Factors affecting sweet potato (Ipomoea batatas (L.) Lam.) production practices in Northern and Southern Ethiopia

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Research Article

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Abstract

Sweet potato (*Ipomoea batatas* (L.) Lam.) is a potential food security crop in the crop–livestock production systems for subsistence smallholder farmers in sub-Saharan Africa. This study assessed the social, ecological, and economic factors that influence sweet potato production in selected districts in Northern and Southern Ethiopia. The research site was stratified into low, middle, and high altitudes. A mixed method, consisting of quantitative and qualitative approaches, was used for data collection. A quantitative questionnaire was prepared and distributed to randomly selected farmer households, followed by qualitative in-depth interviews of key informants from research institutions, local agricultural offices, and researchers working in the study areas. In addition, informal interviews, transect walks, participation in planting, and discussions were used. In both sites, pests, diseases, drought, and lack of adaptable cultivars for different agro-ecological conditions influenced sweet potato production. In Northern Ethiopia, lack of adequate sweet potato knowledge of production practices and planting materials limited farmers from planting the crop widely. In Southern Ethiopia, farmers lost their sweet potato landraces because of the adoption and shifting to cultivating new high-yielding cultivars of sweet potato. This study suggests that farmers' awareness and knowledge on the available cultivars and landraces as well as the relevant agronomical practices and performances should be improved. Moreover, participatory breeding programs for droughts, pests, and diseases tolerant, and nutrient rich and high - yielding cultivars are commendable.

Introduction

In Ethiopia, agriculture is the main source of livelihood for 80% of the population. The sector contributes to 42% of Ethiopia's gross domestic product (GDP) (Shiferaw & Holden, 1998). The country's unique location close to the equator provides bimodal rainy seasons (Mengistu, 2006), known as *Kiremt* and *Belg*. Therefore, rainfed agriculture dominates most of the farming land in the country (Tilahun et al., 2011). Ethiopia's is well known for high crop diversity. The main cultivated crops are cereals, grains, pulses, oilseeds, vegetables, perennial crops (Khat, coffee, hops, and different fruit trees), enset, and root crops (CSA, 2015). Teff (*Eragrostis tef* (Zuccagni) Trotter), wheat (*Triticum aestivum* L) and barley (*Hordeum vulgare* L) are the main staple crops in the Northern Ethiopia (Corbeels et al., 2000), whereas maize (*Zea mays* L)and enset (*nsete ventricosum* (Welw.) Cheesman) are main staple crops in the Southern Ethiopia (Olango et al., 2014). Newly emerging root crops, like sweet potato, require few inputs, have high dual nutrition and energy values for both human and livestock (Claessens et al., 2008), as well as the ability to perform well under different climatic conditions in different agro-ecological zones[1].

Sweet potato is an important root crop mainly to the developing countries and is a food security crop in several countries (Benjamin M. Kivuva et al., 2014). Thus, these distinctive capabilities classify sweet potato as a food security crop (Benjamin M. Kivuva et al., 2014). It is grown in 115 countries where China leads its production. Sweet potato is the seventh most important food crop in the world after wheat, rice, maize, potato, barley, and cassava *(Manihot esculenta)*. Furthermore, it is the second-largest root crop in the world after potato. In Africa, it is one of the most important food crops, especially in SSA countries, where it is the third-most important root crop after cassava and yam (*Dioscorea spp.*)(Woolfe, 1992). In Ethiopia, sweet potato is the second-most important root crop in the country after enset. It provides a healthy diet for millions of people across the country (Gurmu et al., 2015). Moreover, it is commonly cultivated as an integrated crop, along with livestock, in the crop–livestock farming systems (Belehu, 2003). Southern Region and Oromia Region are the main regions that produce sweet potato in Ethiopia (Gurmu et al., 2015). However, Ethiopia's average sweet potato yield is low with 8 t ha^{-1}, although the potential yield is 30 – 73 t ha^{-1}, and the international average is 14.8 t ha^{-1} (Belehu, 2003; Benjamin M. Kivuva et al., 2014).

Growers prefer sweet potato cultivations because of its attributes, including tolerance to a wide range of agro-ecological conditions, lower demand for agricultural inputs, high-yielding potential per unit area per unit time, ease of cultivation and effective vegetative propagation method (Woolfe, 1992). Moreover, it has high nutritive value (primarily of carbohydrates and vitamins) and is suitable to grow on marginal land. Due to all these merits, sweet potato remains as competitive crop for food security crops in developing countries (Gibson *et al.*, 2009). Among the sweet potato cultivars, orange-fleshed sweet potato (OFSP) is a good source of vitamin A (Low et al., 2007).

Sweet potato has wide ecological adaptabilities, which enable the crop to perform well under poor soil conditions. Therefore, smallholder farmers can grow sweet potato in poor soil with little or no fertilizers (Karyeija et al., 1998). However, temperature affects the growth of sweet potato. The optimal growing temperature is 24 °C (Gajanayake et al., 2015). Therefore, low temperature at high altitudes causes frost, and high temperature at low altitudes reduces the crop storage root production (Belehu, 2003). Moreover, high potassium supply (Bourke, 1985) and good soil aeration conditions have been demonstrated to encourage storage root formation (Agbede & Adekiya, 2009). Despite climatic and edaphic factors, viral diseases and insect pests are the most important limiting factors to sweet potato production in Ethiopia (Tesfaye et al., 2013). Viral disease is a major problem to sweet potato production in Southern Ethiopia. The two most common sweet potato infecting virus - Sweet Potato Feathery Mottle Virus (SPFMV) and Sweet Potato Chlorotic Stunt Virus (SPCSV) are reported to have high incidence, especially in Southern Ethiopia (Adane, 2010; Tesfaye et al., 2011; Tesfaye et al., 2013).

In Ethiopia, smallholder sweet potato farmers are vulnerable to crop failure every growing season (Belehu, 2003; Gurmu et al., 2015). Therefore, this study uses a holistic agroecology (Francis et al., 2003) approach to investigate the ecological, social, and economic factors that influence sweet potato production in three agro-ecological zones in Ethiopia. The aim of the present study is to evaluate factors that influence sweet potato production practices of smallholder farmers under different agro-ecological and socioeconomic conditions in Ethiopia. It addresses questions of what agro-ecological and socioeconomic factors are affecting smallholder farmers' sweet potato production practices in selected sites in Northern and Southern Ethiopia.

Materials and methods

2.1 Description of the study areas

Six research sites were chosen in three agro-ecological zones, both in the Southern and Northern Ethiopia. Southern Ethiopia is more suitable for root and tuber crops while the Northern is known for traditional cereal crop production system. In 2013, the Tigray Agricultural Research Institute introduced OFSP to the Tigray region in Northern Ethiopia, in order to tackle vitamin A deficiency among children (Kidane et al., 2013). Based on altitudinal differences, there are three agro-ecological zones, comprising low, middle, and high, which strongly influence crop choice and farming practices in Ethiopia.

The research areas include, Southern Tigray Zone in Northern Ethiopia, lying at 12°15' to 13°41' North, 38°59' to 39°54' East. It was selected as a study area because it produces the most sweet potatoes in the Tigray region. The zone exhibits the three agro-ecological districts. These three districts were chosen because they are accessible by public transport. The Tigray Region has one of the driest climate conditions, with erratic rains (Di Falco et al., 2007). The main soil types are *Vertisols*, *Letosols*, and *Calcisols* (Rabia et al., 2013). Farmers cultivate teff, sorghum, pulses, different kinds of vegetables and fruits in low altitudes, whereas wheat, barley, and legumes are grown in high altitude areas (Rabia et al., 2013). The bimodal rainfall provides the region with an average of 663 mm of rainfall annually (Giday & Ameni, 2003; Yirga, 2010). However, in the last thirty years, rainfed agriculture in Tigray has been significantly affected by local dry spells and erratic rains more than other regions in the country (Abrha & Simhadri, 2015). Also, over 50% of the soil is extremely depleted ((Di Falco et al., 2007). Therefore, famine and drought occur more often in the region, and farmers struggle to sustain their agricultural production (Abrha & Simhadri, 2015). However, the southern part of the country is quite different.

The Wolayita zone is in Southern Region. Based on altitudes, Wolayita zone was stratified into three districts - low, middle, and high altitudes. The Wolayita zone is one of the highest sweet potato production zones in the country. It is one of the most densely populated zones in Ethiopia, with a population of over 1.7 million, and with 290 inhabitants per km^2 (Tekola et al., 2006). Consequently, the landholding size is relatively small and most inhabitants are subsistence farmers (Kebede et al., 2009). Wolayita farmers practice smallholder home gardening with mixed crops, supported with livestock. This diversified system is based on enset (*Ensete ventricosum)* cultivation and combinations of maize, sweet potato, banana, legumes, coffee, and *teff*. It also includes tubers and root crops such as taro (*Colocasia esculenta)*, yam, cassava (*Manihot esculenta)*, and different vegetables (Beyero et al., 2010; Gurmu et al., 2015). The temperature varies between 15 °C and 20 °C, with high annual rainfall ranging between 800 mm and 1400 mm (Hailesilassie, 2015). Nitisols, dark brown soils that contains 35–50 % clay, cover most of the farmland (Buni, 2015; Tolera & Said, 1992).

2.2 Methods

A mixed method, consisting of quantitative and qualitative approaches, was used for data collection. A quantitative questionnaire was prepared and distributed to randomly selected farmer households, followed by qualitative in-depth interviews of key informants from research institutions, local agricultural offices, and researchers working in the study areas. In addition, informal interviews, transect walks, participation in planting, and discussions were used during two field visits from August and October 2016 in the study areas.

In Southern Tigray, sixty questionnaires were distributed in three districts, 20 in each of the three PAs (Table 1).

Table 1: Total number of farmer households and sweet potato farmers in the three selected agro-ecological zones in the Southern Tigray region, Northern Ethiopia.

Altitude	District	Farmer Association (*Kebele*)	Total number of households	Number of households cultivating sweet potato
Low (1400 masl)	Alamata	Gerjale	2066	46
Middle (1500–2300 masl)	Ofla	Zata	2265	0
High (2300 masl)	Mychew	Simret	1643	10

Source: From Relief Society of Tigray and the districts (*Woredas)* offices of Agriculture.

In Wolayita zone, sixty questionnaires were also distributed in the two districts, 20 questionnaires in each of the three PAs (Table 2).

Table 2: Total number of household and sweet potato farmers in three selected agro-ecological zones in Wolayita Zone, Southern Ethiopia.

Altitude	District (*Woreda*)	Farmer Associations (*Kebele*)	Total household size	Number of households cultivating sweet potato
Low (1400 masl)	Humbo	Ambe shoye	575	210
Middle (1500–2300 masl)	Sodo Zuria	Kokate 1	145	123
High (2300 masl)	Sodo Zuria	Kokate 2	102	35

Source: Districts (*Woredas)* offices of Agriculture.

Data analysis

Quantitative questionnaires data were analyzed using Statistical Package for the Social Sciences (SPSS) Ver. 24. Data collected from informant interviews were transcribed, organized, and coded. Then, themes, suggestions, and quotes from these informants were presented to supplement the data collected from the questionnaire.

Results and discussion

In both Southern Tigray and in Wolayita zones, demographic factors varied from farm households to households (Table 3). Most respondents were male, with a median age of 42 and 41 years in Southern Tigray and Wolayita, respectively. This average age shows that there are potential labor forces, which could increase sweet potato production in the long-term. The average number of children was five per family, which indicates high population growth in the research areas. Gebru et al. (2017) reported an average family size of four in Sodo Zuria and five in Damote Gale district of Wolaita Zone. This might decrease the farmland holding size in general, and probably farmers' ability to allocate land to sweet potato farming. In contrast, most of the sweet potato agronomic practices such as land tillage and seedbed preparation require labor. Therefore, it is possible that family members could help with these tasks during any stage of crop growth. The average birth rate in the country is 4.8 births per women, and it is higher in the rural areas (Ayele, 2015). The higher number of family size per household is common in rural families, which is required labor for agricultural farming activities (Okoye et al., 2008; Udensi et al., 2011). Moreover, the illiteracy rate among Southern Tigray farmers is higher than Wolayita farmers. This could influence Southern Tigray farmers' ability to adopt new crops and cultivars such as OFSP, and their agronomical practices. Therefore, farmers could be reluctant to plant new crop varieties such as sweet potatoes they have no knowledge of. A study by Epeju (2005) in Uganda showed that farmers with formal education could deal with production problems better than illiterate ones. In Wolaita Zone, Gebru et al. (2017) reported 10% of farmers were illiterate, and 1.9% were educated attending beyond high school. The proportion of illiterate was 30% in the present study in the study sites in Wolaita Zone (Table 3).

Table 3. Demographic characteristics of respondents in the Southern Tigray and Wolaita zones (%).

Variable	Southern Tigray	Wolaita
Gender (%)		
Male	75	88
Female	25	12
Marital status (%)		
Married	90	93
Widowed	3	5
Single	3	2
Divorced	4	0
Education (%)		
Illiterate	55	30
Primary	28	50
Read and write	10	5
Secondary education	7	15
Farm work (%)		
Men	20	80
Women	13	5
Both	60	12

In Southern Tigray, both men and women are responsible for farm work, from seedbed preparation and planting to harvesting. In Southern Tigray, more women are involved in the sweet potato farming compared to that of Wolayita women. In sub-Saharan Africa, women are the main sweet potato cultivators, which gives them extra money to help their families (Claessens *et al.*, 2008; Karyeija *et al.*, 1998). Furthermore, women in Southern Tigray got better awareness of the health benefits of OFSP for their children, which is promoted by extension officers and NGOs as stated by key informant and informal interviewees and observed during transect walks. A study done by Low et al. (2007) in Mozambique showed that OFSP have a high level of vitamin A content that could reduce malnutrition in children. Wolayita farmers get extra income by selling sweet potatoes on the roadsides, which could probably encourage them to grow the crop. Moreover, in Wolayita, women's role in sweet potato production is limited to harvesting only, while men traditionally take responsibility for cereal crops and cash crops such as maize and coffee. This could limit the Wolayita women's decision to allocate part of their farming land to sweet potato. In the previous study conducted in Wolaita showed that the majority of the respondents were male-headed household farmers (Gebru et al., 2017). Similar trend was also reported in Kenya where more than 60% farmers were male-headed household (Muthoni et al., 2013). The same trend was also reported in Kenya where more than 60% farmers were males (Muthoni et al., 2013). Findings from previous studies by Gladwin (1992) in Malawi showed that men are interested more in growing cash crops. This may suggest that in most of the cases, male farmers are more responsible for farming activities and leaders of the families in developing countries, particularly in Ethiopia. Males mostly involve in agriculture activities that require physical work. This is also connected to culture.

Pest and disease, climatic factors, and yield

Pests and diseases hindered the sweet potato production in the two zones (Figs.1and 2). Sweet potato weevil *(Cylas puncticollis)* and sweet potato butterfly *(Acraea acerata)* are the most common pests. In Africa, sweet potato weevil and sweet potato butterfly are the dominant sweet potato pests in Ethiopia (Getu & Adahanom, 1989; Shonga et al., 2013). Sweet potato viral diseases can reduce the crop yield from 56 % up to 98 % (Adam et al., 2015). In Wolayita, Sweet Potato Feathery Mottle Poty Virus (SPFMV) and Sweet Potato Chlorotic Stunt Virus (SPCSV) reduce sweet potato yields. These viruses are the most common sweet potato viruses in Africa (Untiveros et al., 2008). High incidences of SPFMV and SPCSV infections were reported in Wolayta zone in southern Ethiopia (Tesfaye et al., 2011). The perception and knowledge of farmers about sweet potato viruses and the impacts on its performance appear negligible. In this regard, farmers' adequate information is critical for the management of these viruses and insect pests. Farmers' perception and knowledge on plant viruses was low in Asia (Schreinemachers et al., 2015). In Tanzania, study revealed that farmers have very little information about economically important sweet potato viruses and the impacts on sweet potato yields (Rwegasira et al., 2007).

Drought also affects the crop's yield (Figs. 1 and 2). In Wolayita, the effect of drought on sweet potato yield is more severe than in Southern Tigray; although, the region receives more annual rainfall than the Southern Tigray. This might be because Wolayita farmers received lower amount of rainfall in the last years than they used to. This study confirms previous studies in Ethiopia and Tanzania, indicating that drought, pests, and diseases were among the main factors affecting the sweet potato yields ("Editorial Board," 2015; Gurmu et al., 2015; Kapinga et al., 1995). A study in SSA claimed that sweet potato is the second crop, after wheat is predicted to drop in yield by 2050 due to climate change (Ringler et al., 2010) and sweet potato is known as a drought-tolerant crop (Jansson & Raman, 1991). Pests, diseases, and drought reduce sweet potato production and leave farmers with few options such as planting other crops, renting their farms to others, and selling their farm and looking for different jobs.

In Southern Tigray, farmers do not intercrop sweet potatoes with other crops due to lack of experience in cultivating sweet potato. In Wolayita though few farmers practice intercropping sweet potato with other crops, most of the farmers do not practice intercropping because they had previously experienced lower yield. This circumstance indicates the complexity of growing two or more crops at the same time in the same field. They plant sweet potato in the moisture-rich soils at the end of the main rainy seasons to have planting materials available for the next cropping season. Farmers plant *Hawassa-83* cultivar as a single crop to get a good yield. This is because *Hawassa-83* might not compete enough with other crops for nutrients, soil moisture, and sun light. Carlson (2008) and Lebot (2009) stated that shade-tolerant sweet potato cultivars can be intercropped with early maturing maize varieties. For example, a study conducted in the semi-arid Rift Valley in Ethiopia showed that intercropping sweet potato with maize had no effect on sweet potato vines, but it reduced sweet potato yield during the dry season (Carlson, 2008). In contrast, another study in Uganda indicated that maize and sweet potato intercropping produced decent amounts of biomass for both crops, without impacting upon sweet potato yield (Lebot, 2009). This finding suggests that sweet potato can be intercropped with other crops. However, further research is needed to study the effect of sweet potato cultivars intercropping with other crops.

Figure 3 shows sweet potato planting materials sources in the Southern Tigray. Sweet potato farmers in the research areas experienced limited choices of sweet potato cultivars. The Tigray Agricultural Research Institute introduced sweet potato varieties to the region after an adaptation trial on eleven sweet potato cultivars. Two OFSP cultivars was identified, *Tula* and *Kulfu,* which could adapt to the local climates*. Moreover, the* Institute produces “disease-free” sweet potato cultivars and gives to donor organizations to distribute them to farmers with the aim to reduce malnutrition in the region. In Southern Tigray, respondent sweet potato farmers cultivated *Tula* and *Kulfu* because of their nutritional and high-yield values. In the low altitude, all the respondents cultivated sweet potato in small parcels, with an average of 177 m^2 $farmer^{-1}$. This is because of the enabling and suitable climate and fertile soils. Besides, Alamata Agricultural Research Center is also located in the district, which motivates farmers to plant the crop. Furthermore, it is easy to access the district by transport for NGOs from other regions and districts. However, this raises questions about the long-term sustainability of The International Potato Center (CIP) and the sweet potato projects of distributing planting materials to farmers every season. For instance, one researcher explained, *“donor organizations cannot sustain their distribution of sweet potato planting materials to farmers for long period”*. While, in the middle altitude, none of the respondent farmers planted sweet potato because they did not receive planting materials from donor organizations or elsewhere. In the high altitude, 30 % of respondents cultivated sweet potato, with an average of 933 m^2 $farmer^{-1}$. Donor organizations lack the economic capacity to distribute sweet potato planting materials to farmers.

Figure 4 shows sweet potato planting materials sources in the Wolaita Zone. In Wolayita, white-fleshed sweet potato cultivars that consist of *Hawassa-83* and *Nechi, Kulfu, Tula, Pino*, and *Guntute* OFSP cultivars were the commonest traditional cultivars. However, farmers abandoned their landraces of *Nechi*, *Pino*, and *Guntute* because of the introduction of high-yielding cultivar *Hawassa-83* (*Gadisa*)*.* In SSA, sweet potato landraces are better adapted to local climates with high pests and diseases resistance (Abidin, 2004).This might also be due to pest and disease infestations. Altieri et al. (1987) mentioned that farmers discard their local cultivars, for example, in favor of high-yielding ones, or plant large farming areas with one single cultivar. Furthermore, the sweet potato farmers appear to have lost knowledge and practices that are related to these cultivars such as planting and harvesting time, weeding, pest and diseases control, and post-harvest management. Nevertheless, farmers’ knowledge is different from the knowledge farmers receive from extension services. The farmers' knowledge is based on years of experiences from local climatic and soil conditions (Koohafkan & Altieri, 2010; Meijer et al., 2015){Koohafkan, 2010 #214;, 2015 #12;Koohafkan, 2010 #214;Reij, 1986 #250;Meijer, 2015 #285}. Extension officers' knowledge is probably based on research stations, without considering smallholder farmers' various socioeconomic and climatic zone conditions (Belay & Abebaw, 2004). Planting virus infected plants not only reduce yield but will also give poor quality roots. Moreover, infected plant has less resistance to the attacks of insect pests (Bryan et al., 2003; Feng et al., 2000; Benjamin M Kivuva et al., 2014; Yang, 2010). Extent of viral diseases and its impact on yield varies among farmer fields in Ethiopia (Tesfaye et al., 2013). Bishaw and Turner (2008) reported 80-90% of seed systems in developing countries are informal or traditional. Continuous use of infected sweet potato plant materials from the same mother stock over season hinders achievement of optimum yields (Adikini et al., 2016).

In the low altitude, extension officers visited all the sweet potato farmers regularly, while they only visited 50% of them in the high altitude. However, most of the respondent sweet potato farmers obtained planting materials from local agricultural offices as opposed to other sources (Figure 3). In Wolayita, extension officers visited 80 % of the farmers twice a year during planting time to distribute fertilizers, or seeds, but not specifically to help and advise the sweet potato farmers. Extension officers' numbers of visits and training are limited to a few sweet potato farmers every season. This paper shows that extension officers may not have the capacity and adequate sweet potato knowledge to help farmers grow more sweet potatoes. In both zones, the numbers of sweet potato researcher and extension officers are few cannot assist large numbers of farmers in such big areas, difficult topography, and limited infrastructure, compared with researchers working with cereal crops and cash crops. Similar findings by Belay and Abebaw (2004) in south-western Ethiopia showed that extension officers were overloaded with the number of farmers they were supposed to help. This affects farmers' ability to plant sweet potatoes, adopt new cultivars, and practices that could increase crop production. For instance, Southern Tigray farmers may not find it economically viable to replace traditional cereal crops with sweet potato. While Wolayita farmers might possibility consider replacing sweet potato with cereals or other crops. Lack of access to improved variety, absence of disease-free planting materials, climate change and limited land size affected yield of sweet potato (Okonya & Kroschel, 2016; Shields & Fletcher, 2013).

In Tigray, Agricultural Research Centers and CIP also have limited capacities to research into the various problem sweet potato farmers' encounter. They lack technical facilities (e.g., laboratories, greenhouses with controlled environment), technicians, and funds, to produce quality disease-free sweet potato planting materials. This includes to what extent disease-free sweet potato planting materials are clean from diseases, which pathogens they are clean from, and for how long these planting materials will be cleaned from pathogens. Besides, for how long The Tigray Agricultural Research Institute can multiply planting materials to farmers in the region. Research Centers in the two zones also have a big knowledge gap in sweet potato cultivation, along with a lack of shared knowledge between the Research Centers and local agricultural offices. For example, one researcher in southern Tigray said, "*farmers know how to cultivate cereal crops without support from government or NGOs, but this is not the case of sweet* *potato"*. However, farmers received their planting materials from different sources including exchanging planting materials with neighbors (Figs. 3 and 4).

In the research areas, farmers use different practices and methods for sweet potato farming. These practices include the use of hand tools like shovels, mattock, and hoes in smaller land sizes, while they use oxen in bigger plots to prepare the soil for planting. In Southern Tigray, planting time is once a year in the main rainy season during June and July. Sweet potato farmers cannot save sweet potato vines for the next planting season because of the long dry season. In Wolayita, farmers plant sweet potato twice a year, at the beginning of the main rainy season in April and May, and after harvesting of the main crops in *Meher*[2] season in October and November. This enabled many Wolayita farmers to save planting materials after harvest by planting sweet potato vines near their homes (home garden) during the dry season and, thus, to keep planting materials for the next planting season. In both study areas, weeding and harvesting is done manually.

Farmers do not use chemical fertilizers or pesticides. Instead, they use combinations of agroecological practices like crop rotation, animal manure, and crop residues to maintain soil fertility. However, fertilizers (DAP[3] and urea) and pesticides are applied to other crops such as wheat, teff, maize, and sorghum. Some of the sweet potato farmers in Wolayita use a mixture of cow dungs as pesticides by splashing the mixture on affected sweet potatoes' leaves.

In southern Tigray, 93% of the respondent farmers experienced production problems (Figure 1). In the erratic rainy season, sweet potato performed better than Irish potato and wheat, whereas sorghum, barley and maize performed better than sweet potato. Farmers used diverse techniques to cope with lack of rain; 38.3 % used supplementary irrigation, 21.7% planted different cultivars, 15% planted tree traces to capture the runoff water when it rains, 8.3 % harvested water, 5% planted different crops, and 11% did nothing. Moreover, some farmers combined two or three techniques to tackle the lack of rainfall. However, only one-third of the farmers faced a water-logging problem during the rainy season. Thus, farmers used traditional drainage systems to dispose of surplus water, and applied manure to loosen the soils for crop cultivation.

In both zones, farmers found it difficult to prioritize the main production problem among the production problems they had in their farms. In response to lack of rainfall, 57% did nothing but wait for the rain, while 30 % used the traditional method for coping with the rain shortage period. The traditional method implied the use of oxen for land tillage and covering the soil surface with plant leaves (mulch) during the rainy season, to keep the soil moisture for longer times. Moreover, 73% of the respondents reported that the main rainy seasons were severely difficult for root crops production. 32% of the farmers had a water-logging problem. Therefore, farmers planted different crops and used drainage systems to remove the surplus water.

In both research areas, the farmers did not rely solely on sweet potato production to sustain their livelihood. Therefore, 45 % and 25 % had off-farm jobs in the southern Tigray and Wolayita, respectively. These jobs were in daily labors, petty trade, and handicraft. Sweet potato farmers did not know how much they harvest or the amount they consume. The crop obtains a poor price on the markets and lacks consumer interest. Moreover, farmers did not sell sweet potato vines to other farmers. In Southern Tigray, farmers do not know how to cultivate, process, and eat sweet potatoes. Therefore, they were unwilling to use part of their land to cultivate sweet potato, which is cultivated only for household consumption. In Wolayita, farmers also consumed most of their production, and sold any surplus to the local markets. It is common that women sell boiled sweet potato in the roadsides in nearby cities during nighttime.

In the research areas, farmers' perceptions and experiences could limit their ability to recognize the main production problem related to sweet potato production. This shows the complexity of the production problems that farmers are dealing with. Farmers might mistake ecological factors such as drought for pest and virus infestation. A finding from previous study showed that farmers thought sweet potato vines' failure to grow in Uganda was because of drought, while the crop was in fact infested by millipedes (*Diplopoda*) (Ebregt et al., 2004).

Limited infrastructure and government budgets suggest that Farmers Field School (FFS) can help farmers to identify, analyze, and find possible solutions related to sweet potato production problems. FFS is a participatory learning approach, where extension officers' jobs are to facilitate farmers' meetings. Meetings take place in their fields, and farmers learn through field experiments and problem-solving situations. Farmers can implement methods and practices that are suited to their local climatic conditions and cultural desires (Godtland et al., 2004). In Wolayita zone where applied Integrated Nutrient Management (INM) on maize were able to reduce the use of inorganic fertilizers by 50%, without substantial differences in yield (Kebebe et al., 2007). Thus, FFS brings new ideas from the sweet potato farmers themselves that can help them manage some of the crop challenges, increase the sweet potato yield, and sustain their livelihood.

Conclusion

Combinations of social, ecological, and economic factors were found to influence sweet potato production in southern Tigray and Wolayita zones. In these zones, factors such as pests and diseases, drought, and lack of suitable cultivars for different climatic conditions affected the sweet potato yield. In southern Tigray, lack of sweet potato planting materials and associated knowledge constrained farmers from cultivating the crop widely. Further, farmers grow Orange-Fleshed Sweet Potato OFSP mainly for its health benefits and secondarily to generate extra income. In Wolayita, due to the introduction of high yielding cultivars, sweet potato landrace varieties were lost, and farmers grew widely Hawassa 83.

If researchers and NGOs recognize the diversity of farmers' knowledge and sweet potato landraces, then the crop yield may increase through breeding programs at different locations. These breeding programs could include researchers working together with male and female farmers to breed cultivars suitable for different conditions, with high nutritional value and yield, that are drought-tolerant, and that have high resistance to pests and diseases. Moreover, this might provide planting materials during the dry season. Thus, sweet potato yield and knowledge could increase throughout the country, with farmers becoming an important part of this change.

Declarations

The authors declare no conflict of interest.

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Data availability:

Authors contributions:

Ahmed Aldow: Conceptualization; data curation; formal analysis; investigation; methodology; resources; validation; visualization, writing—original draft; writing—review & editing.

Getachew Sime Feyissa: Resources; validation; validation; review & editing

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Data availability statement

An example of questionnaire and informant interview used for this study were added to the appendix.

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Footnotes

1. In Ethiopia, agro-ecological zone is the climatic conditions based on different factors such as elevations, soil, rainfall, and locations Mengistu, A. (2006). Country Pasture/Forage Resource Profiles. *Ethiopia View Article PubMed/NCBI Google Scholar*. .
2. Is the main harvesting season Bewket, W. (2009). Rainfall variability and crop production in Ethiopia: Case study in the Amhara region. Proceedings of the 16th International Conference of Ethiopian Studies, starting from September and can last until February. The duration of this season can vary throughout the country.
3. Diammonium phosphate fertilizer.

Figures

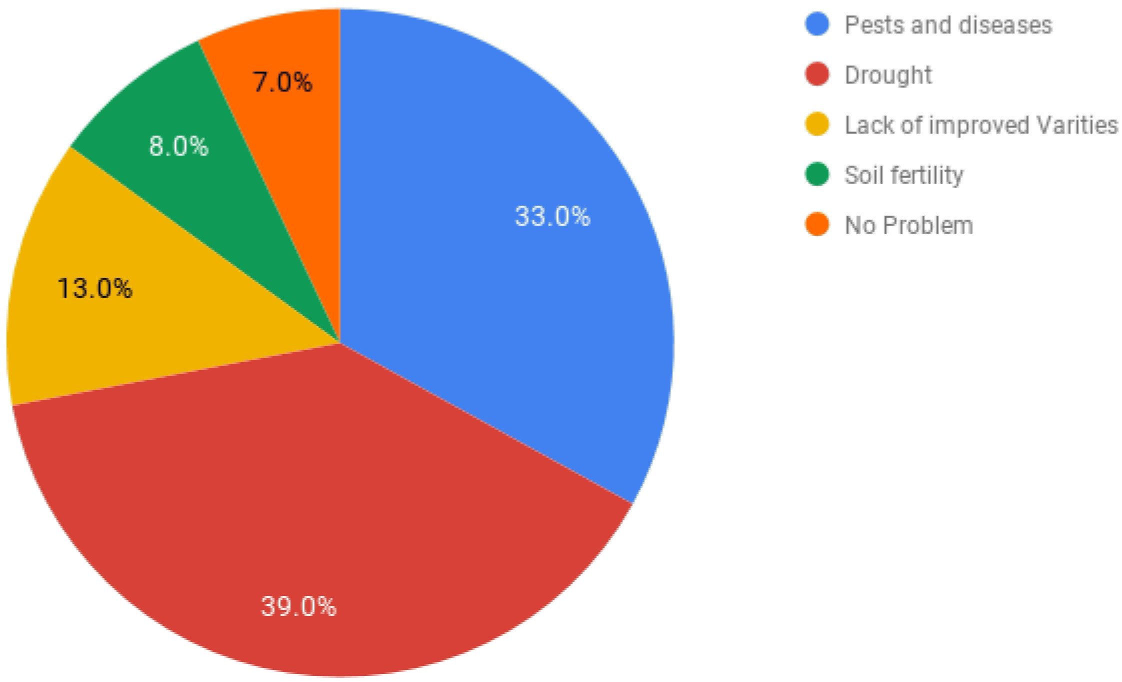

Figure 1

Distribution of the production problems among the sweet potato farmers in Southern Tigray Zone

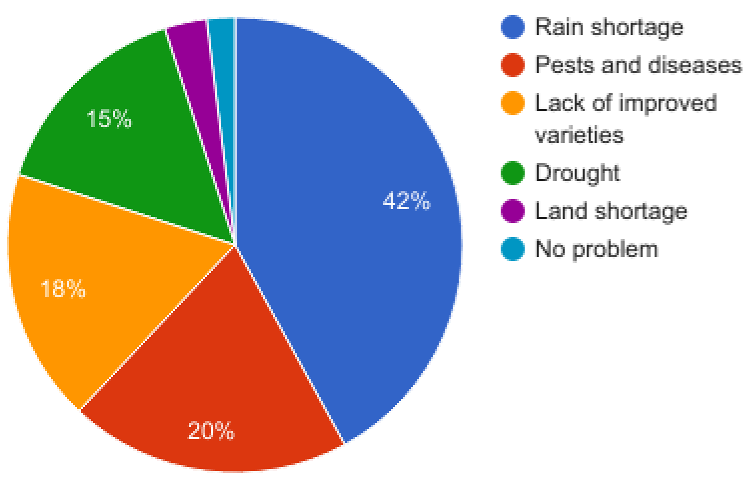

Figure 2

Distribution of the production problems among the sweet potato farmers in Wolayita zone.

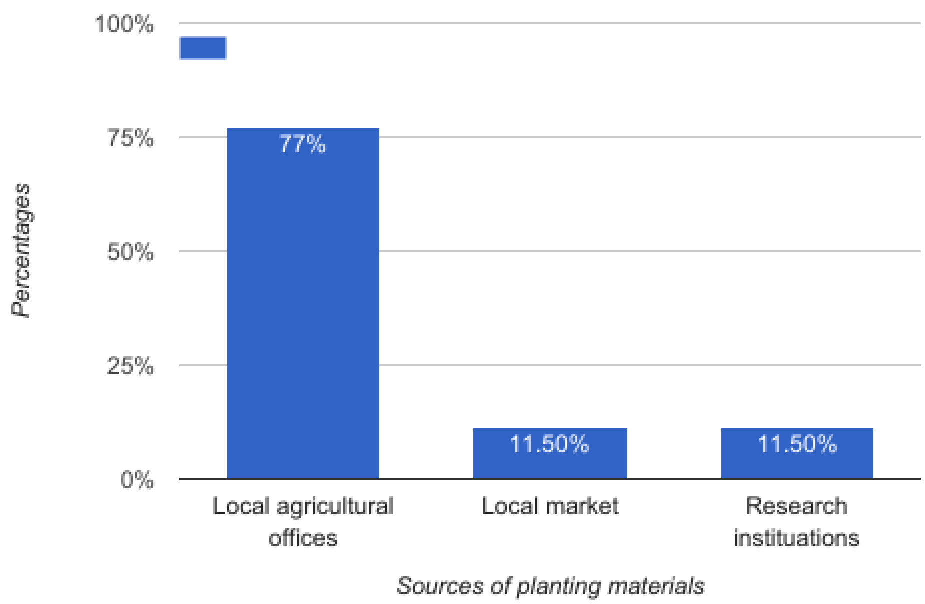

Figure 3

Sweet potato planting materials sources in the Southern Tigray.

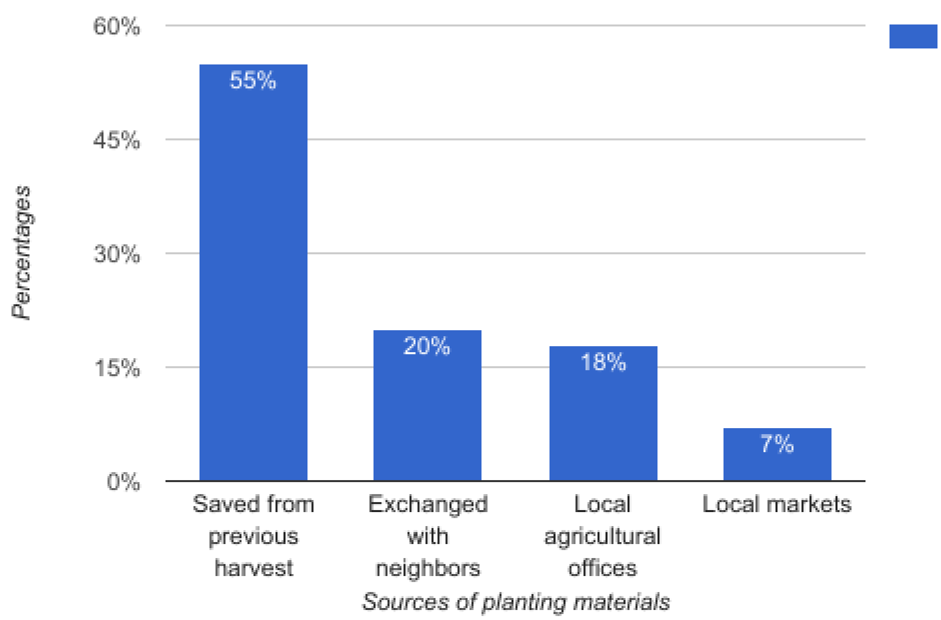

Figure 4

Sweet potato planting materials sources in the Wolayita Zone.

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