

Review Article

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Aeroponics and Sand Hydroponics: Alternative Technologies for Pre-basic Seed Potato Production in Ethiopia

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Abstract: Potato is the third most important food crop worldwide after rice and wheat in terms of human consumption, and global production exceeds 374 million metric tons. Despite this immense importance, potato yields from small-scale farmers in most developing countries including Ethiopia fall far below their capacity, mainly because of insufficient access to high quality seed and limited knowledge on crop husbandry. Moreover, 98.7% of the seed being used come from the informal seed system which lacks appropriate phytosanitary schemes. Frequent seed degeneration nature and low multiplication rate of the crop also provoked less productivity of potato. Hence, technological improvements are necessary for increasing potato productivity and decreasing different bottlenecks of the crop. Aeroponics, sand hydroponics and tissue culture based seed multiplication techniques are currently accelerating the supply of disease free seed potato to the country. Thus, to take advantage of the yield capability of potato by improving the maximum production determinant elements like seed quality, these alternative pre-basic seed potato multiplication technologies could be duly verified and used as an option to boost the yield of potato.

Keywords: Aeroponics, sand hydroponics, pre-basic seed, potato, Ethiopia

Introduction

Potato (*Solanum tuberosum* L.) is a staple non grain crop in the world. It is a critical tuber crop in terms of

food security in the current world context of population growth and increased hunger rates. According to the International Potato Centre (CIP 2017) more than a billion people worldwide eat potato, and global total crop production exceeds 374 million metric tons. The broad, fertile highlands of East, Central, West, and Southern Africa are blessed with a temperate climate and generally dependable rains (Abdulwahab et al. 2016).

These regions present ideal conditions for growing potato, a well-established, nutritious crop with high market demand (Demo et al. 2009; Kyamanywa et al. 2011). Potato production in Sub-Saharan Africa (SSA) has more than doubled since 1994, with 70% of that growth concentrated in eastern Africa FAO and CFC (2010).

Potato is amongst one of the few top cash crops on farms as small as half a hectare. Troubling is that many farmers are trying to meet the growing demand for potato by expanding the areas under production rather than tackling productivity constraints. This leads potato yields of small-scale farmers in the region fall far beyond their potential, mostly due to a forceful combination of insufficient supplies of high quality seed and limited awareness of better seed and crop management practices. Consequently, potato yields in Sub-Saharan Africa including Ethiopia are dismally low within the range of 6–10 t/ha (Demo et al. 2015; Mohammed et al. 2016; CTA 2014).

For many potato farmers the access to quality planting material for vegetatively propagated crops is very critical to improve their productivity as well as the livelihood of the rural community (Abdulwahab et al. 2016; Alfayo 2016). Even though possibilities exist alongside the seed potato price chain, simple demanding situations take away farmers from benefitting completely from the crop. First is the minimally functional seed potato systems in most of developing countries, that bound the delivery of high-quality seed potato to satisfy increasing demand. Poor quality seed lowers yield potential and continually keeps smallholder incomes low due to minimal harvest with poor quality produce (Berga and Gebremedhin 1994;

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Millam and Sharma 2007; Endale et al. 2008; Limenih and Tefera 2014; Waga et al. 2016). Secondly, good farming practices for both seed and ware potato are not well understood or habitually applied by farmers.

As a study reported by Roy (2014) seed became the most critical concern to ensure the harvest with acceptable quality and to capacitate the productivity by 15-25%. Moreover, seed incurred 40–60% of the cost of potato production (Gildemacher et al. 2011; Sharma et al. 2015). Therefore, improving seed potato quality and availability would be one way of improving the productivity of potato. Furthermore, the conventional method of propagation is one of the slowest methods of seed multiplication for potato due to its low multiplication rate unless some of the accelerated seed potato multiplication systems are implemented (Otazu 2010; CIP 2017b; Lemma et al. 2018).

To offset these seed related and other yield hindering issues of potato, Ethiopia adopted different seed potato multiplication schemes (Abebe et al. 2014). With the collaboration of the Ethiopian Institute of Agricultural Research (EIAR) and CIP, different Rapid Multiplication Techniques (RMTs), like tissue culture produced plantlets, screen house pots, aeroponics (Lemma et al. 2017), and sand hydroponics, which was implemented in the country since 2013, have been used to boost up selected potato varieties released in the country. Since then the seed production system in the country is being accelerated due to the efficient use of rapid seed multiplication techniques. The Holetta Research Centre, which is used as the seed bank for most potato growing highlands of the country generated and disseminated mini-tubers to different parts of the country. Therefore, the objective of this paper is to review the role of aeroponics and sand hydroponics used as a pre-basic seed potato multiplication techniques.

Potato Seed System in Ethiopia

With the absence of a universally settled definition for different seed systems, there are three different types of seed production systems, i.e. formal, alternative and informal seed production systems (Schulz et al. 2013; Nteranya 2015; Hirpa et al. 2010). Like other crops, roots and tuber crops have a well established legal frame work used for seed certification and inspection purposes, even though it is not yet implemented.

In the alternative system, farmer cooperatives and farmer groups (farmer cooperatives in the following) with technical support and supervision from the national research and extension system produce seed of relatively high quality, in the same way by special

projects and universities. In contrast, the informal system is characterized by the absence of quality control mechanisms. Relatively poor quality seed, derived from farmers' own fields (farm-saved), and local markets or exchanges from neighbors is planted for an unspecified number of generations. According to Berga (2012) and Gildemacher et al. (2009), Ethiopia, like other Eastern Africa (Kaguongo et al. 2013) uses both formal and informal seed systems. As illustrated by (Gildemacher et al. 2009), the informal system is the major seed production system accounting for 98.7% of the total potato seed produced in the country at the same time the alternative system meets 1.3% of the country's seed requirements. Otieno et al. (2017) also reported that across East Africa, the formal seed system only provides a small share (<20%) of smallholders' seed in the region. Most farmers source seed from informal seed systems, including own-saved seed, exchanges with neighbors, and local seed markets.

Basic seed production is a vital component of the strategy for organizing a potato seed program that involves different techniques. A pre-requisite to a successful and sustainable seed scheme is a continuous supply and maintenance of pathogen-free pre-basic seed (Gebremedhin et al. 2008). The total area covered with potato in Ethiopia for the year 2006 was around 160,000 ha (Gebremedhin et al. 2006). The annual seed requirement for that respective year was therefore around 320,000 tons; out of which 315,840 tons (98.7%) are supplied by the informal seed system and the remaining 4,160 tons by the alternative system from different seed sources including research institutions.

Soilless Pre-basic Seed Potato Production Technologies

The use of soilless propagation techniques provides distinctive opportunities for producing seed potatoes at enhanced rates in a controlled environment with no, or a minimal incidence of pests and diseases. In addition to bacterial and fungal diseases, potato is infected by more than 30 viruses and virus-like agents (Millam and Sharma 2007). Being systemic pathogens, potato viruses are able to disseminate through the tubers accordingly leading to substantial levels of crop degeneracy with every increase in the number of production cycles (Miassar et al. 2011). Thus, the yield losses attributed to virus infection are not only confined to a particular year but also accumulated over years throughout the crop lifecycle (Endale et al. 2008) with each successive propagation, as long as the infected tubers are used as seed for the new cropping season. To check this

spread of viruses and other pathogens, most seed potato certification schemes in use today are largely based on a uni-directional principle, whereby a certified nuclear stock is used to initiate a seed multiplication scheme. Hence, meristem culture could considerably reduce the disease by using the upper tip and less disease concentrated shoot tips.

Accelerated propagation rates with continual substitution of newly multiplied generation seed reduce the seed's exposure to field-borne diseases, minimize the accumulation of tuber-borne diseases and, additionally, facilitate the rapid introduction of new varieties enabling initial market benefits for the producer (Otazu 2010; Schulte-Geldermann et al. 2013). These soilless seed production techniques play an important role in these activities, and the critical *in vitro* and semi-*in vivo* phases almost invariably rely on the use of one or more of the range of soil-free techniques that have been developed (Millam and Sharma 2007). At Holetta, these soilless techniques transformed the conventional production capacity of mini-tubers under screen house pots from 43,773 to 433,742 under screen houses (Figure 1) (Lemma et al. 2018). The overall clean mini-tuber production capacity increased from around 43,000 to 650,000 and consequently the productivity was improved due to quality seed source.

***In vitro* micro propagation system**

The key benefit of tissue culture generation lies in the production of ample high quality and uniform planting material that may be eminent on a year-round basis under

aseptic conditions no matter the season and climate IAEA (International Atomic Energy Agency, 2004; Narula et al. 1998; Mahmond 2006; Ibsa et al. 2013). However, the technology demands a huge amount of capital, labour and energy (Badoni and Chauhan 2010). Even though, labour is cheap in many developing countries, the resources like skilled man power and advanced equipments are challenging the progress. In the current era, bioreactors are becoming the solution for multiplication of huge plantlets and may cut down the cost of plant production, which is not properly implemented yet in most developing countries (Ogero et al. 2012). In all instances, such alternatives have to be incorporated without reducing the efficiency of plant propagation and compromising the plant quality (Ahloowalia et al. 2004; Batool et al. 2014; Sharma et al. 2015).

Sand hydroponics technology for quality seed production

In current scenario, soilless production technologies are being an option for the production of quality early generation seed potato to fill the gap of seed demand. Sand hydroponics is the system of growing plants using nutrient solution dissolved in water without the use of soil as a growing medium. Plants can take all the required nutrients directly through their roots in dissolved form (Factor et al. 2007). The word hydroponics is derived from Greek phrases *hydro*, meaning water and *ponos*, which means labour. It is

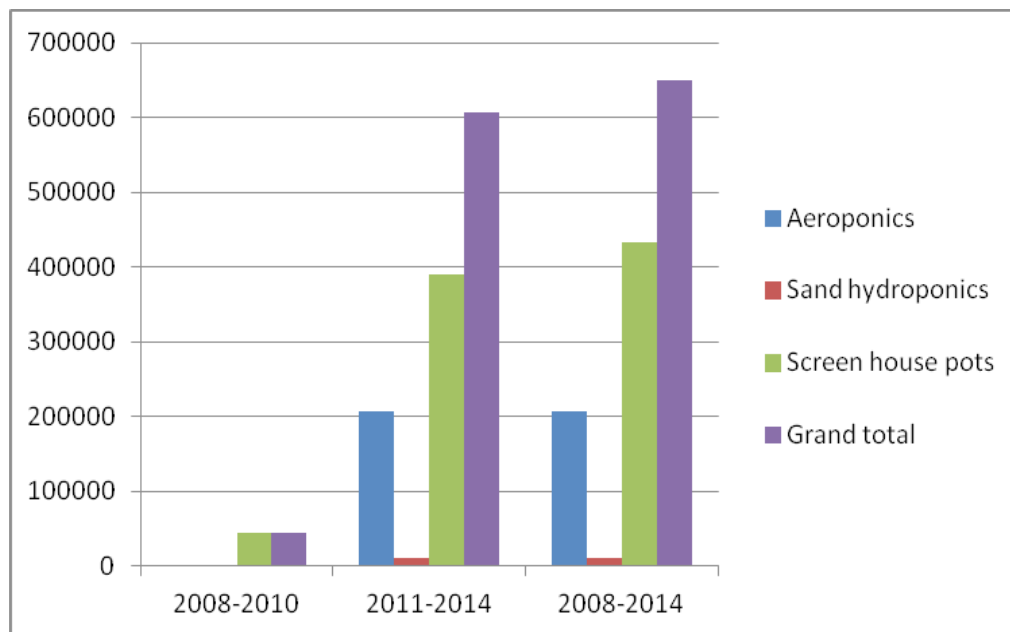


Figure 1: Mini-tuber production trends of Holetta Research Centre at screen house bases with aeroponics, sand hydroponics and pots

the technique that involves the growing of plants in water mixed with all the necessary plant nutrients or in an inert medium such as gravel, block or cockpit. The technology is well suited to locations and situations where the land is scarce or soil is poor in quality, and population pressure is the challenge to expand the farming lands. In hydroponics technology one could harvest the same output only in 20% of land compared to soil gardens.

With this regard, hydroponics crop production has significantly increased in recent years worldwide, as it allows a more efficient use of water and fertilizers as well as better control of climate change related pests (Libia et al. n.d). In addition to these, hydroponics production could boost the crop quality and productivity, which results in higher competitiveness and economic benefits to growers. It is documented that hydroponics was practiced many Centuries ago in the Amazon, Babylon, Egypt, China and India where ancient men and women used dissolved manure to grow cucumber, water melons and other vegetables in sandy riverbeds. One of the chief merits is that hydroponic plant growers could produce higher yields. A 1-acre (0.4ha) hydroponics green house produces the same output as 10 acres (4ha) of field (Naik and Karihaloo 2007). The technology was first piloted in 2013 in Ethiopia at Holetta Research Centre and used as a tool to multiply early generation seed potato. Since then, more than 10,000 high quality seed potato was produced to support the seed production chain of the research centre.

Aeroponics technology for pre-basic seed potato production

Aeroponics is a version commonly attributed to work via NASA in the 1960s and 1970s, where research was undertaken on food production in minimal gravity situations on the fundamental hydroponic technique that has been better through using nebulizers, foggers or other devices to create a fine mist of solution to enable nutrient convey to plant roots (Millam and Sharma 2007). Commercial production of seed potato by using aeroponics is already progressing in many countries since 2006 (Faran et al. 2006). For instance, at the Huancayo, Peru CIP produced more than 100 mini-tubers per plant by using simple and available materials. Current efforts are underway to incorporate the technology in Sub-Sahara African countries for the production of quality starting seed potato (Otazu 2010). CIP has evolved and efficiently examined a “3G” seed strategy (funded through USAID) that enables very fast multiplication of early generation seeds using the aeroponics technology, which reduces the number of field generations from six to

only two (CTA 2014). Simultaneously the cost of production and serious disease transmission was also reduced as well as enabled the mass production of quality seed with this approach (Abebe et al. 2014).

Aeroponic units had been introduced at the research level in Ethiopia, Kenya, Rwanda and Uganda at the respective national agricultural research systems (Kyamanywa et al. 2011). Preliminary results from these pilot countries are promising and there is need to promote the technology to private seed sectors (Kyamanywa et al. 2011; Mbiri et al. 2015; Lemma et al. 2017). Because the need for quality seed is highly demanding from time to time and needs a huge amount of resources, that could be challenging for the government institutions if attempt is continued by the governments alone (Gildermacher et al. 2011; Sharma et al. 2015).

Since its establishment in Ethiopia at Holetta Research Centre, the seed potato production capacity was highly improved. Quality seed of potato production was also increased by 206,566 mini-tubers, while it was nil before the establishment of the technology (Lemma et al. 2018). The technology is also space efficient compared to field multiplication. Potato plants can grow up to 148 cm stem height and 300.8 cm root length. Furthermore, spacing for plants is 25 cm by 20 cm (i.e. 20 plants per square meter) area unlike conventional method, which takes 60-70 cm between rows and 20-30 cm between plants based on different factors (Otazu 2008; Lemma et al. 2017). With aeroponics technology, an individual potato plant can produce over 100 mini-tubers in a single row as opposed to conventional method that create approximately eight daughter tubers only in the course of a year while only five to six tubers per plant are produced using soil in the green house (Otazu 2008).

Plant and nutrient handling in aeroponics system

To be effective in aeroponics seed production system, optimal planting material is a pre-requisite. With this regard, *in-vitro* plantlets are preferred due to their freedom from diseases (Otazu 2010). However, they need to be handled with maximum care by skilled man power and all the sanitation procedures should be properly implemented. Additionally, the technician in the green house should owe the pH and electrical conductivity (EC) of the nutrient, which is going to be nourish the plants. The pH is the measure of how acidic or base the nutrient concentration should be optimum for that particular plant (Todd et al. 2000; Bill et al. 2003). Because the yield and quality of the produce in the

greenhouse production system highly depends on optimum nutrient supply. This implies an efficient management of all the plant growth factors involved in crop nutrition, nutrient solution composition, water quality and supply, nutrient solution temperature and the pH and EC of the nutrient used (Lemma et al. 2017). However, the problem may vary from place to place based on water chemical quality and other factors. This will be a problem when concentrations are too high, and yield may be even reduced (Otazu 2010). According to Lemma et al. (2017) the EC and pH of water used for aeroponics greenhouse for seed potato production at Holetta condition was 1.5 ms/cm and 6.8 respectively.

Effects of Good Quality Seed on Potato Productivity

Potato yields are affected by several factors. Seed quality is a very crucial one (Abebe et al. 2014; Otazu 2010; Limenih and Tefera 2014; Hirpa et al. 2010). The average yield increase from the use of good quality seed is 30 to 50% compared to farmers' seeds. The yield difference between good quality and inferior seed was very huge in many developing countries including Ethiopia (Endal et al. 2008). Healthy and seeds having good biological quality might be free of any viruses, bacteria, fungal and other pathogens. Seed multiplication started with clean stocks should be the key step in most vegetatively propagated crops (Abebe et al. 2014). Then appropriate seed multiplication schemes should be practical and be implemented according to classes of seed multiplication (Fengyi 2008). The mastery of large yield gap between farmers to farmers and countries to countries could be use of improved and farmer-saved seed systems, which are low seed replacement, inferior seed quality and low adoption of good crop husbandry (Buddhi et al. 2016; Hirpa et al. 2015 and 2010).

Once the new variety of potato is released and maintaining the seed quality as well as appropriate agronomic practices are implemented, some cultivars could yield 50 to 60 t/ha for over 100 years (Fengyi 2008).

The seed potato market and its threats for potato growers

An incredible trouble in potato seed development is the relatively high degeneration rate of initially healthy seed. In many countries, the seed quality would be degraded only with two or three multiplications. In a seed production scheme based on clonal selection, eight to ten years of production could be required before

large commercial qualities are available (Kees 2007). Keeping the health of the seed for such a long time could be the most challenging to growers in many countries (Endale et al. 2008). In countries that lacks adequate supply of certified seed, there are often traditional seed multiplication areas like the higher elevated parts of the country where the movements of aphids and other insect pests are low. Seed degeneration could be relatively slower due to virus transmission by vectors (Donyu et al. 2004). In such situations, potato growers might? buy seed from traditional areas to refresh their own stock and use this for the production of ware potatoes or for multiplication as seed for the next crop (Demo et al. 2009). Conversely, farmers in developed nations try to buy quality seed each year when they did not have better alternatives to access quality seed (Hirpa et al. 2015; Kees 2007). For instance, Algeria, Egypt, Morocco and Tunisia are the major importing countries of seed potatoes whereas Canada, Netherlands, France and United Kingdom are countries exporting considerable quantities of seed (Kees 2007).

The seed trade contribution of Africa by far was almost 2% to the global market and the continent needs to develop its various seed systems to increase the share in the global market (CTA 2014). An implementation of partnership of research, enterprise and government is necessary to achieve the goal of their agricultural productivity. Thus, the need on investing on human development, science and technology, infrastructure, and various development activities are a pillar to forward the seed sector and to increase the competitiveness in the world market (Kaguongo et al. 2013; Kyamanywa et al. 2011). The other threat in seed marketing is the fate of disease transmission across countries. So, as suggested by Alfayo (2016) various phytosanitary measures should have to put in place by member countries to mitigate risks of pest entry.

Summary and Conclusion

Potato is grown in more than 150 countries with the average yield of about 16 t/ha. However, yields in most developed continents like North America and Europe are over 40 t/ha. In some experimental plots the yield raised 70 to 80 t/ha. Contrary to this, the yield in most developing countries is between 10 to 20 t/ha. This enormous yield gap could be due to various production constraints with the possibilities to overcome the gap between developed and developing countries. Inaccessibility of disease free and clean seed is among the major constraints that hinder yield potential of potato in most developing countries like Ethiopia. Since

many years back technological innovations have been intended at increasing productivity of potato which have an important role for enhancing the contribution of the crop to the global food system. However, intensive review and documenting relevant information on these issues were not well organized. Hence, summarization of the past efforts made on seed potato technological advances and their out puts could be crucial and used as a tool to create awareness on the contribution of aeroponics and sand hydroponics for the improvement of potato productivity.

Conflict of interest: Authors declare no conflict of interest.

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