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Research paper

Farmers' knowledge and practices of potato disease management in Ethiopia

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ABSTRACT

Effective management of potato diseases such as bacterial wilt and late blight depends to a large extent on farmers' knowledge of the diseases as well as on the integration of recommended management methods in their daily practices. Late blight has continued to be a dominant potato disease for many decades in Ethiopia, whereas bacterial wilt has emerged more recently with a devastating impact on the country's potato production systems. A survey of 261 randomly selected farmers was carried out in three major potato growing districts in the central highlands of Ethiopia to examine farmers' knowledge and management practices of the two diseases, and to analyze the role of relevant knowledge in their practices. Considering their different characteristics, three groups of farmers were distinguished: producers of quality declared seed, producers of normal seed and producers of ware. The study shed light on the vital role the lack of knowledge about the diseases plays in shaping farmers' daily potato production practices. Most farmers could recognize symptoms of the diseases on infected leaves and stems. However, they had very limited knowledge of the diseases including their causal agents, spreading mechanisms, and effective management methods, although they knew a little bit more about late blight than about bacterial wilt. Therefore, to effectively manage the diseases, farmers need to learn about the diseases and how to manage them in their local context applying a feasible combination of management options through a community-based approach. The effectivity of such an approach could be enhanced by stipulating operational standards in bylaws and through continuous monitoring of changes in farmers' practices and environmental monitoring for disease occurrence by leveraging an interactive mobile-based platform.

1. Introduction

Potato (*Solanum tuberosum* L.) is the fourth most important food crop in the world after maize, rice, and wheat. It provides more food per unit area than any other major food crop (FAO, 2008; Devaux et al., 2014). In Ethiopia, on top of being a key crop for food and nutrition security, potato is a vital source of income for many smallholder farmers in the Ethiopian highlands due to its high yield, combined with its early maturity and high nutritional value (FAO, 2008; CSA, 2012; CIP, 2011; Gildemacher et al., 2009a; Haverkort et al., 2012; Gildemacher et al., 2009b). Currently, potato is cultivated on more than 296,000 ha of land in the country, engaging more than 3.7 million smallholder farmers and with an annual production of about 3.6 million tonnes (CSA, 2016).

Despite its importance, the production of potato has been challenged by several biotic and abiotic constraints prevailing in the country. Potato yield per unit area has remained low with a national average of approximately 12.3 Mg/ha (CSA, 2016), which is low compared to the achieved yield of up to 65 Mg/ha on research station and about 50 Mg/ha on farmers' field, under good management practices and using improved varieties (Berihun and Woldegiorgis, 2013).

Among the major biotic constraints that have severely affected potato production in Ethiopia, late blight has been identified as the most important (Woldegiorgis et al., 2008; Kassa and Eshetu, 2008). The disease develops and spreads rapidly under high relative humidity, moderate temperature, and substantial rainfall. It infects potato leaves, stems, and tubers at any stage of development and has a potential to destroy the whole potato field within a few days.

Considering the importance of the late blight problem, several potato research and development projects have been implemented in the

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country. Late blight management approaches which include the use of resistant varieties, fungicide application, and cultural practices such as early planting, hilling and mechanical haulm killing before harvesting have been tested and recommended by the national agricultural research institute (Woldegiorgis et al., 2008). Studies show that management practices such as fungicide application and use of resistant varieties have been adopted by some potato farmers in different parts of the country (Tesfaye et al., 2013). However, late blight has continued to be a serious problem contributing to a significant yield reduction in the Ethiopian potato production system.

More recently, another potato disease, bacterial wilt, has become the most serious threat to the country's potato production (Gorfu and Woldegiorgis, 2013). The prevalence of bacterial wilt has been historically limited to a few parts of the potato-growing areas in Ethiopia until recent years (Lemessa and Zeller, 2007; Henok et al., 2007). With the rapid expansion of potato production in the country, the distribution of the disease has been increasing. And currently, the disease has spread nationwide. According to recent studies, the disease has affected the seed potato production system and it has reached an epidemic level in some districts (Gorfu and Woldegiorgis, 2013; CIP, 2016; Abdurahman et al., 2017). Overall, given the drastic prevalence of both bacterial wilt and late blight in the country, controlling the spread of the diseases is currently a big concern of potato farmers and other actors in the potato innovation system.

In the literature, much is known about the nature of the pathogens that cause the two diseases and effective measures for prevention and control of their spreading (Hayward, 1991; Yuliar et al., 2015; Arora et al., 2014). This does however not imply that smallholder potato farmers in developing countries like Ethiopia have adequate knowledge of the diseases given the complex socio-ecological nature of these problems. A recent diagnostic study conducted in the Ethiopian potato innovation system and published in this special issue has pointed out that the design and implementation of effective management interventions for the two diseases require an understanding of the systemic, multiple and interacting technical and institutional aspects (Damtew et al., 2018). The study recommends a community-based approach (mobilizing farming community and strategizing other local actors) to effectively manage the diseases in the context of smallholder farmers in Ethiopia (Damtew et al., 2018). Similarly, previous studies in many countries have recommended an integrated approach using a combination of disease management options as a plausible strategy to effectively manage bacterial wilt (French, 1994; Priou et al., 1999; Lemaga et al., 2005; Elphinstone and Aley, 1993) and late blight (Lal et al., 2017; Cooke et al., 2011; Garrett et al., 2001). Furthermore, addressing such complex socio-ecological challenges requires continuous monitoring and learning, and translating new scientific knowledge to foster the capacity of farmers to act collectively (Brown et al., 2010; Cieslik et al., 2018).

In the current digital era, the increasing availability of Information Communication Technologies (ICTs) has enabled management and monitoring of complex ecological challenges by generating timely and context-specific information (Cieslik et al., 2018). Likewise, in relation to complex potato diseases like bacterial wilt and late blight, mobile-based technologies have been suggested as potential ICTs to stimulate collective and connective action among farmers by generating locally relevant information (Damtew et al., 2018; Cieslik et al., 2018). However, the extent to which farmers in Ethiopia have access to mobile phones and how mobile-based platforms can be leveraged for disease monitoring and information sharing among smallholder farmers are not clear. Furthermore, for developing an effective community-based approach, good insight into farmers' knowledge and information needs in relation to the different aspects of the diseases is required. Understanding the role of knowledge in farmers' practices is also an important starting point for developing a community-based management strategy that fits the context of the country's potato production systems.

This diagnostic study was designed to investigate farmers' knowledge of various aspects of bacterial wilt and late blight and to examine how the knowledge on these diseases contributes to or hinders good farmers' practices of preventing and controlling the diseases. It is recognized that relevant knowledge may consist of both scientific knowledge and local knowledge and abilities to deal with the diseases in the local context. Hence, the study focuses on farmers' understanding of scientific knowledge on the diseases and recommended management methods as well as their local knowledge on how to deal with the diseases. The findings of this study are relevant for the design of a community-based potato disease management in the context of smallholder farmers in Ethiopia. Moreover, the study offers an important scientific contribution to our theoretical understanding of how farmers' practices are related to knowledge in relation to the management of plant diseases and how mobile-based technologies can foster disease monitoring and collective action. The main objective of the study was to identify basic requirements for a community-based management strategy that induces a learning process among farmers for effective management of bacterial wilt and late blight in the central highlands of Ethiopia. The implications of the study were identified by exploring what types of learning approaches would fit the current situation of farmers' knowledge and practices. To achieve the overall objective, four related research questions were formulated:

1. What would be an effective disease management strategy for smallholder potato farmers?
2. What knowledge do farmers have about bacterial wilt and late blight and their management methods?
3. How are farmers' practices related to this knowledge?
4. What are the implications for a community-based intervention and monitoring approach by leveraging a mobile-based platform?

This paper is organized as follows. Section 2 develops a conceptual framework for the study. This is followed by Section 3 with a brief description of the methodology including study design and sample selection, description of study sites, data collection and analysis, and profile of sample farmers. In Section 4, the results are presented, and in Section 5 the findings are discussed. Section 6 draws conclusions.

2. Conceptual framework

The purpose of this section is to present a conceptual framework employed in this study. Three concepts relevant to crop disease management are key in this study. These are potato diseases, knowledge and practices.

2.1. Potato diseases

Plant diseases result from complex interactions among a susceptible host plant, a pathogen, and the environment (Vanderplank, 2012; Scholthof, 2007). Several human activities like cultural practices including application of chemicals modify this interaction (Burdon et al., 2014). Environmental factors such as temperature, moisture, soil pH, wind, light, and soil type play a huge role in disease development and severity (Scholthof, 2007; Schumann, 1991). Plants are considered to be diseased when they are infected by a pathogen and their normal development and functioning are disrupted. Hence, plant diseases significantly diminish growth and yield or reduce the usefulness of a plant or a plant product (Beresford, 2007; Van der Plank, 2013). Plant diseases may also lead to complete destruction of the entire plant under conditions favorable for the disease. Plant diseases can be grouped by the causal agent involved such as fungal diseases, bacterial diseases, and viral diseases (Vanderplank, 2012; Schumann and D'Arcy, 2006). Good understanding of the pathogen that causes a disease, its characteristics and life cycle, and its effective management options are critical to control or suppress the adverse effects of a plant disease (Van der Plank, 2013). This study focuses on the two major potato diseases in

Ethiopian potato production systems, bacterial wilt and late blight, which are complex ecological problems. These diseases are caused by pathogens that have intricate life cycles and diverse spreading mechanisms.

2.2. Knowledge

For effective management farmers need to have good knowledge of different aspects of the diseases, such as causal agents of the diseases, their life cycle, their visible symptoms on infected potato plants and tubers, how they spread from one area to another or from one plant to another, and effective management options. Without knowledge of these features of the diseases, it is difficult to effectively deal with them.

Knowledge is a generic concept that needs to be specified to be a useful analytical tool. Scholars from many fields have developed different perspectives and attach different meanings to the concept of knowledge. For Churchman (Churchman, 1971), knowledge is a collection of information, as an activity or as a potential residing in the user to help him adjust behavior to changing conditions. Taking an interpretive view, Davenport and Prusak (Davenport and Prusak, 1998) define knowledge as “a fluid mix of framed experience, values and contextual information and expert insight that provides a framework for evaluating and incorporating new experiences and information.” According to this perspective, knowledge originates from and is applied by humans.

Different taxonomies of knowledge have been proposed by different scholars that got prominence in different scientific or practice domains. Lundvall and Johnson (1994) consider knowledge as the key resource for economic growth. They categorize relevant knowledge into four broad categories: know-why (scientific knowledge of principles or interpretative frameworks based on experience and intuition), know-what (knowledge about facts), know-how (skills of doing different kinds of things practically) and know-who (who knows what and can do what). Know-what and know-why are usually referred to as explicit knowledge since they are easy to codify and communicate whereas know-how and know-who are tacit knowledge, which is invisible and difficult to share (Nonaka, 1991; Polanyi, 1967). This perspective on knowledge has gained prominence among innovation scholars who study learning economies. Learning mechanisms are also related to the type of knowledge to be generated, exchanged or transferred. Know-what and know-why are primarily learned by reading books and other materials and attending lectures or trainings, while learning know-how and know-who is primarily rooted in experiential learning and in social interaction (Lundvall, 1992).

As disease management entails implementing a range of activities that require different types of knowledge, our study borrowed this perspective to examine the different knowledge aspects of farmers in the management of bacterial wilt and late blight. In the context of this study, know-why refers to knowledge on the causal agents and spreading mechanisms of the two diseases as farmers are not necessarily expected to understand the delicate and complex life cycles of the pathogens in order to properly manage the diseases. Know-what includes farmers’ recognition of the diseases, symptoms on infected potato plants and tubers, diagnosis methods, and management methods, whereas know-who refers to farmers’ knowledge of who can provide relevant information or their sources of information in their respective areas in relation to effective management of the two diseases, including fellow farmers, extension workers, NGO staffs and researchers, among others. Finally, know-how refers to farmers’ skills to implement effective disease management practices.

2.3. Practices

Relevant knowledge shapes disease management only if it is integrated into farmers’ daily practices. The concept of social practices has been used by many scholars (Leeuwis, 2004; Shove et al., 2012). Practices are patterns of human action that are common in different contexts due to social influences. Peoples’ practices are shaped by a number of factors including what they believe to be true (beliefs about consequences of actions/practices, perceptions of likelihood and risk), what they aspire to achieve, what they think they are able to do (which includes availability of skills and competence), and what they think they are allowed and/or expected to do (Leeuwis, 2004). Likewise, according to Shove et al. (2012), a social practice is defined by available materials (things, technologies, and physical entities), competences (skills, know-how, and techniques) and the meaning attributed to it (symbolic meanings, ideas and aspirations). This perspective contends that while people may know why, in order to integrate relevant knowledge into their practices, it must be meaningful in their local context, they need to possess or have access to appropriate technologies and develop appropriate skills and local knowledge of how to apply scientific knowledge in a specific context. This concept of practices thus allowed us to give special emphasis to the role of knowledge in farmers’ practices of bacterial wilt and late blight management.

3. Materials and methods

3.1. Study design and sample selection

A survey aimed at understanding farmers’ disease management practices and their knowledge of bacterial wilt and late blight was conducted. To select sample farmers, a multistage sampling technique was used.

In the first stage of selection, three sample districts (Gumer, Doyogena and Wolmera) were chosen purposefully from two major potato growing regions of the country, Southern Nations, Nationalities, and Peoples' (SNNP) region, and Oromia region. These districts are among the major potato growing districts located in the central highlands of Ethiopia. Due to variations in terms of local conditions such as agricultural production systems and access to potato technologies, the districts were selected purposefully for the study expecting variations in farmers’ practices in relation to potato diseases management.

Gumer is located in the Gurage zone of the SNNP region at 220 km from Addis Ababa. The agroecology of the Gumer district is moist cool highlands with bimodal rainfall and with annual rainfall of about 1600 mm. Its altitude ranges from 2800 to 3000 m. Doyogena district is also located in the SNNP region of Kampata Tembaro zone, at about 260 km south west of Addis Ababa, with an altitude ranging from 1900 up to 2800 m. The district also has a bimodal distribution of rainfall with an annual rainfall of around 1400 mm. Wolmera district is located in the Oromia region, about 40 km west of Addis Ababa, with a bimodal rainfall distribution. This district receives an average annual rainfall of around 1100 mm and its altitude ranges between 2060–3380 m. Wolmera district has been one of the hubs of the seed potato market over the last 15 years since the Holeta Agricultural Research Center (HARC) of the Ethiopian Institute for Agricultural Research (EIAR) and the International Potato Center (CIP) have been operating in the area. HARC and CIP have started operating in Gumer and Doyogena districts in recent years. This may probably lead to different disease management practices among the districts since the farmers in Wolmera district have had relatively better access to information on potato production and disease management practices.

In the second selection stage, three broad categories of potato farmers were discerned, because their knowledge was expected to differ (although the categories were not mutually exclusive): producers of quality declared seed (QDS), producers of normal seed and producers of ware potatoes. QDS producers are farmers who are registered to produce seed that conforms to the minimum standards for seed potato production and undergoes some certification process (CIP, 2016; ESA, 2015) that is legislated in the seed production law. Since they are required to understand and adhere to quality seed production procedures stipulated in the QDS regulation they must have good knowledge of

Table 1
Numbers of interviewed farmers.

Sample districts	Number of sample farmers			Total
	QDS producers	Normal seed producers	Ware potato producers	
Gumer	23	27	32	82
Doyogena	17	18	41	76
Wolmera	–	40	63	103
Total	40	85	136	261

potato diseases and potato production practices and inform themselves. Normal seed producers are those farmers who are usually organized in groups or cooperatives to produce seed potatoes. Their seed does not pass a certification process, but is expected to meet minimum requirements and therefore these farmers should have better knowledge than ware producers. Ware producers produce table potatoes either for home consumption or for marketing. There are no quality standards for ware potatoes. The knowledge of ware growers about diseases is expected to be least, because they primarily get information from fellow farmers and extension workers unlike producers of QDS and producers of normal seed who get substantial support from agricultural research centers, universities and non-governmental organizations.

Lists of potato growers (population) in the study sites were obtained from the respective district offices of agriculture and natural resources and sample farmers were randomly selected from these lists. The sample size was determined with the proportional stratified sampling method, with 95% confidence interval and 5% margin of error. Overall, a total of 261 farmers were selected and interviewed in the field. Detailed numbers of interviewed sample farmers are indicated in Table 1.

3.2. Data collection and analysis

A questionnaire developed by the researchers was used to collect data from the sample farmers. The questionnaire was aimed at getting a clear picture of farmers' knowledge of bacterial wilt and late blight. Both structured and semi-structured questions were used.

Farmers' know-why and know-what were investigated by comparing the current knowledge of scientists with farmers' knowledge of the generic issues of the nature of the diseases, causes, the spreading ways of the diseases and management methods. The review of the state-of-the-art of scientific knowledge of bacterial wilt and late blight was carried out on the basis of a literature study (the know-why among scientists; see Sections 4.1 and 4.2).

The tacit knowledge forms of know-who and know-how are ideally investigated with participant observation and long, in-depth interviews. The know-who was investigated by asking about the farmers' knowledge not only about the sources of information, but also about the type of knowledge obtained from different sources and whether mobile phones were sufficiently used by farmers to be the future source of information. To tackle the potential drawbacks of asking about know-how in a survey, the farmers' were questioned about their actual disease management practices. Hence, practices such as crop rotation, seed renewal, use of late blight resistant potato varieties, and sorting infected/damaged seed and ware potatoes at harvest were given due attention in the questionnaire about how to address the diseases. Moreover, to triangulate and complement the findings of the survey, additionally in-depth interviews were conducted with six purposely selected farmers to generate qualitative information about their know-how and know-who.

The questionnaire was pre-tested with three farmers in each sample district. Few revisions on the content and the ordering of questions were made based on observations and reflections from the pre-test. The survey was conducted in a face-to-face interview style during November and December 2016. In addition to the questionnaire, farmers were asked to differentiate the symptoms of bacterial wilt and late blight that they knew during the interview. The questions were supported by providing colored photographs, which showed infected symptoms of bacterial wilt and late blight on potato leaves, stems and tubers.

The survey data were analyzed using descriptive statistics (percentage, frequency and mean) to present findings in summaries and tables. Pearson Chi-square test was used to determine whether there was significant difference in potato production practices and farmers' knowledge of bacterial wilt and late blight management among farmers of different categories, and study districts. All the quantitative analyses were done using SPSS (Version 22) software.

3.3. Profile of sample farmers

Of the 261 respondent farmers for the study, 87% were male and 13% were female. The average age was 42.7 ± 13.1 years, with many farmers (46%) between 36 and 55 years old. The majority of the respondents (67%) had formal education, either primary school (grade 1–8) or secondary school (grade 9–12). Only 18% of the farmers were illiterate. All sample farmers were smallholders, with an average potato farm size of 0.56 ± 0.57 ha; the majority of them (53%) had less than 0.5 ha. Farmers in Wolmera district owned relatively larger potato fields than the farmers in Gumer and Doyogena districts. The average potato field size ranged from 0.37 ha in Gumer to 0.83 ha in Wolmera district, and from 0.50 ha for ware potato producers to 0.64 ha for normal seed producers.

4. Results

4.1. Know-why of bacterial wilt of scientists

Bacterial wilt is a damaging potato disease, caused by *Ralstonia solanacearum* (Yabuuchi et al., 1995). The pathogen is categorized as seed-, soil- and water-borne since it spreads through the use of infected seed as planting material, infected soil, surface run-off and contaminated irrigation water (Hayward, 1991; Janse, 1996; Elphinstone et al., 2005). The pathogen can also be introduced to a crop field through contaminated farm tools when used for cultivation and weeding. Once the pathogen is established in a potato field, it can survive in the soil for many years and thus prohibits subsequent production of potato in that field (Hayward, 1991; Denny et al., 1994).

Ralstonia solanacearum is a widespread pathogenic bacterium that causes a wilt disease with severe effects on more than 200 host plant species which include many economically important solanaceous crops such as potato, tomato, eggplant, tobacco and chili (Hayward, 1991; Elphinstone, 2005). This bacterium enters the host plant roots, colonizes the xylem and makes the host plant collapse (Vasse et al., 2005; Genin, 2010). It has effective pathogenicity determinants to invade and colonize and destroy host plants. Visible symptoms of the infected plants are wilting, stunting and yellowing of the foliage. When the seed potato tuber is infected by this bacterium, the vascular ring decays and slime oozes are released from it until the tuber is completely destroyed (Vasse et al., 2005). After destroying the host plant, the bacterium is released to the environment and survives in soil, water or other host plants including weeds. It exhibits successful strategies for survival in harsh conditions through diverse survival forms until it contacts with a new host plant (Hayward, 1991; Vasse et al., 2005). The pathogen can also form latent infections, where host plants contain a bacterial population but without visible symptoms of infection (Aliye et al., 2015; Priou et al., 2001; Swanson et al., 2007). In Ethiopia, wide spreading of the disease has been found to be associated with latently infected seed distribution across the country (Abdurahman et al., 2017). The disease is also indigenous in many areas of the country.

Bacterial wilt is difficult to control essentially because of its diverse host plant species, its transmission through latent infection, the multitude of sources of infection, and long survival of the pathogen in the soil. Recent advances in control measures include chemical, biological, physical, phytosanitation and cultural practices (Yuliar et al., 2015). But chemical control has not been proven to be efficient to control bacterial wilt since the pathogen survives in deeper soil layers (Hayward, 1991; Huet, 2014). Also, chemicals have damaging effects on the environment. Likewise, even though studies have shown the potential value of some biological control agents, their suppression capacity is usually too low to be commercially used at large scale or requires high rates of inocula (Whipps and Gerhardson, 2007; Champoiseau et al., 2010). Physical methods like soil solarization using transparent plastic mulches have been proven to be effective against the pathogen although they are also difficult to be implemented by smallholder farmers (Yuliar et al., 2015). Thus, phytosanitation and cultural practices are the recommended and most widely used methods to eradicate or reduce bacterial wilt (Yuliar et al., 2015; Champoiseau et al., 2010). Phytosanitations include planting disease-free tuber seed on disease-free field, decontamination of farm tools, decontamination of irrigation water, diversion of surface run-off, and quarantine measures. Cultural practices include crop rotation of 5–7 years of excluding host plants, soil amendment, roguing of plants with symptoms of bacterial wilt and burning them, destruction of host weeds, and removing and destroying rotten tubers and potato haulms by burning (Li and Dong, 2013; Lemaga et al., 2001a; Lemaga et al., 2001b). Overall, several studies have proven that an integrated management strategy using a combination of phytosanitation and cultural practices is the most feasible approach to control bacterial wilt (Yuliar et al., 2015; Lemaga et al., 2005; Champoiseau et al., 2010). In addition, in order to effectively control the disease and prevent it from further spreading, a community-based approach is important through cooperation among farmers. The farmers need to make a concerted effort by practicing the cultural and phytosanitation measures to significantly control the disease in their community (Van de Fliert et al., 1998; Pradhanang et al., 1993).

4.2. Know-why of late blight of scientists

Late blight of potatoes is also a devastating disease and it is caused by a fungus-like, microscopic oomycete pathogen *Phytophthora infestans* (Mont.) de Bary (Erwin and Ribeiro, 1996). This pathogen is predominantly dispersed aerially from one place to another and disseminates to healthy plant tissues via rain splash or on wind currents. *Phytophthora infestans* can infect and destroy all plant parts, including leaves, stems and tubers of potato plants (Cooke et al., 2011; Garrett et al., 2001; Erwin and Ribeiro, 1996). It grows and reproduces rapidly on the host plant and results in severe epidemics during conditions of high moisture and moderate temperatures (Harrison, 1995; Coffey and Gees, 1991).

Symptoms of late blight infection on potato leaves include blackish water soaked lesions, and whitish sporulation of the pathogen around the margin of the lesions (Arora et al., 2014; Erwin and Ribeiro, 1996). The symptoms usually begin near the edges or leaf tips and lesions expand quickly, turn dark brown, and damage the plant. Symptoms of late blight on potato stems are elongated and dark brown lesions while the disease results in irregular reddish brown colored lesions on the surface of the tubers. At advanced stages of the disease, brown rot can be found on the tuber (Arora et al., 2014; Ingram and Williams, 1991).

Management methods for late blight include genetic, chemical, biological and cultural methods (Struik et al., 1997; Ke-qiang and Forrer, 2001; Bouws and Finckh, 2008). Genetic control method refers to the use of potato varieties having resistance to the pathogen that causes the disease. Resistance varieties stop or slow down the development of the disease (Kirk et al., 2005). A number of potato varieties that are resistant to late blight are being produced in many countries including Ethiopia. Chemical control using fungicides that are capable of preventing infection or of slowing down the disease are also effective and constitute predominant late blight management methods. Broadly there are two kinds of fungicides, contact and systemic. Contact fungicides only protect plant area where fungicides are applied and plant leaves developed after application of the chemicals are not protected against the pathogen. But systemic fungicides are absorbed through the plant foliage or roots and they are capable to protect leaves formed after the application (Cohen and Coffey, 1986). Biological methods consist of reducing late blight infection by using live microorganisms that have antagonistic effects against *Phytophthora infestans* (Struik et al., 1997; Ke-qiang and Forrer, 2001). Practicality and effectiveness of biological methods are, however, uncertain in the context of smallholder farmers (Ke-qiang and Forrer, 2001). Cultural practices include scheduling planting time, use of early maturing cultivars, use of pre-sprouted seed tubers, destruction of volunteer potato plants, making high hills to avoid or reduce contact of tubers with sporangia coming from infected foliage, foliage cutting two to three weeks before harvesting, timely harvesting, and destruction of discarded tubers by safely burying or burning, among others (Cooke et al., 2011; Garrett et al., 2001).

With an integrated disease management approach of a combination of resistant varieties, fungicides and cultural practices late blight could be controlled with low dose and frequency of fungicides (Kirk et al., 2005). Furthermore, an integrated approach is more economical for smallholder farmers besides reducing environmental pollution (Kirk et al., 2005; Namanda et al., 2004). Moreover, cooperation among farmers is important for effective control of the disease by avoiding infection from sources of inoculum in the environment (Ortiz et al., 2009). Hence, similar to that of bacterial wilt, a community-based approach seems to be a promising strategy to reduce late blight severity. In the Ethiopian context, an integrated disease management approach has been adopted by the national research system as a strategy to control late blight. In this regard, about 30 late blight resistant potato varieties have been released over the last three decades and are now in production in different parts of the country (Berihun and Woldegiorgis, 2013). Nonetheless, the pathogen has developed new races and most of the varieties have become susceptible to late blight and the farmers are largely relying on application of fungicides (Shimelash, 2015). This makes the use of a combination of methods more compelling to effectively control the disease.

4.3. Know-why of bacterial wilt of farmers

The farmers in the study areas were unaware of the causal agent of bacterial wilt and gave different assumptions based on their personal opinions and/or from what they heard other farmers say. None of the farmers mentioned the cause of this disease to be a pathogen. The farmers provided different explanations and confused a causal agent of the disease with various environmental factors, ranging from water shortage, insects, and earthworms to planting high moisture content seed potato, and waterlogging (saturation of soil with water). Farmers who claimed that water shortage is the cause of bacterial wilt seemed to perceive it as a normal plant wilting from moisture stress. Waterlogging as a cause for bacterial wilt was particularly mentioned by farmers who were producing potato using irrigation.

The majority of the farmers (60%) did not know bacterial wilt spreading mechanisms. But 40% of the farmers reported that they knew how bacterial wilt spreads and described different methods they thought it spreads through. Among these farmers, 63% and 52% of them mentioned infected seed potato and infested soil, respectively. Only few farmers, 7%, pointed out contaminated farm tools as a means for the spread of the disease. But none of the farmers mentioned other bacterial wilt spreading mechanisms such as contaminated irrigation water, and infected alternative host plants. In addition, none of the farmers was able to recognize latent infection (symptomless transmission) of bacterial wilt.

4.4. Know-why of late blight of farmers

Concerning the causal agent of the late blight disease, 97% of the farmers associated it with abiotic factors like rainfall, humidity and cloud that rather are environmental conditions contributing to the development and spread of the pathogen that causes late blight. Only few farmers (3%) mentioned the cause of late blight to be microorganisms. This shows that the majority of the farmers, including producers of quality declared seed and of normal seed, did not recognize the actual cause of late blight.

Almost none of the farmers recognized the methods by which late blight spreads from one area to another, even though few farmers mentioned it to be through infected seed. It is important to note that none of the farmers mentioned wind or water as a spreading mechanism for late blight. As such, the farmers did not consider neighboring potato farms as a source of infection, which can potentially influence farmers' practice in view of the need to collectively act to effectively combat the disease.

4.5. Know-what of bacterial wilt and its management methods of farmers

The majority of the farmers (72%) reported to know bacterial wilt, although not necessarily by its name. When the farmers were shown photographs of bacterial wilt symptoms on potato leaves and tubers without mentioning the name of the disease, most of the farmers recognized the symptoms as a problem they had in their potato fields or observed it in their neighborhood, both during *Belg* (short rainy season) and *Meher* (long rainy season) seasons. Overall, it was much easier for farmers to identify pictures of bacterial wilt symptoms on the leaves than on tubers. The farmers did identify general wilt of the potato plant. However, they did not recognize other common symptoms such as yellowing of foliage and stunting of the potato plant that can be associated with bacterial wilt. Statistically, there was a significant association between farmers' knowledge of the disease and their location/district (Table 2) with farmers in Wolmera Woreda relatively having better understanding of the disease (Pearson Chi-Square = 81.136, $p < 0.001$). But there was no statistically significant association between farmers' knowledge of the disease and the category of producers (Pearson Chi-Square = 1.309, $p = 0.520$).

Farmers' knowledge of different management methods for bacterial wilt was also limited. Among the farmers who reported to know bacterial wilt, most of them (84%) mentioned roguing plants with symptoms of bacterial wilt as an effective management method for the disease (Table 2). Cultural management methods were mentioned only by a few farmers and included planting bacterial wilt free seed (28%), crop rotation (19%), and decontamination of farm tools (3%). Furthermore, about 7% of the farmers, mostly ware potato producers, mentioned chemical application as a management method for bacterial wilt (Table 2).

4.6. Know-what of late blight and its management methods of farmers

Similar to the case of bacterial wilt, during the survey, farmers were shown photos of late blight symptoms on potato leaves, stems, and tubers without mentioning anything about the disease. The majority of the farmers (94%) recognized the symptoms as a disease problem they had in their potato fields, mainly during the main rain season (*Meher*). Again, similar to the case of bacterial wilt, the farmers more easily recognized the disease on potato leaves and stems than on potato tubers. Only few farmers, 6%, could not recognize late blight from the picture shown to them. All farmers in Wolmera district recognized the disease while 88% and 93% of the farmers in Gumer and Doyogena, respectively, identified the problem and there was a statistically significant association between farmers' understanding of the disease and their location/district (Pearson Chi-Square = 12.671, $p = 0.002$). But there was no statistically significant association between farmers' knowledge of the disease and the category of producers (Pearson Chi-Square = 1.596, $p = 0.450$).

Overall, more than 92% of the farmers reported that fungicide application was an effective method to control late blight, with 100%, 94% and 89% representing producers of quality declared seed, normal seed and ware, respectively (Table 3). A significantly larger proportion of farmers in Gumer district (99%) reported fungicide application as a prominent method to control late blight compared with 85% and 93% of the farmers in Doyogena and Wolmera districts, respectively. About 26% and 11% of the farmers also reported use of late blight resistant potato varieties and cultural methods like early planting and crop rotation as effective late blight management methods, respectively.

4.7. Know-who: sources of information on bacterial wilt and late blight management

The majority of the farmers (68%) mentioned that they had received some information on bacterial wilt and late blight from different sources. Among these farmers, the majority of them were QDS producers (93%), followed by normal seed producers (72%), and ware producers (58%). Statistically, there was a significant association between farmers who received some kind of information on the diseases and the type of farmers (Pearson Chi-Square = 16.670, $p = < 0.001$). Furthermore, the majority of the farmers in Wolmera district (84%) got access to information compared to 61% and 54% of the farmers in Gumer and Doyogena districts, respectively; there was a statistically significant association between farmers who got information on the diseases and their districts (Pearson Chi-Square = 20.057, $p = < 0.001$). This variation among the study districts may be due to the presence and operation of the Holeta Agricultural Research Center in Wolmera district for more than three decades.

Of the farmers who got information on the two diseases, most of them (64%) mentioned extension workers as the main source of information followed by fellow farmers (42%), non-governmental organizations (NGOs) (22%), agricultural researchers (19%) and seed

Table 2
Farmers' know-what of bacterial wilt management methods.

Bacterial wilt management options recognized by farmers	% within type of farmers[a]			% within districts[a]			% of total respondents (n = 147)
	QDS (n = 22)	Seed (n = 52)	Ware (n = 73)	Gumer (n = 11)	Doyogena (n = 47)	Wolmera (n = 89)	
Planting bacterial wilt free seed potato	41	40	15	9	30	29	28
Roguing plants with symptoms of bacterial wilt	86	81	85	82	72	90	84
Crop rotation	59	21	6	9	40	9	19
Chemical application	0	4	11	18	11	3	7
Decontaminating farm tools	5	8	0	0	1	3	3

[a] Multiple answers were possible as most farmers reported more than one practice.

Table 3
Farmers' know-what of late blight management methods.

Late blight management options recognized by farmers	% within type of farmers[a]			% within districts[a]			% of total respondents (n = 246)
	QDS (n = 39)	Seed (n = 81)	Ware (n = 126)	Gumer (n = 72)	Doyogena (n = 71)	Wolmera (n = 103)	
Chemical/fungicide application	100	94	89	99	85	93	92
Use of resistant varieties	46	25	20	18	28	29	26
Cultural methods (early planting and crop rotation	5	14	10	4	11	15	11

[a] Multiple answers were possible as most farmers reported more than one practice.

producer cooperatives (11%). This seems to indicate that extension workers and other fellow farmers are the most important sources of information on potato diseases for the farmers in the study districts. On the other hand, almost equal proportions of QDS producers (32%) and normal seed producers (31%) reported NGOs as important sources of information, whereas only 9% of ware producers mentioned NGOs as an information source. This is explained by the considerable support that NGOs provide to seed producers in major potato growing districts in the country. Also, about 33% and 24% of normal seed and QDS producers, respectively, reported agricultural researchers as a source of information compared with only few ware potato producers (5%). This seems to suggest that seed producers are more likely to be targeted by agricultural researchers than ware potato producers.

Among the farmers who got some kind of information on bacterial wilt and late blight, most of them (83%) got information on management methods of the diseases followed by their symptoms (41%), their causes (27%) and modes of spread (22%) (Table 4). Relatively, more QDS farmers (54%) and normal seed producers (33%) got information on the causal agents of the diseases compared with only 11% of ware potato producers (Table 4). Thus, the farmers got much less information about know-why of the diseases. This seems to be the reason why sometimes most farmers did important things like crop rotation but not for disease management purpose. Likewise, more producers of QDS (46%) and normal seed (25%) acquired information on modes of spread of the diseases while only 9% of the ware producers reported acquiring information on the same topic. Overall, the reason why most farmers reported getting more information on management methods than other generic aspects of the diseases seems to suggest that the information sources usually give more focus to management methods of the diseases than their causal agents and spreading mechanisms.

4.8. Know-how: farmers' management practices of bacterial wilt and late blight

In this section, a variety of farmers' practices of bacterial wilt and late blight management are presented considering the role of knowledge in these practices. Some practices are specific to each kind of disease while others are common to both diseases as described in the following section.

4.8.1. Practice of crop rotation

Most of the farmers (95%) reported to grow potato in rotation with cereals, pulses or other vegetables, with all QDS producers and normal seed producers practicing it. The few farmers (5%), who reported not practicing crop rotation, were all ware potato producers. Statistically, farmers' practice of crop rotation was significantly associated with the category of the farmers (Pearson Chi-Square = 12.575, $p = 0.002$) but not with location/district of the farmers (Pearson Chi-Square = 5.647, $p = 0.059$).

In relation to the length of crop rotation, nearly half of the farmers (48%) commonly practiced a one-season interval, with only 13% of the farmers practicing a three-season interval (Table 5). But the number of seasons of crop rotation was significantly associated with the type of farmers (Pearson Chi-Square = 12.575, $p = 0.002$), with quality declared seed farmers relatively practicing more seasons of crop rotation than normal seed producers and ware producers. Twenty-eight percent of QDS producers, 38% of normal seed producers and 62% of ware producers practiced only a one-season interval of crop rotation. About 26% of QDS producers practiced a three-season interval of crop rotation compared to 15% and 8% of normal seed and ware producers, respectively.

Generally, most farmers considered benefits of crop rotation in view of improving soil fertility to avoid yield reduction due to plant nutrient depletion from the soil. They did not fully recognize the role of crop rotation for controlling soil-borne diseases such as bacterial wilt. As a result, many farmers practiced a one-season interval of crop rotation, which is an ineffective practice for disease management. This is further evidenced by only 19% and 11% of the farmers who reported crop rotation as a management practice for bacterial wilt and late blight, respectively, as pointed out in Sections 4.4 and 4.5. Furthermore, the survey revealed that none of the normal seed and ware potato producers practiced crop rotation for more than a three-season interval while only 5% of the QDS farmers applied the practice for more than three seasons (Table 5).

4.8.2. Practice of seed potato renewal

Renewal of seed potato is not a common practice among the majority of all types of farmers in the study areas. Only 13% of the farmers, the majority of whom were quality declared seed producers or normal seed producers, renewed seed potato during the last five years. Other farmers had been planting potato for an unspecified number of generations without changing it. Particularly, ware potato producers seemed to be less experienced in seed potato renewal. They did not know the generation of their seed potato as they had been using the

Table 4
Kind of information that farmers received on bacterial wilt and late blight.

Kind of information	% within type of farmers			% within districts			% of total respondents (n = 179)
	QDS (n = 37)	Seed (n = 61)	Ware (n = 81)	Gumer (n = 50)	Doyogena (n = 43)	Wolmera (n = 86)	
Management methods	86	82	78	68	91	88	83
Spreading mechanisms	46	25	9	22	40	13	22
Mode of diagnosis	60	46	28	40	44	40	41
Causes	54	33	11	36	42	15	27

Table 5
Interval of crop rotation.

Number of seasons	% within type of farmers			% within districts			% of total respondents (n = 248)
	QDS (n = 39)	Seed (n = 85)	Ware (n = 124)	Gumer (n = 75)	Doyogena (n = 76)	Wolmera (n = 97)	
One season	28	38	62	57	32	55	48
Two seasons	41	47	30	31	53	30	38
Three seasons	26	15	8	12	13	15	13
More than three seasons	5	0	0	0	2	0	1

same seed for over many generations. They usually retained seed for the next planting season from their previous harvest or bought it from the local market. Many farmers had a general understanding that productivity declines if the same seed is used over and over without being renewed. However, they did not associate it with management of seed-borne diseases like bacterial wilt and late blight. It was not common to hear farmers associating the benefit of seed renewal with disease management. This is also evident from the low percentage of farmers (Tables 2 and 3) who mentioned seed related attributes ('planting clean seed' for bacterial wilt and 'resistant varieties' for late blight) as management options. On the other hand, those few farmers who knew the contribution of seed renewal to disease management, did not necessarily renew their seed due to very limited supply of basic seed and high price which hindered the farmers from practicing seed renewal.

Overall, only 13%, 9% and 15% of producers of QDS, normal seed, and ware, respectively, used new seed potatoes within the last five years. Producers of QDS and normal seed who reported to renew their seed had purchased basic seed from agricultural research centers. However, ware potato producers just bought seed potato of unknown origin from local market or neighbor farmers, which had been recycled for a number of generations. It is important to note that this practice of renewal of ware producers is not effective to prevent diseases from spreading, even though a considerable number of them claimed to renew their seed potatoes. Statistically, there was not a significant association between the practice of renewing seed potatoes and the farmers' category (Pearson Chi-Square = 1.328, $p = 0.515$), or their district (Pearson Chi-Square = 3.307, $p = 0.191$).

4.8.3. Practice of handling infected/damaged seed and ware potatoes at harvest

Nearly all farmers (97%) reported sorting as a practice to separate infected/damaged potato from healthy looking ones at harvest. Usually, the farmers tried to sort both infected/damaged seed potato tubers and ware potato from healthy looking ones through visual observation. When asked what they did with infected/damaged potato tubers, about 42% of the farmers reported that they would leave them on the field, of whom 8%, 39% and 54% were QDS producers, normal seed producers, and ware producers, respectively. On the other hand, nearly 30% of the farmers reported that they would collect and bury infected/damaged potato tubers sorted during harvesting, whereas about 19% of the farmers would throw infected/damaged potato tubers away at the farm side (Table 6). Only 3% of the farmers reported collecting and burning of the infected/damaged potato tubers. Thus, only few farmers properly disposed diseased/damaged seed potato and some farmers even thought that leaving infected/damaged potato tubers on the field would improve soil fertility with little regard for possible contamination of the soil by potato diseases like bacterial wilt. Their current practice of handling infected/damaged potato tubers contributed more to the spread of the diseases rather than controlling them. Most farmers did not know the importance of sorting infected/damaged potatoes at harvest from the perspective of controlling bacterial wilt and late blight. They did sorting mainly to separate and dump rotten or damaged potato tubers from healthy looking ones before home consumption, marketing or storing for seed. Furthermore, referring back to farmers' knowledge of effective management methods of the two diseases (Tables 2 and 3), sorting diseased seed potato was not among the few management options known to many farmers.

4.8.4. Practice of roguing and use of clean seed

The majority of the farmers (80%) mentioned that they applied the practice of roguing potato plants with symptoms of bacterial wilt infection as a management method. Among these farmers, 68%, 81% and 82% were producers of QDS, producers of normal seed and producers of ware, respectively. There was a significant association between the practice of roguing and study district (Pearson Chi-Square = 15.388, $p < 0.001$). A significantly larger proportion of farmers in Wolmera district (90%) reported practicing roguing of potato plant with symptoms of bacterial wilt as one of the methods to manage bacterial wilt, while 73% and 62% of the farmers in Doyogena and Gumer districts, respectively, pointed out the same method. These farmers usually removed infected potato plants with visible symptoms and threw them at the farm side or in ditches. But such practice has a striking implication for spreading of the disease instead of controlling it. Thus, farmers' current practice of roguing plants with symptoms of bacterial wilt is not effective mainly due to lack of knowledge among farmers on the spreading mechanisms of the disease. Furthermore, about 26% of the farmers reported to practice planting bacterial wilt free seed potato. Farmers that reported planting seed free from bacterial wilt infection, usually tried to visually confirm whether seed potato was infected or not, without understanding and considering the possibility of latent infection of seeds. Thus, they thought that clean seed potato can be distinguished from infected seeds through visual observation. Forty-two

Table 6
Farmers' practice of sorting out infected/damaged seed and ware potato at harvest.

What farmers do with infected/damaged seed and ware potatoes	% within type of farmers[a]			% within districts[a]			% of total respondents (n = 147)
	QDS (n = 22)	Seed (n = 52)	Ware (n = 73)	Gumer (n = 11)	Doyogena (n = 47)	Wolmera (n = 89)	
Leave on the field	8	39	54	33	24	63	42
Collect and burn	0	4	4	5	0	4	3
Collect and burry	43	39	20	23	42	26	30
Throw away at farm side	20	13	22	14	30	14	19
Use as livestock feed	50	21	15	38	21	11	22

[a] Multiple answers were possible as most farmers reported more than one practice.

percent of QDS producers and 39% of normal seed producers mentioned using seed free from bacterial wilt compared with only 15% of ware producers. Nonetheless, availability of bacterial wilt free seed is questionable given the current prevalence of the disease, latent infection of the pathogen that causes the disease, and lack of a standard seed certification scheme based on laboratory testing in the country. Also, some farmers reported that they applied chemicals expecting that these chemicals could suppress bacterial wilt. As there is no chemical that can help control bacterial wilt on the market, it seems that they applied chemicals like fungicides or pesticides, which further indicates the lack of know-how among these farmers.

4.8.5. Practice of fungicide application

More than 87% of the farmers reported practicing fungicide application to manage late blight. The majority of quality-declared seed producers (97%) reported to practice fungicide application to control late blight as was the case for normal seed producers (91%) and ware potato farmers (82%). Statistically, there was a significant relationship between fungicide application and the category of farmers (Pearson Chi-Square = 6.569, $p = 0.015$). But there was no significant relationship between farmers' practice of fungicide application and their district (Pearson Chi-Square = 3.028, $p = 0.220$), with 89%, 82%, and 90% of farmers in Gumer, Doyogena and Wolmera districts, respectively, practicing fungicide application to control late blight.

Most farmers reported applying fungicides they got from private vendors or cooperative unions without understanding the efficacies of the fungicides and without choosing which product to use. They also did not understand late blight pressure in the surrounding and they simply applied when they observed the symptoms of late blight infection. Further, the farmers did not understand the importance of collaboration with neighbor farmers to reduce the inoculum pressure in the area. The most commonly used fungicides in the study sites were Ridomil and Mancozeb, while many farmers were not able to differentiate between the two kinds of fungicides. Most of the farmers reported to apply three to five times per season, depending on the severity of the disease and availability of fungicides. In this regard, the dosage and frequency of applications were questionable given farmers' limited know-how of appropriate fungicides application practices.

Furthermore, during key informant interviews, all farmers mentioned that the farmers applied fungicides individually when the disease occurred without being aware of the importance of collective action to reduce the inoculum of the pathogen from their respective area. In many instances ware potatoes and seed potatoes were planted in neighboring fields, but the farmers practice different time and frequency of fungicide applications.

4.8.6. Practice of using late blight resistant potato varieties

Potato growers in all the three districts tended to grow improved potato varieties, with the majority of the farmers (65%) producing improved varieties only. Across all the three districts, few farmers (10%) grew local varieties only, and all of them were ware potato producers, whereas nearly 25% of the farmers produced both local and improved varieties. Relatively, more farmers in Wolmera district (83%) were growing improved varieties only, compared with 50% and 61% of the farmers in Gumer and Doyogena districts, respectively, (Table 7).

The majority of the farmers (100% of QDS producers, 97% of normal seed producers, and 87% of ware producers) reported Gudane as the dominant potato variety they were growing. Overall, three popular potato varieties, Gudane, Belete and Jalene were grown by 92%, 45%, and 33% of the farmers that reported growing improved varieties, respectively (Table 8). These improved varieties were released by Holeta Agricultural Research Center (HARC) primarily as late blight resistant. But the farmers reported that particularly Jalene variety became highly susceptible to late blight, which might be due to seed degeneration as the farmers have been continuously growing this variety since it was released in 2002 and its resistance could be broken by the pathogen. On the other hand, Belete variety was grown by 87%, 45% and 29% of producers of QDS, normal seed, and ware, respectively (Table 8). Even though Belete variety has been the most recent of the potato varieties released by the national research system, it has also become susceptible to late blight and farmers do not grow it without repeated application of fungicides. In relation to using late blight resistant potato varieties, farmers have better understanding of the importance of resistant varieties. However, since the existing potato varieties have become susceptible to late blight, farmers did not rely on this practice alone as an effective management method.

4.9. Use of mobile phone among farmers

Most of the farmers in the study sites (73%) owned a mobile phone, of whom only about 2% of the farmers had smart phones. The highest rates were reported from Wolmera district (82%), while in Doyogena and Gumer districts 72% and 62% of farmers owned mobile phones, respectively (Fig. 1). On the other hand, among the farmers who owned mobile phones 81% of the farmers were normal seed producers, followed by 73% and 68% of the farmers who were producers of QDS and ware, respectively (Fig. 2). Further about 45% of the farmers who had a mobile phone were between 18 and 35 years, while only 12% of the farmers who had mobile phones were above 56 years. This signifies that younger farmers were more likely to own mobile phones. Furthermore, 82% of the farmers who owned a mobile phone attended either primary or secondary schools while only 8% of the farmers who had mobile phones were illiterate.

During key informant interviews, the farmers indicated they used mobile phones to communicate various social issues with their family members, relatives, and other farmers in their community. In addition, the farmers used mobile phones to communicate with agricultural extension workers, district level agricultural experts, agricultural researchers and cooperative officers mainly to check availability of agricultural inputs, arrange meetings and/or field visits, access market information, and report agricultural problems, among others.

5. Discussion

This diagnostic study was designed to examine whether farmers' knowledge of the two major potato diseases, bacterial wilt and late blight, and their management methods hinders or contributes to effective disease management practices. The findings provide relevant

Table 7
Type of potato varieties grown by farmers in the study sites.

Type of potato varieties	% within types of farmers			% within districts			% of total respondents (n = 261)
	QDS (n = 40)	Seed (n = 85)	Ware (n = 136)	Gumer (n = 82)	Doyogena (n = 76)	Wolmera (n = 103)	
Local varieties only	0	0	19	4	18	7	10
Improved varieties only	90	73	54	50	61	83	65
Both improved and local varieties	10	27	27	46	21	10	25

Table 8
Improved potato varieties grown by farmers in the study sites.

Major improved potato varieties grown	% within type of farmers[a]			% within districts[a]			% of total respondents (n = 236)
	QDS (n = 40)	Seed (n = 85))	Ware (n = 111)	Gumer (n = 79)	Doyogena (n = 62)	Wolmera (n = 95)	
Gudane	100	97	87	87	97	93	92
Jalene	33	42	26	52	16	28	33
Belete	87	45	29	46	42	45	45
Guassa	0	6	15	17	0	10	9
Other improved varieties	5	2	6	6	0	6	5

[a] Multiple answers were possible as most farmers reported more than one potato variety.

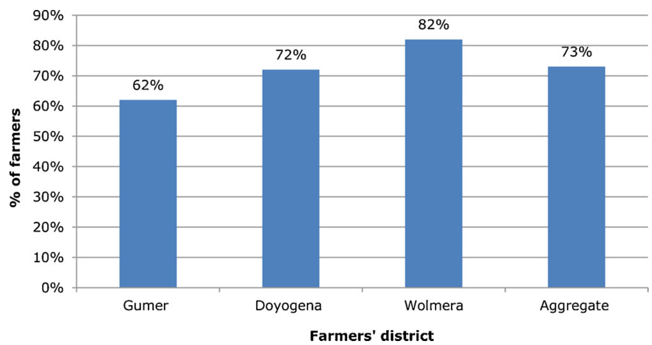

Fig. 1. Mobile phone use by farmers' district.

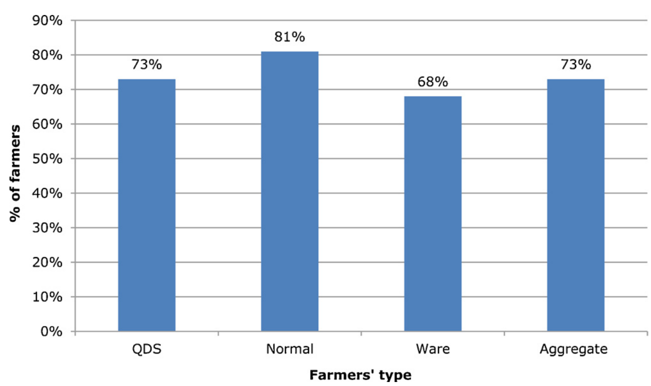

Fig. 2. Mobile phone use by farmers' type.

insights regarding the requirements for developing an intervention strategy for smallholder potato farmers in Ethiopia. In order to be effective, such strategy 1) has to be community-based because of the spreading mechanisms of the diseases, and 2) needs to combine cultural practices with phytosanitary measures, according to recent insights (Yuliar et al., 2015; Lemaga et al., 2005; Champoiseau et al., 2010).

5.1. Knowledge of farmers about bacterial wilt and late blight

The study findings show that all the groups of farmers evidently had limited know-why, know-what, know-who, and know-how of the two diseases, when mirrored to scientists' understanding of the diseases. None of the farmers recognized the cause of bacterial wilt to be a pathogen. Rather, the farmers erroneously reported the cause to be unrelated factors such as shortage of water, insects, earthworms, and waterlogging. Likewise, most farmers did not know the cause of late blight. They associated a causal agent of late blight to be abiotic factors like rainfall, humidity and cloud. This finding is consistent with that of Nyankanga et al. (2004) who reported that most of the potato farmers in Kenyan highlands associated late blight with weather conditions. Although not fully accurate, this is relevant knowledge, because such environmental conditions favor the development of the pathogen that causes the disease (Mizubuti et al., 2000; Mizubuti and Fry, 1998).

Unlike the causal agents of the diseases, most farmers could recognize the symptoms of both bacterial wilt and late blight on leaves and stem. But the majority of the farmers could not recognize the visible symptoms of the diseases on the seed tubers. While a considerable number of farmers (40%) correctly mentioned infected seed and soil to be mechanisms through which bacterial wilt spreads, they could not act upon this knowledge. Moreover, none of the farmers knew about the latent (symptomless) infection of bacterial wilt and hardly any of them was aware of the other spreading mechanisms of bacterial wilt like infected host plants, contaminated irrigation water and contaminated farm tools (Hayward, 1991; Janse, 1996; Genin, 2010). This limited know-why has an essential implication for the prevalence and management of bacterial wilt (Hayward, 1991; Genin, 2010). Without a good understanding of its various spreading mechanisms, it is difficult to effectively control the disease.

Regarding late blight, none of the farmers were aware of the spreading mechanisms of late blight. But, since the pathogen that causes late blight is mainly air-borne and largely disperses by wind (Lima et al., 2009), farmers should be aware that they can be affected by the practice of other farmers in neighboring fields. The finding signifies that farmers may think that their potato field is safe, despite the occurrence of the diseases in their neighbors' fields. Moreover, as a consequence they seem not to recognize the importance of concerted effort to deal with the diseases.

Producers of ware potato reported agricultural extension workers and fellow farmers to be the most important sources of information on bacterial wilt and late blight management. In contrast, agricultural research centers and NGOs were reported by both QDS and normal seed producers as major sources of information on the diseases. This finding aligns with the considerable support that agricultural research centers and NGOs provide to seed producers in the country. There are, however, no significant differences in knowledge about causes and spreading mechanisms between ware potato producers and (both kinds of) seed producers. The only significant difference between the groups concerns the know-what of crop rotation and fungicide application. There are also very few differences between the districts; in the district with an agricultural research center in the area, more farmers recognized the diseases.

The overall lack of knowledge regarding causes and spreading mechanisms of bacterial wilt may be explained by the fact that it has only recently become a severe problem (Gorfu and Woldegiorgis, 2013; Abdurahman et al., 2017) and development initiatives have not yet given due attention to the disease (Gorfu and Woldegiorgis, 2013). The lack of knowledge regarding late blight is rather surprising, because it has been the major potato disease in Ethiopian potato production systems for many years and the farmers have been receiving different forms of supports to deal with the disease. A possible explanation for this is that the efforts to increase farmers' knowledge did not include all relevant learning approaches that are related to the different forms of knowledge. Know-what and know-why are learned through reading and attending trainings while know-how and know-who can be learned mainly through experiential learning and in social interaction (Lundvall, 1992). This research as well as other reports indicate that many seed potato producers were trained in potato production and disease management practices in the country (CIP, 2016; CIP, 2013), which emphasizes particularly the know-what. Therefore, the current limitations regarding the other categories of knowledge underlines the need for supporting the farmers to learn through a combination of appropriate approaches.

The know-why could be increased via for instance a training about the causes and spreading mechanisms of the pathogens for both bacterial wilt as well as late blight. Diagnostic tools or kits combined with tailor-made advices may help to effectively diagnose and visualize the pathogens and stimulate the farmers to take action. In addition to these well-known classic methods, the sharing of information about the prevalence of the disease may contribute to the know-what of farmers. In addition, it is crucial to provide farmers the room to generate the know-who and know-how for the management of both diseases. As these local forms of knowledge can only be generated by farmers themselves in the local context through experiential learning, social interaction should be stimulated.

The focus on seed producers in previous knowledge dissemination efforts may appear to be reasonable given the limited supply of quality seed in the country (Gildemacher et al., 2009b; Hirpa et al., 2010; Schulz et al., 2013). But in view of an effective disease management effort, QDS and normal seed producers may not succeed in controlling the diseases if ware producers' practices continue to increase disease inoculum in their surroundings. Therefore, for effective management of both diseases, this finding indicates the importance of addressing all categories of farmers in a learning and collaborated approach including the producers of ware potatoes.

5.2. Farmers' practices related to their knowledge

The findings of the study indicate that all the three categories of farmers had better know-how of effective management methods for late blight such as use of fungicides and resistant potato varieties than for bacterial wilt.

For bacterial wilt, the dominant management practice reported by all categories of farmers was roguing of plants with symptoms of disease infection. But this practice alone is not effective in controlling the disease if it is not combined with other cultural practices like crop rotation, soil amendment, and phytosanitation. This study also found that the farmers were just uprooting and throwing the infected plants away at the farm side or in ditches which could have serious implication for spreading the disease instead of controlling it. This further confirms that the know-how of the farmers is limited. Unexpectedly, QDS producers also reported the same practice which makes the practicality of the zero-tolerance level of bacterial wilt that is currently stipulated in the QDS scheme questionable (ESA, 2015) and has striking implications for the quality of seeds produced by these group of farmers. Some farmers also mentioned the use of quality seed to control bacterial wilt. However, given the current prevalence and embedding of the disease in the country's seed system (Gorfu and Woldegiorgis, 2013; CIP, 2016; Abdurahman et al., 2017) and due to a lack of formal seed certification system in the country (Gildemacher et al., 2009b; Hirpa et al., 2010; Schulz et al., 2013), the seed potatoes that the farmers receive may be infected with bacterial wilt. In addition, farmers' practice of crop rotation was found to be ineffective from the perspective of bacterial wilt control. They mostly practice one-season interval of crop rotation while the requirement for QDS producers is at least three seasons of rotation with non-host plants (ESA, 2015) and five to seven years of crop rotation are recommended for effective elimination of the inoculum from infested soil. Also the farmers did not renew seed potatoes for many years and they continued to plant seed potatoes of unknown generations and none the farmers, not even most QDS producers, could tell the generation of seed potato they were planting. Particularly, for producers of ware potatoes who mainly use farm saved seeds as planting material, this practice coupled with short interval of crop rotation increases *Ralstonia solanacearum* build up in their potato fields.

Regarding late blight, most of the farmers (87%) practiced application of fungicides. However, the farmers did not recognize what type of fungicides (contact or systemic fungicides) to use and when to apply. Farmers did not apply fungicides before they observed the first symptoms of late blight on the potato plant, which is ineffective in controlling the disease as the pathogen spreads quickly. Despite the availability of various decision support systems (DSS) that can help farmers optimizing the use and timing of fungicide applications in developed countries (Wharton et al., 2008; Shtienberg, 2013), so far none of them has been introduced to Ethiopia. The farmers still spray fungicides in a conventional way and hence often with limited success in controlling the disease.

These findings show that the farmers' practices are somewhat informed by know-what of disease management: the majority of the farmers applied some crucial management strategies such as application of fungicides for late blight control, roguing of plants with symptoms of bacterial wilt infection, and planting late blight resistant potato varieties for disease management reasons. Their knowledge is however too limited to apply these measures in an effective way. This stresses the conclusion above, that additional know-how is necessary to perform these practices effectively for disease management purpose. Moreover, some other practices that are also relevant for management of the diseases (like crop rotation, and sorting of infected potatoes) were undertaken for other than disease management reasons. This indicates that additional know-why may increase the value of these practices for farmers and stimulate them to understand their multiple functionality. It, hence, seems useful to develop a learning approach in which the know-why is generated and embedded and integrated with the know-what.

5.3. Implications for a community-based intervention and monitoring approach

The finding of this study has important implications for the development of a community-based approach to effectively deal with bacterial wilt and late blight in Ethiopian potato production systems.

Addressing the above mentioned limitations of farmers' knowledge is imperative for effective disease management. That is, the farmers need to learn about different aspects of the diseases including, causes, diagnosis methods, spreading mechanisms, effective management methods and how to integrate these into their daily practice, and importance of concerted effort, among others. To learn to manage the diseases in an effective way the conventional methods of training and instructing farmers may not suffice. In order to stimulate the development of all relevant forms of knowledge, farmers themselves need to be stimulated to generate and revise local knowledge in an experiential and interactive learning approach.

Such learning to do things differently is a process (Beers et al., 2016) that needs to be integrated into the community-based strategy. A good start for stimulating farmers to be openly involved in such a learning process may be to raise their awareness of the interdependency among them in the local area. A relevant second step may be to define what concerted action may lead to quick improvement in this area and how monitoring would help them to recognize the effectivity of the farmers' actions. What combination of measures fits in the cultural and ecological context of a specific community can be investigated in this way by farmers and experts. This exploration may stimulate the farmers to undertake these concerted actions.

Further, for the community-based intervention to be enabled, enforced and evaluated, an institutional arrangement at community level may be important (Ostrom, 1990). That is, the farmers can mutually agree on operational standards of what should be done and should not be done, from the perspective of disease management specifically and potato production more generally.

For bacterial wilt, the following phytosanitary and cultural management practices could for instance be integrated and stipulated in the bylaws as operational standards:

- Practicing crop rotation with non-host plants and with appropriate rotation length;
- Roguing and burning potato plants with symptoms of bacterial wilt infection;
- Eradicating host weeds from potato fields and irrigation canals;
- Decontaminating farm tools before using for potato cultivation and harvesting;
- Making diversion ditches to prevent surface run-off from infected field into potato fields that are down slope.

Similarly, for late blight, the following management practices could be translated into operational standards to be confirmed by the farmers.

- Applying the right dose and type of fungicides at the appropriate time;
- Cutting foliage two to three weeks before harvesting;
- Destroying volunteer potato plants that can be sources of late blight inoculum.

If the farmers have come to an agreement, it is important to track to what extent farmers are changing their practices in line with the operational standards. An ICT-based platform may support monitoring of the community-based intervention and disease occurrence. A first function of an ICT-based platform hence would be to monitor and account for their practices towards one another. Additional purposes of a platform could be 1) early warning of prevalence and spreading of the disease; 2) provision of contextualised advices; 3) provision of generic information; 4) evaluation of practices; by investigating which practices seem most effective, practical and affordable and why, in order to be able to change direction if needed.

The platform could make use of mobile phones, since the study shows that the majority of the farmers in the study sites were using these devices to communicate on various social issues and access different kinds of information. This result is consistent with the findings of the Agricultural Transformation Agency (ATA) (ATA, 2013) that reported rapid expansion of mobile phone use in Ethiopia and seems to suggest that mobile phones can be tapped into for bacterial wilt and late blight diagnosis and management in the study sites. Several studies have also reported the potential role that mobile-based platforms can play for agricultural development in many developing countries (Aker, 2011; Asenso-Okyere and Mekonnen, 2012). Mobile-based technologies such as voice call, Short Message Service (SMS) and Interactive Voice Response (IVR) are commonly considered more appropriate and promoted for agricultural information sharing and enabling collective action in smallholder farmers context in many developing countries (Aker, 2011; Asenso-Okyere and Mekonnen, 2012). Similarly, some mobile-based initiatives have been implemented in Ethiopia by the ATA and the Ethiopian Commodity Exchange (ECX) to support agricultural extension service and provide market information, respectively (ATA, 2013; Meijerink et al., 2014).

On the basis of this study, we surmise that mobile phones can have an added value in the process of information sharing in a community-based approach and potato farmers may access information about effective disease management methods through SMS, voice call or IVR. Disease occurrence can also be possibly monitored and exchanged in these ways. Specifically for late blight, mobile phone can serve as a means for timely information sharing among farmers regarding the occurrence of the disease and for receiving timely information on when to apply fungicides based on proper prediction of disease occurrence. Practices could be reported and summaries of achievements can be shared via the phones. A platform needs to be developed in order to be able to collect and interpret data regarding both diseases, for the exchange of information among the farmers, for the development of advice, et cetera. But, it is important to consider farmers' need and context as such platforms can be constrained by many factors like network interruptions in rural areas and costs of communication.

In sum, it seems that a mobile-based platform can leverage a community-based intervention for effective bacterial wilt and late blight management in the study sites. Such monitoring would serve three goals:

1. Stimulate a learning process in which know-why, know-what, know-how and know-who become closely connected and adapted to the local context, by reflecting on what works and what does not work in the specific context and change the standards accordingly;
2. Stimulate collective action, by increasing trust among farmers and show that their efforts are worthwhile and sanction free-riders;
3. Connecting professional expertise of agricultural extensionists and researchers with farmers in need for advice in specific situations.

6. Conclusion

The study has provided new insight into farmers' knowledge of bacterial wilt and late blight in Ethiopian potato production systems. The study has indicated that farmers have limited know-what and know-why as well as know-who and know-how to effectively deal with the diseases in their specific local context. Regarding the first two types of knowledge, there were significant incongruences between scientific explanations and farmers' understanding of the diseases and practices to deal with them. Further, the study has shown that farmers' practices contribute to the spreading of the diseases rather than effectively manage them due to a lack of relevant and applicable knowledge among farmers. Previous extension efforts have not had the desirable effect although farmers had relatively better know-what and know-how of late blight than bacterial wilt.

Overall, given the current prevalence of the diseases and their diverse spreading mechanisms, there should be an emphasis for a community-based approach with due consideration of the social and biophysical dimensions of the diseases. The proposed community-based approach should comprise four basic elements 1) interactive learning, 2) combination of effective management practices (phytosanitation and cultural practices), 3) bylaws and 4) monitoring by leveraging mobile-based technologies on a digital platform. Farmers' knowledge of the diseases, which informs their management practices, needs to be enhanced in a learning approach that integrates generic and local knowledge. Moreover, the farmers need to act collectively and integrate several management practices in their efforts towards dealing with each disease. To enable a collective action among the farmers, community-based bylaws with mutually agreed upon operational standards can be a good institutional arrangement. Appropriate mobile-based technologies such as voice call or SMS can support the monitoring of the changes in farmers' practices and the prevalence of the disease.

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