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Review

Use of aeroponics technique for potato (*Solanum tuberosum*) minitubers production in Kenya

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In Kenya, potato productivity is severely constrained by limited high quality seed tubers; this is precipitated by inefficiencies in various stages in the seed production system. Production of certified seed starts with meristem tip cuttings in the tissue culture. The resultant plantlets are grown in pots in the greenhouse and/or screen-house for production of minitubers (generation 0). In Kenya, production of minitubers through aeroponics systems has been introduced. This paper discusses the production of potato minitubers using aeroponics. Important considerations that should be addressed before setting-up an aeroponics based potato minituber production system are also discussed. Research areas to optimize production and improve field performance of mini-tubers produced through aeroponics are also presented.

Key words: Aeroponics, clonal multiplication, hydroponics, minituber production, rapid multiplication techniques, tissue culture.

INTRODUCTION

Aeroponics is a plant culture technique in which mechanically supported plant roots are either continuously or periodically misted with nutrient solution (Barak et al., 1996). The international union of soil-less culture defines aeroponics “as a system where roots are continuously or discontinuously in an environment saturated with fine drops (a mist or aerosol) of nutrient solution" (Nugali et al., 2005). The basic principle of aeroponics is to grow plants in a closed or semi-closed environment by spraying the plant's roots with a nutrient-rich solution. Ideally, the environment should be kept free from pests and diseases so that the plants may grow healthier and quicker than plants grown in a soil medium. However, because most aeroponic environments are not properly closed, pests and disease may still be a threat. As aeroponics is conducted in air combined with micro-droplets of water, almost any plant can grow to maturity because of an abundant supply of oxygen, water and nutrients.

Perennial plants have been maintained for as long as 13 months in the aeroponics system (Peterson and Krueger, 1988).

In addition to commercial crop production, aeroponics system has been used for studies on root system especially root micro-organisms (Hung and Sylvia, 1988; Khan and Sinclair, 1992; Sylvia and Jarstfer, 1992; Wagner and Wilkinson, 1992), root response to drought (Mavoungou et al., 1982; Hubick et al., 1986; Robertson et al., 1990a, b), effects of oxygen concentrations on root growth (Shtrausberg and Rakitina, 1970; Soffer and Burger, 1988) and plant cultivar differences in root growth (Truong and Beunaid, 1978). Aeroponics offers researchers a non-invasive means to examine plant roots during development. It also allows researchers a large number and a wide range of experimental parameters to use in their work (Stoner, 1983). The ability to precisely

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control the root zone moisture levels and the amount of water delivered makes aeroponics ideally suited for the study of water stress. Hubick et al. (1986) evaluated aeroponics as a means of producing consistent, minimally water-stressed plants for use in drought or flood physiology experiments. Use of aeroponic systems to evaluate plant response to nutrient regimes has been infrequent, nutrient uptake rates in aeroponics systems is unknown (Weathers and Zobel, 1992). Barak et al. (1996) suggested that the nutrient uptake rates could be calculated by measuring the concentrations and volumes of influx and efflux solutions in cranberry plants.

This paper discusses the production of potato minitubers using aeroponics in Kenya. Important considerations that should be addressed before setting-up an aeroponics-based potato minituber production system are also discussed. Research areas to optimize production and improve field performance of mini-tubers produced through aeroponics are also presented.

HISTORY OF AEROPONICS USE

Techniques of growing plants without soil were first developed in the 1920s by botanists who used primitive aeroponics to study plant root structure; aeroponics has long been used as a research tool in root physiology (Barker, 1922). In the early 1940s, the technology was largely used as a research tool rather than an economically feasible method of crop production. Carter (1942) was the first researcher to study air culture growing and described a method of growing plants in water vapor to facilitate examination of roots. Fifteen years after the study of Carter (1942) and Went (1957) named the air-growing process in spray culture as “aeroponics”.

Aeroponics has been used successfully in production of several horticultural and ornamental crops (Biddinger et al., 1998). Aeroponic system has been applied successfully in Korea for potato seed tuber production (Kang et al., 1996; Kim et al., 1999). Ritter et al. (2001) demonstrated that minituber production using aeroponics under temperate conditions substantially improved yields. Farran and Mingo (2006) reported a minituber yield of 800 tubers/m^2 at a plant density of 60 plants/m^2 over a five month period with weekly harvests. This translates into a multiplication rate of 1:13. They also found the field performance of aeroponically produced tubers to be similar to minitubers produced from the pots. At the International Potato Centre (CIP) in Peru, yields of over 100 tuberlets /plant were obtained (Otazu, 2010). Lommen and Struik (1992) found that the number and timing of the harvests were the key factors in optimizing minituber production.

Aeroponics technology is being tested in several African countries for the production of potato minitubers(Lung’aho et al., 2010). In Kenya, pilot units have been set up at KARI-Tigoni, Genetics Technology International Limited, Kisima Farm, Suera Farm and Agricultural Development Farm, Molo.

OVERVIEW OF POTATO SEED PRODUCTION IN KENYA

Shortage of good quality seed potato is one of the most important factors limiting potato production in Kenya (MoA/GTZ, 2009). The annual national certified seed potato requirement was estimated to be 300,000 tons (MoA/GTZ, 2009). Basic potato seeds are produced by Kenya Agricultural Research Institute (KARI) Tigoni whose physical capacity is limited and Kisima Farm (a private company) (Riungu, 2011). Consequently, Agricultural development cooperation (ADC) can only produce 1% of the national certified seed requirement (Ayieko and Tschirley, 2006). Due to limited supply, the certified potato seeds are highly priced and the cost of seeds account for 42% of the total production costs (Kaguongo et al., 2008). As a result, farmers depend on seed from informal sources which include farm-saved (self supply), local markets, and neighbours (Muthoni et al., 2010). Self-supply is the major source of potato seed tubers for most farmers (Kaguongo et al., 2008). This informal system leads to the use of poor quality seeds and often accelerates the spread of seed-borne diseases (viruses, bacteria wilt, and nematodes) (Ng'ang'a et al., 2003).

Production of basic and pre-basic seed tubers in Kenya

Production of disease-free potato seed tubers starts with tissue culture using meristem tip culture (KARI, 2007). The *in-vitro* plantlets produced are then multiplied 3 to 4 times in the laboratory using nodal cuttings. Six to seven weeks after the last multiplication step, the plantlets are transferred into the sand trays where excess media is carefully removed from the roots using tap water and they are then transferred into seedling trays containing sand substrate. The water and nutrient solution is added in the ratio of 1:1 and watering is done each day until they are transplanted into the aeroponic boxes or pots for production of pre-basic seeds (generation 0) (Muthoni et al., 2011). The generation 0 seed tubers obtained are then multiplied in the field for three generations to produce basic seeds. The three generations (1, 2 and 3) are only meant to increase the amount of seeds. The basic seeds are then supplied to Agricultural Development Corporation (ADC) to produce certified seeds; the certified seeds are then sold to farmers for production of ware potatoes (KARI, 2007). During pre-basic seed production, the germplasm is indexed regularly to ascertain the absence of viruses. According

to Muthoni et al. (2010), efficiency in pre basic seed potato production is important for certified seed potato production. At KARI-Tigoni however, most pre-basic seeds are produced using the pot method. This technique requires soil sterilization leading to high fuel costs. In addition, the technique has a low multiplication rate (6 to 8 tubers /plant) unlike aeroponics (50 to 100 tubers per plant (Otazu, 2010; Muthoni et al., 2011). Because of this, an aeroponic unit was set up at Kenya Agricultural Research Institute-Tigoni in 2008 by the international potato centre (CIP) to enhance prebasic (minitiuber) production.

AEROPONICS SYSTEM FOR POTATO MINITUBER PRODUCTION AT KARI-TIGONI

The greenhouse/screen-house facility

An aeroponics system for seed tuber production is housed in a tall screenhouse; the conventional screen house is too low for incorporation of the aeroponics system (Otazu, 2010). When using aeroponics, it is desired to maximize the vertical dimensions of the screen house. This is because both the root system and the foliage usually grow longer than in the pots (Otazu, 2010). In the aeroponics unit at KARI, Tigoni, potatoes have grown up-to 110 to 140 cm tall. Shorter greenhouses also tend to get hotter. The screen-house is roofed with asbestos sheets to keep out dust and fungal spores. The roof is then covered with shading net to lower the temperature in the greenhouse. The roof and doors are properly sealed to keep off insects. The sides are be made of fine net to keep off insects.

Growth boxes

The growth boxes are placed inside the screen house. The boxes to be used depend on the capacity of the screen house and the amount of minitubers required. In KARI-Tigoni, boxes of 60 × 45 × 85 cm depth are used. The growth boxes (chambers) have a framework of steel bars; the lid, sides and bottom are made of Styrofoam. The lids are removable. The lids have 2 cm diameter holes at a spacing of 10 × 10 cm into which short perpex pipes (½ an inch in diameter) were inserted. The plants are fitted into these pipes. The sides are also movable to allow frequent harvesting and monitoring of the root system. At the floor, the chambers are fitted with drainage pipes; these are inclined to allow flow of the nutrients back to a reservoir tank. The tank is placed underground to maintain low temperatures and to allow free flow of the nutrient solution.

Temperature regulation

Temperature in the aeroponic unit should be regulated according to Otazu (2010); the roof needs to be covered by a shade net to regulate the temperature inside the screen house. Day temperature should not be higher than 30°C and lower than 4°C. The best temperature for tuberization is 10 to 15°C during the night and around 20°C during the day. At KARI-Tigoni, the temperatures are regulated using a shade net and maintained at 18 to 23°C during the day and 14 to 15°C at night.

Power

Power is needed to operate the fertigation system. In KARI-Tigoni, electricity is the main source of power. A fuel-driven generator is used when there is no electricity.

Crop management

After fixing the plants in the perpex pipes, a small piece of thin sponge is wrapped around the crown of the plant to seal off the hole completely and to hold the plant in an upright position. The sponge is then covered with a piece of black polythene paper fastened with masking tape. This is to ensure that the boxes are dark inside. For tuber formation, total darkness is required; otherwise, the stolons will develop into foliage. Six weeks later, the lower leaves of the plant are cut and the plant pulled slightly down inside the box to promote more stolon development. When tending the crop, sanitation procedures observed include washing hands with disinfectant, dipping shoes into a footbath and sterilizing all equipment used using common disinfectant as this is to avoid spreading diseases.

Nutrient management

Fog nozzles (36 L/h) are fitted on the underside of the lid of the growth chamber. The aeroponic system is calibrated to mist for 5 min at 15 min intervals. The draining solution flows back into the reservoir tank by gravity. Farran and Mingo (2006) used systems that mist for 10 s at 20 min intervals. The nutrient solution has an EC which does not exceed 2.0 mS/cm. In potato minituber production at KARI-Tigoni, nutrient solution of EC values between 2.0 and 2.5 dSm^{-1} has been used. The pH of the nutrient solution does not exceed 7.3; the optimum is 6.5 to 6.8. The nutrient solution is changed in every four weeks to replenish the nutrients and maintain the correct pH. According to Farran and Mingo (2006), the following nutrient solution gives satisfactory minituber yield: KNO_3 (0.4 me/l); Ca $(NO_3)_2$ (3.1 me/l); NH_4NO_3 (4.4 me/l) and $MgSO_4$ (1.5 me/l), at a pH of 5.7. The following nutrient solutions have been used with satisfactory results in the Kenyan potato program (Table 1).

Quality control

Leaf samples were collected from the plants for virus

Table 1. Composition of 500 L nutrient solution for seed potato production (Farran et al., 2006).

Nutrient	Quantity
KNO_3	252 g
$Ca(NO_3)_2$	118 g
KH_2PO_4	68 g
$MgSO_4$	246
Fe(EDTA) Fe 6%	9 g
Micro (fetrilon)	12
pH	5.7

*Fetrilon combi is a commercial foliar micronutrient powder that has the following formulation: 9% MgO, 3% S, 4% Fe, 4% Mn, 1.5% Cu, 1.5% Zn, 0.5% B, and 0.1% Mo.

indexing using ELISA (enzyme linked Immuno-sorbent assay) tests. At least two ELISA tests were conducted; the first test was conducted one month after transplanting and the second test two to three months after transplanting.

Harvesting and handling of minitubers

Two weeks after transplanting, the early maturing potato varieties began to produce tuberlets. Harvesting of minitubers commenced when they attain at least 8 g. This corresponds to the size of 0.5 cm in diameter. It is better to harvest in the morning when it is cool (Otazu, 2010). During the first harvest, all minitubers larger than 1.5 cm in diameter are removed. This is done in order to enhance more tuber initiation. Subsequent harvests are done every 10 to 14 days. Harvesting continues until plants are about six months old. Harvested minitubers are left to cure for 2 weeks before cold storage. This is because they have imbibed a lot of water during development and they can rot if they are taken to cold store immediately.

FACTORS AFFECTING PRODUCTION OF MINITUBERS IN AEROPONIC SYSTEM

1. Temperature: it should be 18 to 20°C during the day and 14 to 15°C at night (Otazu, 2010).

2. Nutrition: Calcium is required for stolon tip development and to promote tuber initiation (Balamani et al., 1986). When N supply is in excess, there is an excessive vegetative growth and delayed tuberization (Kang et al., 1996).

3. Mechanical stress: Lugt et al. (1964) reported that aeroponics cultures perform better when roots grow in air without mechanical obstruction.

4. Light: Absolute darkness is necessary for tuber formation, with minimum light penetration; the stolons develop into new stems.

5. Lowering of plant: Hand pulling down the plants after each harvest is necessary to increase the formation of new stolons with tubers (Lommen, 1995).

6. Harvesting: Repeated harvesting increases yield especially tuber number. This may be due to the removal of the dominant large tubers, which allows initiation of new tubers (Lommen, 1995).

DISCUSSION

Aeroponics technique is a rapid multiplication technology (RMT) able to produce large numbers of minitubers in one generation, thus, allowing bulking of large number of potato seeds. This eliminates the need for field generations 1, 2 and 3 thereby reducing costs and saving time.

Aeroponics system offer several advantages over other methods. These include:

(i) Aeroponics optimizes root aeration resulting in more yields than classical hydroponics (Soffer and Burger, 1988).

(ii) Aeroponics uses little water that is, $1/10^{th}$ to $1/30^{th}$ of the water used in field production of the same amount of potatoes.

(iii) There is good nutrient recirculation, control of nutrients and pH.

(iii) No sterilization of growing media is required thus, minimizing the costs. There are no soil-borne diseases, weeds and nematodes in aeroponic systems.

(iv) An aeroponics system as a whole, allows for uniform water availability to plants.

(iv) Extended growing season that is, crops can be grown all the year around and hence more yields.

(v) Intensive production in a small space that is, more plants per unit area and hence, more yields.

(vi) No loss of fertility and so no crop rotation is needed in field grown crops.

(vii) Closer plant spacing is possible and moveable plant channels allow greater production from equal areas for some crops.

(viii) Use of biological controls including beneficial insects and safe methods of insect control are possible and practical in a controlled environment system.

(ix) According to Muthoni et al. (2010) and CIP (2010), the method is up to ten times more effective than with the conventional techniques.

(x) The minitubers can be harvested at any size seed the user wants, from 5 to 30 g. Spraying fertilizers directly on to the roots makes it possible for the growth phase to continue for more than 180 days without interruption, which does not happen with conventional techniques.

(xi) Harvesting of minitubers in aeroponic systems is convenient, clean, and permits a greater size control through sequential harvesting. It also increases yield especially tuber number; this may be due to the removal of the dominant large tubers, which allows initiation of

new tubers as well as the development of existing ones (Lommen, 1995; Ritter et al., 2001). Aeroponics also has got its share of disadvantages. These include:

(a) Minimum light penetration of the stolons develop into new stems. Maintaining total darkness is a problem because the sides are regularly opened to monitor the root growth and harvest minitubers; therefore absolute darkness is necessary for tuber formation.

(b) It is labour and cost intensive for example, the staking of plants, manual harvesting and pulling down of the plants after each harvest lowering of plant. Hand pulling down the plants after each harvest is necessary to increase the formation of new stolons with tubers. This calls for a lot of work.

(c) Start-up costs of aeroponics are also high. It costs about 24,000 dollars to set up a simple system able to produce 80,000 minitubers in a year.

(d) Aeroponic systems are dependent on low volume of nutrient solution that is available to the root system and any losses of power to pumps can produce irreversible damages including complete loss of plantlets.

(e) There are variations in nutrient requirements by various varieties; hence toxicities and deficiencies are likely to occur.

(f) Lack of water and chemical buffering capacities in the system when power cuts occur must be compensated by security systems (alarms, pumps), high infrastructure costs, high technology and a specialized organization of growers.

(g) Functional system including rooting due to tubers being touching the box floor leading to blockage of the drainage system.

(h) For large-scale minituber production in aeroponic system, an economic evaluation is necessary for soil-less culture and particularly aeroponics, to validate the technology as low cost for disease-free minituber production.

(i) Temperature: Ideal temperature should be 18 to 22°C during the day and 14 to 18°C at night. Maintaining this temperature is a challenge because the screen house does not have automatic control.

CONCLUSION AND RECOMMENDATIONS

To optimize aeroponics system, various issues need to be addressed:

(a) Harvesting intervals should be longer to increase the number of larger seed minitubers. Plants from small minitubers are sensitive to heat and drought stress due to the small size of mother tubers. They are also less vigorous and less competitive against weeds that plants from larger tubers (Struik and Lommen, 1990).

(b) An economic evaluation is also necessary to ascertain the viability of aeroponics systems in the developing countries for minituber production.

(c) Studies on appropriate nutrient solutions, plant densities, number of harvests and harvest intervals, as well as all interactions between production factors need to be investigated.

(d) Effects of lowering the plants by hand pulling down of plants after each harvest (as a way of increasing the formation of new stolons and tubers) on overall yield should be investigated.

(e) Best production time needs to be determined in each area depending on weather and planting season since day time with temperatures higher than 30°C are too warm for aeroponic plants and these temperatures are not desirable for tuberization to occur.

(f) Pest and disease control need to be optimized as they are different from those encountered in field potato production.

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