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Full Length Research Paper

Potential of aeroponics system in the production of quality potato (*Solanum tuberosum* l.) seed in developing countries

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The production of potato seed under conventional system has not been effective in avoiding or reducing the build up of pathogens and has consequently led to reduced quality potato seed and low crop yields. Plants once cleaned through meristem culture and induction of tuberization under aeroponics system, produce high quality potato seed tubers rapidly that are free from contamination of pathogens. Further multiplication of potato seed tubers under aeroponics also compliments tissue culture (micropropagation), as it clones minitubers in a short time and reduces numerous labour steps associated with direct use of plantlets from tissue culture into the field in the post flask stage. Mini-tubers from air-rooted plants are planted directly in the field without a need for acclimatization to such environments. This system, as is the case with micropropagation, has potential to increase income and reduce cost of production of quality seed, thereby, making it more accessible to growers in developing countries where potato production is heavily constrained by the use of poor quality seed tubers. This review gives an insight on the potential of aeroponics in compliment to plant tissue culture in revolutionalizing the potato seed production in the agricultural systems of developing countries.

Key words: Aeroponics, tissue culture, potato seed.

INTRODUCTION

Potatoes are among the ten most important food crops in the world. Its production in developing countries, like Malawi has been increasing due to increasing demand for food which has led to increased area of production unlike in developed countries where diversification of diets and life styles has slowed down its production. However, the yields of potatoes in developing countries are increasing at a decline rate (FAO, 2008; Table 1). This decline in yield is mainly as a result of the use of poor quality seed by farmers. Farmers use previous seasonôs harvest as seed tubers and such seed favours a build-up of tissue borne pathogens and this leads to significant loss of yield and tuber quality due seed degeneration.

There are several seed production techniques that are currently used world wide such as tissue culture, hydroponics and aeroponics. Among these techniques, initial experimental studies have shown that aeroponics is one of the most effective techniques because of its perceived numerous advantages over these other techniques (Ritter et al., 2001; Otazu, 2008).

This paper is part of the literature review that discusses the benefits of using aeroponics system as a potato seed propagation method in agricultural systems.

CHALLENGES OF CURRENT CONVENTIONAL POTATO SEED PRODUCTION

There are a number of potato propagation techniques that are currently used world wide to multiply seed potato

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Table 1. World potato production in million tonnes, 1991 to 2007 (Source: FAOSTAT, 2008).

Country	Year								
	1991	1993	1995	1997	1999	2001	2003	2005	2007
Developed	183.13	199.31	177.47	174.63	165.93	166.93	160.97	159.97	159.89
Developing	84.86	101.95	108.50	128.72	135.15	145.92	152.11	160.01	165.41
World	267.99	301.26	285.97	303.35	301.08	312.85	313.08	319.98	325.30

and among them are: (1) conventional seed potato production, (2) micropropagation, (3) hydroponics and (4) aeroponics. However, most farmers of the developing countries are engaged in potato seed multiplication using the conventional method of producing seed tubers. While all the methods have got limitations and challenges, the conventional technique has the highest limitations in producing high quality seed tubers under the poor resource farmerôs conditions.

Conventional techniques

Conventional techniques of seed potato production involve the use of potatoes that are propagated by harvesting and replanting the tubers in the field. The tubers used for planting are known as "seed potatoes", as opposed to "potato seeds". Seed potato growers select better quality tubers for seed and discard those of poor quality. The diseased and healthy plants are identified and separated and the healthy tubers are used for the next season's production. However, this method of seed production has proved to be laborious (labour intensive), prone to pest and disease infestation and time consuming.

Considering that vegetatively propagated crops especially potatoes are prone to both viral and bacterial diseases, the conventional production of seed potatoes favors disease build-up, which drastically reduces crop yield (Badoni and Chauhan, 2010; El-Komy et al., 2010). If the mother potato plant becomes infected with a disease during the growing season, each of the new daughter tubers is likely to be infected as well.

During the growing season, growers check seed fields visually for signs of disease and remove infected plants through the process of rouging. However, visual inspection, particularly for primary infection, is unreliable, time consuming and requires a well experienced eye (Lapierre and Signoret, 2004; Phytocultures Ltd, 2008). Inevitably, the quality of seed potato produced in subsequent generationsôdeclines substantially.

The conventional method of propagation is one of the slowest methods of seed multiplication. Compared with other seed propagation techniques like tissue culture and aeroponics, this traditional method would create approximately 8 daughter tubers only in the course of a year (Hussey and Stacey, 1981; Otazu, 2008). This method has also shown to be time specific particularly in tropical and sub-tropical regions where potato is a winter crop (Burton, 1989). In addition, the method requires a seed producer to have enough land if he is to enter into commercial seed production. This however, is associated with high labour cost in managing big fields.

Tissue culture techniques

Plant tissue culture is the science of growing plant cells, tissues or organs isolated from the mother plant, on artificial media. This is facilitated through the use of a liquid, semi-solid or solid growth media in sterilized tubes or containers (Figure 1).

Tissue culture is one of the important new methods of plant propagation available to growers. The use of tissue culture technique in seed production has resulted into mass production of potato plants in a very short period of time. The system is characterized by very flexible rapid multiplication giving a high rate of multiplication (Beukema and Van de Zaag, 1990; Pruski, 2001).

Meristem culture is one of the important plant tissue culture applications for elimination of viruses from planting materials (Naik and Karihaloo, 2007; Badoni and Chauhan, 2010). It is a procedure in which apical/axillary growing tip (0.1 to 0.3 mm) are dissected and allowed to grow into plantlets on artificial nutrient media under controlled conditions. This technique for virus elimination is based on the principle that, many viruses are unable to infect the apical/axillary meristems of a growing plant and that a virus free plant can be produced if a small piece of meristematic is propagated (Wang and Hu, 1980; Kassanis, 2008). Apical meristem has a number of unique characteristics that has made elimination of virus possible and some of the features include: (1) vascular system through which viruses are spread is not developed in the meristematic region, (2) chromosome multiplication during mitosis and high auxin content in the meristem may inhibit virus multiplication through interference with viral nucleic acid metabolism and (3) existence of virus inactivating system with greater activity in the apical region than elsewhere (Naik and Karihaloo, 2007). The other advantage of meristem culture is the maintenance of genotype identity, since meristem cells preserve their genetic stability more uniformly (Grout, 1990). When materials have been cleaned of the pathogens, they can be mass multiplied for use as planting materials.

Figure 1. A picture of potato plantlets in a solid growth media in a tissue culture growth chamber (Chiipanthenga 2009, unpublished).

Tissue culture is not limited by the time of the year or weather. Healthy plants can be grown in a laboratory at any time of the year. In addition, conditions in the laboratory are ideal and therefore, conducive to all year round production scheduling. It also saves an enormous amount of daily care required by conventional cuttings and seedlings (Tudge, 1988; Mahmond, 2006). Tissue culture is also used in somatic hybridisation, the induction and selection of mutants and biosynthesis of secondary products (Beukema and Van der Zaag, 1990).

Application of tissue culture alone has been practiced in different countries such as Vietnam as a revolutionized seed potato production. This technology is now well mastered and has been used in the successful micro-propagation of several plant species in several countries (Bachraz, 1995). However, in the case of potato, seed tubers are the best planting materials hence, application/ adoption of plant tissue culture alone in seed potato multiplication has been low.

Most developing countries fail to maximize tissue culture technology due to high operational costs involved as it requires specialised equipment which is very expensive to acquire. In addition, different nutrients, energy sources, vitamins and growth regulators used for media formulation are also very expensive (Badoni and Chauhan, 2010).The techniques of tissue culture require specialised skills and knowledge which can only be acquired after going through formal training. Most of the plant tissue culture laboratories that have been established in the National Agricultural Research (NAR) institutions and Universities for the past two decades have not been fully utilized beyond under-graduate and postgraduate training. The lack of venture into commercial micro-propagation of the important crops has also probably contributed to the low adoption of the technology in developing countries, since most farmers involved in potato seed production are illiterate and most countries do not have the capacity to conduct such specialized trainings.

Inadequate sterilisation can result in 100% contamination, particularly when using field grown material. The success of any tissue culture propagation depends on the ability to transfer plants from a sterile environment to a non-sterile environment. For tissue culture to be adopted commercially, this stage must be done with high survival rates at low cost. Such ways of reducing contamination in tissue culture have been proved to be time consuming, labour intensive and therefore, very costly (Shahsavari, 2010; ISAAA, 2010).

Plants in tissue culture grow under very humid conditions in the culture tubes and have very little layer of wax on their surface. The wax is important in preventing excess water loss and to some extent, protecting against disease attack (Hamilton, 2004). As a result, plants obtained from tissue culture are more susceptible to transporting shock and prone to wilting, pests and diseases attack once transported to the field. The micro-propagated plantlets therefore, require a hardening off period every time planting materials are produced prior to planting them in the field (Dhawan and Bhojwani, 1987). The use of plant tissue culture as a routine method of potato seed production would be costly but these techniques can be used to eliminate the pathogens, produce required initial material and then, use another

Figure 2. A picture of seed potatoes showing a prolific potato seed propagation and root air optimization in an aeroponic system (CIP, 2008).

efficient and cheaper system to rapidly produce high quality seed tubers for commercial production.

THE POTENTIAL OF AEROPONICS TECHNIQUE

Aeroponics is the process of growing plants in an air or mist environment without the use of soil or an aggregate media. The word aeroponic is derived from the Latin meanings of 'aero' (air) and 'ponic' (work) (Farran and Mingo-Castel, 2006). This is an alternative method of soil-less culture in growth-controlled environments. Aeroponics system refers to the method of growing crop with their roots suspended in a misted nutrient medium.

Benefits of aeroponics

The growing of potato plants in aeroponics system is considered as safe and ecologically friendly for producing natural, healthy plants and crops. Multiplication of seed potatoes using aeroponics has advantages over the other systems or techniques including, conventional seed potato production, hydroponics and plant tissue culture techniques. Reports show that the system is ten times more successful than conventional techniques, tissue culture and hydroponics, which take longer and are also more labour intensive (CIP, 2008). The system has the ability to conserve water and energy. Aeroponics system uses nutrient solution recirculation hence, a limited amount of water is used. It comparatively offers lower water and energy inputs per unit growing area (Ritter et al., 2001; Farran et al., 2006).

Using aeroponics for cloning improves root growth, survival rate, growth rate and maturation time (Stoner, 1983). Studies have shown that, the mean tuber yield under aeroponics is better than when the same material is left to produce tuber under conventional means (Otazu, 2008, Tsoka et al., 2008). Such results clearly show that, aeroponics system can be effectively used for potato propagation (Goo et al., 1996; Ritter et al., 2001; Factor et al., 2007). The aeroponics system optimizes root aeration. This is true because the plant is totally suspended in air, giving the plant stem and root systems access to 100% of the available oxygen in the air which promotes root growth. Such environment also gives plants 100% access to the carbon dioxide concentrations ranging from 450 to 780 ppm for photosynthesis hence, plants in an aeroponics environment grow faster and absorb more nutrients than regular hydroponics plants (Ritter et al., 2001). This is in line with Sun et al. (2004) who reported that, the aeroponics system increased stomatal conductance of leaf, intercellular CO_2 concentration, net photosynthetic rate and photochemical efficiency of leaf.

Aeroponics method of propagation is one of the most rapid methods of seed multiplication. An individual potato plant can produce over 100 minitubers in a single row (Otazu, 2008), as opposed to conventional method that create approximately 8 daughter tubers only in the course of a year while only 5 to 6 tubers per plant are produced using soil in the greenhouse in 90 days (Hussey and Stacey, 1981; CIP, 2008) (Figure 2).

Another advantage of aeroponics system is that of easy monitoring of nutrients and pH. Aeroponics system provides precise plant nutrient requirements for the crop,

Figure 3. Aeroponic boxes lined with plastic in Rosario Falcon, International Potato Center (February 2009) (A) and at Universal Industries Ltd, Njuli-Estate in Malawi, 2009 (B).

thereby, reducing fertilizer requirement and minimizing risk of excessive fertilizer residues moving into the subterranean water table (Nichols, 2005). Aeroponics system also allows the measurement of nutrient uptake over time under varying conditions. Barak et al. (1996) used an aeroponic system for non-destructive measurement of water and ion uptake rates for cranberries. All these results clearly show that, aeroponics is a research tool for nutrient uptake and opens up possibilities for the monitoring of plant health and optimization of crops grown in closed environment. Aeroponics production system is very space efficient, with plants taking up minimal room. In contrast with other techniques such as hydroponics and conventional system, aeroponics exploits better vertical space for root and tuber development (Stoner, 1983). The environment under aeroponics is kept free from pests and diseases since plant-to-plant contact is reduced hence; plants grow healthier and quicker than plants grown in a medium. In addition, if a plant becomes diseased, it is quickly removed from the plant support structure without disrupting or infecting the other plants (Figure 3). As a result, many plants can grow at higher density (plants per unit area) than in the traditional forms of cultivation such as hydroponic and soil (Stoner, 1983).

The system clones plants in less time and reduce numerous labour steps associated with the other techniques such as tissue culture techniques (Stoner, 1998). In addition, the air-rooted plants are cloned and transplanted directly in the field without a fear of a seedling being prone to wilting and leaf loss, due to transplant shock.

Potential challenges of aeroponics system

The worst inconvenience relies on water droplet size (Stoner, 1998). Large droplets lead to less oxygen available to the root system, while fine droplets produce excessive root hair without developing a lateral root system for sustained growth. The system also requires constant power supply throughout the growing season and any prolonged interruption of power to water-pumps may lead to irreversible damages of plants.

The system requires a number of maintenance operations which may be costly in developing countries. For instance, mineralization of the ultra-sonic transducers requires maintenance and may be prone to potential component failure (Stoner, 1998). This may also lead to failure of metal spray jets and misters which may restrict the plant to have an access to the water thereby, causing the plant to lose turgidity and wilt. People who are going to conduct this seed production must be well trained. The technicians managing the aeroponics need to have additional knowledge of crop physiology hence, it may be limiting. In this case, the best approach would be to have few farmers engaged in high quality seed production as a business by applying aeroponics system. However, while only a few farmers may be involved in potato-seed production using aeroponic system, many others will be able to access improved quality, low-cost seed (CIP, 2008).

JOINT APPLICATION OF TISSUE CULTURE AND AEROPONICS SYTEM

Aeroponics system itself can be inadequate in viral disease-free seed potato production if not complemented with tissue culture's meristem culture application. The meristem culture has to be applied in elimination of any viral pathogen from the desired clone of the potato before multiplying the plantlets to be used in the aeroponics system to produce pathogen-free seed tubers (Kane,

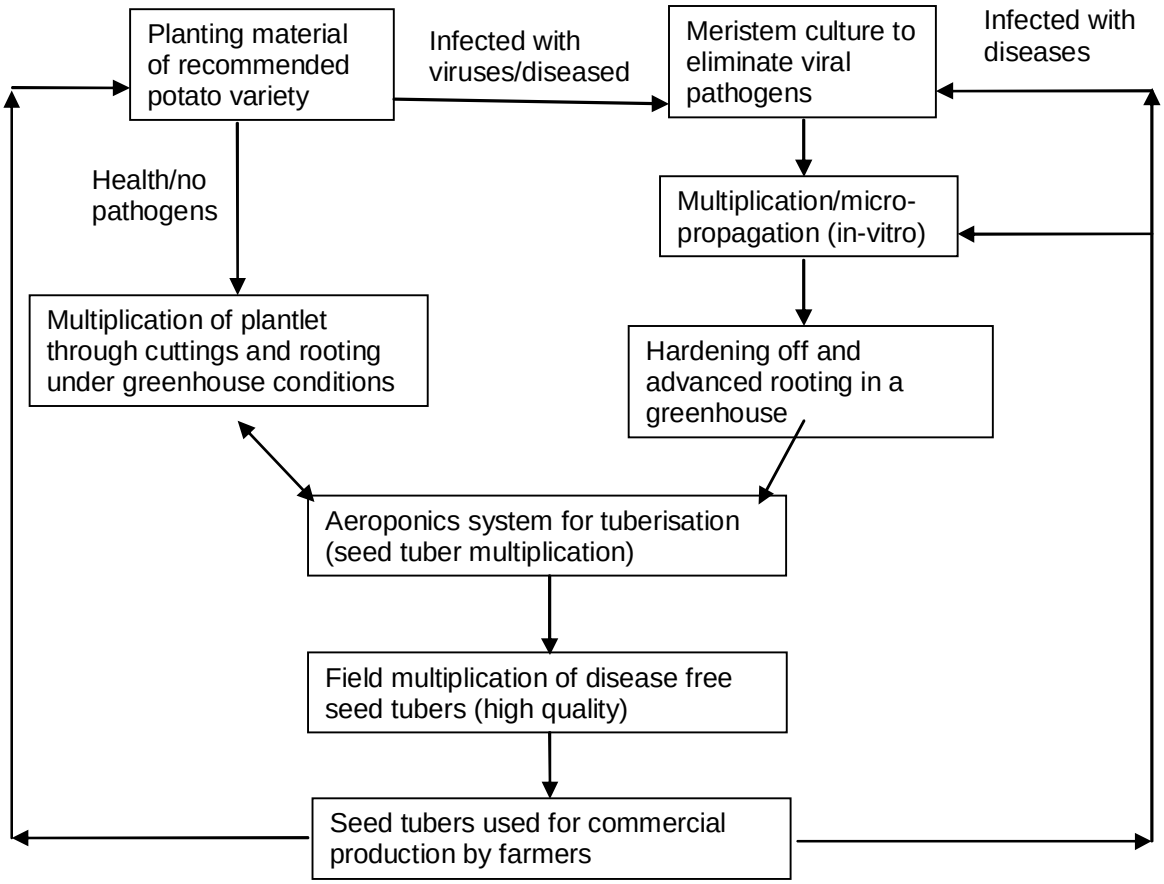

Figure 4. A schematic presentation of how aeroponics system and plant tissue culture techniques are applied to produce disease free seed potatoes.

2000). A stock of viral-free planting materials can be maintained under both tissue culture conditions and in an insect-free screen house where re-infection cannot occur. The plant stocks maintained in a tissue culture laboratory have to undergo the hardening off stage each time before getting into the aeroponics system (Correa et al., 2009), while those maintained in a greenhouse do not require any hardening off before taken into the aeroponics system (Figure 4). There is however, a need to determine the number of subcultures that can be made *in vitro* before somaclonal variation sets in.

CONCLUSIONS

Aeroponics system complemented by plant tissue culture promises a great potential to transform seed potato production in developing countries. Considering the potential benefits of the system such as rapid production of seed, spacious, good nutrient monitoring system, improvement of growth and survival rate of plantlets, constant air circulation and ecologically friendly, this system has a potential of revolutionizing potato seed production industry in developing countries. This system has a potential of significantly increasing income and reduce time and cost of production of quality seed potatoes to make them more accessible to growers in developing countries.

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