# Looking backward to find a path forward for the sustainable flow of suitable potato varieties to Eritrean potato farmers

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# Looking backward to find a path forward for the sustainable flow of suitable potato varieties to Eritrean potato farmers

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**ABSTRACT**

The lack of a sustainable flow of suitable potato varieties is a major contributing factor to low productivity and production of potato in Eritrea. This study examined the history of potato variety introductions to identify weaknesses, a path forward and enable the sustainable flow of suitable potato varieties to potato farmers. The research approaches included: reviewing the history of potato variety introductions to Eritrea, consultation with local and international stakeholders and a survey assessing potato variety preference. Over 70 varieties of potato have been introduced and 14 varieties approved through the official system but with only three currently available. Many farmers rely on poor-quality seed from unofficial sources. The analysis led to the identification of priorities for improvement: strengthening research institutions to create networks for potato variety sourcing; strengthening local regulatory institutions to implement registration and release standards; engaging potato farmers in the variety evaluation process; considering Plant Variety Protection and Plant Breeders Rights when establishing potato variety conservation; designing maintenance and multiplication strategies and also allowing the private sector to participate in potato variety seed sourcing and distribution. These options could be the basis of a roadmap making improved potato varieties and seeds available to potato farmers in Eritrea.

**KEYWORDS**

Suitable potato varieties; variety introduction and maintenance; potato farmers; Eritrea

## 1. Introduction

Potato is the primary non-grain food commodity in the world (Rivelli & De Maria, 2018). Its value is recognized in Eritrea both as an income-generating crop and as a source of employment for development. In Eritrea, potato is considered as a vegetable crop and is grown by approximately 5000 commercial and semi-commercial farmers using irrigation water (EIDP, 2015; Ghebreslassie et al., 2014). The climate of the highlands (2001–2400 masl) and midlands (1700–2000 masl) of Eritrea is favourable for almost all year round production (Ali, 2007). Eritrean potato farmers have two to three potato growing seasons.

The current area cropped potato and yearly production are less than 3000 ha and 35,000 tonnes, respectively (MoA, 2019), far below the country's potential (approximately 7500 ha with an estimated potato production of 150,000 tonnes) (EIDP, 2015). One major constraint is the unavailability of officially recognized improved potato varieties (Ali, 2007; EIDP, 2015). Consequently, Eritrean potato farmers are observed by extension staff to use unofficially imported, unknown potato varieties.

In Eritrea, the official variety introduction processes, flow schemes and roles are described below. Firstly, new potato varieties are requested by the National Agricultural Research Institute of Eritrea

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(NARI). Then plant import approval documents are prepared for the requested varieties by the Agricultural Regulatory Service Department (RSD) (AFSTA, 2010).[1] After that, the new varieties are introduced and inspected for quarantine pests at the point of entry by the RSD. Once the varieties are introduced, NARI takes responsibility to test and select the promising varieties, based on their yielding ability. For example, over the last 3 decades, approximately 70 potato varieties have been introduced, out of which, 14 varieties have been approved. The list of the approved varieties is then sent to the Agricultural Extension Department (AED) for bulk importation from international seed companies (Ghebreslassie et al., 2014). AED imported the 14 approved potato variety seeds in bulk, in partnership with donors such as DANIDA, the African Development Bank, Oxfam GB, Care International and IFAD as well as with NGOs such as FAO and VITA (ADF, 2009; EIDP, 2017; FAO, 2006; MoA, 2013). Seed tubers of these approved varieties were imported from European seed companies such as AGRICO, Stet Holland (both Dutch companies) and IPM Potato Group Ltd. (an Irish company) and multiplied for a number of generations until the seed degenerated or lost its potential (ADF, 2009; Ali, 2007). However, currently, Eritrea is not importing potato varieties from AGRICO and Stet Holland but has shifted to IPM. One of the main reasons for this shift included the establishment of a partnership with Irish partners (mainly Teagasc, Vita and Gorta SHA).

In Eritrea, in the first 10 years after independence (1991–2000), limited amounts of approved potato variety seeds were sourced and simply distributed to potato farmers. However, in the subsequent 20 years (2000–2020), the Ministry of Agriculture of Eritrea (MoA) established a managed and centralized seed field multiplication programme in collaboration with partners/donors for commercialization of the approved potato variety seeds. These interventions were targeted to multiply imported seed tubers of recommended varieties by getting seed potato growers to produce seed tubers for sale or distribution to other potato farmers (MoA, 2019). To support the above-centralized seed multiplication programme, MoA established a new Seed Potato Project in collaboration with Irish partners in 2015. The aim of the project was to establish a sustainable seed potato supply system in Eritrea. One of the main components of the project was sourcing and supplying improved and approved potato variety seed tubers. So far, this partnership invited IPM to send its potato varieties to Eritrea on four occasions.

Overall, this importation and multiplication of recommended improved potato variety seeds have become an important policy agenda of the MoA. However, with the exception of three approved potato varieties, all the other approved and adopted varieties are no longer available in Eritrea. This suggests that Eritrea is not successful in making improved varieties sustainably available and accessible to potato farmers. Therefore, this study hypothesizes the variety introductions and maintenance procedures (includes variety sourcing and network, variety testing, variety release and registration, variety conservation/maintenance and multiplication) that need to be taken into consideration in order to make improved varieties sustainably available and accessible to Eritrean potato farmers.

### 1.1. Variety sourcing and network

Many countries use improved potato variety seeds, sourced both from abroad and locally such as India (Pradel et al., 2019). Eritrea can only source varieties from abroad, due to the lack of a local potato breeding programme and the small scale of the potato industry. Eritrea is not self-sufficient in potato genetic resources and it would not be justifiable to establish a conventional breeding programme for the development of new potato varieties. This is mainly due to the small market size, the high investment cost required, the long time period (around 12–15 years) required to develop a variety as an output and the inability to access new technologies and maintain critical mass with researchers. The opportunity cost of breeding would be better spent on improving other aspects of the value chain such as seed certification or sourcing suitable varieties internationally and making them accessible and available. Hence, Eritrea will likely continue to be dependent on imports from other countries for the introduction of new potato varieties. However, partnerships and interactions with recognized organizations (research or seed companies) are needed to secure a sustainable flow of suitable potato varieties.

### 1.2. Variety testing

In the variety testing, it would be advisable to engage farmers so as to readily select and adopt the new

varieties (Muhinyuza, 2014; Thiele et al., 2021), because farmers are key stakeholders who accept or reject potato varieties (RTB, 2016). Generally, participatory variety selection helps farmers to easily adopt new varieties and also helps researchers to decide selection of the suitable varieties correctly (Bajgai et al., 2018; Semman & Mulualem, 2021). As a supportive idea, Kolech et al. (2015) found that participatory variety selection is an effective approach for identifying factors important for the adoption of potato varieties in Kenya. Similarly, Ary et al. (2017) described that poor adoption rate resulted from low participation of farmers in potato clone selection in India. Therefore, farmers' participation in variety evaluation/screening seems critical.

### 1.3. Variety release and registration

In most countries (with established local breeding programmes), new crop varieties usually pass through a series of national and or recommended list trials for release and registration, before being marketed or officially released to farmers (Setimela et al., 2009). However, countries that lack local breeding programmes and use only foreign varieties (as is the case for potato in Eritrea) need a shorter time period and also fewer tests to determine the Distinctness, Uniformity and Stability (DUS[2]) testing procedures for the foreign varieties because the DUS data can be sourced from the country of origin. Therefore, the local evaluation can be determined based on its Value and Cultivation Use (VCU[3]) testing procedure (Michael & Zewdie, 2016). This can help to shorten the variety evaluation process. Moreover, communication with potential suppliers for what variety characteristics are required in Eritrea should be more than important to consider.

### 1.4. Variety conservation/maintenance and multiplication

The next critical step for improved crop variety security is conservation/maintenance and multiplication of varieties. Many countries conserve potato cultivars/varieties in potato gene banks either *in situ* (field) or *ex situ* (in vitro culture) (Huaman et al., 2000), so that they can later be multiplied disease free under close supervision and follow-up. However, the actors responsible for *ex situ* conservation and maintenance (e.g. NARI or RSD in the case of Eritrea) need to consider the ways in which protected/licenced and free varieties are conserved and maintained. This is because the protected/licenced varieties have a grant of Plant Breeders' Rights (PBRs), which is equivalent of a patent. These varieties are not permitted to be maintained freely under the UPOV[4] convention and an understanding of Plant Variety Protection (PVP[5]) law, since PBR is very important (UPOV, 2011). These laws have been established as plant breeders need protection to recover their investment or else there will be little incentive to spend time and resources on breeding new varieties (Kobayashi & Nishikawa, 2021; Nyamwaya, 2015). Normally, the protected/licenced varieties are multiplied by owners of the variety or anyone who has been assigned the right to multiply the variety with an expiry date similar to a patent. Eritrea is neither a member of UPOV nor has ratified any laws in relation to PVP and PBR.

### 1.5. Study objectives and research questions

This study was developed to explore whether the understanding of the above-possible variety introductions and maintenance procedures exist in Eritrea and to suggest options for the future. To achieve these objectives, the study first examined the potato variety introduction network, testing, release, registration, conservation and variety maintenance procedures so as to identify potential improvement options, which contribute to improving the system. Secondly, it assessed the potato variety attributes or potato tuber characteristics, which are preferred by different stakeholders in Eritrea including potato farmers, NARI and AED staff and consumers.

Hence, the following research questions guided this study:

- Why have potato variety introductions largely not been successful in the last three decades and how can this be remediated?
- What are the most preferable potato varieties attributes, from the perception of Eritrean potato farmers and NARI and AED staff?
- What are the most preferable potato tubers characteristics, from the perception of Eritrean potato consumers?

## 2. Research methodology

The study used both qualitative and quantitative data collection methods. Qualitative research is used

widely for policy decisions as it describes the settings in which policies will be implemented (Anderson, 2010). It describes mainly the thoughts or feelings of participants in any research (Sutton & Austin, 2015). By contrast, quantitative research is used widely to collect data that can be counted and expressed numerically. Within the context of this study, the information, either qualitative or quantitative was collected in three ways. These were: (a) a review of 30 years of potato variety introduction history to Eritrea (qualitative), (b) consultation with NARI, RSD and foreign stakeholders (qualitative) and (c) stakeholders potato variety preferences survey (quantitative).

### 2.1. Review of 30 years of potato variety introductions history in Eritrea

Data were collected and reviewed to gain a greater understanding of the potato variety introductions over the last three decades. This was mostly secondary data from MoA reports (mainly NARI) across the years and other local literature in relation to the past and existing status of potato varieties in Eritrea. They were assessed and analyzed to identify and understand the challenges/weaknesses that emerged in terms of potato variety introduction, testing, releasing and registration, conservation and maintenance history.

### 2.2. Consultation with NARI, RSD and international stakeholders

Semi-structured interviews were conducted with NARI and RSD stakeholders and the IPM representative to discuss options on how to register, conserve/maintain and multiply potato varieties in Eritrea as well as on creating networks with other organizations to ensure the availability of improved potato varieties. The stakeholders were selected from NARI and RSD, since those two departments are responsible for introduction and testing (mainly NARI), releasing, registration, conservation or maintenance (both NARI and RSD) and regulation related issues of new plant varieties (RSD) in Eritrea (AFSTA, 2010). In total, five (three from NARI and two from RSD) staff participated. The interviews were conducted face to face in their respective offices during June and July, 2019. Similarly, the Business Development officer of IPM was also interviewed. The discussions related to the networking, partnering and multiplication of licenced potato varieties, under tissue culture in Eritrea.

### 2.3. Stakeholders' potato variety-attribute preference survey

A survey was conducted to identify the most preferable potato variety attributes or tuber characteristics, from the perception of Eritrean stakeholders (potato farmers, NARI and AED staff and consumers). A structured questionnaire was developed to collect primary data from potato farmers (Appendix 1), local potato staff (NARI and AED)(Appendix 2) and consumers (Appendix 3) by interview. The structured questionnaire constituted mainly closed questions. Interviewees were also asked to provide their comments in respect of the list of their preferences of potato variety attributes or potato tuber characteristics (in the case of consumers).

Two groups of potato variety attributes were drawn up for potato farmers and NARI and AED staff. In addition, one group of potato tuber characteristics was drawn up for potato consumers based on Ghebreslassie et al. (2014). The attributes considered for potato farmers and NARI and AED staff included resistance to diseases, earliness, yielding ability, tolerance to heat and drought, seed tuber dormancy, ease of cooking, tuber shape, tuber colour, tuber smoothness and ware potato shelf life. The tuber characteristics considered for consumers included tuber shape, tuber size, tuber colour, ease of cooking, tuber smoothness and ware potato tuber shelf life because consumers are more interested in the final product.

Potato farmers were selected from both high (2001–2400 masl) and mid (1700–2000 masl) altitude regions that are important in Eritrean potato production. In this study, potato farmers were selected from two Zobas[6]/regions (Maekel and Debub) and six sub-Zobas[7] (Dubarwa, Mendefera, Adi-keih, Segeneiti, Dekemhare, Galanefhi and Berik) as these are the main potato growing areas in Eritrea. Only farmers with potato fields were selected and interviews were carried out in the field to gather their perception on desired attributes of potato varieties. This allowed for data collection from those people who are likely to have the relevant knowledge to assist the research (Etikan et al., 2016; Tongco, 2007). This is because, in Eritrea, potato varieties are grown by a small proportion of farmers who own water wells and are financially strong. In some areas, potato varieties are also grown by farmers around dams. In total, 61 potato farmers were selected and were asked to rank the importance of 13 potato variety attributes. The

dates for the interview of potato farmers were arranged in cooperation with sub-Zoba AED staff, who were instrumental in the successful organization of these interviews. The interviews were conducted during June and July 2019.

NARI and AED are the only public institutes that have a long experience (mainly in the last three decades) in potato work, mainly in potato variety selection. So, this study was focused on these two institutions to provide their preference on potato variety attributes. Based on this, 14 staff (3 from NARI and 11 from AED), who had experience in potatoes, were selected. These staff is assigned by MoA to work on potatoes in their respective region/institution. The interviews were carried out in their respective offices.

In addition, two groups of potato consumers were interviewed, one from the capital city of Asmara (highland; 2300 masl), the other from a town in the midlands, named Dubarwa (1950 masl), located in one of the main potato growing areas. A total of 100 potato consumers were interviewed in the respective market places from June to July 2019. They were asked to rank the importance of 12 potato tuber characteristics. All the interviews were conducted in local languages by the researcher and staff of the Seed Potato Project.

The quantitative information collected from potato farmers, NARI and AED staff and consumers were encoded in Microsoft Excel and ranking frequencies were processed and presented in radar charts and interpreted. When an individual respondent (potato farmer, NARI and AED staff or consumer) ranked first for one attribute, the score was total number of attributes/tuber characteristics presented for ranking by the respective stakeholder (e.g. farmers – 13, NARI and AED staff – 15, consumers – 12); if the rank was second, the score point would be one less the total number of attributes (e.g. farmers 13–1, NARI and AED staff 15–1, consumers 12–1) … if the attribute was ranked last, the score would be one (the same for the three stakeholders). Therefore, the overall value of frequency for an individual attribute was calculated as the sum [the number of respondents ranked (*i*th) multiplied by score designated for ranked (*i*th)], where, $i$ = level of ranking.

## 3. Results and discussion

The findings from the historical analysis of potato variety introductions and possible options to address any difficulties are first presented and discussed. Varietal attributes do emerge as one key factor so secondly, the potato variety-attributes preferences of potato farmers, NARI and AED staff and consumers are discussed.

### 3.1. Potato variety sourcing and network procedure

Before independence (1991), the development of potato farming in Eritrea received little or no attention. Since independence, more attention has been given to the introduction of new potato varieties to improve potato productivity and production in Eritrea. During the period 1993–2000, Eritrean potato farmers grew imported (Cara, Diamant and Spunta) and local (Kei-Embaba, Tsada-Embaba, Karneshim, Shashemene and Yeha) cultivars simultaneously (Ghebreslassie et al., 2015). However, since 2001, the introduction of new imported potato varieties increased. Ghebreslassie et al. (2014) reported that imported potato varieties, which matured earlier were higher yielding and more marketable compared to local varieties; thus facilitating the withdrawal of the local varieties from farmers' fields. MoA became interested to work more with imported potato varieties to improve potato productivity and production in Eritrea.

During the first 10 years (1993–2002), imported potato varieties in most of the high- and mid-altitude regions of Eritrea were distributed in the form of aid (ADF, 2009; Ali, 2007). These varieties were distributed mainly with the Self Help programme, FAO (both NGOs) and DANIDA (Donor) (Ali, 2007). This was done in an *ad hoc* fashion, without a strategy to develop a sustainable seed flow system or consideration of further multiplication programmes to ensure seed security in Eritrea. In this early strategy, the imported quality (certified) seeds were simply distributed for ware potato production. However, since 2003, the MoA established a centralized seed field multiplication strategy. One reason for this strategy was that Eritrea's financial situation precluded yearly importation (Ali, 2007). The second reason was to reduce the introduction of undetected pests with regular new imports (RSD, 2017) as Eritrea lacks a strong quarantine infrastructure and system to detect pests. The disease and pest pressures in the country are not properly studied and reported.

Nevertheless, the potato variety multiplication intervention was very slow in speeding up the flow

of potato varieties across years. This can be attributed to a combination of factors. Firstly, the shortage of donor funds and international currency (MoA, 2013) led to inconsistent and limited importation of seeds of the approved potato varieties in Eritrea. Secondly, NARI and AED had limited interaction with international organizations (research, seed companies or donors) to source funds and new potato varieties, mainly due to poor communication infrastructure (Habtom, 2020; personal communication the horticulture research unit at NARI). However, the third influential factor which has to be considered as slowing down the availability of potato varieties and their multiplication in Eritrea is the absence of a private sector. In countries such as Kenya, the private sector is considered the main driver for the availability and access of potato varieties (Kaguongo et al., 2010). The absence of private sector participation in improved variety and seed supply is founded on the belief of Eritrean government (mainly MoA) that potato farmers are small scale, with low purchasing power and with the insufficient skill to manage the improved variety, the seed supply and the multiplications (AFSTA, 2010). This rationale underpins that AED (public institute) is heavily involved in new seed sourcing, distribution and marketing.

As a result of these challenges, seed tubers of unidentified and poor varieties have been unofficially imported over the years by various unlicenced traders (Ghebreslassie et al., 2014) from neighbouring countries (mainly Sudan). This shows that firstly the variety quarantine system in Eritrea was not effective to control poor-quality seeds crossing the borders. Secondly, there was a real shortage of officially imported potato variety seeds in Eritrea. Potato farmers' consultation and farm visits confirmed that the officially imported potato varieties are far better than the unofficially imported varieties, mainly in regard to yielding ability and tolerance to diseases. It is also believed that the seed of the officially imported potato varieties is less degenerated compared to the seeds of the unofficially imported varieties.

Some options in relation to the potato variety introduction emerged through in-depth discussion with NARI and RSD staff. All participating staff highlighted that the capacity of NARI and AED should be strengthened in terms of communication infrastructure and linkages with international organizations to source funds and new varieties from seed potato companies. This option was also supported by Habtom (2020). The participating staff also believed that priority should be given to the introduction of a private sector in variety and seed supply. Whilst this may not be practical in the short term, it could be a priority in the medium to longer term.

### 3.2. Potato variety testing procedures

The historical review showed that new potato varieties in Eritrea have only been evaluated by horticultural researchers at NARI. Potato farmers have not participated in local variety evaluation trials conducted either on-station or on-farm in Eritrea. This resulted in variety rejection or low adoption rates after commercialization due to the existence of undesirable traits such as misshaped tubers, red skin and late varieties. For example, three clones/varieties (Chipsona, Tigoni and 392797) were introduced in 2013, immediately multiplied under tissue culture (NARI, 2016) and approved but they were immediately rejected by farmers who were not happy with their performance. For example, Tigoni was late and had a low yield, 392797 and Chipsona had red-skinned tubers and deformed tuber shapes, respectively (MoA, 2017; potato farm consultation). Therefore, the need for farmers' participation during variety testing and evaluation was recognised as critical for the successful adoption of new potato varieties as farmers are the end users of the varieties to be released and adopted (Valle, 2021).

### 3.3. New potato variety release and registration procedures

Both the release and registration of new crop varieties are practical in the formal seed system (Kuhlmann & Dey, 2021). In many countries, both new variety registration and seed certification systems exist for variety and seed security. Normally, seed certification can be processed for unregistered varieties under a formal seed system. Seed certification helps create quality awareness amongst seed producers and seed users and safeguards the interest of farmers (Spielman et al., 2021). The first objective of variety registration is to create transparency in the seed market. This helps differentiate different varieties with the same name or the same variety with different names at different locations (CIP, 2016). Secondly, new variety registration helps provide relevant information for farmers on the value of crops for cultivation and use.

In Eritrea, a National Variety Release Committee (NVRC) composed of NARI, AED, RSD and Hamelmalo Agricultural College of Eritrea[8] (all public stakeholders) with coordination of RSD has been established (RSD, 2019). This committee prepared 'Technical guidelines for the release of varieties and their packages for field crops (mainly cereals and pulses)'. The main task of this committee is to approve crop varieties before being released to farmers. So far, this committee approved 47 new cereal and pulses varieties (RSD, 2017) and currently these varieties are under the RSD database list. However, the registered variety seeds are not marketed with labels or tags. Whilst the Eritrean seed certification system is established on paper, it is not yet implemented in practice (ascertained through discussion with seed quality and safety unit at RSD). Therefore it is hard to differentiate the registered (could be new and improved) and unregistered (mostly poor in quality) variety in the local market and this is not helpful to safeguard the interest of farmers. However, the registered varieties are kept with relevant field information for further use and this can be considered as the only achievement in variety registration in Eritrea.

To date, the NVRC has not been involved in approving and registering any horticultural crop varieties (including those of potato). Until now, the horticultural research unit at NARI takes sole responsibility to approve new potato varieties. MoA interviewees believed that the weakness of NVRC (in terms of personnel skill) and funding have been the main reasons for failing to set up and implement horticultural crops release and registration standards. The standards can be easily accessible from other countries but the implementation of the standards is not easy in the Eritrean context due to the lack of experience and skill of the RSD institute, which is the main coordinator of the NVRC.

In Eritrean history, more variety evaluation trials have been conducted on field crops (cereals and pulses) than on horticultural crops. Staff who work on field crops is, therefore, more experienced than staff who work on horticultural crops in relation to variety evaluation and release procedures. In addition, local field crops staff has a better network and more experience with foreign field crops experts who work at the International Centre for Agricultural Research in the Dry Areas (ICARDA), the International Maize and Wheat Improvement Centre (CIMMYT), Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), etc. This experience helped the NVRC field crops staff to quickly develop and implement release and registration standards for field crops. Therefore, a suggestion emerging from this study is that RSD staff who work on horticultural crops needs training and interaction with other countries to upgrade their skill so as to set up and implement locally sound standards. The study also urges MoA to source and release funds for establishment of the horticultural crops (including potato) release and registration technical guidelines. This study highlights that RSD needs to take ownership and provide leadership on developing and implementing standards for variety release and registration.

Except for some of the CIP-developed clones, all other foreign potato varieties introduced to Eritrea are already released and registered in other countries. Once a vegetatively propagated crop such as a potato variety is registered as DUS in one country, the possibility to change its Distinctness, Uniformity and Stability in another country (e.g. Eritrea) is low. This means it is not a high requirement to use DUS testing procedures for the registration of new potato varieties in Eritrea. However, the variety registered in one country can change its yield ability, resistance to diseases, tolerance to environmental stresses and other quality parameters with growing conditions when evaluated in another country. Therefore VCU and performance testing procedures are more important to consider for variety approval in Eritrea.

The role of the private sector was raised within the study. As discussed earlier, the private sector is 'absent' in Eritrea. Private sector actors are more active in countries where seed legislation is implemented to officially release, register and also protect new varieties. A useful example for this is in Kenya where many private institutes are actively involved in seed business (ascertained through a visit by the first author to Kenyan seed potato system stakeholders in November 2019). This requires the government to create clear regulations and an enabling environment for the private sector actors to participate as well as enforcing standards and regulations in variety registration, protection and seed certification. The Eritrean context is currently not an enabling environment for private sector to invest in seed systems and it would require clear regulations or local policies for private sectors to invest resources to speed up the implementation of variety registration and seed production. Moreover, seed

certification guidelines need to be in place so as to create transparency on local variety and seed marketing.

### 3.4. Approved potato variety conservation/ maintenance (ex situ) and multiplication

Stakeholders interviewed from NARI, AED and RSD institutes expected the facility of tissue culture at NARI to conserve approved and adopted potato varieties. However, as discussed in the introduction (with the exception of recently released Electra, Burren and Banba), all the other adopted potato varieties disappeared from local availability in Eritrea. This could be due to a combination of many factors. The foremost factor is the lack of knowledge on how to conserve and multiply approved and adopted potato varieties (for both protected and free varieties).

In Eritrea, potato is a high-value and commercial crop (Ghebreslassie et al., 2015). Despite this, it seems that the PVP and PBRs laws are poorly understood for protected potato varieties multiplication. Generally, this is not helpful for further sourcing of new protected potato varieties in Eritrea.

Many developed and developing countries introduced some form of PVP system so that new plant variety production and marketing can be protected and exploited (Visser, 2017). But, the PVP system considers some breeders exemptions including varieties that are used for non-commercial purposes (food source) and also experimental/research. Under the 1991 Act of the UPOV convention, farmers are also allowed to save seeds of the protected varieties on their own holding but they must not be exchanged and sold to another farmer (Oxfam International, 2016).

In Eritrea, PVP was considered as an important requirement in local seed policy (AFSTA, 2010); however, the law is not yet ratified and seems difficult to implement in the short- and medium-term due to the absence of seed companies, limited local crop breeding programmes, dependence on local and farm-saved seeds (mainly cereals and pulses), limited agricultural product import and export.

The predominant belief in the MoA of Eritrea is that most Eritrean farmers are small scale and their main seed source is the farm-saved seed (AFSTA, 2010). As a result, Eritrean potato farmers are involved in retaining farm-saved seeds of the imported protected potato varieties. However, the long-term impact of such unregulated seed multiplication could limit the introduction of new varieties by international breeders and lead to complications in sourcing new seeds. Because in this situation, international breeders can neither control their varieties nor collect royalties for either farm-saved seed or local multiplication.

Emerging from this study are some improvement options to conserve, maintain and multiply potato varieties in Eritrea. Of the NARI staff interviewed, one-third believed that the tissue culture laboratory is not appropriate and that a separate seed bank should be set up under NARI. However, two-thirds of NARI and all RSD staff respondents were in favour of potato variety conservation in tissue culture as the existing tissue culture laboratory has better facilities and skills compared to the RSD and AED. The literature review also supported the second option with examples from countries such as Kenya and Ireland using tissue culture to conserve and maintain potato varieties (Ireland Stat, 2017; Muthoni et al., 2010).

Options in relation to the multiplication of licenced and free varieties were identified through discussion with NARI, RSD and IPM staff and also email communication with the UPOV technical office and observation. All the NARI and RSD staff who participated in this study felt they should prioritize public or free varieties that can be multiplied free on-farm and under tissue culture. Their reasons include, *inter alia*, Eritrea's small market size; policy obstacles for local seed production by foreign companies, and an unorganized market structure. However, they would support the development of bilateral agreements, where possible, to multiply high-grade seeds of a licenced variety. From the literature, there is support for bilateral agreements between the variety owner and user in relation to seed supply and its operation under the variety user home land legislation (Visser, 2017). Under the existing Eritrean policy, partnering with foreign seed companies to supply seed and allowing them to operate in Eritrea is not attractive. However, this may be an option in the future, as private seed companies have been seen to operate (participate in the multiplication of their own imported variety seeds) and contribute to some success (getting quality seed tubers) in some East African countries such as Kenya (KEPHIS, 2016). Of course, success may not be equal for all categories of farmers.

As part of this study, a follow-up meeting was organized between Eritrean Seed Potato Project

representatives and a Business Development officer of IPM in Ireland in August 2019 to discuss agreement options. The researcher of this study also contacted the IPM officer in Ireland. The outcome of both meetings was positive and IPM was willing to consider that Eritrea could multiply a limited quantity of a protected variety using tissue culture and they requested a written proposal that would include the scale and scope of the multiplication as well as market differentiation. Their agreement would be for multiplication for local use only, with assurance of no export to neighbouring countries such as Sudan or Ethiopia. At the same time, IPM agreed to prepare a bilateral agreement document for signature. However, the IPM officer additionally advised that if Eritrea would become a member of UPOV and ratify national laws (in relation to PBRs laws), then they would have more security on their own varieties. For this reason, the IPM office prefers to work in Kenya (member of UPOV) than Eritrea.

The email communication with UPOV technical officer from Geneva, Switzerland highlighted that UPOV membership has many benefits for members (Leontino, 2019). For example, UPOV membership and the presence of national PVP law in Kenya increased the introduction of foreign varieties and also a significantly higher number of varieties were developed and released locally (Nyamwaya, 2015). Even though it is hard to collect and manage royalties from non-members with no local PVP laws, some literature showed that under such circumstances, royalties are added when the seed is purchased (imported) from seed companies (Frank et al., 2007). This can make the seed more costly to the grower. Therefore, this study advises Eritrea to become a member of UPOV to support access to many new agricultural crop varieties and to encourage seed companies to invest in Eritrea.

### 3.5. Stakeholders' potato variety-attribute preferences

Three stakeholders groups (potato farmers, NARI and AED staff and consumers) were surveyed on their choice of potato, varietal attributes or tuber characteristics in the main potato growing regions of Eritrea (Figures 1 and 2). Potato farmers ranked early maturing, disease resistant, high yield and white skinned with white fleshed tubers as first, second, third and fourth with overall frequency values of 716, 685, 515 and 504 (see the final paragraph of the methodology

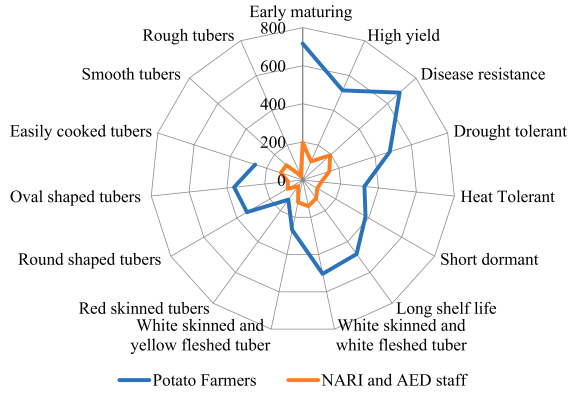


**Figure 1.** Frequency (occurrences) of choice of potato farmers (scales: 61–793) and NARI and AED staff (scales: 14–210) of potato variety attribute. Source: Survey work, 2019.

for method of calculation of these numbers and the scale ranges are 61–793), respectively (Figure 1). Similarly, NARI and AED staff ranked early maturing, disease resistant, drought tolerant and white skinned with white fleshed tubers as first, second, third and fourth with overall frequency values of 196, 194, 147 and 140 (scales: 14–210), respectively (Figure 1). Consumers ranked easily cooked, white skinned with yellowish flesh, medium tubers and white skinned with white flesh as first, second, third and fourth with overall frequency values of 1000, 949, 792 and 777 (scales: 100–1200), respectively (Figure 2).

Both potato farmers and NARI and AED staff perceived that potato production is weakened by the combination of effects such as droughts, pest pressure on farms and small and fragmented farm land (EIDP, 2017). As potato farmers and NARI and AED staff commented, earliness serves several purposes such as helping farmers to grow two or three crops per year. They also added that earliness reduces the crop's exposure to pests and diseases and escape from droughts (Manga et al., 2015). A similar finding was reported by Ghebreslassie et al. (2014). However, potato farmers ranked high yield as one of the top three, whilst high yield is usually associated with late maturity. In this study, potato farmers seem to poorly understand the relationship between maturity type and yielding ability. Some potato farmers also commented that potato varieties resistant to disease and pest improve yields and also help reduce chemical use.

Potato farmers and NARI and AED staff preferred white skinned, white fleshed varieties to white

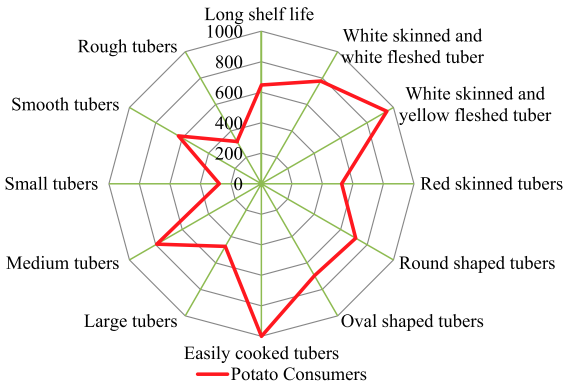


**Figure 2.** Frequencies (scales: 100–1200) of choice of potato consumers on potato tuber characteristics. Source: Survey work, 2019.

skinned, yellow fleshed varieties (Figure 1). However, consumers preferred white skinned and yellow fleshed tubers. The majority of the consumers believed that yellow fleshed tubers are tasty compared to white fleshed tubers. All three stakeholder groups (potato farmers, NARI and AED staff and consumers) preferred white than red-skinned potato tubers. In contrast, in many countries such as Uganda (Namugga et al., 2017), potato farmers preferred most red-skinned potato varieties. In Eritrea, potato farmers and NARI and AED staff explained that there is no local market demand for red-skinned potatoes. The same was observed during local market and farm visits. The possible reasons include consumers' lack of awareness of red-skinned potato tubers. Some consumers also commented that red-skinned potato tubers were considered as red-skinned sweet potato which is not yet well adopted in Eritrea.

Consumers displayed a strong preference for easily cooked potato tubers which require less fuel to boil them as both fuel and electricity are critical in Eritrea. However, easily cooked tubers are usually low in dry matter, a characteristic selected against by the processing industry, due to low frying quality (Lambert et al., 2006). The processing industry is currently not a priority in Eritrea (EIDP, 2015), but its requirement can be incorporated in the future, with an increase in potato production.

The selection priority for both drought tolerance and short dormancy was medium for both potato farmers and NARI and AED staff. Selection of drought-tolerant varieties is considered as a priority in the local research agenda as a coping mechanism for the existing drought problem in Eritrea (EIDP, 2017). Droughts are affecting world potato production (Cabello et al., 2012) including Eritrea. Selection of varieties with a short dormancy was considered as an important attribute by farmers in a focus group discussion held in 2018 in Eritrea. They perceived that varieties that break dormancy quickly in stores help potato farmers to plant them in the appropriate season (e.g. planting: January to end of March, storage: April to May, then planting: June to August, storage: September to October and maybe another planting at end of October for the midlands). The assumption is that varieties with short dormancy break dormancy within two months.

Overall, varieties which are early, disease resistant with white skin and easily cooked tubers are the most preferred, however, this preference can change over time with awareness (e.g. red-skinned potato varieties) and technology (e.g. with introduction of potato processing industry), what is clear is the need to know the current preferences of farmers and consumers that will make new introductions more easily adopted.

## 4. Conclusions

The historical review of this study allowed for a systematic recognition that previous efforts to introduce new varieties of potatoes in Eritrea have not resulted in widespread adoption and or conservation of those varieties. The historical review highlighted that a combination of factors needs to be addressed in a coordinated way, if a sustainable flow of quality seed varieties that farmers and consumers want, is to be developed and maintained.

NARI and AED are isolated from the international agricultural research networks that could support the sourcing of new potato varieties seeds, mainly due to the lack of participation in international forums, poor communication infrastructure and lack of fund sources. Firstly, therefore, this study informs policy makers to strengthen NARI and AED institutes in terms of creating communication platforms and networks with international research organizations or seed companies. Secondly, it is also advisable to prepare and submit seed purchase and variety testing proposals for funding security or allow the private sector to participate in seed sourcing and country management of seed production and distribution.

Previously, stakeholders' potato variety preference was not properly studied to allow consideration of

suitable potato varieties in Eritrea. One of the topics that this study considered is that although around 14 potato varieties were approved since 1993, potato farmers simply accepted some approved potato varieties due to the absence of any alternative access better varieties. Because the Eritrean potato variety introduction system is closed; only public research organizations can introduce, test and take the sole decision to approve varieties and this has been done without farmers' participation. Therefore, the stakeholders' potato variety preference analysis can inform the research institute to look for early maturing, disease resistant, with white skin and easily cooked potato tubers. This study also recommends that MoA strengthen public research to engage potato farmers in the variety evaluation process.

The RSD is not sufficiently well structured to set and implement potato variety approval and registration standards and is also reluctant to enforce developed standards and protocols. Because its' role is not clearly defined and also it is reluctant to take an ownership and leadership role. Firstly, therefore, there is a need to establish locally supportive policy which can push RSD to drive the implementation of seed regulation standards. Secondly, RSD should be strengthened in terms of human skills and facilities to set and implement release and registration standards so as to contribute to a successful variety flow in the system. One way of achieving the latter is to go abroad for training and also develop interactions with other countries for sharing information.

In the Eritrean potato history, potato varieties either licenced or free were sourced from seed companies. However, the necessity of PVP and PBRs for the conservation and maintenance of the licenced potato varieties was not recognized. According to the findings of this study, the short- and medium-term implementation of PVP law seems difficult. However, considering its importance, it needs some consideration with further crop (such as potato) sector development in Eritrea. Therefore, this study informs RSD and NARI to consider the PVP law and possible bilateral agreement with owners of the varieties for local seed production, conservation and maintenance. Similarly, NARI (tissue culture office) needs to consider and design strategies for free varieties conservation and maintenance. The financial side should be ensured through collaboration with donors or by creating an enabling environment for private seed companies to invest in country seed production and maintenance.

We hope, this study achieved the aim of the research topic in consideration of all the challenges/weaknesses that emerged and the improvement options suggested. Based on our findings, we derived important policy implications for potato variety sourcing, testing, releasing, conservation and maintenance procedure in Eritrea. This could help as basis of a roadmap to make improved potato varieties available and accessible to potato farmers in Eritrea. Moreover, this information can help readers understand the situation and fill some knowledge gaps in the potato sector so as to contribute to increased potato productivity and production worldwide, mainly in developing countries.

## Notes

1. AFSTA is an abbreviation designated for African Seed Trade Association report 2010. This report was on harmonization of Seed Policy and Regulations in COMESA Members States: focusing on Eritrean Experience in Seed Policy and Regulation.
2. DUS testing is a way of determining whether a newly bred variety differs from the existing varieties within the same species (the distinctness part), whether the characteristics used to establish distinctness are expressed uniformly (the uniformity part) and that these characteristics do not change over subsequent generations (the stability part).
3. VCU testing is used to test the economic importance of new varieties based on agronomic characteristics. VCU usually tests for yielding ability, resistance to diseases, quality and tolerance to physical environment of new varieties.
4. An abbreviation designated for an International Union for the Protection of New Varieties of Plants.
5. This is established for breeders to provide incentives for development of new plant varieties to contribute to sustainable progress in agriculture.
6. Zoba is equivalent to a province or administrative region.
7. Sub-zoba is next to Zoba which is equivalent to district and county.
8. This is the only Agriculture College that educates students up to MSc level in Eritrea. This college conducts some research work in its own but it shares limited research facilities with NARI. However, the college is the main partner with NARI, AED and RSD on document preparation in relation to seed standard, certification and regulation related topics mainly on field crops (cereals and pulses).

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## Disclosure statement

Denis Griffin is a potato breeder with the Irish Agricultural Research Authority, Teagasc, who has potato breeding agreements with IPM Potato Group Ltd. None of the other authors has a conflict of interest.

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***Professor Struik*** is (co-)author of more than 500 scientific papers published in double refereed international journals; other output includes more than 300 other scientific papers or papers for the general public; 15 books; and more than 160 abstracts in proceedings / books of abstracts. He has completed the supervision of about 120 PhD candidates and is currently supervising about 30 PhD students, many of them working abroad.

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## Appendices

### *Appendix 1. Questionnaire for prioritizing potato variety attributes in Eritrea (potato farmer)*

Dear participant, we appreciate you taking the time to complete the survey

**I. Personnel data:**

1. Your name: _____2. Zoba: _____3. Sub-zoba: _____
4. Tel. number: _____5. Your gender: _____6. Your age: _____ years,
7. Education: _____8. Experience in potato growing _____Years, 9. Working place/location: _____10. Type of farmer (1 = seed potato multiplier, 2 = ware potato grower, 3 = both).

**II. Please rank 1 to 13 according to their importance**

| SN | Potato variety attributes | Rank (1 to 13) | Remark (Please provide your comment) |
|---|---|---|---|
| 1 | Early maturing | | |
| 2 | High Yield | | |
| 3 | Disease resistance | | |
| 4 | Drought tolerance | | |
| 5 | Heat tolerance | | |
| 6 | Short dormant | | |
| 7 | High shelf life (storability) | | |
| 8 | White skinned & White fleshed | | |
| 9 | White skinned & yellow fleshed | | |
| 10 | Red skinned | | |
| 11 | Round shaped | | |
| 12 | Oval shaped | | |
| 13 | Easily cooked | | |

## *Appendix 2. Questionnaire for prioritizing potato variety attributes in Eritrea (local potato staff)*

Dear participant, we appreciate you taking the time to complete the survey

**I. Personnel data:**

1. Your name: _____2. Zoba: _____3. Sub-zoba: _____
4. Tel. number: _____5. Your gender: _____6. Your age: _____ years,
7. Education: _____8. Your Organization: _____
9. Experience in potato work _____Years, 9. Area of specialization/position: _____
10. Working place/location: _____

**II. Please rank 1 to 15 according to their importance**

| SN | Potato variety attributes | Rank (1 to 15) | Remark (Please provide your comment) |
|---|---|---|---|
| 1 | Early maturing | | |
| 2 | High Yield | | |
| 3 | Disease resistance | | |
| 4 | Drought tolerance | | |
| 5 | Heat tolerance | | |
| 6 | Short dormant | | |
| 7 | High shelf life (storability) | | |
| 7 | White skinned & White fleshed | | |
| 8 | White skinned & yellow fleshed | | |
| 9 | Red skinned | | |
| 10 | Round shaped | | |
| 11 | Oval shaped | | |
| 12 | Easily cooked | | |
| 13 | Smooth skinned | | |
| 14 | Smooth tubers | | |
| 15 | Rough tubers | | |

## *Appendix 3. Questionnaire for prioritizing potato variety attributes in Eritrea (consumer)*

Dear participant, we appreciate you taking the time to complete the survey

**I. Personnel data:**

1. Your name: _____2. Zoba: _____3. Sub-zoba: _____
4. Tel. number: _____5. Your gender: _____6. Your age: _____ years,
7. Education: _____8. Experience in potato consumption_____Years,
9. Area of specialization: _____10. Working place/location: _____

**II. Please rank 1 to 12 according to their importance**

| SN | Potato variety attributes | Rank (1 to 12) | Remark (Please provide your comment) |
|---|---|---|---|
| 1 | White skinned & white fleshed | | |
| 2 | White skinned & yellow fleshed | | |
| 3 | Red skinned | | |
| 4 | Round shaped | | |
| 5 | Oval shaped | | |
| 6 | Easily cooked | | |
| 7 | Smooth skinned | | |
| 8 | Rough skinned | | |
| 9 | Small tuber | | |
| 10 | Medium tubers | | |
| 11 | Large tubers | | |
| 12 | High shelf life (storability) | | |