other inputs could increase the yield per unit area. Cultivars that are tolerant to low soil nutrients and responsive to external nutrient inputs are the most efficient and practical approach for improving productivity in low-input, smallholder farming systems (Matsumoto *et al*., 2021). Tolerance to low soil nutrients promotes sustainable production by reducing input costs and environmental impact, while responsiveness to mineral fertilizers enables crop intensification and higher yields. Combining these traits in crop breeding and management strategies holds promise for sustainable, resilient, and productive agricultural systems.

CHAPTER 3

MATERIALS AND METHODS

3.1. Experimental Site

The experiment was carried out at the Semi-Autotrophic Hydroponics (SAH) laboratory and screenhouses of the Yam breeding unit of the International Institute of Tropical Agriculture, Ibadan (IITA) on longitude 3° 89′E; latitude: 7° 49′N; and at an altitude of 239.34m above sea level as shown in Figure 3.1.

3.2. Source of Yam Genetic Materials and Equipment Used

Ten genotypes of white yam were obtained from the Yam Semi-Autotrophic Hydroponics (SAH) laboratory, Ibadan, Nigeria. The genetic material and concentrations of the four different nutrient levels are presented in Tables 3.1 and 3.2, respectively.

The equipment used in this experiment includes SAH culture boxes, weighing balance, polyethylene pots, steel stakes, sphagnum peat (Klassman TS3 media), Konica Minolta SPAD-502 Chlorophyll meter, forceps, surgical blades, aluminum foil, paper towel, beakers, measuring cylinder, oven, autoclave, water bath, Mettler toledo pH meter, Magnetic stirrer, opaque bottles, Tween 20, thermometer, micropipette, crates, sprinklers**.**

3.3.0. SAH Procedure

3.3.1. Preparation of Growth Media and Nutrient Solution

The SAH boxes were carefully perforated with four holes at the top using a soldering iron. This process was performed to allow aeration. The Growth medium used in this study was Klasmann TS3. In each box, 500 mL of Klasmann TS3 was directly measured in a beaker. It was then compressed with a rectangular-shaped container and moistened with SAH-prepared nutrient solution. The SAH nutrient solution was prepared by dissolving all essential nutrients provided as chemical compounds in distilled water in a beaker. The solution was stirred using a magnetic stirrer. The pH of the nutrients was checked using a Metler Toledo, and when necessary, the pH was raised or reduced to 5.7. This was then made up to mark in a 20 L water dispenser, and benzyl amino purine was added. Fifteen planting holes were then created in the substrate-filled SAH box, and the single-node vine cuttings were subcultured from the older boxes.

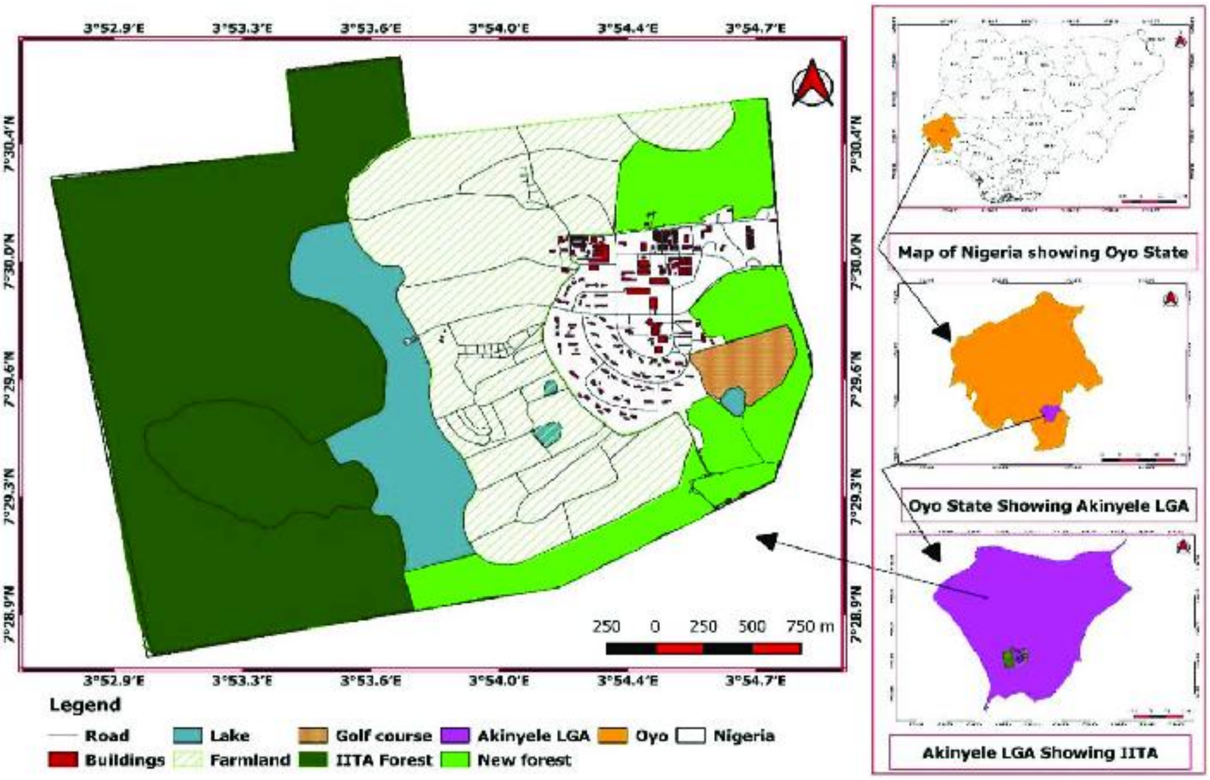

Figure 3.1: Map of the International Institute of Agriculture (IITA) showing the longitude and latitude.

Table 3.1: Yam genotypes evaluated in Ibadan in 2021 for micropropagation at different nitrogen levels

Origin	Specie	Genotype ID
DrDRS*	*Dioscorea rotundata*	DRS002
DrDRS	*Dioscorea rotundata*	DRS027
DrDRS	*Dioscorea rotundata*	DRS044
DrDRS	*Dioscorea rotundata*	DRS074
DrDRS	*Dioscorea rotundata*	DRS104
Breeding line	*Dioscorea rotundata*	TDr8902665
Breeding line	*Dioscorea rotundata*	TDr9519177
Breeding line	*Dioscorea rotundata*	R-031
Landrace	*Dioscorea rotundata*	TDr93-31
Landrace	*Dioscorea rotundata*	Meccakusa

* *Dioscorea rotundata* diversity research set
Source: Jircas Research Highlights, 2020.

Table 3.2: Concentration of the four different nutrient levels used for the study

	ALL-N (g/20L)	1/2N (g/20L)	-N (g/20L)	Control (l)
KNO_3	54.43	27.22	0	0
$CaNO_3.4H_2O$	63.17	31.58	0	0
$CaSO_4.2H_2O$	0	0	46.37	0
$MgSO_4.7H_2O$	32.93g	32.93	32.93	0
$NaH_2PO_4.2H_2O$	14.11g	14.11	14.11	0
K_2SO_4	0	47.04	47.04	0
Iron solution (mL)	200	200	200	0
Water	-	-	-	20

3.3.2 Experimental Design

The experiment was set up in a 10×4 factorial randomized complete block design (RCBD). The experiment was arranged in two blocks, with the first five genotypes under each nutrient and the last five genotypes, based on the variable growth of plants. The experimental layout is presented in Table 3.3, which shows the arrangement of the plants in the screenhouse. The same layout was replicated for genotypes 6 - 10. Each treatment combination consisted of 10 plants (one plant per pot as a replicate). The stakes were inserted into pots for vine training and climbing. The temperature ranged between 21 and 39°C during the study period. The median between transplanting the first and last five genotypes was selected as the transplantation date. Plants were randomly arranged within each block. Each block included four nutrients: Half-N, ALL-N, Control, and -N. Nitrogen was applied to the Half-N and ALL-N nutrient solution in the form of calcium nitrate tetrahydrate ($Ca(NO_3)_2 \cdot 4H_2O$ and Potassium nitrate KNO_3. The control treatment consisted only of distilled water, with no added nutrients or fertilizers, while the -N treatment received all nutrients except nitrogen. Additionally, each nutrient (except control) contained sufficient levels of phosphorus ($NAH_2PO_4)2H_2O$, potassium (K_2SO_4), magnesium, calcium, sulfur $(CaSO_4)_2 \cdot 2H_2O$, $(MgSO_4) \cdot 7H_2O$, and iron solution (Fe-acetate) was added to the nutrient solution. Both Phosphorus and Sodium were added as sodium dihydrogen phosphate dihydrate [$(NaH_2PO_4)_2 \cdot 2H_2O$], potassium as potassium sulfate (K_2SO_4), calcium as calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), magnesium as magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$), and iron in the form of iron-acetate solution. ALL-N contained 54.43 g of potassium nitrate (KNO_3) and 63.17 g of calcium nitrate tetrahydrate ($CaNO_3.4H_2O$), which is equivalent to 15.08 g Nitrogen, 21.06 g Potassium, 2.80 g Phosphorus, 10.74 g Calcium, 4.28 g Sodium, 3.25 g Magnesium, and 2 g Iron. Similarly, Half-N contained 27.22 g of KNO_3 and 31.58 g $(CaNO_3)_2 \cdot 4H_2O$, which contains 7.55 g of nitrogen, 31.64 g Potassium, 2.80 g Phosphorus, 5.37 g Calcium, 4.28 g Sodium, 3.25 g Magnesium, and 2 g Iron), - N excluded nitrogen sources, but included all other nutrients, 21.11 g of Potassium, 2.80 g Phosphorus, 10.8g Calcium, 21.55 g Sodium, 3.25 g Magnesium, and 2 g Iron), and Water (as control).

3.3.3 Establishing Plants in the Laboratory

Yam vines were established in the SAH laboratory in October 2021. They were dissected at one nodal cutting, and 15 vines were planted inside each SAH box filled with an appropriate amount of Klasmann TS3. The boxes were kept closed for the first 14 days to reduce transpiration and allow for the formation of new shoots. The temperature for the plants was maintained at 25±2°C. Ten boxes, each containing 15 plants, were established in the laboratory for each of the ten genotypes. SAH plants were transferred to the screenhouse in two batches. The first five genotypes were transplanted on the 8^{th}

Table 3.3: Experimental layout of the plants and treatments at the screenhouse

ALL-N					CNTRL (Water)					½ Nitrogen					Minus N (-N)				
G1P1	G2P8	G3P8	G4P2	G5P1	G1P1	G2P8	G3P8	G4P2	G5P1	G1P1	G2P8	G3P8	G4P2	G5P1	G1P1	G2P8	G3P8	G4P2	G5P1
G1P3	G2P4	G3P1	G4P5	G5P3	G1P3	G2P4	G3P1	G4P5	G5P3	G1P3	G2P4	G3P1	G4P5	G5P3	G1P3	G2P4	G3P1	G4P5	G5P3
G1P5	G2P5	G3P3	G4P3	G5P7	G1P5	G2P5	G3P3	G4P3	G5P7	G1P5	G2P5	G3P3	G4P3	G5P7	G1P5	G2P5	G3P3	G4P3	G5P7
G1P7	G2P3	G3P2	G4P7	G5P9	G1P7	G2P3	G3P2	G4P7	G5P9	G1P7	G2P3	G3P2	G4P7	G5P9	G1P7	G2P3	G3P2	G4P7	G5P9
G1P8	G2P2	G3P10	G4P9	G5P8	G1P8	G2P2	G3P10	G4P9	G5P8	G1P8	G2P2	G3P10	G4P9	G5P8	G1P8	G2P2	G3P10	G4P9	G5P8
G1P2	G2P10	G3P9	G4P8	G5P2	G1P2	G2P10	G3P9	G4P8	G5P2	G1P2	G2P10	G3P9	G4P8	G5P2	G1P2	G2P10	G3P9	G4P8	G5P2
G1P10	G2P1	G3P6	G4P10	G5P10	G1P10	G2P1	G3P6	G4P10	G5P10	G1P10	G2P1	G3P6	G4P10	G5P10	G1P10	G2P1	G3P6	G4P10	G5P10
G1P4	G2P7	G3P4	G4P4	G5P5	G1P4	G2P7	G3P4	G4P4	G5P5	G1P4	G2P7	G3P4	G4P4	G5P5	G1P4	G2P7	G3P4	G4P4	G5P5
G1P9	G2P6	G1P5	G4P1	G5P4	G1P9	G2P6	G1P5	G4P1	G5P4	G1P9	G2P6	G1P5	G4P1	G5P4	G1P9	G2P6	G1P5	G4P1	G5P4
G1P6	G2P9	G3P7	G4P6	G5P6	G1P6	G2P9	G3P7	G4P6	G5P6	G1P6	G2P9	G3P7	G4P6	G5P6	G1P6	G2P9	G3P7	G4P6	G5P6

G = Genotype, P= Plant

of December 2021, while the last five genotypes were transplanted into pots at the screenhouse on the 16th of December 2021 because the growth rate was slower for the last five genotypes.

3.3.4 Growth Conditions in the Laboratory

Fifteen plantlets were subcultured from the mother plants into new SAH boxes filled with 500 mL of substrate and established in the laboratory for approximately 8 weeks. The average temperature was between 25-27°C at the laboratory and up to 38.9°C at the greenhouse. The source of lighting in the laboratory was LED fluorescent bulbs, with two on each plate on a shelf and central lighting. The LED fluorescent bulbs were programmed to operate on a 12-hour photoperiod using a timer. After eight weeks, the plants were moved to the screenhouse, allowed to acclimatize for a week, and then transplanted into polyethylene pots.

3.3.5. Watering and Nutrient application in the laboratory

Watering was performed biweekly using a nutrient solution at the yam semi-autotrophic hydroponics laboratory. The nutrient solution comprised solutions A and B. Solution A contained 47.2 g of calcium nitrate, while Solution B contained potassium nitrate (20.20 g), potassium phosphate (5.44 g), magnesium sulfate (19.2 g), iron stock (200 mL), and benzyl aminopurine (6 mL). Solutions (A and B) were diluted separately in 20 L of water. Thereafter, 500 mL of each stock solution (A and B) was combined and diluted with water to a final volume of 20 L to prepare the nutrient solution. This water was used to water the plants during the period of establishment in the laboratory.

3.3.6. Acclimatization and Transplanting Yam Plantlets into Pots in the Screenhouse

The plants were grown in the laboratory for 8 weeks. By week 9, they were moved to the screenhouse to allow the plants to acclimate to changes in the environment, such as temperature and humidity. After a week of moving the plantlets from the laboratory to the screenhouse, they were transplanted into polyethylene pots. Before transplanting, each pot was filled with 90 g Klasmann TS3 substrate and moistened with distilled water. The plants were shaken. The average daily temperature in the screenhouse ranged from 22°C to 35 °C throughout the growth period.

3.3.7. Watering and Nutrient Application in the Screenhouse

All the plants were watered twice weekly with the respective nutrients, as described in Table 3.2. However, distilled water was applied to pots that showed excess dryness at midweek to avoid wilting before the next treatment day.

3.4 Data Collection

Destructive sampling was conducted on five of the ten plants. All plants were gently removed from the soil after SPAD measurements. The petioles and leaves were detached from the vines and the number of leaves and fresh shoot biomass were measured. The total fresh shoot biomass (vine, petiole, and leaves) was measured. Leaves, shoots, and tubers were sampled after SPAD measurement and dried at 80 °C for three days to obtain the total shoot dry weight. SPAD values were measured for the first five plants in February 2022, while the last five plants were allowed to continue tuber development and were harvested in June of the same year. Measurements were taken by placing individual leaves into the receptor window, repeating the procedure for three different leaves, and then pressing the average button to record the mean value. The SPAD unit was then recorded from the reading on the display 50 days after the commencement of the treatments. Based on the average growth rate, pictures of one of the remaining five plants were captured to represent each genotype/treatment. All five plants had senesced by 150 days after transplanting (DAT), at which point tubers were harvested and weighed.

Data were collected on the following quantitative traits to assess the assessment of ten yam genotypes.

Number of Leaves per plant (NL, g Leave^{-1}): The number of visible leaves were cut off from the vine and carefully counted manually with the eye.

Chlorophyll Content of the Leaves (SPAD): The SPAD value or chlorophyll content of the leaves was measured using a Konica Minolta SPAD-502 plus a chlorophyll meter. Chlorophyll content was measured by selecting three different leaves per plant (targeting the leaves closer to the top of the plants), and the average of the three data points was calculated.

Shoot Fresh Weight (SFW, g Plant^{-1}): A weighing scale was used to measure the shoot weight (including the vine, petioles, and leaves).

Leave Fresh Weight (LFW, g Plant^{-1}): The weight of the leaves was measured using a weighing scale.

Tuber Fresh Weight (TFW, g Plant^{-1}): All the soil was carefully washed off, and the weight of the tubers was measured using a weighing scale.

Shoot Dry Weight (SDW, g Plant^{-1}) and Tuber Dry Weight (TFW, g Plant^{-1}): The shoots and tubers were dried at 100°C for three days and weighed afterward using a weighing scale.

3.5 Imaging of Plants and Tubers in the Screenhouse

Images of entire plants and tubers were taken in the screenhouse with a custom-made indoor imaging system comprising a blue and white background, white paper meter rule, and Field Book App on a Samsung tablet. Both the blue plastic plates and white background were installed vertically and horizontally, respectively, and positioned in a solid iron frame to provide support. Each pot was placed in a black mark on a white horizontal plate, and the plant was placed in front of a blue background. Images of the plants were taken at 50 days after transplanting (DAT) and for the tuber at 150 DAT (See Appendix 2-6).

3.6 Data Analysis

Analysis of variance (ANOVA) was performed using the generalized linear model (GLM) procedure for a Randomized Complete Block Design in R-studio software (4.4.2). Tukey's Honest Significant Difference (HSD) test for post-hoc comparisons at a 95% confidence level. The level of significance was fixed at an alpha of 5%.

CHAPTER 4

RESULTS

4.1 Mean Squares of Growth and Yield Variables of Ten White Guinea Yam Accessions Evaluated in IITA, Ibadan in 2021/2022

The analysis of variance revealed highly significant differences among the ten yam accessions for all quantitative traits measured after 50 days of transplanting and the interaction between the accessions and nutrients was significant (Table 4.1) in specific traits such as leaf chlorophyll content (SPAD), Shoot Dry weight (SDW), and Tuber Fresh weight (TFW).

4.2 Effect of Nutrient Level on Leaf Chlorophyll Content (SPAD Value) of Ten White Guinea Yam Genotypes Evaluated in 2021/2022

The leaf chlorophyll content of the ten yam genotypes in each of the four nutrient levels used in this study is shown in Table 4.2. In Half-N, DRS104 had the highest mean SPAD value of 39.1 and consistently high means across all treatments. Genotypes DRS044, TDr9519177, and DRS074 closely followed with mean SPAD Values of 35.9, 35.5, and 35.3, respectively, under the same treatment. In contrast, DRS002 had the lowest mean SPAD value of 29.0, and the second lowest mean SPAD value of 29.4 was recorded in genotype DRS027 under the Half-N treatment.

For ALL-N, R-031 had the best performance, with a mean SPAD value of 35.4, followed by DRS044 and TDr9519177, with mean SPAD values of 34.5 and 34.4, respectively. The lowest SPAD value of 25.6 under ALL-N was observed in TDr93-31. In the Control treatment, DRS104 had the highest SPAD value of 36.1, followed by TDr9519177, with an SPAD value of 34.3. Genotype DRS044 had the lowest mean value of 18.4 under the control treatment.

In the - N treatment, TDr93-31 emerged as the genotype with the highest SPAD value of 33.6, followed by R-031 and TDr9519177 with mean SPAD values of 31.2 and 31.0, respectively. In contrast, DRS44 had the lowest mean SPAD value of 18.8, whereas Meccakusa had the second-lowest SPAD value (21.2). Genotypes DRS002 and DRS074 had a SPAD value of 22.5.

Table 4.1: Mean squares for growth and yield variables in ten white yam accessions evaluated in IITA, Ibadan in the 2021/2022 season.

Source of Variation	DF	NL	SPAD	LFW (g Plant^{-1})	SFW (g Plant^{-1})	SDW (g Plant^{-1})	TFW (g Plant^{-1})	TDW (g Plant^{-1})
Accession	9	342.020***	162.880***	5.836***	5.203***	0.234***	6.642***	0.395***
Nutrient	3	447.160***	851.380***	18.764***	16.857***	0.608***	8.432***	0.090
Acc × Nut	27	44.300	74.430***	1.490	1.431	0.0541*	1.273*	0.056

*, **, *** = significant at $p < 0.05$, $p < 0.01$, and $p < 0.001$ respectively, DF = Degree of Freedom; SPAD = Leaf Chlorophyll content, LFW = Leaf Fresh Weight, SFW = Shoot Fresh Weight, SDW = Shoot Dry Weight, TFW = Tuber Fresh Weight, and TDW = Tuber Dry Weight.

Table 4.2: Effect of Nutrient Level on the Leaf Chlorophyll Content (SPAD) of ten white guinea yam genotypes evaluated for growth and yield in 2021/2022 season

ACCESSION	Half-N	ALL-N	Control	- N
DRS002	29.0a	33.5a	23.1abc	22.5abc
DRS027	29.4a	32.7a	21.1ab	29.2abc
DRS044	35.9ab	34.5a	18.4a	18.8a
DRS074	35.3ab	32.9a	24.9abc	22.5abc
DRS104	39.1b	33.6a	36.1c	30.2bc
Meccakusa	30.5a	28.7a	24.2abc	21.2ab
R-031	32.2a	35.4a	21.9abc	31.2bc
TDr8902665	35.2ab	32.6a	25.4abc	24.2abc
TDr93-31	33.6ab	25.6a	24.5abc	33.6c
TDr9519177	35.5ab	34.4a	34.3abc	31.0bc

Means followed by the same letter within a row are not significantly different at 5% probability level

4.3 Effect of nutrient level on Tuber Fresh Weight (TFW) of ten white guinea yam genotypes at 50 Days after Transplanting (DAT) in the 2021/2022 season

At 50 DAT, the highest TFW of 4.37 g and 3.74 g were observed in DRS044 in Half-N and ALL-N (Table 4.3). For Half-N, R-031 had the lowest TFW of 1.17 g. Genotype R-031 also had consistently low TFW under ALL-N and - N, weighing 1.310 g and 1.30 g, respectively. However, under the Control treatment, R-031 displayed a slight increase in TFW, reaching 1.60 g.

In the - N treatment, it was observed that most accessions showed the lowest tuber weight when compared with Half-N and ALL-N, except for TDr8902665. Genotype TDr8902665 showed quite stable performance across all four nutrient treatments, including - N, where it had the highest TFW of 3.02 g. Meccakusa had TFW of 3.57 g and 3.59 g under Half-N and ALL-N treatments, respectively, but its TFW dropped under - N to 1.75 g.

Across all four nutrient treatments, TDr9519177 maintained relatively stable tuber yield (2.52 g, 2.17 g, 2.40 g, and 2.13 g). In the Half-N treatment, DRS027 had the highest tuber yield of 3.15 g and dropped significantly across the other nutrient levels, with the lowest weight observed in the control treatment. Under the ALL-N treatment, genotypes DRS104 and Meccakusa exhibited high tuber yields of 2.69 g and 3.59 g, respectively. Genotype TDr93-31 also had the highest tuber fresh weight of 2.29 g in ALL-N. Meccakusa had the lowest weight of 1.71 g at 50 DAT in - N.

4.4 Effect of nutrient level on tuber fresh weight (TFW) of 10 white guinea yam genotypes at 150 Days after Transplanting (DAT) in 2021/2022 season

Genotype TDr8902665 had the highest tuber fresh weight of 11.07 g in Half-N and 9.97 g in ALL-N at 150 DAT (Table 4.4). It also demonstrated relatively stable performance, maintaining the highest TFW under both the Control (6.91 g) and - N (6.49 g) treatments, as shown in Appendix 2. Genotype DRS044 followed closely after TDr8902665, maintaining the second highest value of 8.21 g and 6.62 g in Half-N and ALL-N, respectively (See Appendix 3).

Table 4.3: Effect of nutrient level on tuber fresh weight at 50 days after transplanting of ten white guinea yam genotypes in 2021/2022 season

Accession	Half-N	ALL-N	Control	- N
DRS002	2.67abc	2.09abc	2.00a	1.51ab
DRS027	3.15abc	1.93abc	1.20a	1.76ab
DRS044	4.37c	3.74c	2.11a	2.10ab
DRS074	2.12ab	1.57ab	1.57a	1.51ab
DRS104	2.23ab	2.69abc	1.97a	1.26a
Meccakusa	3.57bc	3.59bc	2.65a	1.75ab
R-031	1.17a	1.31a	1.60a	1.33a
TDr8902665	3.73bc	3.13abc	2.18a	3.02b
TDr93-31	1.69ab	2.29abc	1.99a	2.10ab
TDr9519177	2.52abc	2.17abc	2.40a	2.13ab

Means followed by the same letter within a row are not significantly different at 5% probability level

Table 4.4: Effect of nutrient level on tuber fresh weight at 150 Days after transplanting of ten white guinea yam genotypes in 2021/2022

Accession	Half-N	ALL-N	Control	- N
DRS002	6.71bcd	4.68ab	2.64a	2.58a
DRS027	3.80ab	4.12ab	2.49a	3.53a
DRS044	8.21cd	6.62bc	3.79ab	4.82ab
DRS074	4.69abc	1.82a	2.00a	2.98a
DRS104	1.91a	2.66ab	1.99a	2.73a
Meccakusa	5.78abc	2.06a	2.64c	3.48a
R-031	3.60ab	2.86ab	3.10ab	3.24a
TDr8902665	11.070d	9.97c	6.91c	6.49b
TDr93-31	3.56ab	2.66a	2.44a	3.41a
TDr9519177	4.02abc	5.69abc	5.17bc	3.56a

Means followed by the same letter within a row are not significantly different at 5% probability level

In Half-N, DRS104 had the lowest tuber fresh weight of 1.91 g, while DRS074 had the lowest TFW of 1.82 g in the ALL-N treatment. In the Control, DRS104 showed the lowest TFW of 1.99 g. However, DRS104 had a higher tuber biomass of 2.73 g under - N, whereas DRS002 had the lowest tuber biomass of 2.58 g. Genotype R-031 had a relatively low tuber biomass of 2.86 g under the ALL-N treatment, compared to 3.60 g under Half N and higher values under the Control and - N treatments.

4.5 Effect of nutrient level on Shoot Dry Weight (SDW) of ten white guinea yam genotypes evaluated in 2021/2022

In Half-N, TDr8902665 had the highest shoot dry weight (0.786 g), whereas the lowest SDW (0.076 g) was recorded in DRS104 (Table 4.5). Similarly, under ALL-N, TDr8902665 had the highest shoot dry weight of 0.636 g compared to other accessions. Genotype R-031 had the lowest SDW under ALL-N. Under the control treatment, DRS044 had the highest SDW of 0.298 g, while DRS104 had the lowest SDW of 0.044 g. In the - N treatment, TDr8902665 again recorded the highest shoot dry weight (0.270 g), showing strong adaptability to varying nitrogen levels. The lowest SDW (0.064 g) under the - N treatment was recorded for DRS104.

4.6 Growth and yield performance of ten yam genotypes under four nutrient levels during the 2021/2022 season

TDr8902665 had the best performance for all traits evaluated under varying nutrient levels (Table 4.6).

Number of Leaves per Plant (NL): The highest number of leaves (15.25) was observed for TDr8902665. Genotype DRS027 had a mean NL of 14.30, whereas DRS074 had a mean NL of 12.65. The lowest number of leaves (4.15) was recorded in genotype R-031, whereas DRS104 and TDr93-31 had 4.70 and 5.05 mean NL, respectively. Meccakusa (9.10) and DRS044 (8.35) had an intermediate number of leaves (Table 4.6).

Leaf Fresh Weight (LFW)

Genotype TDr8902665 had the highest leaf fresh weight (2.547 g), and DRS044 had the second-highest LFW of 1.707 g (Table 4.6). Genotype DRS104 had the lowest LFW of 0.621 g followed by R-031 with a leaf fresh weight of 0.865 g. Genotypes DRS027, DRS074, and TDr93-31 all had LFW values close to 1.0 g. Meccakusa (1.563 g) and DRS044 (1.707 g) showed moderate performance.

Table 4.5: Effect of Nutrient Level on the Shoot Dry Weight of the 10 white guinea yam genotypes evaluated in 2021/2022

ACCESSION	Half-N	ALL-N	Control	- N
DRS002	0.492ab	0.340a	0.192ab	0.138ab
DRS027	0.350ab	0.242a	0.228ab	0.258b
DRS044	0.460ab	0.458a	0.298b	0.220ab
DRS074	0.282a	0.300a	0.172ab	0.148ab
DRS104	0.076a	0.246a	0.044a	0.064a
Meccakusa	0.516ab	0.514a	0.222ab	0.204ab
R-031	0.180a	0.138a	0.116a	0.124ab
TDr8902665	0.786b	0.636a	0.160ab	0.270b
TDr93-31	0.354ab	0.222a	0.108a	0.136ab
TDr9519177	0.134a	0.492a	0.158ab	0.138ab

Means with the same letter are not significantly different at 5% probability level

Table 4.6: Genotypic response to growth and yield across four nutrient levels evaluated in IITA in 2021/2022

ACCESSION	NL	LFW	SFW	TDW
DRS002	12.050bcd	1.661ab	2.156ab	0.429ab
DRS027	14.300cd	1.216a	1.780ab	0.437abc
DRS044	8.350abc	1.707ab	2.347ab	0.641cd
DRS074	12.650bcd	1.317a	1.739ab	0.386b
DRS104	4.700a	0.621a	0.842a	0.400ab
Meccakusa	9.100abcd	1.563ab	2.215ab	0.684d
R-031	4.150a	0.865a	1.098a	0.267a
TDr8902665	15.250d	2.547b	3.219b	0.695d
TDr93-31	5.050a	1.000a	1.382a	0.502bcd
TDr9519177	6.450ab	1.215a	1.643a	0.511bcd

NL = Number of Leaves per plant; LFW = Leaf Fresh Weight; SFW = Shoot Fresh Weight; TDW = Tuber Dry Weight

Means followed by the same letter within a column are not significantly different at 5% probability level

Shoot Fresh Weight (SFW)

Genotype TDr8902665 had the highest SFW of 3.219 g while DRS044, Meccakusa, and DRS002 had an SFW of 2.347 g. 2.215 g and 2.156 g, respectively. Genotype DRS104 had the lowest SFW of 0.842 g, while R-031 had a value of 1.098 g (Table 4.6).

Tuber Dry Weight (TDW)

Genotypes TDr8902665 and Meccakusa had the highest TDW, measuring 0.695 g and 0.684 g, respectively. Genotype DRS044 also had a relatively high TDW of 0.641 g. Genotype R-031 had the lowest TDW (0.267 g). Genotypes DRS027, DRS074, and DRS104 all had relatively low TDW (Table 4.6).

4.7 Variation among ten yam genotypes for growth and yield at different nutrient levels

The ten yam genotypes performed best under the Half-N treatment. The highest values of 12.02, 33.60, 1.933, and 2.560 g were recorded for NL, SPAD, LFW, and SFW, respectively, under the treatment. The values for all traits measured across the ten genotypes under Half-N were comparable to ALL-N, but significantly different from control and - N (Table 4.7). The same trend was observed for all other measured quantitative traits.

The lowest number of leaves was observed under control (6.32), but was comparable to that of - N (6.94). Similarly, the Control treatment recorded the lowest leaf chlorophyll content (SPAD value) of 25.4 recorded across the genotypes, compared closely with - N with a value of 26.4. A similar trend was observed for LFW across the genotypes. Half N resulted in the highest LFW of 1.933 g, comparable to the ALL-N at 1.869 g. Under control, LFW was lowest with a value of 1.13 g, while LFW was 1.21 g under - N. There was significant variation in SDW and TFW among the genotypes at both 50 and 150 DAT across the four nutrient treatments. In contrast, TDW showed no significant differences in TDW among the four nutrient treatments.

Table 4.7: Nutrient response to growth and yield across ten yam accessions evaluated in IITA, in 2021/2022

NUTRIENT	NL	SPAD	LFW	SFW	SDW	TFW 50DAT	TDW 50DAT	TFW 150DAT
Half-N	12.02b	33.6b	1.933b	2.56b	0.363b	2.72c	0.535a	5.34b
ALL- N	11.54b	32.4b	1.869b	2.47b	0.359b	2.46bc	0.524a	4.72ab
Control	6.32a	25.4a	0.837a	1.13a	0.170a	1.97ab	0.481a	3.70a
- N	6.94a	26.4a	0.845a	1.21a	0.170a	1.85a	0.442a	3.70a

Means with the same letter are not significantly different at 5% probability level

NL =Number of Leaves per plant; SPAD = Leaf Chlorophyll content value; LFW = Leaf Fresh Weight; SFW = Shoot Fresh Weight; SDW = Shoot Dry Weight; TFW 50DAT= Tuber Fresh Weight at 50 Days after Transplanting; TDW = Tuber Dry Weight; TFW 150DAT=Tuber Fresh Weight at 150 Days after Transplanting; DAT = Days after Transplanting

CHAPTER 5

DISCUSSION

Screening yam genotypes for their responses to varying nutrients that are essential for growth and yield is crucial for yam propagation. This process facilitates the selection of high-yielding genotypes that are tolerant to low-nutrient conditions and suitable for case-specific production when considering scarce resources. Land preparation, cost of planting materials, staking, weeding, and harvesting are capital-intensive; therefore, it is beneficial to reduce the costs of fertilizers. Selecting yam genotypes that are highly responsive to nutrients can greatly accelerate genetic gains for breeding programmes, considering the reduced cost of production, especially in developing countries such as Nigeria, where fertilizers are often imported.

In this study, ten yam genotypes were assessed for their growth and yield response to four different nutrient levels (Half-N, ALL-N, - N, and Control) at the Yam Rapid Multiplication Laboratory and screenhouse of the International Institute of Tropical Agriculture (IITA), using a semi-autotrophic hydroponic technique during the 2021/2022 growing season.

The significant effect of nitrogen levels and genotype observed in this study suggests that different yam accessions exhibit varying capacities for nitrogen uptake and utilization. The significant differences among the genotypes and nutrients for the number of leaves, leaf fresh weight, shoot fresh weight, and tuber dry weight imply that adequate nutrient treatment required for each yam genotype should be identified and used to propagate the genotype.

According to the Konica Minolta manual, chlorophyll content, which is represented by the SPAD value, increases in proportion to the amount of nitrogen present in the leaf. For most species, a higher SPAD value indicates healthier plants and better yield. In the present study, genotypes generally exhibited higher SPAD values when supplied with ALL-N or Half-N, indicating optimal chlorophyll content under sufficient fertilization. The results of this study are in agreement with those of the glasshouse study conducted by Müller (2018), which showed that the fixed indoor phenotyping station yielded results that robustly reflected the impact of N fertilization rates on early plant growth, leaf SPAD values, and N content.

The low SPAD values recorded in the Control and - N treatments demonstrate how nutrient deficiencies impact leaf chlorophyll content, reflecting suboptimal plant health. Genotype DRS104 with the highest SPAD value under Half-N with strong chlorophyll retention despite reduced nitrogen input also agrees with the report by Ringger (2017), who showed significant relations between SPAD values and N leaf content and between TGI values and N leaf content for the cultivar raja ala. The highest SPAD value recorded for the genotype TDr93-31 under - N suggests its potential ability to maintain chlorophyll levels, even under nitrogen-deficient conditions.

The highest TFW under Half-N and ALL-N at 50DAT recorded for DRS044 showed a high response to the treatments.

Generally, moderate nitrogen availability (Half-N) resulted in increased tuber weight compared to water and - N treatments, confirming the positive role of nitrogen in chlorophyll content as indicated by SPAD values, shoot, and tuber development. The observations from this study are consistent with the findings of Law-Ogbomo and Remison (2008), who conducted two field trials and reported maximum yield at a fertilizer dosage of 300 kg/ha NPK. However, this contrasts with a study by Shiwachi *et al.* (2015), which stated that the role of the application of NPK fertilizer was unclear in tropical yam species and did not influence the yield of water yams despite the application of varying quantities. At 50 days after transplanting (DAT), genotype TDr8902665 recorded the highest shoot dry weight (SDW) under the Half-N treatment, while Meccakusa exhibited the highest SDW under the same treatment, suggesting efficient nitrogen utilization by both genotypes. In addition, the observed lowest shoot biomass across all treatments reported for genotype DRS104 indicates the possible susceptibility of the genotype to nitrogen stress. R-031 also had a consistently low SDW across treatments and weak adaptability to nitrogen fluctuations, as shown in the plant image on Appendix 4. Takada *et al.* (2017) also suggested that water yams absorb nitrogen from the air, which may account for the high shoot fresh/dry weight recorded for genotype TDr8902665 in this study.

In addition, it was observed that the optimal nutrient for yam propagation using the semi-autotrophic hydroponics method of propagation was Half-N because it was significantly better than the Control and - N. However, Half-N and ALL-N were not significantly different. Meanwhile, the findings of Akom *et al*. (2024) on the effect of biochar and organic fertilizer on yam production in Ghana observed no significant differences in the response of soil parameters to treatment, except for total nitrogen, where a decline was observed compared to the control. The same study reported that biochar and organic fertilizers had no significant effect on the vegetative growth of yam plants. However, dry matter production increased significantly, suggesting that later dates and higher rates of biochar application will be useful for yam production.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

The production of yams in Nigeria and Africa faces diverse challenges, one of which is a decline in yield due to the high cost of farm inputs and fertilizers. This has led to a gap in supply, as yam production fails to meet the demands of Africa's teeming population. To curb this and avoid food insecurity in Africa, there is a need to adopt innovative solutions that increase seed production strategies and foster research advancements in genetic gain.

This study was conducted to investigate the effectiveness of the semi-autotrophic hydroponics technique in screening yam genotypes for their response to different nutrient levels (ALL-N, Half-N, control, and - N) using chemical solutions. The experiment was conducted for 150 days, and the first data collection took place 50 days after the plants were transplanted into pots in the screenhouse.

It was confirmed that the choice of genotype and nutrient concentration are important factors for improving yam productivity using the SAH technique. Among the growth and yield variables assessed, a significant interaction between the genotypes and nutrients was revealed for Leaf Chlorophyll content (indicated by the SPAD Value), shoot dry weight, and tuber fresh weight.

The recommended nutrient level for yam SAH production based on the results of this study is Half-N, and the best yam genotype based on this study is TDr8902665. It was stable across all treatments, making it a promising genotype in different nitrogen environments. Semi-autotrophic hydroponics should be further exploited to complement yam seed production to shorten the breeding cycle and increase the yam seed multiplication rate. This system will also aid in the production of disease-free propagules.

The inherent potential of semi-autotrophic hydroponics for identifying genetic variation in nutrient utilization among yam genotypes was demonstrated in this study.

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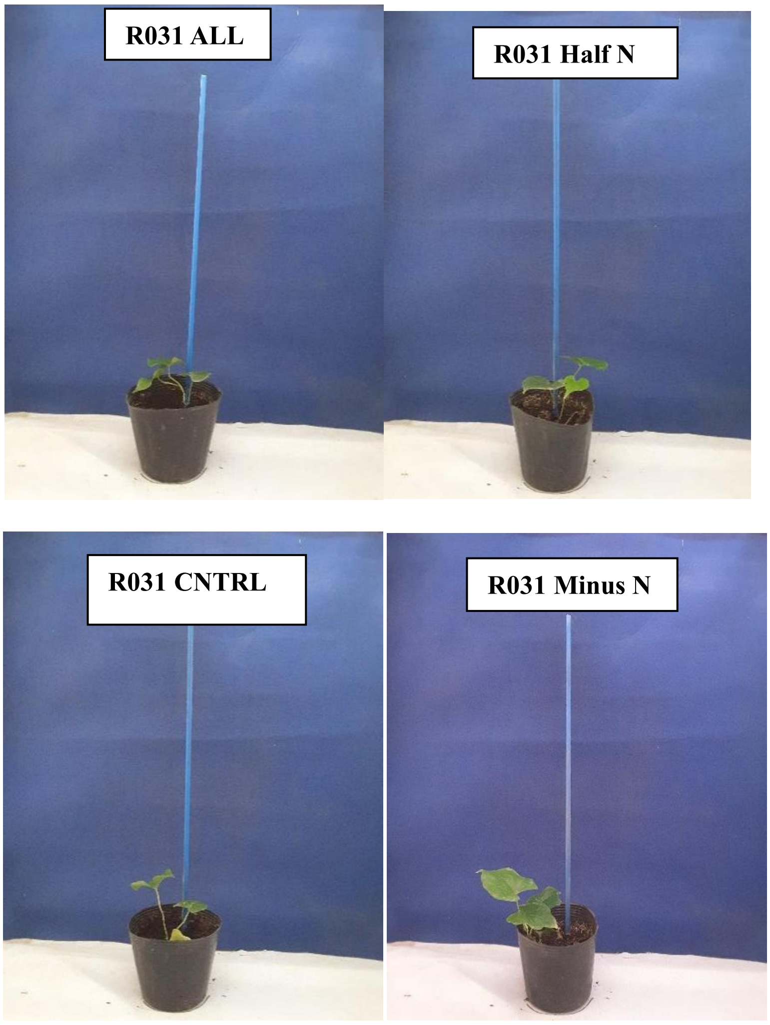
APPENDIX

Appendix 1: Experimental layout of the plants and nutrient treatments at the screenhouse.

Appendix 2: TDr8902665 tubers growth differences at 150DAT across all four different nutrient levels

Appendix 3: DRS044 tubers growth differences at 150DAT across all four different nutrient levels



Appendix 4: Plant growth differences in R-031 at 50DAT across all four different nutrient levels