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ABILITY OF FARMERS TO CORRECTLY ESTIMATE THE SEASONAL IMPACTS OF CLIMATIC FACTORS AND ENVIRONMENTAL-FRIENDLY FARM HABITAT MANAGEMENT PRACTICES ON THE VARIABILITY IN POTATO (*Solanum tuberosum* L.) YIELD, YIELD LOSS, DISEASE INCIDENCE AND PEST POPULATION DENSITY DYNAMIC IN KALEHE TERRITORY, SOUTH-KIVU PROVINCE, EASTERN DRCONGO

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ABSTRACT

Potato (Solanum tuberosum L.) is an important cash and food security crop in the eastern highlands of eastern DRCongo. However, climate change and variability poses a serious risk to sustainable production of the crop. Potato production and productivity are seriously affected by temperature and rainfall variability. Hence, it is important to identify the degree of climate change in specific locality either by determining the perceptions of farmers on the change or and model the ability of farmers to predict correctly the role played by climatic factors among drivers of pests, diseases and yield variability. The aim of this study was to elicit information on potato farmers' perceptions of climate change impacts on potato yield, disease and pest and adaptation measures adopted. It was expected that the ability of farmers to predict drivers of variability in yield and yield loss may be useful in planning for the implementation of sound specific adaptation strategies. Primary data was collected using a questionnaire that was addressed to 340 respondents (20 respondents per village) from 17 villages (localities) in major altitudinal potato growing zones in Kalehe territory, South-Kivu Province. Using a semi-structured questionnaire, farmers were interviewed to capture their opinion about climatic events, landscape and farm management practices. Additional data was collected from the nearest meteorological station about weather factor trends in last 20-50 years. Monthly average data was considered in the analysis as it affects the seasonality response of pests and diseases during the length of growing period. Generalized linear models (GLM) were employed to analyze the ability of farmers to identify key factors influencing the variability of yield, pest population density and disease incidence and their linkage with the choice of adaptation strategies for potato production. GLM was run with the level of knowledge of causes of variability in yield, yield loss, pest density and disease incidence of the crop under different crop management (adaptation) options, cropping seasons, landscape and weather factors. The GLM outputs revealed ability of farmers to identify key drivers for pests, diseases incidence and yield loss variabilities. Some weather factors (maximum temperature, rainfall) had significant effects while other had none. The survey result indicated that most respondents perceived the existence of change in climate variables theses days. They perceived a decrease in rainfall and an increasing trend in temperature. They also mentioned a decreasing trend in yield and an increasing trend in potato yield loss over the last 20-50 years. They attributed the current decrease trend of potato tuber yield and yield loss to variability in several local environmental factors including weather factors and susceptibility of varieties to biotic stresses. In connection with this, they indicated as the decrease (burden) in potato production was due also due to the rise in the incidence of diseases and in the population density of classic and emerging pests and to variability in environmental and climatic factors. The study concluded that most of the farmers have perceived reduced amounts and erratic rainfall as well as increasing temperatures against which they have been using various strategies to sustain potato production, although not enough. Thus, proper choice of adaptation options, enhancing the awareness of farmers and supporting them with the required credit and inputs supply mechanisms may help to adapt potato to the future change and reduce the negative impacts of climate change in the potato growing villages of south-Kivu Province of eastern DRCongo.

Keywords: Farmers' knowledge, Ability to identify, adaptation strategy, Climate Variability, impacts, yield loss, drivers, Potato, impacts, mountain zones, DRCongo.

1. INTRODUCTION

1.1. Impact of Climate Change on Potato

Climate change and extremes (Mwabumba et al.2022) have been adversely affecting food security particularly in rainfed agricultural production systems (Behailu et al.2021) .Globally, an estimated 800 million people are currently experiencing hunger. Food insecurity remains a major concern, especially in developing countries. In sub-Saharan Africa, smallholder farmers, who are both food producers and consumers, manage 80% of all farms but face many challenges including; shrinking farm sizes, limited financial resources and dynamic farming environments. Food insecurity persists among smallholders as various uncertainties together with climate change threats and impacts exacerbate existing vulnerabilities (Mburu 2016). The effects of climate change have highly challenged the productivity of the agricultural sector (Mutunga et al.2017, Bellon et al.2021).

In Africa, agriculture is the source of income for many families and represents over two thirds of livelihoods of the poor. About 65% of full-time employment is in the agricultural sector and over half of the total export earnings derive from agricultural goods. Large losses of agricultural production can be attributed to pests (Biber-Freudenberger et al.2016). In Africa alone 12.8 billion US$ were estimated to be lost to pathogens, insects and weeds between 1988 and 1990. Insects are the economically most relevant pest group and the cause for about 1/3 of the actual crop production equal to 4.4 billion US$ being lost (Biber-Freudenberger et al.2016). Many people in sub-Saharan Africa heavily rely on natural resources and have a relatively low tolerance towards climatic and economic stress because of high poverty levels and lack of alternative sources of income (Biber-Freudenberger et al.2016).

In Ethiopia, flood in 2006 damaged crops on 1907 hectares and declined productivity by 20%; whereas about 15,600 livestock died and 199,902 people need humanitarian support (Bezu 2020). The heavy floods resulted in a loss of 1.5 billion tone topsoil which estimated to US$ 106 million. By 2050 climate change may reduce the Ethiopian GDP by 8-10% and 2.4 million people become food unsecured(Bezu 2020).

Increasing climate variability increases the risks in production and prices of agricultural products. Inarguably, Africa's susceptibility to climate change is high because it hosts the majority of the world's poor who cannot afford the costs of coping mechanisms (Elum et al. 2018). Climate change and crop intensification are key challenges to the livelihoods and wellbeing of the majority of rural smallholder farmers in developing countries, particularly in human-dominated, climate-sensitive highland landscapes where issues of fluvial floods, soil erosion pose serious threats to the livelihoods of smallholder farmers (William 2018).

Global food security is one of the most pressing issues for humanity, and agricultural production that is critical for achieving this, is often under threats such as environmental degradation, climate change and diseases and pests of animals and plants (Sundström et al.2014). Climate change impacted negatively on crop production and the livelihoods of the local farmers (Kom et al.2022). Climate change is predicted to have major impacts on rain-fed agriculture and livelihoods of small-scale farmers in Mexico(Bellon et al.2021).Climate change studies for West Africa tend to predict a reduced potential for farming that will affect the food security situation of an already impoverished population. However, these studies largely ignore farmers ' adaptations and market adjustments that mitigate predicted negative effects(Sonneveld et al.2012).

Climate change is likely to have negative impacts on food security and livelihoods of farmers in Africa through change of the number of generations and distributions of pest species. Agricultural productivity strongly depends on continued innovations to control pests as they develop resistances to different control measures, such as synthetic pesticides, or disperse to new regions. While most studies estimate increasing numbers and distribution for many pest species, responses of individual species may vary depending on, among others, the bioclimatic conditions under different climate change scenarios(Biber-Freudenberger et al.2016). Climate change is affecting the biology, distribution and outbreak potential of pests in a vast range of crops and across all land uses and landscapes. Up to 40% of the world's food supply is already lost to pests; the reduction in pest impact is more important than ever to ensure global food security, reduced application of inputs and decreased greenhouse gas emissions (Heeb et al.2019). Rising temperatures facilitate the introduction and establishment of unwanted organisms, including arthropods, pathogens, and weeds (Gullino et al.2022) .

Climate change will directly affect crops, as well as the fecundity, dispersal and distribution of plant diseases and pests (van der Waals et al.2013). The effect of environmental conditions on disease intensity is clearly illustrated in the classical disease triangle of pathogen, plant host and environment, which is also a reminder that changes in disease incidence due to climate change will vary depending on the individual host responses and the pathogen or pest under consideration (van der Waals et al.2013). Biotic constraints cause major crop losses and, hence, food insecurity in sub-Saharan Africa. Pests and diseases reduce the profitability of root, tubers and banana crops, threaten food security, and constitute a disincentive for investment (Okonya et al. 2019) under current climate change scenarios.

The contribution of potatoes to the global food supply is increasing—consumption more than doubled in developing countries between 1960 and 2005. Understanding climate change impacts on global potato yields is therefore important for future food security. Analyses of climate change impacts on potato compared to other major crops are rare, especially at the global scale (Jennings et al.2020) .

The potato crop has faced challenges from changing seasonal rainfall patterns due to its sensitivity to soil-nutrient and water deficits (Raymundo et al.2014). The adverse effects of high-temperature stress on the potato plant include accelerated haulm growth; with assimilate partitioned more towards the haulm and less to the tubers, reduced photosynthesis, increased respiration, inhibition of tuber initiation and growth, the occurrence of tuber disorders, shortened or abolished tuber dormancy, reduction in tuber dry matter content, and increments in tuber glycoalkaloid level (Borah & Milthorpe 1962).

High temperatures can cause physiological disorders such as irregular shape, pre-mature sprouting, cracking and elevated concentrations of glycolalkaloids in tubers, leading to bitter tubers that can be toxic (Borah & Milthorpe 1962). Higher daily temperatures and changes in rainfall patterns can be expected to increase crop stress, and that may render some of the current production areas less suitable for potato production, resulting in lower tuber yields and quality (Dua et al. 2013). Furthermore, high temperature may favor the increase of population density of some pests. Lower temperature may also favor the increase in the incidence of severe diseases, likely leading to yield loss. Thus, like many other crops, potato stands to be affected by climate change, although not all factors result in negative effects or in yield decrease.

Temperature is expected to be the key driver of considerable declines in potato yields., therefore, improving the adaptation of potato to heat stress could alleviate yield loss in the same line that managing pests and diseases (Raymundo et al.2014). There is a significant interaction between average temperature and amplitude in their effects on the area under the disease progress curve of potato late blight disease under climate change scenarios (Narouei-Khandan et al.2020). Late blight (caused by *Phytophthora infestans*) is a devastating potato disease that has been found to occur earlier in the season over the last decades in Fennoscandia. Possible explanations for this change are climate alterations, changes in potato production or changes in pathogen biology, such as increased fitness or changes in gene flow within *P. infestans* populations. (Lehsten et al.2017).

The strongest negative impacts on potato production are expected in tropical regions with uncertain rainfall patterns (Franke et al.2013). The knowledge of farmers may be incorporated in any program aiming at ameliorating by the development of heat-tolerant cultivars or diseases (Sanabria & L'homme 2013) and or pest resistant varieties. Adaptation strategies are likely to help farmers to reduce or slow the yield decrease to an acceptable percentage level. Adaptation typically consists of a shift in the use of cultivars that have later foliage senescence in terms of thermal time and varieties that a are tolerant to local biotic and abiotic stress factors. Earlier planting and harvest dates, changing to better-adapted varieties, less dependence on soils with low water-holding capacities, crop diversification and expansion of the cultivation od pests and diseases tolerant genotypes are among strategies that should be advised to minimize the reduction of yield pest and variability at the farm level.

In eastern DRCongo, potato is an important food security and cash crop for producers. With future climate change and increased frequency of flood and soil erosion, potato production will face a serious risk, especially in mountain areas. In South-Kivu Province, eastern DRCongo), the majority of crop production is based on rain-fed agriculture, which makes the province vulnerable to weather vagaries. The heavy dependence of the province on rain-fed and subsistence agriculture increases its vulnerability to the adverse effects of these changes. Therefore, crop production is challenged by many factors, of which climate-related disasters like landslide, flood, soil erosion, nutrient depletion, pests and diseases, shift in rainfall pattern and decline in available soil water are the key ones.

Moderate climate warming has a positive effect on the growth of late maturing potato varieties through prolonging the growing season and resulting in higher yields (Gebremedhin & Alemie 2015) . Hence, selecting and identifying the best adaptation responses based on scientific knowledge merits is the foundation for promoting sustainable potato production (Hilmans 2003) in eastern DRCongo.

Greater efforts are required to improve understanding of the complex effects of climate change on multi-species and multi-trophic interactions in the agro-ecological systems inhabited by potato pests, and to use this new knowledge to develop robust and climate-smart management strategies. The importance of integrating local perspectives into international debates about climate change has received increasing attention. Local perspectives on the impacts of climate change often focus on issues of loss and harm and support the widely recognized need for global responses to climate change as suggested by scientists and international institutions (Jurt et al.2015).

Awareness on environmental variability and climate change is an important determinant to adjust farming practices to counteract against the negative effects. Identifying the ability to predict and perceptions of farmers on the impacts of climate variability with their way of understanding may help to provide formulation and use better adaptation mechanisms or strategies (Igoden et al.1990).

Moreover, it will be the best to optimize agricultural production systems in the face of climate change. Thus, understanding farmers' views could offer important insights into the nature of environmental processes that the analysis of scientific data alone cannot capture . Perceived personal experiences can affect climate change belief and the corresponding adaptation and mitigation measures to be taken. Special attention should be paid to assessing farmers' climate change and related anthropogenic factors perception as it requires continued data collection from different contexts and dissemination of new knowledge due to the complex and dynamic nature of climate change.

In mountain areas of Kivu, farmers often plant multipurpose and agroforestry trees as a major adaptation measure since they believe that historic deforestation environmental and degradation are the main cause of current climate change. The alteration of ecosystem services delivery in the landscape is believed to be another key cause of low productivity. There is also a disparity between scientific knowledge and indigenous knowledge. Some times, scientific knowledge is delivered to farmers in a format that is not easy to digest by farmers. To get prosperity and real development there is a need to combine local and scientific knowledge. Thus, scientist must first asses what farmers know with precision. Such existing gap in the understanding of farmers on the main causes of climate change and a potential misconception on the performance of their major adaptation strategy, need to evaluated by scientific community and development actors. The extent to which farmers are affected by climate change depends on their actual exposure, the sensitivity of their farming system, and their adaptive capacity. There is a need to review previous research conducted in eastern DRC concerning climate change impacts on agriculture. Accordingly, the impact of the change on potato crop type as for many other root crops is expected.

In Sub-Sahara Africa, attenuation-adaptation strategies vary timely, contextually and spatially (within communities and even within households), and adaptation measures that fit one specific location are not necessarily transferable to another location. The Kivu provinces are covered by different agroecological zones shaped by the altitude and the forest zone. Adaptation strategies may be specific to each agroecological zone. Hence, collecting climate-related data about a specific crop type could be helpful to have detailed information over the crop types and genotypes which are either impacted or adapted through the change in climate.

There is a growing interest in understanding the linkages between the use of weather and climate information services, the level of knowledge and adoption of climate-smart agricultural practices (Djido et al.2021).The most important factors consist of farmers ’ personal characteristics, farmers ’ livelihood strategies, agricultural extension information sources, and farmers’ climate change perceptions and awareness (Djido et al.2021). Knowledge of farmers’ perceptions of and adaptations to climate change is important to inform policies addressing the risk of climate change to farmers (Sujakhu et al 2015).

Adaptation to climate change refers to the adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities . The adaptation strategies in the agricultural sector include use of new crop varieties, crop diversification, adoption of mixed crop and livestock farming systems, changing planting dates and irrigation (Mutunga et al 2017).

Adaptation mechanisms appropriate and preferred for one crop type might not be necessarily favored for the other crop types and varieties. Also, the mechanisms may be modified depending on the landscape, slope, environment and implemented farming practices (Lemessa et al. 2019). This is because crops vary in agronomic, ecological and environmental requirements. Farmers' response to adapt to climate change could also be specific., and everything may depend on farmers’ ability to identify and predict farming, landscape, farming systems drivers of yield variability and yield loss. In this connection, the questions to be asked are whether farmers producing potatoes in eastern DRCongo are aware of climate change and its consequences on productivity of the crop; it is also important to understand how farmers are responding to climate change in terms of potato production and what adaptation strategies they are using. However, in Kalehe territory, no studies have been conducted on farmers’ perceptions of climate change and its influence on potato production and related tuber-root crops .

Observed climate data are mostly aligned with the farmers ’ perception with respect to temperature, rainfall, floods, droughts landslides (Hasan & Kumar 2019) in tropical regions.. How farmers perceive climate change has an influence on how they adapt to climate change (Hasan & Kumar 2019). Co-production of knowledge between the local and scientific communities provides potential opportunity to assess appropriate responses to climate change (Karim & Thiel 2017)

This research was, therefore, conducted with the aim of eliciting information on smallholder farmers’ perceptions of climate change and its impact on potato production as well as identifying the possible adaptation mechanism to cope with future climate change scenarios, and to determine factors influencing adaptation mechanisms of farmers to climate change. The study aimed also at documenting the popularity, production constraints, pests and diseases, farmers' perceptions on the severity of biotic constraints and the impact of related crop losses on household food security for potato.

1.2. Statement of the Research Problem and relevance for conducting the study

The impact of climate change on subsistence-based agricultural systems has become a challenging issue globally as well as locally (Luitel DR 2020, Munyuli et al.2013).Reliable information on distribution, production, and nutrient quality with respect to associated climate and elevation are crucial for the promotion of local crops that may help increase local food security, livelihoods, and economy(Luitel DR 2020). While the science of climate change is well investigated across most disciplines, people's perception of climate change effects has not been well addressed (Wabwire et al.2020).

In the Great Lakes Region of Central Africa, smallholder farming households are largely dependent on root, tuber and banana crops (Manners et al.2021) . However, the potential impacts of various climate change scenarios on these crops are not well reported. Yet, data-rich insights about the future impacts of climate change on these crops and the adaptive capacity of food systems in the Great Lakes Region is critical to inform research and development investments towards regional climate change adaptation (Manners et al.2021) .

Climate resilience for small holder farmers continues to depend largely on locally available seeds of traditional crop varieties. High rainfall events can have as significant an impact on crop production as increased temperatures and drought(Fenzi et al.2022). Understanding farmer management strategies of agrobiodiversity, especially during a challenging climatic period, is necessary to promote a more tailored response to climate change in traditional farming systems(Fenzi et al.2022).

At the centre of smallholders ' adaptation is a need to understand their perceptions on key climatic scenarios so as to glean helpful information for key decision-making processes. At the moment, downstream information regarding these circumstances remain scanty, with many smallholders being ' on their own ' , in spite of the imminent threats from shifting precipitation patterns, rising temperatures, and intensifying droughts. At the sub-national levels, potential impacts of these situations are likely to deepen due to extensive cases of land use transformations, habitat degradation, plummeting water resources capacity and common inter-ethnic conflicts, among other negative externalities (Simotwo et al.2018). How individual perceptions of climate anomalies translate into the collective, however, is not clear .This is an important gap in the literature as we can expect that an individual's perceptions of climate anomalies are likely to be affected by a range of factors, including shifting baseline syndrome, change blindness and memory illusions (vanGevelt et al.2020).

Farmers ' perception of climate variability can significantly influence their coping, mitigation, and adaptation potential. Farmers ' perceptions can significantly determine the adoption of climate-smart agriculture technologies, and environmental determinants can strongly influence climate variability coping strategies (Mairura et al.2021). Perceptions are essential in adapting to climate variability. Enhancing access to weather forecast information is also important to enhance farmer's perceptions and also effectively implement adaptation strategies such as changing planting dates in Coco farm in Ghana (Ehiakpor et al.2016).

A better understanding of climate extremes at short and long timescales is therefore crucial to minimize the potential impacts of these extremes (Gemeda et al.2022). Changing rainfall and temperature patterns due to climate change have different effects on crop yields, yield loss and om emergence of pests and diseases. The effects also depend on the season of the year in which the change in temperature or rainfall takes place and the extent of the change (mild or extreme). Climate variability and change phenomenon is occurring in eastern DRCongo and affecting several communities depending on potato growing although it is assumed to be in a different degree from place to place across various altitude levels, landscape topography, environment and agroecological zones found within the study province.

Considering the history of recurrent rainfall variability in eastern DRCongo, conducting long-term trend and variability studies with robust methods to obtain important information on what has been changing in the past few decades has a vital contribution. The analysis of rainfall for agricultural purposes should include information on the knowledge of farmers and changes in precipitation; the start, end, and length of the rainy season; and the distribution of rainfall amounts through the year, and the risk of dry spells.

Climate change affects both the quantity and quality of the production of crops and the effect of climate change might be pronounced on potato since it is highly susceptible to rapid climate changes and related risks (Saue & Kadaja 2011). Potato being an important cash and food security crop, mountain zones of eastern DRCongo, is suffering from reduced yields due to too much rainfall (which causes leaf disease), pests and disease, lower prices at the farm gate and poor quality for marketing channels, low soil fertility status (due to erosion and nutrient depletion) from the soil (no organic residues are returned back to the field). Also potato yield is expected to be affected by uncertainty of rainfall both in terms of amount and distribution which is further may aggravate climate change and variability.

The effects of climate change on plant pathogens and the diseases they cause have been reported in some pathosystems. Climatic changes have been predicted to affect pathogen development and survival rates with possible modification of host susceptibility, host-pathogen-vector interaction that could lead to changes in the impact of diseases on food crops(Mbong et al.2019). The identification of potential benefits in plant protection that may emerge from future climate change has not been explored as extensively as the potential threats (Juroszek & Von Tiedemann 2013).

The improvement and application of pest and disease models to analyse and predict yield losses including those due to climate change is still a challenge for the scientific community. Applied modelling of crop diseases and pests has mostly targeted the development of support capabilities to schedule scouting or pesticide applications (Donatelli et al.2017).

The major reasons for the low yield and yield loss of potato stem from flood, landslides pests and diseases, soil erosion, a shift in rainfall pattern and decline in available water and nutrients at the farm scale level. Therefore, in addition to diversifying and allocation of lands for potato production, it is better to consider the problems to be faced under climate change and identify adaptation measures both for the production and post harvest handling of the crop. This require collecting basic knowledge of farmers about pests and diseases management under climate change scenarios. Thus, the first critical step is to understand the extent of the potato production problems caused by climate change and variability in interactions with other drivers. Since farmers are the one to implement any useful measures that can be suggested by researchers and others stakeholders, it is important to understand and the ability of farmers to identify drivers of yield variability and loss. Any adaptation measures that build on knowledge, views , opinions of famers is likely to be adopted-implemented durably even after scientist have left.

Potato plays a key role in ensuring food security of a great community in eastern DRCongo. However, climate change could have a great impact on current and future potato production in the region. This may create the alteration and replacement of the production areas with the new crop types, along with, it might also be necessary to adopt attenuation and mitigating measures that could aid minimizing the influence over potato crop. The change may also affect the agricultural potential of regions by modifying soil nutrient water balances, with consequences for potato land suitability, ability, and workability though it will influence the way potato crop develops, grows and yields, it will also impact on the viability of rainfed potato production and demand at local and regional market levels. Therefore, changes in soil fertility level, landscape and in agro-climatic conditions will influence cultivar choice, agronomic husbandry practices, and the economics of production in eastern DRCongo .

Smallholder farmers are continuously in a state of challenges from climate change variability and impacts. The communities are some times severely challenged by the negative impacts of climate change and the ability to endure these changes may be constrained by technical, information, environment, institutional and financial capacity (Ndugu & Bhardwaj 2015) . Unless appropriate adaptation measures are taken, climate change may continue frustrating farmers' efforts to achieve sustainable agricultural production and food security for Congolese people. However, developing such strategies will require information from the farmers since the ability to adapt and cope with climate change depends on their knowledge, skills, experiences and other socio-economic factors (Ndamani & Watanabe 2015). . Two steps have to be recognized whenever there is a need to develop any adaptation strategies for farmers: initially, it require the perception that climate is changing, and later responding to any new changes.

Climate change and global warming will also influence arthropod diversity, geographical distribution, population dynamics, herbivore-plant interactions, activity and abundance of natural enemies, emergence of new biotypes of insect pests, and crop losses associated with insect pests(Sharm & Dhillon 2018). Changes in geographical distribution, diversity and abundance of insect pests will also be influenced by changes in the cropping patterns triggered by climate change. Major insect pests such as cereal stem borers (Chilo, Sesamia, and Scirpophaga), the pod borers (Helicoverpa, Maruca, and Spodoptera), aphids, and white flies may move to temperate regions, leading to greater damage in cereals, grain legumes, vegetables, and fruit crops. Global warming will also reduce the effectiveness of pest-resistant cultivars, transgenic plants, natural enemies, biopesticides, and synthetic chemicals for pest management (Sharm & Dhillon 2018). As a result, economic relationships between the costs and benefits of pest control will undergo a major change (Sharm & Dhillon 2018). Therefore, there is a need to generate information on the likely effects of climate change on insect pests to develop robust technologies that will be effective and economic in future under global warming and climate change (Sharm & Dhillon 2018).

Data on the human element of climate change impacts, especially regarding labor for agricultural production, remain scarce, and our understanding of implications of the impact of climate change on the ability to work in labor-driven economic systems remains scarce (Yengoh & Ardö 2020). Understanding these pathways of climate change impact on crop pests and diseases can support decisions about mitigation and adaptation measures and sustainable management of pests. It requires holistic solutions, including effective phytosanitary regulations, globally coordinated diagnostic and surveillance systems, pest risk modeling and analysis, and preparedness for pro-active management. Preventive mitigation and adaptation measures, including biosecurity, may be key to reduce projected increases in pest risk in agriculture, horticulture, and forestry (Gullino et al.2022) .

Field surveys are necessary to be conducted to identify appropriate and optimal agronomic/ management practices and considerations as recommendations for optimal crop production; practices like fertilizers, spacing, planting date, compliance with agricultural calendar, adoption of effective measures to reduce the burden of pests and diseases,… . The perception of local farmers on climate change is therefore an important aspect towards successful climate change adaptation strategies(Mutunga et al 2017).

People's perception and understanding of climate can be an important asset when it comes to adaptation to climate change impact; however, it takes consideration for the development of policy design and implementation on modern mitigation and adaptation strategies by the governments and other civil society organizations (Negi et al. 2017). The knowledge of local people and farming communities for rural landscape management and sustainable use of bioresources is gaining credence as a key strategy to cope up with climate change and variability (Negi et al. 2017).

Agricultural household survey together with field observation, focus group discussions and interviews can amplify understanding of the process of the farmers' climate change adaptation practices since they may contain socioeconomic and socio-cognitive aspects in the process of farmers' climate change adaptation.

Farmers must clearly perceive climate change to implement autonomous adaptations and support planned adaptation and mitigation initiatives(Datta & Behera 2022). It is also important to bridge the knowledge gap between farmers and stakeholders by disseminating accurate weather information in combination with agricultural advice and targeted initiatives, especially for the older and female farmers (Datta & Behera 2022). Climate-smart agriculture adaptation strategy is an important strategy for supporting farmers against climate change challenges. However, adoption among smallholder farmers particularly remains low in in Sub-Saharan Africa (Andati et al.2022). Interventions intended to improve yields and climate adaptation require an understanding of the main drivers of yields across farms (Asante et al.2021).

Adaptation measures once they are identified, may enable to evaluate and choose the best alternatives, and helps to perform latest way of production system to address climate-related risk shocks and ensures the survival of small scale farmers. Once the level of knowledge of farmers is understood including their ability to identify drivers and predict further changes and impact, further assists to either change or modify production systems in line with the effect of climate change, and assists to design policies to tackle the challenges that climate change is posing on smallholder farmers. Moreover, identifying the adaptation strategies for particular crop than for the entire agricultural sector helps to device an appropriate climate change policy.

In eastern DRCongo, studies on climate change impacts and risks, disasters and adaptation strategies on agriculture, are scares although in Nyamukubi village for example (Kalehe territory) people suffer times to times from the negative impacts on climate-related natural disasters(soil erosion, landslides, floods, river over flow,…). Up to date, adaptation strategies on staple and root crops (potato, cassava, sweetpotato) remain largely not well studied. Unless such huge knowledge and information gaps are covered, it may be technically complicated for farmers to adopt and implement any suggested strategy to cope up with climate variability.

Although potato is widely produced in Eastern DR Congo, the potential impact of climate change on the productivity of the crop has not yet been investigated. The resilience of farmers living in mountain zones require taking into account their knowledge and comply with their ability to predict drivers having negative impacts on their crops. Furthermore, the perception of farmers on climate change effects on potato, the consequences of other biotic and abiotic stress factors on varieties(landraces, improved, released, clones), and also the adaptation measures that the growers are using to cope with the changing climate have not well studied in the area. Identifying and knowing how various drivers may affect the future of potato in the area through capturing farmers' knowledge may have its benefit in identifying suitable adaptation strategies for the crop in eastern DRCongo. Hence, this study seeks to assess ability to predict correctly and the awareness of potato farmers on climate change and variability, understand the extent and severity of the vulnerability of the potato sector to climate change and identify the farmers' response and adaptation strategies to the problem.

1.3. The Objective of the Study

1.3.1. General objective

To contribute to the advancement of generation of knowledge likely to be used in developing effective and strong and smart adaptation strategies for potato farmers

1.3.2. Specific objectives

(i)To evaluate farmers' ability to predict with precision drivers of potato yield variability and yield loss

(ii) To capture the current perceptions of farmers about climate change and determine driving factors influencing the variability in the pests and disease incidence

(iii) To elucidate farmers' perceptions of climate change and estimate, analyze and evaluate the impact of climate change on potato production and explore potential adaptation measures and coping mechanisms of farmers to climate change in the major potato growing areas of eastern DRCongo

1.4. Hypotheses

(i) Farmers are not able to predict correctly key drivers of variability in yield and yield loss in eastern DRCongo

(ii) Farmers have limited information of the interactive association effect of climate variability, landscape and anthropogenic management factors on the dynamic of the population density of pests and incidence in potato cultivation in eastern DRCongo

(iii) Farmers cannot link correctly the variability in pest incidence to yield loss, thus, adopt and implement poor adaptation strategies in the major potato growing areas of eastern DRCongo

2. MATERIEL AND METHODS

2.1. Description of the study territory and targeted sites (villages)

The study survey was conducted in major potato growing villages of Kalehe territory, eastern DRCongo. Some potato growing villages (Nyamutwe, Lemera, Bogamanda, Bushaku, Tchofi, Luzira, Cibandja, Muhongoza, Bushushu, Nyamukubi, Mukwidja, Nyabibwe, Makengere, Kiniezire, Nyamasasa, Kanungu and Minova) are shown in Figure-1c . The different study sites (villages) are located in environments of various/different altitude, landscape slope, agro-ecologies, land use intensity, and local microclimates along the main road Bukavu-Goma. Kalehe territory is mainly a highland and the altitude vary between 1000m and 2800m above the see level. The mean annual rainfall received ranges from 800m to 2500m and is bimodal. The short season rain (Season B) usually starts in February and ends in May, and the long season (Season-A) rainfall occurs between September and January., the dry season (season C) occurs between June and August(Munyuli et al.2017a). The relative humidity varies between 60 and 90%. The minimum and maximum annual temperatures range from 9˚C to 17˚C and 19˚C to 29˚C, respectively (see figure-2). The landscape topography of Kalehe territory constitutes a very complex terrain that includes gently sloping dissected plains and plateaus to moderately steep and undulating medium to high gradient hills(mountains).

2.3. Data Types, Sources and Collection Methods

2.2.1. Secondary and historical data collection.

Additional information on historical and current data of weather factors (average monthly minimum temperature, maximum temperature, rainfall , wind speed, relative humidity…) was collected from the nearest meteorological station (data was collected from Lwiro Research center meteorological service. The research center is located at about 20-90Km of the Kalehe territory. Ecologically, data collected from about 50 Km radius, can be considered as standard for the study area (Munyuli et al.2017b).

Fig-1a: The Map of DRCongo with its 26 Provinces including south-Kivu (Sud-Kivu in French) Province

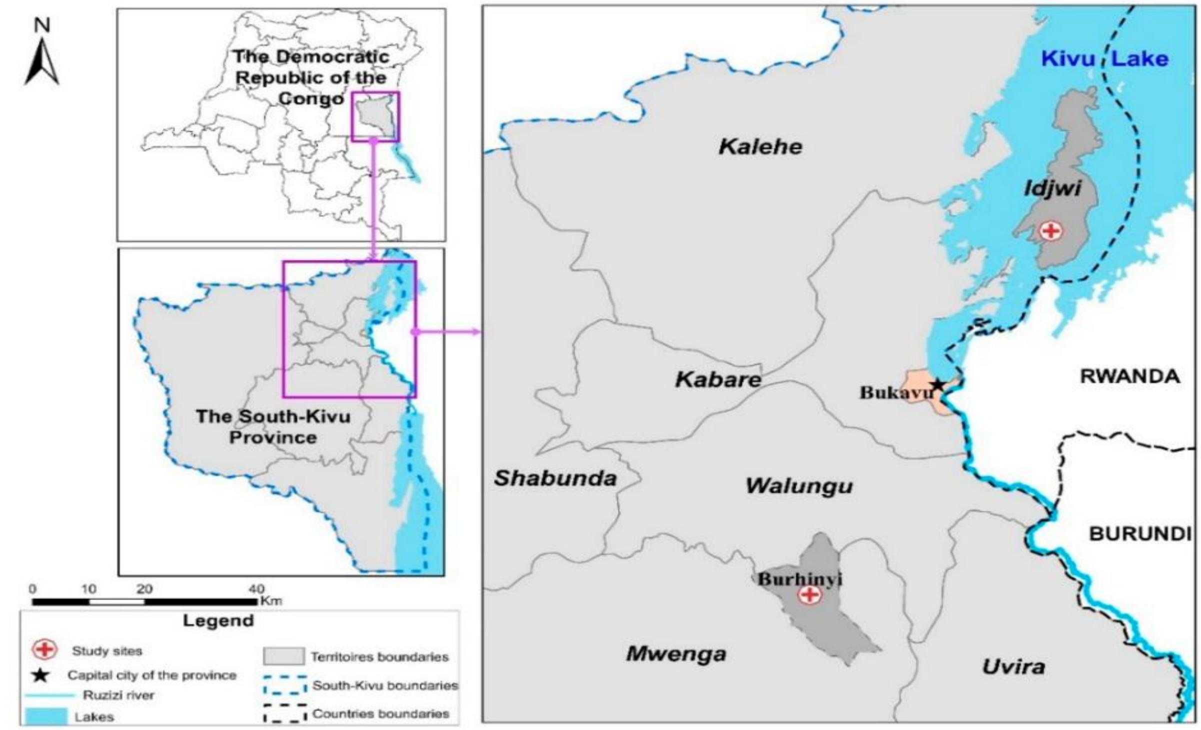

Fig-1b: The Map of the South-Kivu Province showing its territories including Kalehe territory

Fig-1c: The Map of Kalehe territory showing names of some of the surveyed villages(sites) where potato is grown (Nyamutwe, Lemera, Bogamanda, Bushaku, Tchofi, Luzira, Cibandja, Muhongoza, Bushushu, Nyamukubi, Mukwidja, Nyabibwe, Lushere, Makengere, Kinyezire, Shanje,Nyamasasa, Kanungu, Minova, Bulenga) following the R4 national road Bukavu-Goma on the shore of Lake Kivu, eastern DRCongo

2.2.2. Primary data collection

-Elaboration of the questionnaire and training of research-field assistants involved in data collection

A questionnaire was elaborated based on the aims of the study. The questionnaire was pre-tested before conducting the field survey for appropriateness (clarity, adequacy and sequence of questions), and revised according to the feedbacks from pre-test. The pre-test was done on farmers drawn from the adjacent territory (Kabare territory) for farmers who were not supposed to be part of the study as recommended (Munyuli et al.2017).

Trained enumerators with experience in data collection were engaged to collect the data under the supervision of the major researcher. The enumerators were given training by the researcher on data collection, and interviewing techniques and how to approach respondents. At the end of each day, questionnaires were cross-checked and discussed on different difficulties and challenges met the enumerators.

2.3. Sampling techniques

The selected villages for this study (Figure-1b) are among the classical major areas of potato cultivation production in Kalehe territory. Potato is produced in these villages both as cash and food crop. Therefore, the survey interviews were conducted in these selected villages. Households interviewed were selected randomly wherever a list of potato growers was available from the chief of village. The total number of households interviewed was determined using a probability proportional to the sizes of the population of potato growers of each village from which sample households were selected. In only one village, respondents were selected purposively as no potato grower list was available. The producers were scattered and they were interviewed along main routes a cut cross the villages while the researcher was walking. The researcher was walking along the main village route and interviewing farmers if only found in a garden with potato. Additional information was collected during meeting with leaders, chiefs, key informants, coordinator of famers cooperatives and associations and with various stakeholders involved in the potato value chain met at different local markets.

Sampling techniques are methods of selecting samples from the population. Sampling allows an in-depth study of objects in the population from a sample area(Munyuli et al.2022a). Under this, the researcher used both simple random sampling and purposive sampling technique to get more detailed information about the study. The researcher employed a simple random sampling technique (a probability sampling method where all elements had an equal chance of being selected) in the study area. The simple random sampling method selected a sample without bias from target and accessible population of potato growers from a given village. It was important for such method to be employed to ensure that all respondents had a given equal chance of being selected. It also helped in minimized bias and simplified analysis of results from different responses that were provided by respondents .

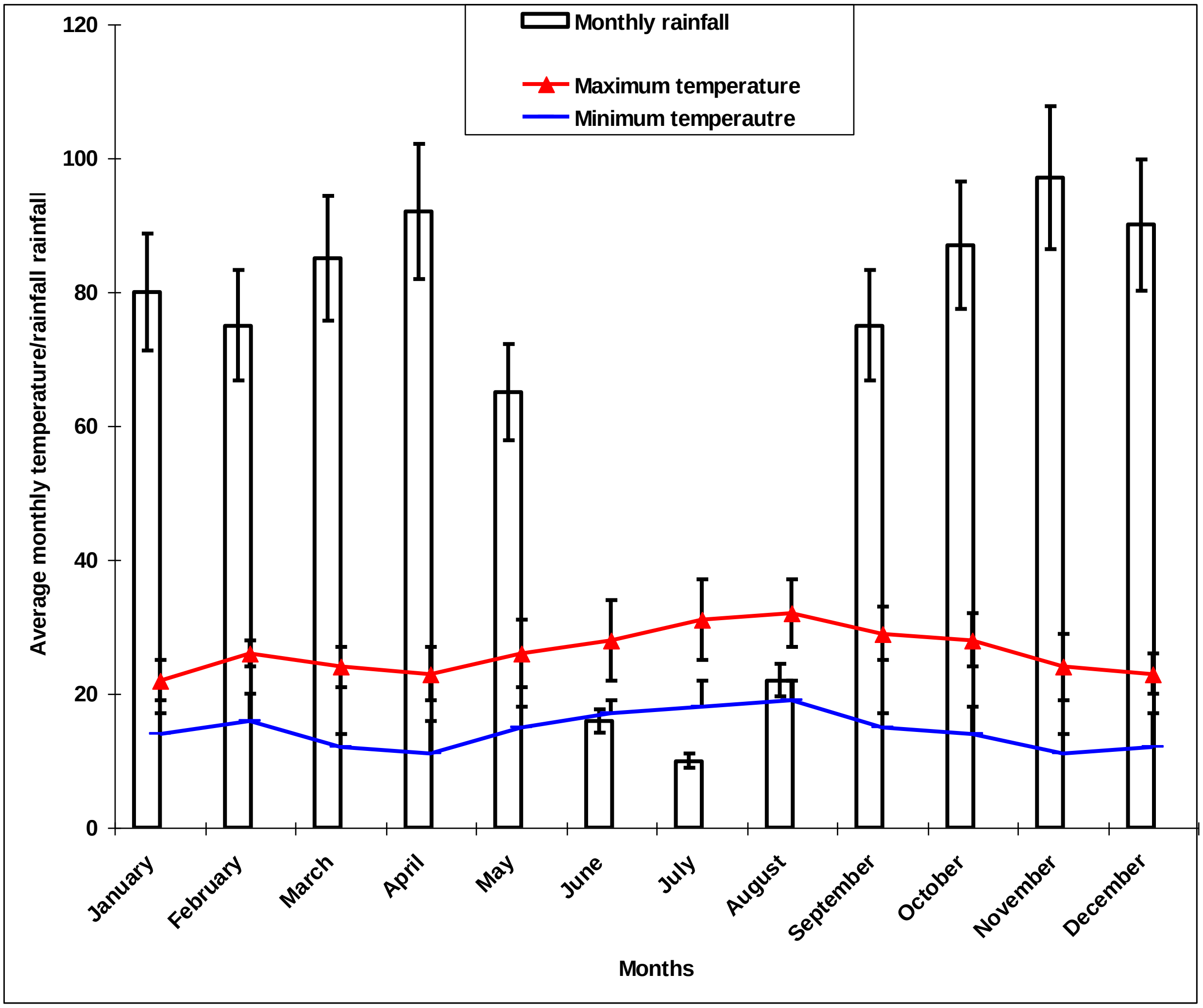

Figure-2: Trends in annual rainfall and temperatures in Kalehe territory 1975-2022 (bars above each column are representing standard errors), Data from Lwiro research center meteorological service

Sample size

-For the farmers' perception data, a multi-stage random sampling design was employed for the selection of the sample respondents across various socio-economic economic characteristics (age, sex, farming experience, marital status, education level,..).

Larger sample size enable to get findings that are more accurate. Some times if all elements in a population are identical then the selection of an even smaller one can provide an absolutely accurate information, and reasonably good estimate during research process, if population of study area is homogenous. With farmers, they vary in age, experience and marital status or wealthy status', thus a large sample is better than a small sample. The full population of potato growers was not even known by village chiefs. There was a enormous large population of farmers in the villages. There were inconsistencies in the number of potato growers between the list of potato cooperative leaders and the list of village chiefs , it was not possible to apply any sampling formulas. Based on statistical guidance's, purposive sampling was further used to select randomly 30-50% of available potato growers at the day of research activity in that village. Each research day key informants were almost fewer in the village. Interviews or discussions were conducted with those who were available.

2.4. Conduct of the interviews and training of enumerators

In this study, both primary and secondary data were collected based collected by the use of semi-structured questionnaire with open, closed and binary questions. Questionnaires were provided to support the questionnaire method of data collection. Structured questionnaire involved close ended questions in some villages. Data were collected through individual interviews, focus group discussion with members of potato production association in each village. Additionally key informants' interviews were with traders, cooperative leaders and chiefs of villages.

In some cases, researchers were helped by research assistants experienced. These qualified enumerators had adequate crop production knowledge as well as they were very knowledgeable of the local language during administration of the questionnaire. Enumerators were previously well-trained and briefed on the overall objective of the survey.

Assessment and evaluation conducted through use of questionnaires, face-to-face interviews, site visits and observation

2.4.1. Individual interviews and on-farm field observations

The sample questions were administered to about30-50% respondents who were selected randomly from the list of available respondents(potato growers) as it was provided by village chief and leaders of farmers 'association in selected among the major villages cultivating potato in Kalehe territory. Interviews were conducted for about 30 minutes with each respondent in local languages. Individual interviews were conducted preferable in the farm of potato to enable asking for additional questions and making direct field agroecological observations on the health of potato, the variety grown, and collecting data on pests and diseases while assessing their impact on yield and yield loss. To help farmers clearly identifying the pests and diseases symptoms, a guide with photos of symptoms of disease attacks or images of pests (life stage involved) was carried out in the field and shown to farmers so that they could remember and show the place of damages and infestations within the potato field.

The researcher constructed an interview guide in advance with questions that were clearly understood by the respondents in order to respond clearly with great ease and passion on climate variability and change, impacts of climate change and adoption of farming practices among farmers to adapt and mitigate climate change.

Primary data were collected through field individual interviews with household member who was responsible for the production and management of potato. Each potato producer was interviewed for about 30 minutes. The semi-structured questionnaire was mainly composed of binary, closed and open-ended questions. The data were collected to generate the necessary information on: occurrence and incidence of diseases, population density dynamics, disease outbreak periods, prevalence of seasonal variability in the incidence of pests and diseases of potato crop, on the causes of variability in the incidence of pests and diseases and yield, on the occurrence of seasonal variability in the yield loss, on the response of different varieties to diseases and pest pressures, of the other drivers likely influencing the yield variability such as climatic factors, landscape, habitat management and farming practices,.. on the potential sources of climatic vulnerability and the perception of farmers on environmental and climate changes in the area over the las 20-50 years, on the currently implemented and adopted adaptation strategies. The data collection was focused on the main actors namely producers/growers. Farmers were asked to provide their opinion about the key drivers of pests, diseases and yield variability. The ability of farmers to identify factors likely causing the decline in yield was appreciated during discussion with each of them. For pests and diseases, guides with photos of the pest or symptoms of the diseases were made available to farmers to help them naming quickly the pest. Only diseases(bacterial wilt and late blight) and pests(whiteflies and aphids) that could be easily cited by most respondents were retained during empirical modeling in Stata.

2.4.2. Focus group discussions

Focus group discussion were employed mainly to collect in-depth qualitative information about groups‟ perceptions on climate variability and change, attitudes and experience. This was achieved by the use of open-ended questions. Focused group discussions compared with household questionnaire interviews, allowed sensitive issues to be more freely discussed in groups when individuals are reluctant to discuss them alone with a stranger. Focus group discussions , were held, at each village level, which comprised at least 6-8 people including men, women and youth who were members of the village potato association. The focus group discussions were carried out at the house of the association found within the village. The focus group discussions were conducted to complement and compare with the information gathered from the questionnaires used during individual interviews.

Accordingly, one focus group discussion which contained 6-8 farmers each, in each village (at the place of meeting) was conducted after finishing with individual interviews. The focus group discussion aimed at finding out additional problems/constraints/challenges faced by farmers . This was important to get at the local level to get insights into the real situation on the ground and also to explore and understand farmers' knowledge, ability to predict, perceptions, awareness and perceived environmental/climate change impacts on agriculture practices and adaptation strategies.

2.4.3. Key Informants Interviews

A key informant is an expert source of information which were used for interviewing knowledgeable people within the society who are likely to provide the required information, ideas and insights on a particular subject, in environmental degradation and climate change and variability contexts. Key informants were environment and natural resource officers, available extension officers, local leaders and chiefs of villages, small scale village traders of potato, leaders of cooperative and non-government associations and farmers' associations having officers in the villages. All these kind of key informants were interviewed to provide more in-depth information on the issues of climate change and its impact on pest and disease incidence variability as well as yield loss variability. The researcher did this in order to acquire specific data and information from respondents believed to be more knowledgeable and skilled with the content of the study territory.

2.5. Definition of variables

Across cropping seasons, data collected for the current study included both dependent and independent variables(See Table-1)

Table-1: Variable definitions and measurements
Definitions, Expected Signs (predicted relationship), and Description Variables

	(1): Dependent variables	**Type**
Yield (t/ha)	Perception of yield (tones/ha) variability each cropping season (0=No, 1=Yes)	Binary
Yield loss (%)	Perception that yield loss (%) is mainly due to diseases and pests (0=No, 1=Yes)	Binary
	Pest population density dynamics/outbreaks, abundance, occurrence (numbers counted), pest infestation and damages estimation	
Whiteflies	Perception that potato whiteflies (*Bemisia tabaci* L.) population density is varying theses days each cropping season (0=No, 1=Yes)	Binary
Aphids	Potato aphids (*Myzus persicae* Sulzer) population density varying each cropping season (0=No, 1=Yes)	Binary
	Disease prevalence (%), incidence (%) and severity (scale:1-5)	
Bacterial wilt	Potato bacterial wilt, *Ralstonia solanacearum* (Smith 1896) incidence and severity varying each cropping season (0=No, 1=Yes)	Binary
Late blight	Late blight (*Phytophthora infestans* (Mont.) de Bary) incidence & prevalence is variable each cropping season (0=No, 1=Yes)	Binary
	(2): explanatory/Independent variables Variables hypothesized to affect knowledge of farmers	**Hypothesis: Mostly expected negative/positive effect-impact(influence) signs**
	Individual characteristics	
Age	Age (years)	Continuous (+/-)
Sex	Sex: (0 = female, 1= Male)	Binary (+/-)
Education	Education level (years schooling)	Continuous
Experience	Experience in agriculture (years farming)	
Previous training on IPM & climate	Had ever received training on pest and diseases identification/management (0=No, 1=Yes)	Binary(+)

impact information services		
	Weather factors and some of its variability	
Monthly rainfall	Total rainfall ,monthly means, (mm/day)	Continuous (+/-)
Rainy days	Length of rainy days (Number of rainy days/ month)	Continuous (+/-)
Rainfall regularity	Rainfall regularity (0=No, 1=Yes)	Binary (+)
Rainfall onset	Rainfall onset (0=earlier, =late, 2=aborted/interrupted)	Binary (+/-)
Relative humidity	Atmospheric relative humidity, monthly means (%)	Continuous (+/-)
Max temperature	Maximum temperature, monthly means (˚C)	Continuous (+/-)
Min temperature	Minimum temperature, monthly means (˚C)	Continuous (+/-)
Temperature rise	Continuous rise(increased) in the earth surface temperature (0=No, 1=Yes)	Binary (+/-)
Sunshine	Sunshine (hours/day)	Continous (+/-)
Windspeed	Windspeed (m/s)	Continuous (+/-)
	Biophysical/ecological/Environmental factors for the location of the field studied	
Altitude	Altitude or elevation (masl) [(0=Low:700-900m, 1=Mid:1000-1400m, 2=High: 1500-2500m)	Multivariate (+/-)
Land topography	Overall landscape topography (0=Lowland, 1=highland)	Binary (-)
Land slope	Landscape slope aspect (0= marshland, 1= flat, 2= gentle, 3=sloppy hillside, 4= fields with steep slope, 5=fields with mixed slope gradients)	Multivariate (-)
Level soil fertility	Level of fertility of soil of the farm landscape (0=Low, 1=Medium, 2=High)	Multivariate (+/-)
Land-use intensity	Historical land-use intensity (0=Low, 1=Medium, 2=High)	Multivariate (-)
Land vulnerability/extreme events	Landscape disaster vulnerability driving forces (0=flash flood & river and stream overflowing their banks, 1=water/soil erosions, 2=landslides, 3=mining, 4= destruction/oldness of basic infrastructures, 5=ongoing insecurity/civil unrest	Multivariate (-)
	Cropping seasons	
Cropping season	Cropping season (0=Long rains A: September-January, 1=Short rains B: February-May., 2=dry season C: July-August)	Multivariate (+/-)
Cropping calendar	Farmers' compliance with cropping calendar by the farmer (0=No, 1=Yes)	Binary (-)
	Period of planting dates (0=earlier, 1=normal, 2=late)	Multivariate (+/-)
	Farm characteristics & field agronomic practices	
Farm size	Farm size: [0=small (0-25-05ha), 1=medium (0.50-1.05ha),2=large (1.05h-2ha)]	Multivariate (+/-)
Natural fertilizer	Use natural fertilizers such as compost, manure, mulch	Binary (+/-)

	or mixtures (0=No, 1=Yes)	
Phytosanitary	Quality of chemical & phytosanitary measures applied by farmers (0=Poor, 1=Medium, 2=Good)	Multivariate(+/-)
IPM applications	Integrated pest management practices (0=pest trap crops planted, 1=use of natural pesticides/botanicals, 2=intercropping, 3=mixture of varieties)	Multivariate (+)
Variety grown	Type of varieties grown (0=landraces, 1=improved, 2=imported, 3= diverse varieties grown sole or in mixture	Multivariate (+)
Farming practices	The type of other farming practices implemented by the farmers (1=weeding/earthing,2=natural fertilizers, 3=crop rotation, natural management of pesticides with botanicals,…)	Multivariate (+)
	Habitat management, companion cropping, compliance with environmentally-friendly farming practices to encourage natural enemies and multiple ecosystem services delivery in the field	
Area non crop	Area of non-crop in the landscape (%)	Continuous (+)
Non-crop management	Non-crop landscape management applied (0=fallow, 1=hedgerows, 2=terracing, 3=contour buffer/filter strips, 4=field margin borders of grass/trees)	Multivariate (+)
Trap cropping	Cultural trap cropping (0=push-pull, 1=multiple and diverse attractant legume plants, 2=crop rotation)	Multivariate (+)
Soil erosion	Conservation practices against nutrient-soil-water erosion applied (0=No, 1=Yes)	Binary (+)
Neighbor crops	Type of neighborhood crops (0=legume based, 1=cereal based, 2=tuber/root crops, 3=vegetables,)	Multivariate (+)
Agroforestry type	Agroforestry system applied (0=none, 1=simple/multi-strata coffee-banana system, 2=homegarden, 3=Improved tree fallows, 4=mutipurpose (fodder,shrubs) trees, 5=woodlots, 6=Alley cropping, 7=windbreaks scattered trees, 8=Fruit orchard, 9= Homegardens systems	Multivariate (+/-)
Agroforestery tree density in the farm landscape	0= 0-1 trees/100m^2, 1=2-10/100m^2, 2= 11-20 trees/100m^2, 3>21-25 trees/100m^2	Multivariate (+/-)

2.5.1. Dependent variables

Data related to perceptions (level of knowledge) of farmers about sources or causes of variability of yield, yield loss, pest population dynamics, disease incidence were considered as dependent variables in this study.

2.5.2. Independent variables

Empirically, the dependent variables were assumed to be influenced by simultaneously or not by some or all independent variables (interactively or individually) retained in the current study. Data related to landscape, environmental, climatic factor (temperature, rainfall, wind speed,…), cropping system, farm management, socio demographic characteristics, institutional issues, climate change variability were gathered and recorded as independent variables. Moreover, data were gathered on factors that may have influenced farmers' preference for a particular adaptation mechanism and way of its implementation.

Independent variables are likely influencing the adaptation mechanism implemented by a farmer. Previous trainings by the farmer was included as a variable because they are likely to be one of the important sources of information directly relevant to agricultural production. The choice of the households for adaptation mechanisms/strategies may be directly or indirectly interrelated with environmental-landscape and climatic factors. Also, factors/variables such as sex, age, household size, level of education, marital status, year in farming, types of crop variety grown, size of the farm, production system, and types of institution, may have a significant impact in the decision of a farmer to implement a given adaptation strategy.

Independent variables may influence the capability of a farmer to predict the impacts of relative risks to climate and other farming risks such as pest, diseases, market price fluctuations, vulnerability of farming activities to climatic factors, and management strategies to adapt to climate and weather-related risks (e.g. using different varieties and crop type, changing planting dates, use of the early maturing variety, diversifying from farm to non-farm activities, increasing the use of natural pest management strategies, moving to different sites, water harvesting techniques, soil conservation practices).

2.5.3. Hypothesized/expected influences of individual socio-economic independent variables on the perception of farmers and choice of adaptations strategies

-Sex of the respondent: This variable is a dummy variable, which takes 1 if sex of respondent is male, 0 otherwise. Gender of the household heads plays a significant role in adoption of technologies or practice to climate change or recall of traditional indigenous. Both men and women tend to contribute and have different levels of knowledge and adoption decision makings in different spheres of agricultural life and access to assets and resources. Therefore, male and experienced respondents are often more likely to be knowledgeable of weather events and to adopt new adaptation technologies (strategies) to overcome negative impacts of climate change as they are likely to have better access to extension services/development actors, traditional knowledge and are always willing to take risks than female and young respondents. Thus, the sex may have positive or negative influence on the adoption of different climate smart agricultural practices.

-Age of respondent: It is a continuous variable measured in years since the time of birth. Older farmers who have long time experience on farming are likely to adopt new technologies than younger farmers since they can take risks, are more flexible and can assess modern technologies . Old farmers are more knowledgeable of weather vagaries than young farmers. The age of may be hypothesized to have positive or negatively influence the ability to predict key drivers of variability of biotic and abiotic stresses of potato yield.

Educational level of respondent: Education as a continuous variable measured in years of formal schooling of the household head. Education can equip and enhance individual's access to and use information on climate change and the technology strategies options they can use in response . The educated farmers have the ability to receive, decode and understand climate change information relevant to making innovative decisions regarding climate change adaptation. Therefore, education level was hypothesized to have negative/ positive influence on the adoption of best adaptation practices/measures.

Household size of the respondent: It is a continuous variable. It refers the total number of members of a household converted to adult equivalent. The larger adult equivalent may have, the more the labor force available for production purpose . Therefore, there is the possibility of having more alternative sources of income to overcome households‟ food shortage. Large number of family member can adapt to the effect of climate change easily. Large family size is normally associated with better labor endowment hence higher likelihood of using more labour intensive adaptation strategies. Some of the climate e adaptation practices are labour intensive and they require huge capital investments. Adaptation might require additional labour which might be provided by a large household size. On the other hand, a household with large family size may be forced to divert part of the labour force to non/off-farm activities in attempt to earn income to ease consumption pressure induced by large family size. Its was therefore hypothesized that household size may have a positive or negative influence on knowledge level and ability to adopt smart adaptation practices. It was therefore hypothesized that, a large household size might positively influence the adoption of best adaptations practices as it reduces labour constraints.

Farming experience of the respondent: Farming experience of a respondent is a continuous variable defined as the total number of years the household head has spent making farming decisions. The more experienced the farmer is, the more aware he/ she is of potential benefits of improved farm management practices, the better he/she is knowledgeable and informed about wind speed, temperature and precipitation changes in the territory. In addition, the more experienced a farmer is, the more he/she is likely to employ adaptation measures that reduce the impact of climate change on his/her agricultural activities. Sometimes, when it comes on adaptation strategies to climate change farming experience that matters more than merely the age of household head. Hence, it was hypothesized that farming experience positively or negatively influence the probability of using different climate change adaptation strategies as well as citing correctly key drivers of potato yield loss.

Farm size of the respondent: Farm size is a continuous variable measured in hectares or acres. The bigger the farm size, the more likely the farmer is knowledgeable of some pests and diseases as well as adopting suitable farming and adaptation practices. Large pieces of land provide provisions for flexibility regarding changes in farming practices. The farmers with large sizes of land are likely to benefit from specific crop management technologies as some techniques are only targeted to larger farms . The households with small land holding are less likely to adopt improved varieties because of the associated costs preferring traditional varieties just for home consumption and small village market trading. It was therefore hypothesized that farm size may positively or negatively affect the adoption of good adaptation practices.

Soil fertility status of the farm of the respondent: It is a dummy variable taking 1 if farmer perceives the soil to be fertile, 0 otherwise and measured as farmer's perception of the status of their soil fertility and susceptibility to soil erosion. Based on farmer's perception of the fertility status of their land, poor soil fertility status increase the probability of a farmer adopting several conservation practices in order to adapt to climate change impacts and effects. Thus, the level of fertility was hypothesized to have a positive or negative influence on adoption of smart agricultural practices such as soil erosion conservation measures

Previous training on agriculture and climate information: previous training and agriculture and climate change is a dummy variable taking the value 1 if the farmer had have access to training practices, 0 otherwise. Participation of farmers in related agricultural training programs can enhance awareness and level of knowledge of farmers about the impact of climate change and adoption of appropriate adaptation strategies. Farmers having access to training tend to be more progressive and receptive to climate smart agricultural practices compared to others who do not. Thus, access and exposure to any kind of training is hypothesized to affect positively the level of knowledge of climate change impacts and adaptation strategies.

Membership to a social group like cooperative associations: It is a dummy variable taking 1 if farmer belongs to a social group, 0 otherwise. Farmers who belong to a social group for instance cooperative are likely to have awareness about climate change information from their groups compared to those who are not involved into those groups and thus membership to a social group increases the likelihood to adopt good adaptation practices/strategies. This study hypothesized a membership to social group to positively influence the adoption of conservation practices to adapt to climate change and variability.

2.6. Data analysis

2.6.1. Descriptive statistics

To address the research objectives, the data analysis was done by using both descriptive statistics and statistical models. Descriptive statistics were used to analyze the primary and secondary data. Statistical tools such as means, percentages, and frequencies were used to summarize and categorize the information gathered about adopted implemented adaptation strategies/measures of farmers. Empirically, econometric regression models were selected they are mostly appropriated to explore linkages (relationship, impacts, effects) between of binary response variable or and explanatory variables of the level of knowledge of farmers. Descriptive statistics tools such as mean, standard deviation, percentages, t-test, and chi-square were used to analyze and present institutional-policy-socio-economic-demographic characteristics and perception of farmers to climate variability and choice of adaptation strategies. A histogram with bar chars was built to summarize historical meteorological data from research station of Lwiro

2.6.2. Econometric models to identify determinants of knowledge of key drivers of variability in pest population density, disease incidence and yield loss across seasons and environments.

Inferential statistical tools were used to analyze the relationship and association of different dependent and independent variables. Secondary data from meteorological services were combined with opinion of farmers (perception data) to detect the ability of farmers to identify with precision key drivers of variability in pests, disease and yield, using econometric models. The study modeled the influence of the set of different independent variables (landscape, individual, farm management, climatic factors, water conservation, crop diversity and rotation, agroforestry, planting resistant varieties....) on the level of knowledge of causes of variability in pests, diseases and yield at the farm levels (see Table-1 for more details about the variables).

To identify the ability of farmers to predict correctly the drivers of variability in yield loss and incidence of pests and diseases, primary data (from the interviews) and secondary data(meteorological data) were therefore integrated. Generalized linear models (GLM) were employed to empirically test which drivers (explanatory or independent variables such as socioeconomic characteristic and weather attributes: monthly rain fall, temperature, wind speed,..) were likely being associated with knowledge of respondents of the dependent variables.

Different econometric models (i.e, generalized linear models: GLM) were used to identify drivers or determinants of adoption of climate smart practices and to identify the ability of farmers to predict drivers of verifiability in pests and diseases. These methods include discrete choice regression models like the binomial/multinomial/multivariate gaussian identity, gaussian log, inverse gaussian, probit, logit, poisson, Log-log, bernoulli, and gamma link-functions. Economic models are commonly used to analyses adoption of farmers of adaptation strategies as well as to capture the interdependence and relationship between them, as well as the potential correlation between unobserved disturbances (error term). The help in mining unobservable links between variables (binary-multinomial qualitative, quantitative) . For instance, binary gaussian identity/logit/probit models can help in estimating the influence of mixed qualitative and quantitative drivers on a single measure, with only binary outcomes (i.e.1=yes, 0= no) of response variable(i.e. indigenous knowledge). Generalized linear models can be employed even when the distribution of the raw data is unknow or not normal.

GLMs provide the direction (negative /positive) of the effects/impacts of independent (explanatory) variables on the dependent (knowledge of cause of variability in yield, pest and disease incidence) variables. Further, differentiating the equation of models with respect to the explanatory variables provides marginal effects of the explanatory variables (the probability of change in the dependent variable with a unit change of the independent variable) was extracted. Also generalized linear models (multinomial link function) may be useful when the bivariate response models involve more than two possible outcomes. The models may be useful when the outcome variables are unordered and mutually exclusive, and if the respondent can choose only a single outcome from among a set of independent alternatives. Various recent empirical studies of technology adoption and climate change adaptation decisions assume that respondent consider a set of possible responses , but choose to adopt particular practices that maximizes their expected utility and current indigenous knowledge. Practically adoption of adaptation strategies by farmers are not mutually exclusive rather interdependent to each other. Thus, one must consider the possibility for a simultaneous use of more than single climate smart adaptation agricultural practices on farm plot as well as the potential for interdependence between these different practices.

The GLM multivariate models regression model may be or not simultaneously employed to model the influence of a set of explanatory variables on most adopted practices or level of knowledge of the farmers. GLMs can allow the analysis of potential correlation between unobserved and/or unmeasured disturbances/impacts/effects (error terms) as well as the correlation between the drivers and the response variable (i.e. level of knowledge of variability of pest and disease incidence). Correlation among the level of knowledge of the influence of a given driver on variability in yield may be due to complementarities or substituabilities of provided scientific knowledge, if the model can simulate maximum likelihood with large numbers of iteration random draws.

GLMs are multivariate-multiple/binary dependent latent variables. Hence, modelling purposes in this study, the ability of predicting key drivers of variability in yield, pest and disease, combined both individual, socio-economic and demographic characteristics, agronomic farming information such improved crop varieties, tolerant or resistant varieties, crop rotation, changing planting time ,agroforestry practices, on-farm soil and water conservation practices, landscape and land use intensity factors,. Consequently, the model assumed that each binary observed variable takes a value 1 if, and only if, the latent variable is greater than zero of the dependent variable (knowledge of cause of variability of yield loss). The latent variable is assumed capturing the un-observed response associated with a level of knowledge of the respondent in the study area for the influence of observed characteristics . The un observed characteristics are captured by the stochastic error term(a vector of parameters that are estimated in the models). The error terms are distributed multivariate normal with mean of 0 and a variance covariance matrix as given below with values of 1 on the leading diagonal and correlations as off-diagonal elements.

GLMs were built in the software to determine the probability of association of independent factors (qualitative and quantitative) with dependent factors(qualitative binary).GLMs may be applied to linearly link dependent variables to variables(factors) or covariables(co-factors) through specific link function of data distribution(Poisson, probit, logit, Bernouilli, Gaussian identity, ,…). GLMs models analyses and measure the effects/impacts (level of influence power) of independent variables on the binary dependent variable. These models allow for non-observed factor (un-seen/un-observed events/phenomena) to be free related (error terms) with the dependent variable. GLMs are used even when the dependent variable is not normally distributed and the model has the ability of eliminating collinear variables among independent variables. GLMs integrate other types of models classically used by scientists such linear regressions for dependent variables normally distributed logistic models for binary or dichotomous data,.. In this study, GLMs tests were selected with an error distribution and log-link functions, followed with a probability test (log-Likelihood) with several level of interaction. GLMs models generate calculate the constant terms (measuring the overall impacts of dependent variables on the response variables), with selection of the Bayesian information criterion (BIC) and Akaike's information criterion (AIC) tools. GLMs were built in STATA software (version 12 for windows 2012, Stata Corp LP, College Station, USA).

3. RESULTS

3.1. Farmer's knowledge of key weather-landscape drivers of yield variability and of variability in the incidence of pests and diseases across cropping seasons

The survey results indicated that most of the respondents perceived changes in the climate variables (rainfall, temperature, wind speed, relative humidity) and in related landscape-agronomic management practice variables. It is likely that respondents were aware of any changes in rainfall, temperature and wind speed patterns, although they reported it with different levels of appreciation of the problems.

Respondents living in hilly sites perceived decreased amounts of rainfall whereas those living in lowlands perceived increased and fluctuating amounts of rainfall. Concerning temperature, most of the respondents from mid altitude villages perceived an increasing trend whereas lowland farmers perceived a decreasing trend. Hilly living farmers perceived fluctuating temperatures (minimum and maximum temperatures) and vagrant wind speed. Most farmers perceived that the occurrence of speedy winds was increasing (due to agroforestry tree cutting, deforestation), which would pose a serious threat to potato production, particularly in village with sloppy landscapes. Observations and views of the farmers about weather factor variability is likely to meet scientific observations obtained during field work. This means farmers from Kalehe are able to predict correctly factors with strong impacts on yield and yield loss or to variability in the incidence of pests and diseases.

3.2. Farmers' perception of change of extreme climatic events and disasters

Some farmers perceived increments in minimum temperature whereas about other perceived declines in maximum temperature. Farmers were able to identify and know the onset and cession date of rainfall; such information is vital for compliance with the local agricultural calendar to avoid crop production being affected by extreme weather variables. The largest proportion of the interviewed farmers also indicated that across the short and long rainy seasons, rainfall is currently starting late during the last four decades (since the epidemic wars started). This result is consistent with the meteorological services observations. This means that it is possible to integrate opinion of farmers in strategies in any adaptation strategy targeting such farmers. Based on their experiences, awareness, agro-ecological conditions, and others, the perceptions of the households varied in magnitude according to the age of farmer.

To counter the problems, farmers indicated that they were forced to adopt and implement soil-nutrient and water conservation, crop diversification and varieties mixture during planting periods, using environmentally-friendly farming practices, introducing pest and diseases resistant and marketable varieties. Respondents also reported that across the cropping seasons, they were encountering some environmental shocks as a result of climate change risks such as soil erosion, strong flood, landslide, disease outbreaks, insect infestations and/or heavy damages in combination with one or more of these shocks. Respondents reported that they encountered various environmentally-born shocks such as soil erosion, flood, disease outbreaks, rising insect infestations and damages. Farmers indicated that there was emergence of new pests and diseases in their villages for which they did not know what to do. Key informants narrated that that crop production is currently challenged by climate-related disasters like flood, pests and diseases, soil erosion, the shift in rainfall pattern, variability in temperature and wind speed and decline in availability of water in soils for the crop in hilly regions. Reduced yield (yield loss) and prevalence of more diseases and insect pest are the most obvious impacts climate change that any experienced farmer can observe (Munyuli et al.2022). More interestingly, farmers citations of key variables associable with the variability in yield loss was evidence that they may be able to address positively challenges of extreme events of climatic conditions like heavy rain fall, overflow of rivers, strong flood and soil erosion on sloppy landscapes.

3.3. Farmers' perceptions of the impact of climate change on potato

Interviews with farmers revealed that currently potato production was affected by climate change and variability in Kalehe territory, since most of them indicated a decreasing trend in potato yield these days. The households also reported potato crop failures mainly due to increase in the activities of potato pests and with increase in the incidence of severe diseases, in addition to current occurrence of new emerging un-known pests and diseases. For example, farmers from Bushaku village experienced complete failures of potato production during the past years mainly to occurrence of late blight that has become resistant to traditional fungicides they used.

Farmers attributed the decrease in tuber yield of potato production to the impact of climate change and variability and to related environmental drivers. Farmers from Lemera study site attributed the failure of potato production to lack of quality tuber seed or lack of access to improved and resistant varieties since old varieties they cultivate, have become susceptible to pests and diseases. The households indicated that they opted for crop diversification and mixture of genotypes in the same field to address the problem of crop failures and to find tuber in response to market demands.

Comparative yield advantages and market values were the main selection criteria for replacing potato with other lucrative or commercial crops. They cultivated varieties that are highly resistant to adverse effects of biotic and abiotic stress such as climate changes and expect high yields. Such actions by farmers to minimize yield loss may be attributable to the urgency of coping with the negative effects of climate variability. Varieties with early maturity, that are flood-soil erosion tolerant or and pest & disease-resistant are always targeted by farmers in order to slow down or even stop the adverse effects of environmental and climate change and variability, and slow negative impact on food and nutrition security in the study areas.

3.4. Influence of the individual characters on the perception of climate variability impacts

Farmers' educational level had a significant impact on perceiving variability in yield loss. It is likely that perception of climate changes is dependent or inherent sensitivity of a person rather than the educational level of the farmer. Education level may not necessarily affect the perception of climate variables by the farmer, experience will affect strongly. Farming experience has a positive effect on some climate change adaptation strategies and may help to stimulate response to the negative effects of environmental and climate changes on crop production.

The gender of the household, place (environment of the village where the respondent is living), and extension service may have significant impacts on the level of knowledge and awareness of meteorological information influence on potato growth and production. It is expected that awareness of climate information and extension service may affect significantly or impact the selecting crops and varieties with good storage and market prices in a specific area. This implies that improving the extension services could have an impact on climate information. Extension services foster adaptation through enhancing farmers' training, demonstrations and awareness of climate variability and knowledge on adaptation measures fitting their local ecologies.

3.5. Farmers' believe and knowledge of the climatic factors, environmental, landscape and habitat management practices likely explaining the variability in potato yield, yield loss (%), seasonal occurrence and abundance of pests and disease incidence (%)

Empirically, the generalized linear models (GLMs) revealed significant explanatory drivers with effects/impacts on the knowledge of respondents. GLMs revealed that the knowledge of farmers varied significantly (P<0.05) among the study villages. The place of living of the household, access to extension services, and indigenous awareness of the respondents on meteorological information had a significant (P<0.05) impact on perceiving climate variability. Also, the age of the household and the awareness of their meteorological information had a significant impact on perceiving rainfall variability affecting the incidence of pests and diseases. The perception of yield loss variability across cropping season, was revealed being significantly associated the rainfall and maximum temperature or demographic factors

3.5.1. Farmers 'perception of the drivers the cause of variability in the prevalence of aphid population density in the farm-landscape

Farmers' perceived independent variables that had negative/positive (Table-2) influences on the response variable, as revealed by the general linear model (GLM), included: the age (z=4.28, P<0.0001), sex (z=-4.68, P<0.0001), education level (z=-2.89, P=0.004), experience (z=-3.15,P=0.02), the previous training on IPM and climate change (Z=2.48, P=0.013) received by the respondent., by the total monthly rainfall (z=-3.30, P=0.001), the number of rainy days/month, (z=1.96, P=0.050), the current rainfall variability (z=2.18, P=0.030), the day of rainfall onset (z=- 4.96, P<0.0001), the relative humidity (z=-2.58, P=0.010), the maximum temperature (Z=4.47, P<0.0001), the minimum temperature (z=5.83, P<0.0001), the continuous rise (increase) in the earth surface temperature (z=-5.61, P<0.0001), the amount of daily sunshine (z=3.06, P<0.0001), the intensity of wind speed (z=4.28, P=0.0001), the altitude (z=-4.68, P<0.0001), the landscape topography (z=-2.89, P<0.0001), the land slope aspect (z=-3.15, P=0.002), the level of soil fertility of the farm landscape (z=2.48, P=0.013), the historical land use intensity (z=-2.87, P=0.004), the landscape disaster vulnerability driving forces (z=-3.20, P=0.001), the cropping season (z=3.48, P=0.001), the compliance with cropping calendar (z=-2.01, P=0.045), the farm size (z=2.0, P=0.036), the quality of chemical & phytosanitary measures applied by farmers, the use natural fertilizers such as compost, manure, mulch or mixtures , the integrated pest management options (Z=-4.66, P<0.0001), the type of variety grown (z=-2.94, P=0.003), the percentage of area of non-crop in the landscape (z=5.20, P<0.0001), the type of non-crop landscape management applied (z=3.38, P=0.001), the cultural trap cropping (Z=4.87, P<0.0001), the conservation practices against nutrient-soil-water erosions applied (z=-5.45, P<0.0001), the type of neighborhood crops, the agroforestry system applied , the agroforestry tree density (z=4.64, P<0.0001), (Table-2).

3.5.2. Farmers 'perception of the drivers of the cause of variability in the population density of whiteflies at the farm-landscape

Farmers' perceived independent variables (Table-3) that had negative/positive influences on the response variable, as revealed by the general linear model (GLM), included: age (z=-3.84, P<0.0001), experience (z=-2.24,P=0.025), previous training on IPM and climate change (Z=2.73, P=0.006) , total monthly rainfall (z=-2.93, P=0.003), the number of rainy days per month (z=-3.29, P=0.001), the period of rainfall onset (z=4.24, P<0.0001), the maximum temperature (Z=3.66, P<0.0001), the minimum temperature (z=-2.86, P=0.004), the continuous rise (increase) in the earth surface temperature (z=-22.34, P<0.0001), the intensity of wind speed (z=-10.07, P<0.0001), the altitude (z=4.80, P<0.0001), the level of soil fertility of the farm landscape (z=-3.30, P=0.001), the historical land use intensity (z=-2.878, P=0.004), the cropping season (z=-2.93, P=0.003), the farm size (z= -6.34, P<0.0001),the quality of chemical & phytosanitary measures applied by farmers (z=4.60, P<0.0001), the use natural fertilizers such as compost, manure, mulch or mixtures (z=3.07, P=0.002) , the integrated pest management options (Z=4.31, P<0.0001), the type of variety grown (z=2.06, P=0.040), the percentage of area of non-crop in the landscape (z=-2.88, P=0.004), the type of non-crop landscape management applied (z=3.07, P=0.002), the cultural trap cropping (Z=2.06, P=0.040), the conservation practices against nutrient-soil-water erosions applied (z=4.60, P<0.0001), the type of neighborhood crops (z=-6.34, P<0.0001), the agroforestry system applied(z=-4.77, P<0.0001),(Table-3).

3.5.3. Farmers ‘perception of the drivers of the cause of the progressive rise in the bacterial wilt incidence at the farm-landscape

Farmers’ perceived independent variables (Table-4) that had negative/positive influences on the response variable, as revealed by the general linear model (GLM), included: age (z=2.31, P=0.021) of the respondent, the experience (z=-2.08,P=0.037), the previous training on IPM and climate change (Z=2.23, P=0.026), total monthly rainfall (z=-5.42, P<0.0001), the number of rainy days/ month, (z=20.99,P<0.0001), the current rainfall variability (z= -2.22., P=0.026), the day of rainfall onset (z=-3.14, P=0.002), the relative humidity (z=27.45, P<0.0001), the maximum temperature (z=2.99, P=0.003), the minimum temperature (z=5.02, P<0.0001), the amount of daily sunshine (z=2.65, P=0.008), the intensity of wind speed (z= -3.31, P=0.001), the land slope aspect (z=3.60, P<0.0001), the level of soil fertility of the farm landscape (z= -3.27, P=0.0001), the cropping season (z=2.21, P=0.027), the compliance with cropping calendar (z=-2.45, P=0.0014), the farm size (z=-2.31, P=0.021), the quality of chemical & phytosanitary measures applied by farmers (z=2.71, P=0.007) the use natural fertilizers such as compost, manure, mulch or mixtures (Z=-3.71, P<0.0001), the type of variety grown (z=3.28, P=0.001) ,(Table-4).

3.5.4. Farmers ‘perception of the drivers of the cause of the progressive rise in incidence of late blight at the farm-landscape

Farmers’ perceived independent variables (Table-5) that had negative/positive influences on the response variable, as revealed by the general linear model (GLM) included: the age (z=2.04, P=0.041), sex (z=-2.85, P=0.004), experience (z=-2.16,P=0.030), previous training on IPM and climate change (Z=3.96, P<0.0001)., total monthly rainfall (z=-16.39, P<0.001), the number of rainy days/ month, (z=3.85, P<0.001), the current rainfall variability (z=-4.83, P<0.0001), the relative humidity (z=-3.20, P=0.001), the minimum temperature (z=3.41, =0.001), the amount of daily sunshine (z= -3.03, P=0.002), the intensity of wind speed (z=-2.88, P=0.004), the altitude (z=2.90, P=0.004), the level of soil fertility of the farm landscape (z=-3.47, P=0.001), the landscape disaster vulnerability driving forces (z=2.59, P=0.010), the cropping season (z= -6.04, P<0.0001), the compliance with cropping calendar (z=-2.63, P=0.008),the quality of chemical & phytosanitary measures applied by farmers (Z=2.71, P=0.007), the use natural fertilizers such as compost, manure, mulch or mixtures(z=2.84, P=0.004), the integrated pest management options (Z=4.06, P<0.0001), the type of variety grown (z=3.71, P<0.001), the conservation practices against nutrient-soil-water erosions applied (z=-3.73, P<0.0001), the type of neighborhood crops (z=-5.07, P<0.0001), the agroforestry system applied (z=-5.06, P<0.0001) (Table-5).

3.5.5. Farmers ‘perception of the drivers of the sources of variability in yield loss (%) at the farm-landscape

Farmers' perceived the independent variables (Table-6) that had negative/positive influences on the response variable, as revealed by the general linear model (GLM), included: age (z=3.48, P=0.001), sex(z=-2.01, P=0.045), experience (z=-3.38,P=0.001), total monthly rainfall (z=-3.48, P=0.001), the number of rainy days/ month, (z=-2.35,P=0.019), the current rainfall variability (z=-2.57, P=0.010), the relative humidity (z=-2.15, P=0.031), the amount of daily sunshine (z=-2.44, P=0.015), the land slope (z=2.63, P=0.008)), the level of soil fertility of the farm landscape (z=-5.74, P<0.0001), the cropping season (z=3.41, P=0.001), the farm size (z=2.23, P=0.026), the integrated pest management options (Z=-3.36, P=0.001), the type of variety grown (z=-1.96, P=0.049), the type of farming practices applied by the farmer (z=2.38, P=0..017) , the conservation practices against nutrient-soil-water erosions applied (z=2.49, P=0.013),the type of neighborhood crops (z=-2.56, P=0.010), (Table-6).

3.5.6. Farmers' perception of the drivers of the sources of variability in seasonal yield (t/ha) at the farm-landscape

Farmers' perceived independent variables (Table-7) that had negative/positive influences on the response variable, as revealed by the general linear model (GLM), included: age (z=-2.30, P=0.022), education level (z=3.54, P<0.0001), experience (z=3.14,P=0.002), previous training on IPM and climate change (Z=4.26, P<0.0001), total monthly rainfall (z=-2.57, P=0.010), the relative humidity (z=2.63, P=0.008), the maximum temperature (Z=-5.74, P<0.0001), the amount of daily sunshine (z=3.41, P=0.001), the altitude (z=2.23, P=0.026), the landscape topography (z=-2.35, P=0.019), the land slope aspect (z=-2.44, P=0.015), the level of soil fertility of the farm landscape (z=-3.36, P=0.001), the compliance with cropping calendar (z=-2.56,P=0.010), the quality of chemical & phytosanitary measures applied by farmers (Z=-2.15, P=0.031), the integrated pest management options (Z=-1.96, P=0.049), the type of variety grown (z=2.49, P=0.013), the type of farming practices implemented by the respondent (z=2.20, P=0.028), the cultural trap cropping (Z=-3.48, P=0.001) (Table-7).

3.6. Farmers' perception of adaptation response to climate change impacts

3.6.1. Adaptation mechanisms used by farmers

The results of this study indicated that almost most households interviewed were implementing adaptation mechanisms to sustain with the change in climate and local environment. Thus, they used cold tolerant or heat-escape varieties, disease-tolerant genotypes, planting hedges against soil erosion, using natural products to control pests and diseases water harvesting, crop diversification, variety mixture at the planting stag,….use of early maturing crop varieties.

Most respondents used different management options interchangeably. Hence, agricultural policy decision-makers should be recommended to integrate strategies adopted by farmers to help in the improvement and development of specific mechanisms for these communities growing potato in the Kalehe territory. According the results of interviews, it appear necessary for breeders to develop and release new varieties likely meeting climatic, pests, diseases and market challenges of farmers. It is important to develop a strong system for the provision of information and sensitize farmers to adopt different strategies for adaptation to climate change to escape shocks related to environmental degradation and variability.

Different adaptation options were used by the respondents such as change to a new varieties, use of soil and water conservation practices in hilly areas, the diversification of crops,... However, lack of information and capital, absence of extension services, may among other, affect the adaptive capacity of the respondents. Under current pressures by various drivers, it is expected that the yield loss with continue rise by 10-20% each year. Without adopting compensating measures, the potato crop may be abandoned in the next few years. Farmers are had a good knowledge of drivers of variability in pests and yield loss of potato.

3.6.3. Factors affecting the choice and type of adaptation mechanisms

Farming experience may influence on the use of early maturing crops, pest-tolerant and new crop varieties, tree planting, water conservation practices and increasing cultivating land. Depending on the experience, farmers can develop suitable innovative climate smart technologies. Hence, either directly or indirectly the probability of identifying the best adaptation options against climate change and land degradation in mountain areas may be linked to the age and experience of the respondent.

The use of early maturing crops, and income diversification may be affected by the sex of the respondent, although the age may not impact on stopping potato cultivation and substitution with other crop type. During the survey, it was observed that availability and access to extension services, early warning information, and awareness of meteorological information, were likely impacting on the level of knowledge of key drivers of pest population dynamics across environments(villages) considered in this study.

3.6.4. Access to climate information for adaptation to climate change

Although most farmers were not in contact with providers of agro-climatic information , they were able to assess the potential impacts of risks derived from weather variability. Meteorological information are expected to be delivered in villages through radio, TV, neighbors, market, religious leaders, newspapers, and agricultural extension offices. However, because of civil unrest , most farmers are more concerned with their own safety than potato production since they are not sure if they will not be displaced be fore the harvest of their crops . However, creating awareness on metrological condition and implementing early warning information, may use such media if one is aiming at scaling-up and disseminating technologies with large impact on livelihood and food security of the rural populations. Limited access to climate information or to environmental-friendly practices may affects farmers’ awareness, preparedness, ability to predict correctly and ultimately their choices of adaptation strategies or mechanisms. Most farmers heavily depend on their own perceptions of climate change and variability, even if access to meteorological information may have positive effects on the use of adaptation mechanisms.

The viability of reliable information (scientifically validated) about the seasonal forecast of weather conditions and climate variability is necessary to understand the climatic condition and to take some measures against adverse effects. Access about future climate change and access to formal and informal institutions and education may tend to strongly govern each respondent adaptation decisions. The knowledge of climate information (indigenous and scientific based) can help to use more than one mechanism options and also creates the chance of adding more than one adaptation option. Stakeholders are supposed to play an important role of promoting the dissemination of useful climate change information to enable farmers combining it with their own indigenous knowledge for the development of adaptation options that can reduce the negative impact of climate change and variability in crop production .Access to best climatic information may help farmers to choose best climate smart adaptation options, to cope up with climate variability, such crop diversification, change in planting date, use of resistant varieties.

Table-2 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the cause of variability in the prevalence of aphid population density)* **across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo**

GLM type: Probit Model						
Response(dependent) variable : knowledge of cause of the variability of the aphid population density	**Coef.**	**Std. err.**	**Z**	**p>z**	**95 % IC**	
Independent variables :						
Individual characteristics						
Age	1.385858	.3240853	4.28	**0.000**	.7506626	2.021054
Sex	-.7763215	.1658169	-4.68	**0.000**	-1.101317	-.4513264
Education	-.5805046	.2011972	-2.89	**0.004**	-.9748439	-.1861653
Experience	-1.073451	.3403848	-3.15	**0.002**	-1.740593	-.4063095
Previous training on IPM	.6953892	.280439	2.48	**0.013**	.1457388	1.24504
Weather factors and some of its variability						
Monthly rainfall	-.1939288	.0588233	-3.30	**0.001**	-.3092204	-.0786372
Rainy days	.2200702	.1120391	1.96	**0.050**	.0004775	.4396629
Rainfall regularity	.1390961	.0639203	2.18	**0.030**	.0138147	.2643775
Rainfall onset	-.3020463	.0608518	-4.96	**0.000**	-.4213137	-.1827789
Relative humidity	-.1970233	.0762287	-2.58	**0.010**	-.3464289	-.0476178
Max temperature	.6233429	.1394059	4.47	**0.000**	.3501124	.3501124
Min temperature	.3994078	.0685443	5.83	**0.000**	.5337522	.5337522
Temperature rise	-.2664814	.0475113	-5.61	**0.000**	-.3596019	-.1733609
Sunshine	.16513	.054036	3.06	**0.002**	.0592213	.2710386

Windspeed	1.385858	.3240853	4.28	**0.000**	.7506626	2.021054
Environmental factors for the location of the field studied						
Altitude	-.7763215	.1658169	-4.68	**0.000**	-1.101317	-.4513264
Land topography	-.5805046	.2011972	-2.89	**0.004**	-.9748439	-.1861653
Land slope	-1.073451	.3403848	-3.15	**0.002**	-1.740593	-.4063095
Level soil fertility	.6953892	.280439	2.48	**0.013**	.1457388	1.24504
Land-use intensity	-.7717207	.268442	-2.87	**0.004**	-1.297857	-.2455841
Land vulnerability	-.8782002	.274341	-3.20	**0.001**	-1.415899	-.3405017
Cropping seasons						
Cropping season	5.843374	1.679049	3.48	**0.001**	2.552499	9.13425
Cropping calendar	-.102203	.0509295	-2.01	**0.045**	-.2020231	-.0023829
Farm characteristics & field agronomic practices						
Farm size	-6.02294	2.868705	-2.10	**0.036**	-11.6455	-.4003806
Phytosanitary	-2.270003	.6721739	-3.38	**0.001**	-3.58744	-.9525665
Natural fertilizer	1.426541	.7438046	1.92	0.055	-.031289	2.884371
IPM applications	-4.73563	1.016622	-4.66	**0.000**	-6.728173	-2.743086
Variety grown	-1.964142	.6674972	-2.94	**0.003**	-3.272412	-.6558713
Farming practices	.0583285	.0407393	1.43	0.152	-.0215192	.1381761
Compliance with environmentally-friendly farming practices to encourage ecosystem services delivery						
Area non crop	3.501588	.6730797	5.20	**0.000**	2.182376	4.8208
Non-crop management	1.716428	.507977	3.38	**0.001**	.7208114	2.712045
Trap cropping	1.017272	.2089648	4.87	**0.000**	.6077084	1.426835
Soil erosion	-3.049638	.5596661	-5.45	**0.000**	-4.146563	-1.952713
Neighbor crops	1.655666	.4206432	3.94	**0.000**	.8312207	2.480112
Agroforestry type	.274514	3.797028	0.07	0.942	-7.167525	7.716553
Agroforesrry tree density	1.803147	.3885116	4.64	**0.000**	1.041678	2.564616
_cons	-.5375826	2.764235	-0.19	0.846	-5.955384	4.880219
Other statistics : Log likelihood = -50.82819542, AIC(**Akaike's information criterion)** = .6084802, BIC (**Schwarz's Bayesian Criterion)** = -1863.007						

Table-3 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the cause of variability in the prevalence of whiteflies population density)* across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo

(Poisson Distribution Log Model)						
Response variable : Knowledge of the cause of variability in the population density of whiteflies	Coef.	Std. Err.	Z	P>|z|	[95% Conf. Interval]	
Predicting/Independent variables :						
Individual characteristics						
Age	-.0752699	.0195935	-3.84	**0.000**	-.1136723	-.0368674
Sex	.0016349	.0037286	0.44	0.661	.0056731	.0089428
Education	.0229586	.0120002	1.91	0.056	.0005613	.0464786
Experience	-.0571828	.0254735	-2.24	**0.025**	-.10711	-.0072557
Previous training on IPM& climate services	1.17273	.4289236	2.73	**0.006**	.3320552	2.013405
Weather factors and some of its variability						
Monthly rainfall	-.0116858	.0039881	-2.93	**0.003**	-.0195023	-.0038693
Rainy days	-.0186622	.0056703	-3.29	**0.001**	-.0297758	-.0075486
Rainfall regularity	-.0059083	.0058218	-1.01	0.310	-.0173188	-.0055023
Rainfall onset	.0296795	.0070007	4.24	**0.000**	.0159583	.0434007
Relative humidity	.0229586	.0120002	1.91	0.056	.0005613	.0464786
Max temperature	.0168678	.004607	3.66	**0.000**	.0078382	.0258975
Min temperature	-.0169053	.0059053	-2.86	**0.004**	-.0284794	-.0053312
Temperature rise	-.5703436	.0255306	-22.34	**0.000**	-.6203828	-.5203045
Sunshine	-.0244825	.0476815	-0.51	0.608	-.1179366	.0689715
Windspeed	-.4077877	.0404926	-10.07	**0.000**	-.4871517	-.3284237
Environmental factors for the location of the field studied						
Altitude	.0420467	.0087582	4.80	**0.000**	.0248808	.0592125
Land topography	-.0135272	.0102663	-1.32	0.188	-.0336488	.0065944
Land slope	-.0021166	.004134	-0.51	0.609	-.010219	.0059859
Level soil fertility	-.0074817	.0022642	-3.30	**0.001**	-.0119194	-.003044
Land-use intensity	-.0015374	.0005335	-2.88	**0.004**	-.002583	-.0004918
Land vulnerability	.0139361	.013442	1.04	0.300	-.0124097	.0402819
Cropping seasons						
Cropping season	-.0116858	.0039881	-2.93	**0.003**	-.0195023	-.0038693
Cropping calendar	-.0038575	.0045725	-0.84	0.399	-.0128195	.0051044
Farm characteristics & field agronomic practices						
Farm size	-.0506504	.0079947	-6.34	**0.000**	-.0663197	-.0349811
Natural fertilizer	.0144173	.0047007	3.07	**0.002**	.0052042	.0236305
Phytosanitary	.0537899	.011693	4.60	**0.000**	.0308722	.0767077
IPM applications	.0696655	.0161569	4.31	**0.000**	.0379985	.1013324
Variety grown	.011325	.0055087	2.06	**0.040**	.0005281	.0221219
Farming practices	.0080864	.0889563	0.09	0.928	-.1662647	.1824376

Compliance with environmentally-friendly farming practices						
Area non crop	-.0015374	.0005335	-2.88	**0.004**	-.002583	-.0004918
Non-crop management	.0144173	.0047007	3.07	**0.002**	.0052042	.0236305
Trap cropping	.011325	.0055087	2.06	**0.040**	.0005281	.0221219
Soil erosion	.0537899	.011693	4.60	**0.000**	.0308722	.0767077
Neighbor crops	-.0506504	.0079947	-6.34	**0.000**	-.0663197	-.0349811
Agroforestry type	-.0097193	.0020382	-4.77	**0.000**	-.0137142	-.0057245
Agroforestry tree density	-.0019147	.0070952	-0.27	0.787	-.0158211	.0119917
Const-	2.576408	.1852735	13.91	**0.000**	2.213279	2.939538
Other statistics : AIC **(Akaike's Information Criterion),** = -2.321107, Log likelihood = 913.4517764, BIC (**Schwarz's Bayesian Criterion)** = -4585.018						

Table-4 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the cause of* **Causes of the progressive rise in bacterial wilt incidence) across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo**

	GLM type : Gaussian Log Model					
Dependent variable : Causes of the progressive rise in bacterial wilt incidence	**Coef.**	**OIM Std. Err.**	**Z**	**P> |z|**	**[95% Conf. Interval]**	
Independent variables:						
Individual characteristics						
Age	.0791992	.034326	2.31	**0.021**	.0119215	.1464769
Sex	-.0506244	.0569402	-0.89	0.374	-.1622252	.0609763
Education	.0952297	.0656834	1.45	0.147	-.0335074	.2239668
Experience	-.1166618	.0559768	-2.08	**0.037**	-.2263743	-.0069493
Previous training on IPM& climate services	.2592678	.1164648	2.23	**0.026**	.031001	.4875346
Weather factors and some of its variability						
Monthly rainfall	-0.0807424	0.0148967	-5.42	**0.000**	0.1099394	-0.0515454
Rainy days	-.4347333	.0207161	-20.99	**0.000**	-.4753361	-.3941304
Rainfall regularity	-.0314662	.0141453	-2.22	**0.026**	-.0591904	-.003742
Rainfall onset	-.0337027	.0107212	-3.14	**0.002**	-.0547159	-.0126896
Relative humidity	.564484	.0205614	27.45	**0.000**	.5241844	.6047837
Max temperature	.0387299	.0129607	2.99	**0.003**	.0133274	.0641323
Min temperature	.0589904	.0117606	5.02	**0.000**	.03594	.0820408
Temperature rise	-.0021144	.0116266	-0.18	0.856	-.0249022	.0206733
Sunshine	.0299645	.0113201	2.65	**0.008**	.0077775	.0521516
Windspeed	-.0395785	.0119487	-3.31	**0.001**	-.0629974	-.0161596
Environmental factors for the location of the field studied						
Altitude	-.022194	.0143272	-1.55	0.121	-.0502748	.0058867
Land topography	.003945	.0058454	0.67	0.500	-.0075118	.0154017
Land slope	.041803	.0116176	3.60	**0.000**	.019033	.0645731
Level soil fertility	-.0018574	.0005682	-3.27	**0.001**	-.0029712	-.0007437
Land-use intensity	-.0071345	.0124189	-0.57	0.566	-.0314752	.0172062
Land vulnerability	-.000314	.0023699	-0.13	0.895	-.0049589	.0043309
Cropping seasons						
Cropping season	.0124023	.005601	2.21	**0.027**	.0014245	.0233802
Cropping calendar	-.0081632	.0033253	-2.45	**0.014**	-.0146807	-.0016458
Farm characteristics & field agronomic practices						

Farm size	-.0109354	.004738	-2.31	**0.021**	-.0202218	-.001649
Natural fertilizer	-.0582189	.0156867	-3.71	**0.000**	-.0889643	-.0274734
Phytosanitary	.0242128	.0089458	2.71	**0.007**	.0066795	.0417462
IPM applications	.0148013	.0105317	1.41	0.160	-.0058405	.0354431
Variety grown	.0180981	.0055184	3.28	**0.001**	.0072823	.0289139
Farming practices	.2734577	.1782278	1.53	0.125	-.0758624	.6227778
Compliance with environmentally-friendly farming practices to encourage ecosystem services delivery						
Area non crop	-.0009402	.0096441	-0.10	0.922	-.0198423	.0179619
Non-crop management	.0079281	.0081122	0.98	0.328	-.0079714	.0238276
Trap cropping	-.008651	.0075689	-1.14	0.253	-.0234857	.0061837
Soil erosion	-.0141001	.0137848	-1.02	0.306	-.0411178	.0129175
Neighbor crops	.014094	.0144908	0.97	0.331	-.0143075	.0424954
Agroforestry type	.0011455	.0095977	0.12	0.905	-.0176657	.0199568
Cons_	1.537149	.1375551	11.17	**0.000**	1.267546	1.806752
Other statistics: Log likelihood =446.910531, AIC **(Akaike's Information Criterion),** = -1.29326, BIC (**Schwarz's Bayesian Criterion)=** -3682.072						

Table-5 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the cause of* **Causes of the progressive rise in ate** ***blight incidence*** **) across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo**

GLM type: **(Gaussian Log Model)**						
Dependent variable : causes of rise in progressive rise in the incidence of late blight	Coef.	OIM Std. Err.	Z	P> |z|	[95% Conf. Interval]	
Independent variables :						
Individual characteristics						
Age	.0077631	.0037971	2.04	**0.041**	.0003209	.0152053
Sex	-.011849	.0041551	-2.85	**0.004**	-.0199929	-.0037051
Education	.0024352	.0034332	0.71	0.478	-.0042937	.009164
Experience	.0193718	.0089508	-2.16	**0.030**	-.0369151	-.0018285
Previous training on IPM & climate change	.1254574	.0317177	3.96	**0.000**	.0632919	.1876229
Weather factors and some of its variability						
Monthly rainfall	-.5614012	.0342504	-16.39	**0.000**	-.6285307	-.4942717
Rainy days	.0777883	.0202083	3.85	**0.000**	.0381807	.1173959
Rainfall regularity	-.3262251	.0675863	-4.83	**0.000**	-.4586918	-.1937583
Rainfall onset	-.0014606	.0365164	-0.04	0.968	-.0730314	.0701102
Relative humidity	-.0239448	.0074776	-3.20	**0.001**	-.0386006	-.009289
Max temperature	-.0131084	.0405728	-0.32	0.747	-.0926296	.0664127
Min temperature	.1406884	.0412535	3.41	**0.001**	.059833	.2215438
Temperature rise	.0621612	.0342182	1.82	0.069	-.0049053	.1292278
Sunshine	-.1276731	.0421397	-3.03	**0.002**	-.2102655	-.0450807
Windspeed	-.1212013	.04204	-2.88	**0.004**	-.2035982	-.0388044
Environmental factors for the location of the field studied						
Altitude	.2246102	.0774881	2.90	**0.004**	.0727363	.3764841
Land topography	.0799494	.0443229	1.80	0.071	-.0069218	.1668207
Land slope	-.0007294	.0195186	-0.04	0.970	-.0389851	.0375264
Level soil fertility	-.0517269	.0149165	-3.47	**0.001**	-.0809627	-.0224912

Land-use intensity	.0275592	.0165169	1.67	0.095	-.0048133	.0599317
Land vulnerability	.0040435	.0015625	2.59	**0.010**	.0009811	.007106
Cropping seasons						
Cropping season	-.0315633	.0052232	-6.04	**0.000**	-.0418006	-.021326
Cropping calendar	-.0922644	.0350323	-2.63	**0.008**	-.1609264	-.0236024
Farm characteristics & field agronomic practices						
Farm size	.019784	.0182941	1.08	0.280	-.0160719	.0556398
Natural fertilizer	-.0981729	.0345406	-2.84	**0.004**	-.1658712	-.0304746
Phytosanitary	-.0946926	.0349339	-2.71	**0.007**	-.1631618	-.0262234
IPM applications	.0244357	.0060185	4.06	**0.000**	.0126396	.0362318
Variety grown	.5040164	.1362575	3.70	**0.000**	.2369567	.7710762
Farming practices	-.0379203	.0844161	-0.45	0.653	-.2033727	.1275322
Compliance with environmentally-friendly farming practices to encourage ecosystem services delivery						
Area non crop	.0088405	.0132356	0.67	0.504	-.0171009	.0347818
Non-crop management	.0103022	.0151024	0.68	0.495	-.0192979	.0399023
Trap cropping	.0427287	.0389393	1.10	0.273	-.0335909	.1190483
Soil erosion	-.1782258	.0477247	-3.73	**0.000**	-.2717646	-.084687
Neighbor crops	-.1841848	.036323	-5.07	**0.000**	-.2553765	-.1129931
Agroforestry type	-.3622496	.0716436	-5.06	**0.000**	-.5026684	-.2218307
_cons	2.848148	.4108833	6.93	**0.000**	2.042831	3.653464
Other statistics : Log likelihood = -133.1289517, AIC (**Akaike's Information Criterion** = .6011039, BIC (**Schwarz's Bayesian Criterion),** =-3460.083						

Table-6 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the sources of the variability in yield loss*) across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo

GLM type: Logit Model						
Dependent variable: knowledge of the Sources of variability of yield loss (%)	Coef	Std.err	Z	p>IzI	[95% Conf. Interval]	
Independent variables						
Individual characteristics						
Age	5.843374	1.679049	3.48	**0.001**	2.552499	9.13425
Sex	-.102203	.0509295	-2.01	**0.045**	-.2020231	-.0023829
Education	-.0157903	.0145911	-1.08	0.279	-.0443883	.0128077
Experience	-2.270003	.6721739	-3.38	**0.001**	-3.58744	-.9525665
Previous training on IPM & climate change impact	1.426541	.7438046	1.92	0.055	-.031289	2.884371
Weather factors and some of its variability						
Monthly rainfall	.1260499	.036237	-3.48	**0.001**	-.1970731	-.0550266
Rainy days	-.045397	.0192882	-2.35	**0.019**	-.0832012	-.0075928
Rainfall regularity	-.0791667	.0308124	-2.57	**0.010**	-.1395579	-.0187755
Rainfall onset	-.0135943	.0318083	-0.43	0.669	-.0759375	.0487488
Relative humidity	.0824778	.0383236	-2.15	**0.031**	.1575907	-.0073649
Max temperature	-.0298218	.0319209	-0.93	0.350	-.0923855	.0327419
Min temperature	.0477296	.0297852	1.60	0.109	-.0106482	.1061075
Temperature rise	-.0425205	.0409072	-1.04	0.299	-.1226972	.0376562
Sunshine	.0617752	.0253629	-2.44	**0.015**	.1114856	-.0120648

Windspeed	697273	.0949078	0.73	0.463	-.1162885	.2557431
Environmental factors for the location of the field studied						
Altitude	.0043874	.0339991	0.13	0.897	-.0622495	.0710244
Land topography	54861	.032492	0.17	0.866	-.0581971	.0691693
Land slope	.0888358	.0337384	2.63	**0.008**	.0227098	.1549619
Level soil fertility	-2362871	.0411925	-5.74	**0.000**	-.317023	-.1555513
Land-use intensity	-.0351162	.0516576	-0.68	0.497	-.1363633	.0661309
Land vulnerability	-.0750866	.0511276	-1.47	0.142	-.1752949	.0251216
Cropping seasons						
Cropping season	.1307288	.0383551	3.41	**0.001**	.0555542	.2059035
Cropping calendar	.0989066	.0560116	1.77	0.077	-.0108741	.2086873
Farm characteristics & field agronomic practices						
Farm size	.0012141	.0005453	2.23	**0.026**	.0001453	.0022828
Natural fertilizer	-.0298474	.0402233	-0.74	0.458	-.1086837	.0489889
Phytosanitary	-.002981	.0038742	-0.77	0.442	-.0105744	.0046123
IPM applications	-.1433458	.0426284	-3.36	**0.001**	-.226896	-.0597957
Variety grown	-783964	.0399039	-1.96	**0.049**	.1566066	-.0001861
Farming practices	.0662065	.0278247	2.38	**0.017**	.0116711	.120742
Compliance with environmentally-friendly farming practices to encourage ecosystem services delivery						
Area non crop	.0152449	.0229356	0.66	0.506	-.0297081	.0601979
Non-crop management	-.0096568	.0182897	-0.53	0.598	.0261904	-.045504
Trap cropping	.0082546	.0188723	0.44	0.662	-.0287345	.0452437
Soil erosion	.029384	.0117983	2.49	**0.013**	.0062598	.0525082
Neighbor crops	-.0215619	.0084168	-2.56	**0.010**	-.0380584	-.0050653
Agroforestry type	.0031278	.0161288	-0.19	0.846	-.0347397	.0284841
cons |	1.606631	1 .42539	3.78	**0.000**	.7728769	.440385
Other statistics : Log likelihood = -544.7528565, AIC **(Akaike's Information Criterion)**= 1.254147, BIC **(Schwarz's Bayesian Criterion)** = -6045.501						

Table-7 : Generalized Linear Model (GML) estimating the probable independent variables likely influencing the response variable (*farmers knowledge of the* sources of variability in crop yield) across cropping seasons, landscape and environments , South-Kivu Provine, eastern DRCongo,

GLM Type: Gaussian Log Model						
Dependent variable: sources of variability in seasonal yield (t/ha)	Coef	Std.err	Z	p>IzI	[95% Conf. Interval]	
Independent variables:						
Individual characteristics						
Age	-.0235548	.0102485	-2.30	**0.022**	-.0436414	-.0034682
Sex	-.0077781	.025678	-0.30	0.762	-.058106	.0425498
Education	.7731183	.2182317	3.54	**0.000**	.3453921	1.200845
Experience	.3868849	.1231876	3.14	**0.002**	.1454417	.6283282
Previous training on IPM	1.564822	.3670075	4.26	**0.000**	.8455004	2.284143
Weather factors and some of its variability						
Monthly rainfall	-.0791667	.0308124	-2.57	**0.010**	-.1395579	-.0187755
Rainy days	697273	.0949078	0.73	0.463	-.1162885	.2557431
Rainfall regularity	.0043874	.0339991	0.13	0.897	-.0622495	.0710244
Rainfall onset	54861	.032492	0.17	0.866	-.0581971	.0691693
Relative humidity	.0888358	.0337384	**2.63**	**0.008**	.0227098	.1549619
Max temperature	-2362871	.0411925	-5.74	**0.000**	-.317023	-.1555513
Min temperature	-.0351162	.0516576	-0.68	0.497	-.1363633	.0661309

Temperature rise	-.0750866	.0511276	-1.47	0.142	-.1752949	.0251216
Sunshine	.1307288	.0383551	3.41	**0.001**	.0555542	.2059035
Windspeed	.0989066	.0560116	1.77	0.077	-.0108741	.2086873
Environmental factors for the location of the field studied						
Altitude	.0012141	.0005453	2.23	**0.026**	.0001453	.0022828
Land topography	-.045397	.0192882	-2.35	**0.019**	-.0832012	-.0075928
Land slope	.0617752	.0253629	-2.44	**0.015**	.1114856	-.0120648
Level soil fertility	-.1433458	.0426284	-3.36	**0.001**	-.226896	-.0597957
Land-use intensity	-.0009421	.0014572	-0.65	0.518	-.0037981	.0019139
Land vulnerability	.0152449	.0229356	0.66	0.506	-.0297081	.0601979
Cropping seasons						
Cropping season	-.0096568	.0182897	-0.53	0.598	.0261904	-.045504
Cropping calendar	-.0215619	.0084168	-2.56	**0.010**	-.0380584	-.0050653
Farm characteristics & field agronomic practices						
Farm size	.0118346	.0228976	0.52	0.605	-.033044	.0567131
Natural fertilizer	.0082546	.0188723	0.44	0.662	-.0287345	.0452437
Phytosanitary	.0824778	.0383236	-2.15	**0.031**	.1575907	-.0073649
IPM applications	-783964	.0399039	-1.96	**0.049**	.1566066	-.0001861
Variety grown	.029384	.0117983	2.49	**0.013**	.0062598	.0525082
Farming practices	.0991341	.0450234	2.20	**0.028**	.0108898	.1873784
Compliance with environmentally-friendly farming practices to encourage ecosystem services delivery						
Area non crop	.0179983	.0102176	1.76	0.078	-.0020278	.0380243
Non-crop management	.0105469	.0136793	-0.77	0.441	-.0373579	.0162641
Trap cropping	.1260499	.036237	-3.48	**0.001**	-.1970731	-.0550266
Soil erosion	.0972226	.053331	-1.82	0.068	-.2017494	.0073042
Neighbor crops	.0050725	.0177727	0.29	0.775	-.0297613	.0399063
Agroforestry type	.0240377	.0248256	0.97	0.333	-.0246196	.072695
Cons-	1.606631	1 .42539	3.78	**0.000**	.7728769	.440385
Other statistics : Log likelihood = -544.7528565, AIC **(Akaike's Information Criterion)**= 1.254147 , BIC **(Schwarz's Bayesian Criterion)**= -6045.501						

Table-8: **General adaptation options and potato specific adaptations options used by the respondents in highlands**

General use of adaptation options & mechanisms	% (x±se) Yes	%(x±se) NO
Planting new varieties/clones	71.19 ± 5.93	28.85 ± 2.62
Planting early maturing & high yielding varieties	86.88 ± 7.24	13.22 ± 1.22
Planting pest-diseases tolerant genotypes	45.62 ± 3.86	54.39 ± 4.94
Planting land races in mixtures	67.45 ± 5.62	32.87 ± 2.98
Shifting to another lucrative crop	50.46 ± 4.21	49.64 ± 4.59
Growing market demanded crop variety	67.91 ± 5.65	32.12 ± 2.91
Use of natural insecticide/fungicides	89.3 1± 7.44	10.71 ± 2.97
Diversification of income & employment sources	60.31 ± 5.25	39.71 ± 2.25
Wild harvesting/poaching of wildlife	29.61 ± 1.56	69.49 ± 3.86
Change into livestock rearing	18.22 ± 0.95	81.81± 4.54
Soil-nutrient and water conservation	77.43 ± 4.73	22.61 ± 1.25
Diversification and mixture of different kind of	76.11 ± 4.06	23.91 ± 2.17

varieties		
Joining militia or mining sites	49.72 ± 2.61	50.31 ± 4.57
Migrating in other /urban areas	59.99 ± 3.16	39.99 ± 3.63
Specific potato adaptation options		
Crop diversification & genotype mixtures	77.25 ± 3.68	22.88 ± 1.68
Substitution of the crop by vegetable/fruit crops	82.6 ± 3.93	17.06 ± 1.22
Delay in planting	75.56 ± 5.55	24.15 ± 1.75
Use of improved varieties/genotypes	60.42 ± 2.86	39.18 ± 2.84
Stopping cultivation & engaging in petty trading activities	69.09 ± 3.29	30.97 ± 2.21
Growing potato in marshlands to target harvest during seasons of high prices and demand	37.38 ± 1.78	62.69 ± 4.47

4. DISCUSSION

4.1. Farmers' Perception on Climate Change Impacts

Access to awareness about climatic conditions and information about future climate change enables farmers to adjust their farming practices in response to climate change. Awareness of climate change and its impacts, is an important determinant of farm-level adaptation . The extent to which farmers are affected by climate change depends on their actual exposure to climate change, the sensitivity of their farming system and their adaptive capacity (Shuaib 2016).

There has been a need to focus on adaptation research that seeks to investigate actual knowledge and adaptations at the farm level, as well as the factors that appear to be driving them. It is assumed that farmers who have adapted to climate change have better food production level than farm households that did otherwise . Awareness, ability to know and predict with precision and access to information to future change in climate change, access to agricultural extension and credit services are determinants that made difference on farmers to take adaptation measures.

The study survey revealed that most of the respondents were aware of climate change over the years and adopted various smart strategies to cope with it. Farmers perceived an increase in wind speed and a decrease in rainfall pattern. The temperature patterns were perceived as of increasing trend. Farmers who did not develop good adaptation mechanisms are those who were constrained by lack of capital or who faced continuously civil unrest in their villages. Respondents indicated that they were not getting reliable early warning meteorological information from institutions. Farmers mentioned that the frequent yield failure of potato should be attributed to the interaction of several factors including heat, coldness, disease, insect pests, soil nutrient depletion, erratic rainfall patterns,…

Meteorological stations should provide needful information to farmers about appropriate dates of onset and cessation of rainfall to enhance potato production and to develop adaptation options to produce the crop in the face of climate change and variability (Okonya et al. 2013). There is a need to develop relevant crop production packages pertaining to optimum agronomic practices, including predicated future climate change scenarios and their adaptation options for each crop variety type (Okonya et al. 2013). During a farmers' survey , that a fall in productivity, yield and income of farmers, high incidents of potato diseases, scarcity of water for irrigation, increased cost of production through the high cost of adaptable inputs to the high application of agrochemicals and fertilizers were observed as climate changed impacts on small scale potato farmers in Cameroun (Ndemaze 2022). In Ethiopia, respondents interviewed in different agro-ecological communities had perceived declining precipitation and increased temperature. They also reported that the frequency of extreme events like drought, flood, frost, and storm had increased (Dendir & Simane 2021).

Future climate simulations including adaptation to climate change through changing planting windows and crop varieties show that yields are expected to increase in most cases as a result of longer growing seasons and CO2 fertilisation. Average global yield increases range from 9 to 20% when including adaptation. Potato agriculture is associated with lower greenhouse gas emissions relative to other major crops and therefore can be seen as a climate smart option given projected yield increases with adaptation (Jennings et al.2020).

In Bhutan, study survey revealed that farmers' sensitivity and perception of the impact of climate change vary spatio-temporally, demographically, and occupationally(Namgyel et 2023). Respondents (76.7%) noticed the changing climate patterns over the last ten years, while landless households (3%) noticed no discernible impacts. A rise in temperature was the most sensitive variable reported, followed by erratic precipitation, a change in plant phenology, and a shift in wildlife occupancy patterns (Namgyel et 2023). Respondents (48%) reported drought, scanty rain, floods, and diseases that moderately affected agriculture crops and livestock, while few respondents (42%) perceive that climate change is a driving factor for human–wildlife conflict because of increasing wild animal movement towards their region(Namgyel et 2023).

Farmers were aware of climate change and climatic factors influencing pest prevalence on vegetable in RSA(Phophi et al.2020). Rainfall variations, crop diseases, pests, and high cost of inputs have been the major challenges facing potato production in Ethiopia (Adem 2021). Respondents (43%) agreed that rainfall variation was the main cause of decreased potato yields, 24% by crop diseases and pests, 15% by high cost of inputs, 10% by inadequate improved seed and 8% by soil erosions. It was therefore recommended that soil and water management practices such as mulching, digging of trenches, water harvesting, crop diversification as adaptation measures to be applied by farmers to cope with rainfall variation in Ethiopia (Adem 2021).

In RSA, it was found that there are higher probabilities of perceiving climate risk among farmers who experience more emotive mental imagery and those with stronger egalitarian values. It was suggested that farmers who perceive climate change based on affective impression and direct personal experience are more likely to suffer cognitive bias in their perceptions compared to farmers who perceive climate risk based on knowledge and analytic processing of climate information (Hitayezu et al. 2017)

Factors related to direct personal experience override knowledge and analytical factors in explaining climate risk perception among small-scale farmers set the stage for a new strand in behavioural decision research that focuses on the psychology and sociology of climate risk perception and mitigation in farming communities (Hitayezu et al. 2017).

In Kenya, farmers perceived that higher temperatures, decreased rainfall, late onset and early retreat of rain, erratic rainfall patterns and frequent dry spells were increasing the incidences of droughts and floods (Chepkoech et al.2018). Meteorological data provided some evidence to support farmers' perceptions of changing rainfall. Farmers perceived reduced yields and changes in pest infestation and diseases in some vegetables to be prevalent in the dry season (Chepkoech et al.2018). A study conducted in Solomon Islands, on the ecological impact of climate variability and change on yield and growth of root crops sweet potato (*Ipomoea batatas*), cassava (*Manihot esculenta*), taro (*Colocasia esculenta*) and yam (*Dioscorea alata*),showed that farmers experienced changes and variability in temperature and rainfall patterns from year to year. These changes triggered droughts, cyclones, flooding, increased runoffs and soil erosion, loss of soil fertility and nutrient loss which had direct and indirect effect on root and tuber crop growth and yield (Quity 2012). In Sweeden, the importance of increasing temperature due to climate change on both potato crop and *Phytophthora infestans* development was studied by simulation, and it was found that higher temperatures may be more detrimental for the pathogen than for the crop (Gonzalez-Jimenez et al.2023).

4.2. Farmers' adaptation mechanisms as affected by the demographic factors such as the age, sex, size of the household and farm size

Age of respondent: The perception to climate change and the adverse impacts of climate change on the potato crop was not variable based on the age groups. The study revealed that the ways of expression of views and knowledge of key drivers of yield loss variability or of the magnitude of impacts of pest and disease incidence were not necessarily varied based on the age groups. Generally, the age of respondents always has a significant effect on the perception of climate change and adaptation measures adopted and implemented in a given household. Older people have high ability of the perception of climate change and environmental changes. In fact, more clear responses and ability to predict correctly drivers with high impact of yield loss was depending on the experience of the respondent. The probability of adopting/planting new crop type and/or variety, crop diversification, soil and water conservation practices, and using natural and botanical pesticides in the control of pests and diseases, generally increase with the age of respondent. Although there is no clear final consensus on how age affects adoption decisions, as compared to younger respondents, mature farmers were found to be able to judge and evaluate in their own criteria available technologies, even innovate news since they have knowledge and technical expertise, which may enable them to make decisions of the best bet technologies and information.

Sex of the respondent : The gender of respondent may not influence the use of available climate change adaptation options Also, the perception on climate change may or not be affected by gender of the respondent, as type and preference to adaption options may vary across agro-ecologies and environments. It was observed that age, experience and the gender had high influences of the probability of using any type of adaptation options such as using early maturing crop varieties, pest and disease resistant cultivars, diversifying income and abandoning cultivating potatoes. Women, generally preferred early maturing varieties while pest and disease resistant varieties may be preferred by male respondents, depending on the price at the local market .

Respondents may fail to adopt any available climate smart options, not because on the gender but mainly because of the limited access to land, information, market, inputs, and political institutions as well as a result of traditional social barriers and on going epidemics wars and civil unrest. Women have ever been victims of violence and raping by rebel groups have non interest in adopting any adaptation options. Households are more likely to adopt smart climate change adaptation mechanisms in areas where there is some kind of social justice and relative peace stability.

Educational status of the respondent: The ability of farmers to predict key factors likely affecting the variability in yield loss and in the seasonal incidence of pests and diseases, may not be necessarily influenced by the formal education status , but informal education such as training, demonstration, fairs , participatory trials,… may have a significant impact on the use of adaptation options and on the level of identification with precision of the drivers of pest population density dynamics in the field . More experienced farmers are assumed to have better knowledge about weather information and its implication on potato production. Elsewhere, it is expected that education may enhance farmers' ability to receive, access information, interpret and comprehend information relevant to making innovative decisions in their farms, especially in engineering and conceiving innovative climate smart technologies.

Size of the respondent: The size of the household may impact on the adoption of some adaptation options . As the household size increases, the probability of implementing the integrated use of different adaptation options may increase due to the increased labor availability. It was observed that household size influenced adaptation strategy adopted by the respondent because of its association with labor endowment. It is argued that a larger household size enables the adoption of technologies by availing the necessary labor in one hand and enabling the generation of additional income from extra labor invested in off-farm activities. However, Kalehe territory is one of areas with high infant mortality within DRCongo. In Kalahe territory, labor availability may be reduced because children and youth prefer joining militia groups and mining sites to expect becoming richer quickly

Farm size : The farm size may had impact on the use of adaptation options. Farm size may significantly and positively increase the likelihood of adaptation to climate change as well as providing opportunities for crop and revenue diversifications and help distribute the risks associated with unpredictable weather factors. It was observed that a location, size and specific characteristic of a farm was dictating the need for a specific adaptation method to climate change. In Kalehe territory, farmers with large size of potato farms, were also found to be more knowledgeable on the management of potato diseases while farmers with small farm size are sensitive to damages and high infestation of pests with the incumbent yield loss.

4.3. Adaptation Options to Climate Change in Agriculture

Agriculture as an economic activity is exposed to various forms of menace ranging from weather variability, pests' infestations and diseases attack, to price fluctuations in the markets (Kamau 2020) and climate and environmental variabilities. Though climate change has been the talk of the day, many farmers in the grassroots have hardly adopted any response options and have continued to suffer losses from the inherent effects of climate change (Mutunga et al.2017).

Coping with the vulnerability and negative effects of climate change on agriculture requires mitigation at the policy level and adaptation at the farm level. Adaptation does not occur without influence from other factors such as socio-economic, cultural, political, geographical, ecological and institutional that shapes the human-environment interactions

(Saguye 2016). Adaptation can reduce climate-related risks in human-managed systems on regional and local scales, and often with a short lead time (Medany & Hassanein 2006). However, its scope is generally limited to specific systems and risk types. Mitigation tackles the cause of climate change while adaptation tackles the effect of the phenomenon. Therefore, adaptation is critical in developing countries like DRCongo.

Promoting mass communications, questioning level of knowledge and outreach activities, adaptation and mitigation options and researching climate change can aid to minimize the future possible impacts of climate change. Moreover, the issue of adaptation is particularly relevant for developing countries due to their high vulnerability to climate change impacts. Thus, reducing vulnerability to climate change through adaptation measures is also increasingly considered as a prerequisite for sustainable development

Adaptation measures such as the use of different crop varieties, planting trees, conserving soil, planting early or late, are among the best adaptation measure to suggest to famers for mitigating negative effects of climate change. Soil and water conservation measures are important in maintaining crop productivity and building resilience against climate change. Transitioning to heat-tolerant and biotic-resistant crop genotypes would be necessary if the climate change renders current crops unsuitable in the future The agro-ecological settings of farmers such as climate, land scape and soil are expected to influence their adaptation to climate change. Evidence shows that farmers adopt and respond differently to climate change depending on their local ecologies.

Climate-smart pest management is a cross-sectoral approach that aims to reduce pest-induced crop losses, enhance ecosystem services, reduce the greenhouse gas emissions intensity per unit of food produced and strengthen the resilience of agricultural systems in the face of climate change. Through the implementation of climate smart, crop production, extension, research and policy act in coordination towards more efficient and resilient food production systems (Heeb et al.2019., Abdul-Razak & Kruse 2017, Osbahr et al.2008).).

Education, primary occupation, credit, social group, cultivated land, and access to information on stress-tolerant varieties significantly influence the adoption decision of the farmer (Raghu et al.2022).There are positive and significant effects of education, extension (access to extension services and participation on field days), and ownership of communication devices specifically radio on the adoption of climate-smart agricultural practices in Ethiopia(Diro et al.2022) .

Factors such as perception of climate change, previous experience of crop failure, recurrent drought & landslide, and access to information about climate change, occurrence of pests and diseases, agricultural extension contacts, access to farmer-to-farmer extension services, and perception of land infertility, social network, age, education level, farming experience, household size, cultivated land size, annual income, and livestock holding have the ability influence decision-making process about the choice of adaptation measures in Ethiopia (Darge et al.2023).

The age of the head of the household, the number of crop failures in the past, changes in temperature and precipitation significantly influenced farmers ’ perception of climate change in wet lowland parts of Ethiopia. On the contrast, in dry lowland condition, farming experience, climate information, duration of food shortage, and the number of crop failures experienced determined farmers ’ perception of climate change in Ethiopia(Asrat & Simane 2018). Overall , farmers' adaptation decision in both the wet and dry lowland conditions is influenced by household size, the gender of household head, cultivated land size, education, farm experience, non-farm income, income from livestock, climate information, extension advice, farm-home distance and number of parcels. However, the direction of influence and significance level of most of the explanatory variables vary between the two parts of the study area.

A study was conducted in Rwanda., and it was found that challenges to adoption of agroforestry to support climate change adaptation and food security were related to land scarcity, poverty, limited technological and financial capacity among most smallholder farmers, limited engagement of smallholder farmers in agroforestry research and an inclination for short term benefits that could hinder adoption of agroforestry which has a long term investment(William 2018). There was a shift in rainy day frequency. Most smallholder farmers believed that the onset of short rains comes earlier in recent years compared to more than ten years ago. In response, most farmers reported that they plant crops earlier in the season. Respondents strongly agreed that soil erosion within farms proximal to streams was a serious threat. They supported the idea of establishing a riparian buffer to help entrap sediments and mitigate soil erosion within farmlands adjacent to streams, with the engagement of extension services, financial incentives and technological assistance to cope up with costs and benefits of riparian zone management (William 2018).

During semi-structured interviews and focus group discussion with farmers to identify farmers' perceptions of reasons behind low yields in North West region of Cameroun (Yengoh & Brogaard 2014). Main reasons of low production reported were: the long and more frequent dry spells and late start of the start of the rainy season, land scarcity, lack of money to invest in agriculture and labour scarcity. Farmers can therefore provide useful insights on why they think there are large yield gaps within their local production environments. In line with the results, any intervention that promotes the use of adaptation measures to climate change may account for location-specific factors that determine farmers' perception of climate change and adaptive responses thereof (Asrat & Simane 2018).

In Ethiopia, farmers have adopted crop diversification, planting different crop varieties, changing planting and harvesting dates to correspond to the changing pattern of precipitation, irrigation, planting tree crops, water and soil conservation techniques, and switching to non-farm income activities (Saguye 2016). Climate change and decline in arable land is forcing subsistence farmers to abandon the less productive but well adapted local crops for the newer short term and drought-tolerant crops decimating agrobiodiversity further (Njeru et al.2022).

In Rwanda it was found that the current situation of climate variability and change has had an adverse impact on the country's agricultural systems and the overall economy as well. The changing patterns of precipitation and temperature, as well as the more frequent appearances of extreme events like floods and droughts, landslides, may lead to a decline in soil fertility and productivity, as well as an increase in incidences of plant diseases(Hakorimana & Akcaoz 2019).

Since farmers are not well equipped to cope with these climate risks, urgent action is needed to sustainably protect livelihoods and ecosystems(Hakorimana & Akcaoz 2019). Lack of research and reliable climate data, limited knowledge about mitigation and adaptation strategies in general, poor farming and processing practices, restricted access to technologies, inadequate financial resources, and insufficient communication are among the key constrains for farmers in Rwanda. Among the adaptation options for implementation, more effective distribution of inputs such as fertilizer and pesticides, investments in farming equipment, improvement of extension services and research, as well as restructuring of the institutional frameworks and development plans(Hakorimana & Akcaoz 2019).

In Kenya, research results offered strong evidence that smallholders' livelihoods are inextricably reliant on their food production and dietary requirements. Cropping seasons rather than longer timescales dictate smallholders' decision-making and planning. Threats from climate change climate variability poses more impacts on seasonal productivity. Smallholders place greater emphasis on two food security dimensions availability and access, paying considerably less attention to utilization and stability. Therefore, farmers needs the leveraging current formal and informal institutional arrangements to bolster food security outcomes as well as improve adaptive capacity to climate variability for farmers. Farmers need also support through providing relevant agro-climatic information, offering functional financing, brokering new knowledge, assisting in scenario planning for risk management, and reducing access barriers in pre-production processes (Mburu 2016).

Farmers report increasing stresses due to temperature increase and droughts. In Cameroun, changing the planting dates (15.8%), traditional moisture holding practices, (22.2%) and the adoption of mixed cropping (19.1%) were some of the local coping mechanisms currently adopted by farmers(Mbue et al.2016). The autonomous adaptation strategies adopted by farmers include; adjusting the season calendar, using tolerant varieties and breeds, applying integrated crop production models, and income diversification in Vietnam (Phuong et al.2018). Four factors were found to be significant ($p<0.05$) in influencing the spread of adaptation measures farmers adopted: farm income, the number of available information sources, number of workers on the farm, and farmable land available during the summer season. Farmers report several barriers to implement adaptation strategies including; market price fluctuations, lack of skilled labour, lack of climate change information, and lack of capacity to learn and apply techniques in their daily practice (Phuong et al.2018).

In Niger, it was found that on average, temperature had a larger effect on crop yields so that the increase in precipitation could still be a net loss of crop yield (Akumaga et al.2018). Thus, management or adaptation factors, such as soil fertility, had a much larger effect on crop yield than the climatic change factors (Akumaga et al.2018). In Henan Province in China a study survey revealed that 57% of the respondents perceived the direct impact of climate change during the past 10 years, with 70.3% believing that climate change posed a risk to their livelihood. A multinomial logit model revealed that land ownership, knowledge of crop variety and the causes of climate change, as well as the belief of climate change, were all positively related to the likelihood of employing adaptive strategies. Moreover, the percentage of households engaging in agriculture activity, and years of engaging in farming were both negatively correlated with famer's likelihood of adopting adaptation strategies. More importantly, farmers with high incomes were less likely to adopt adaptive strategies and more willing to engage in other business activities (Zhai et al 2018).

In Tanzania, farmers reported that the prevalence of climate stresses including dry spells, unpredictable floods, pests and diseases in rural areas (Balama et al. 2013). Due to these stresses, farmers have developed local adaptation strategies which are farming and non-farming. Farming strategies were crop diversification for food and cash and shift of cropping calendar (Balama et al. 2013). Non-farming strategies include the use of forest products, livestock rearing, fishing, petty trade, casual labours and remittances. Inferential statistics showed that family size, number of years the respondent lived in the village, trend of rainfall and temperature are the factors influencing adaptation strategies positively (Balama et al. 2013) .

In Ethiopia, smallholder farmers were more susceptible to climate change due to their reliance on a single rain season and lack of climate change adaptation technologies (Bekuma et al.2023). It was found that absence of crop insurance, a lack of training and demonstration, a lack of non-farm employment, a lack of weather forecasting and early warning, shortage of finance, the high price of farm inputs, and reliance on a single rain season were the main barriers preventing farmers from adapting to climate change (Bekuma et al.2023). The most popular indigenous adaptation techniques used by smallholder farmers included mixed cropping of local variety, reducing social and religious rituals, mixed farming (local crop and livestock), and reducing the amount of food consumed (Bekuma et al.2023).

In Kenya, a study conducted and it was found that correlation coefficient, indicated association between smallholder ’ s perceptions and farm sizes ($r = 0.430; p \leq 0.01$) and education levels ($p \leq 0.05$), farm sizes ($p \leq 0.01$).Smallholders ’ perceptions intersected with various intervening subtleties. Smallholders' adaptive capacity was largely not associated with their socioeconomic characteristics as most of the respective components such as education, and livelihood streams, were barely fully-fledged. Moreover, the constraints against their adaptive capacity were mainly related to the existing policies and their respective implementations at the downstream levels with limited attribution to the farm-level interventions. It was thus incumbent upon the decision-makers, and other key stakeholders to explore avenues for amplifying the smallholders ’ desired adaptation schemes while down-sizing the existing adaptation bottlenecks in the area(Simotwo et al.2018). In RSA, it was observed that significant drivers affecting choice of adaptation approach include climate information, gender, farm size, education level, farmer experience, decreasing rainfall and increases in temperature as farmers’ determinant choices of adaptation to climate change. While, on the other hand, off-farm resources, headed households and age had no significant impact on the choice of coping and adaptation approach to climate change and shocks (Kom et al.2022).

Like in Rwanda, famers were found to be highly vulnerable to precipitation variation like soil erosion during heavy rain in March through May and drought from June through August of each year(Hakorimana & Akcaoz 2019).

In Nepal, climatic variability trend from scientific perspective mostly matched with the views of respondents. Increasing trend of temperature, decreasing rainfall, and growing degree day temperature for crops supported the yearly change in yield; however, the total suitable area may decrease in the future due to climate change (Luitel DR 2020). In Kenya, some households perceived climate changes effects resulted into a decrease in crop yield, resulting in increased household food insecurity, while some perceived water stress at household level, but mainly for those who relied on surface water, well water, borehole, and the natural spring. In addition, some of the households perceived shortage in energy sources, particularly hydroelectric power was said to be sensitive to the changes in climate. These perceptions were based on households' experiences, and partially the results were found to be consistent with physical science of climate change(Wabwire et al.2020).

The results of a study conducted in Ethiopia showed that the majority of farmers perceived the rise of temperature (82%) and reduction of rainfall (87%) in their locality. All categories of responders are also aware of the increment of erratic rainfall onset and cessation for the last two decades. Meteorological analysis demonstrates increases in minimum temperature (0.8◦C), maximum temperature (1.4◦C), and reduction of rainfall (40 mm) per decade (Behailu et al.2021) . The study concluded that farmers ' perception is consistent with the meteorological data trend and variability analysis. In view of the findings, it is recommended that adequate and regular information should be provided to the community about current and emergent climate variability manifestations relevant for agricultural decisions in Ethiopia (Behailu et al.2021) .

Barriers to farmers' adaptation are not exclusively restricted to socio-economic factors and resource constraints; e.g. land tenure, technical knowledge, market, social relationship, credit, information, health care, and demographics in Vietnam (Dang et al.2014). Maladaptation, habit, and the perception of the importance of climate variability and adaptation are found as additional constraints as it was observed in Vietnam. Observed differences in farmers ' and agricultural officers ' perspectives regarding barriers to farmers ' adaptation suggest important policy implications (Dang et al.2014).

In Kenya, small holder farmers were aware of climate change, its drivers, and its effects. The main barriers to climate change adaptation include unpredictable weather patterns, financial constraints, and limited agricultural training. Group membership and site negatively influenced climate change adaptation. Household head's education, experience, remittance receipt, access to credit on inputs, climate change perception, access to weather information, and cultivated farm size positively influenced climate change adaptation. The negative prediction of group membership needs to be emphasized to prevent demotivating farmers from joining community associations. The study highlights the need to incorporate farmers' perceptions of climate change, climate awareness creation, and monetary assistance to enhance climate change resilience among smallholder farmers (Musafiri et al.2022). It was also recommended that local adaptation strategies to be streamlined to relevant policies in order to enhance local farmers' adaptive capacity and become helpful in facing both present and future climate change effects (Balama et al. 2013).

Through participants knowledge and experiences of climate change impacts, potato farmers responded by modifying their farming practices to adapt to the impacts of climate change. Amongst the recurrent strategies adopted include irrigation, constant change of seeds, high application of agrochemicals, fertilizers and change of planting dates. The findings also revealed that the adaptation strategies have had serious challenges that have rendered strategies very limited thus increasing the vulnerability of these farmers to climate change impacts. Most of the challenges accounted for were related to the government's inability to successfully accompany small scale potato farmers by promoting their adaptation efforts and in turn promote agriculture (Ndemaze 2022).

4.4. Determinants of farmers' level of knowledge of the key socio-economic, farm landscape, weather and environmental drivers of variability in yield, yield loss disease incidence, pest population density dynamics over seasons and environments (villages)

This study was conducted with the objective analyzing the perception of potato producing farmers on climate change and identifying the possible adaptation mechanism to cope with future climate change in the territory. Generalized linear models were employed to analyze factors influencing farmers' ability of predicting sources or drivers of variability in yield loss and pest incidence. The model was also run to investigate the effect of different landscape, environmental and agronomic practices on the yield loss, variability in disease incidence and pest population dynamics under current and future climatic conditions.

The GLMs revealed the ability of farmers to predict or identify explanatory variables involved in explain variability in yield, yield loss and disease incidence across seasons and sites. The study also revealed that the largest proportion of the respondents were aware of key climate change factors., thus they developed and implemented appropriate adaptation options to cope up with climate change.

In Cameroun, binomial logistic regression model (based on farmers surveys) demonstrated statistically significant useful agricultural area ($\beta = 0.348$, $p<0.0001$), soil fertility ($\beta = 0.568$, $p<0.05$),*Dioscorea* spp. ($\beta = 0.926$, $p< 0.05$), precipitation during these 10 to 30 years ($\beta = 0.582$, $p < 0.05$), and annual income ($\beta = 0.002$, $p <0.01$) all contributed to lessening smallholder farmers' vulnerability to unfavorable climate variability and change (Chimi et al.2023) .

In Ethiopia, the major factors identified to be driving farmers' investment in adaptation practices were age, level of formal education and level of awareness of climate change issues (Saguye 2016). The major factors constraining them from adapting to climate change were poverty; farmland scarcity and inadequate access to more efficient inputs, lack of information and poor skills, land tenure and labour constraint. Logit regression was used to identify key factors that influence the strategies employed by famers for adaptation to climate change (Saguye 2016). The result of the logit model showed that annual farm income, farming experience, knowledge of climate information, education and extension access variables are significant determinants of climate change adaptation strategies. Thus, promulgation of policies to ensure that farmers have access to physical, human and social capital will enhance farmers' ability to respond effectively to changing climate conditions (Saguye 2016). The findings underscore the need for farmers' education, awareness creation, poverty alleviation and increased access to more efficient inputs as potent tools for climate change adaptation in Ethiopia (Saguye 2016).

The research characterizes the engagements across multiple institutional scales and the types of agents involved, providing insight into emergent conditions for adaptation to climate change in rural economies. The logit analysis explores local responses to climate shocks, food security and poverty reduction, through informal institutions, forms of livelihood diversification and collective land-use systems that allow reciprocity, flexibility and the ability to buffer shocks. However, the analysis shows that agricultural initiatives have helped to facilitate effective livelihood renewal, through the re-organisation of social institutions and opportunities for communication, innovation and micro-credit in Mozambique (Osbahr et al.2008). Also, in Bangladesh, during a farmers' survey, a logit model explained that education, family size, farm size, family income, farming experiences and training received were significantly related and influential factors to perception of climate change (Uddin et al.2017).

Insect pests are a major cause of crop yield losses around the world and pest management plays a critical role in providing food security and farming income in Sub-Saharan Africa. In Nigeria, a study aiming at linking household characteristics, cropping systems, farmers' perceptions of pest severity and management to the landscape, land-use, agronomic, biophysical, and socio-economic context in which agricultural production takes place, was conducted using semi-structured village survey (Zhang et al.2018). The empirical study revealed that application of fertilizers (chemical and manure) was negatively related to reported pest severity. It was also reported that pest suppressive and pest severity was negatively associated with the proportions of forest and unused land at the landscape scale in a diverse landscape agricultural settings. The generalized model indicated pest severity was lower in mixed-cropping systems than in mono-cropping systems, reinforcing the idea of a pest suppression benefit of diverse cropping systems (Zhang et al.2018). From the surveys, it was found that the presence of non-crop areas in the landscape and the diversification of agroecosystems may be a viable strategy for smallholder farmers to manage pests with limited reliance of chemical insecticides although actual pest management decisions may be influenced by a wide range of context-specific factors in Nigeria (Zhang et al.2018).

In Nepal, a research revealed that farmers' strategies for adaptation to changes are mostly related to socioeconomic drivers and to some extent to climatic factors (Sujakhu et al 2015). Thus, existing opportunities to cope with changes relate mostly to non-climatic variables such as available resources, government policy, labor supply, market conditions, and property rights; therefore, these variables need to be considered during adaptation planning (Sujakhu et al 2015). Farmers' communities identified the need for more efficient water management and for adjusting farming practices to better utilize the potential of already promising activities such as livestock management, milk production, crop diversification, and cash-crop production to respond to climate change and other hazards (Sujakhu et al 2015).

A study was conducted on cocoa farm in Ghana. It was found that current on-farm yields in this country are low and are expected to decrease in response to climate change, through warming and shifts in rainfall (Asante et al.2021). Mixed-effects models showed that the fixed effects (i.e., landscape environmental variables) only explained 7% of the variability in yields whilst fixed and random effects together explained 80%, suggesting that farm-to-farm variation played a large role (Asante et al.2021). Climate-related factors had a larger effect on yields than edaphic factors, with radiation of the main dry season and that of the previous year having the strongest effects on on-farm- and tree yields, respectively. Productivity was more strongly driven by environmental factors (Asante et al.2021). It was concluded that agronomic management coupled to environmental conditions was the dominant determinant of on-farm cocoa yields in Ghana (Asante et al.2021) .

Altitude has a strong influence on coffee yield, benefits of shade trees, and soil quality. Socio-ecological constraints, such as farm and household size, and access to forests and markets, play a crucial role in determining what constellation of ecosystem services benefit farmers' livelihoods resulting in different sustainable intensification pathways(Liebig 2017),. Inherent trade-offs in socio-ecological conditions, and aligning these is required for achieving the multiple objectives of livelihood improvement, sustainable intensification of crop production, and biodiversity conservation in coffee agroecosystems of Uganda(Liebig 2017). Correlation and regression analysis were used to determine the relationship between rainfall, arable land expansion, fertilizer use and crop yield in Rwanda. It was found, the rainfall variations were determinant for the crop yield increment under Rwanda conditions (Mikova et al.2015). The intensification of extreme flood's and, as rule, flooding of agricultural lands in connection with rainfall augmentation was also allocated (Mikova et al.2015).

Firewood collection, charcoal production, population growth, and poverty were ranked as the important drivers perceived by local communities to be responsible for land use change dynamics (Munthali et al.2019) and yield loss in Malawi and several areas of Africa.

Climate change and variability cause direct yield losses as a result of adverse environmental conditions and indirectly through losses resulting from insect pests attack. Smallholder farmers are likely to face huge yield losses as a result of the changes in the abundance and distribution of insect pests in Zimbabwe(Chapoto 2016). Increased abundance of insect pests, decreased natural resource base and reduction in social safety nets were perceived to be the major climate change risks that were experienced by the smallholder farmers. The majority of the farmers (89%) have also expressed experiencing an increase in the incidence of insect pests such as aphids, stem borers, termites, diamond back moths, bollworms and whiteflies throughout the agro-ecological regions Zimbabwe (Chapoto 2016). Insect pest models that support adaptation planning also need to be developed to forecast climate change events, the distribution of insects in space and time and the corresponding pathogens that are transmitted by these insect pests(Chapoto 2016).

Climate change is having an overall negative impact on crop production worldwide (Mahdu 2019). The vast majority of climate change impacts on crop production result from fluctuations in precipitation and temperature, which lead to flooding, water scarcity, and increases in insects and pests, diseases, and weeds (Mahdu 2019, Ademe et al. 2020). Cropping systems and diversification have been demonstrated to reduce insect pests' prevalence and damage by influencing behavior and population dynamics during colonization, establishment and population development phases of infestation (Mutyambai et al. 2022).

Increasing temperature and altered precipitation patterns have the potential to increase the distribution and the abundance of insect pests in Zimbabwe(Chapoto 2016). This is likely to increase the use of chemical insecticides thereby exposing the farmers and the consumers to the hazards associated with overuse of chemical insecticides(Chapoto 2016). Government intervention through insect surveillance at both spatial and temporal scales is of importance in reducing yield loss as a result of insect pest hazards(Chapoto 2016). Early warning systems to increase farmer awareness on the impending insect pests' hazard and policies to reduce overuse of insecticides is of importance under changing climate conditions. Promoting the use of alternative insect pest control strategies are likely to be suitable for insect pests is also vital for a more efficient management of insect pests thereby reducing crop losses to due to insect pest attack (Chapoto 2016). The increasing temperatures and erratic rains, as well as diseases and pests do reduce crop yields in the arid and semi-arid regions of Kenya (Mutunga et al.2017). In Nepal, farmers reported increases in crop pests, hailstorms, landslides, floods, thunderstorms, and erratic precipitation as climate-related hazards affecting agriculture. They responded in a variety of ways including changing farming practices, selling livestock, milk, and eggs, and engaging in daily wage labor and seasonal labor migration.

With more efficient support and planning, some of these measures could be adjusted to better meet current and future risks from climate change (Sujakhu et al 2015)

Reduced agro-biodiversity loss (yield loss) and enhanced resilience in the face of the increasing climatic variability through crop diversification could be major co-benefits in areas with widespread poverty and dryland farming (Hitayezu 2015). Agronomic practices, such as mixed cropping systems and weeding, as well as field characteristics, including soil type , landscape slope and crop variety characteristics have been observed to negatively influence pest infestation and damage in maize cropping systems. Thus, agronomic practices, as well as field and crop characteristics, need to be considered in designing sustainable pest sustainable management strategies (Mutyambai et al. 2022).

The viability of crops(i.e, coffee) in Uganda is endangered by multiple factors such as climate change, population pressure and price volatility. Sustainable intensification through inter-cropping is believed to improve farmers livelihoods, facilitate adaptation of crop production to climate change, and contribute to crop sector development and biodiversity conservation in coffee growing areas of Uganda(Liebig 2017),

Consolidated infrastructural setup, proper early warning system, disaster monitoring centres, better transport connectivity within remote islands, better livelihood opportunities, education, and awareness may help in improving the socio-economic conditions of the communities in understanding of climate change impacts and indicated adaptive and mitigation measures to improve coastal society exposed to climate change-induced hazards in India (Sahana et al.2021)

5. CONCLUSIONS & RECOMMENDATIONS

Climate variability is one of the major factors that affect crop production in south-Kivu Province . Potato is a major food security and cash crop for small scale farmers inhabiting the highlands of Kalehe territory. Currently, the productivity of the crop is being negatively affected by climatic-environmental factors (drivers), by the lack of good quality seed tubers for planting, disease, insect pests, soil erosion, landslide and soil nutrient depletion for farms located on slopy landscapes . Climate variability and change is one of the main environmental factor constraining production of the crop in the territory. As major elements of climate change, temperature and rainfall variability cause heat and moisture stress, thereby leading to poor growth and productivity of potato in the territory.

The results of this study have revealed considerable variability and trends of temperature and rainfall over the 20-50 years period may have occurred in eastern DRCongo. It is likely that temperatures have increased over time and precipitation has exhibited high variability across seasons and agroecologies

The study further revealed that variability across seasons in terms of rainfall amount and distribution. There is also a trend for the overall rainfall amount to reduce continuously while the maximum temperature is progressively increasing. This variation may be at the base of currently observed frequent and recurrent floods, landslides, soil erosion,... In addition, the region is under civil unrest and generalized insecurity and poor governance. This political instability coupled with violence and natural resources plundering, exacerbate the situation of people living in rural areas and who are mostly depending on potato growing activity. There is a general fear that if current trend in rainfall and temperature variability continue , potato productivity may be affected., yet potato is number one lucrative crop in eastern DRCongo, especially after the failure of coffee production (the former green gold).

Climate variability problem may lead to increased vulnerability of farmers to shocks and induce them to replace potato with other crops that are less sensitive to climate change. Once the potato cultivation is abandoned, several farmers may not have any more enough farm revenue for buying new lands, catering for school children, paying hospital bills and creating new investment ventures including trading minerals. Such situation may force farmers to join rebel militia or artisanal mining ores or migrating in other environments that are expected to be suitable for life including urban areas.

The observed trend in temperature in particular signifies negative impact on the growth and development cycle of potato. This implies loss of cash income for farmers as well as exacerbated household food and nutrition insecurity. This means production of potato in the study area should suit the changing climate and management of the crop should be designed to suit weather variables. Therefore, it is important to create regional awareness on the existing as well as impeding climate variability in potato producing areas, identify adaptation options for improving of the crop and increase farmers' resilience to climate change.

Depending on a range of factors, the impacts of climate change may differ in magnitude even in a single territory or agro-ecological zone. Both the current and future climate change scenarios may affect potato production. In the future, it will be important to analyze the past trends of climate variables like temperature and rainfall and to identify projected future climate change scenarios for potato production in the eastern DRCongo. More importantly, studying the ability of farmers to predict and the perception of farmers on climate change variability is basic foundation for developing and proposing strategic and appropriate adaptation options . Development stakeholders and actors cand design suitable adaptation mechanisms to cope with climate change and minimize the associated risks of further reduction in potato productivity and yield loss.

Farmers indicated that over the past 20-50 years, potato yield was decreasing while disease outbreak and population density of pests were increasing. Several reasons were mentioned by farmers to explain the causes of yield failure, including erratic rainfall and incidence of pest and diseases rising-up. Although farmers have been abandoned to themselves , development actors consider opinion of farmers while building adaption options for farmers. It may be vital to combine indigenous with scientific knowledge during the development of climate smart adaptations strategies. The substitution of potato crop by another crop (such as tomato,…) because of fear of low market value, continuing yield loss in potato, should be discouraged by all stakeholders involved in the development and prosperity of rural areas in Kalehe territory. In this regard, there is a need to develop appropriate farming practices likely helping in the reduction of tuber yield or failure of the crop due to pest and diseases pressures.

Generally, the study result suggests that it is the best alternative to compose a design and develop the appropriate adaptation options and modifying measures and consider opinion of farmers; to tackle the problems raised over change in the pattern of monthly, seasonal and yearly weather (rainfall and temperature) variables. Finding of this study may be used to extend the studies further in other areas and help to provide an insight into the precipitation and temperature variability of the area. Future research should be geared towards developing on farm experiments to screen potato genotypes that are tolerant to climatic risk factors as well as being pest-disease resistant for cultivation during both in highlands, mid and lowlands during the long and short rainy seasons in a double cropping system to enhance farmers' income, food security, and resilience to climate shocks.

Regarding the variability in climatic factors, it was reported that theses days, both annual, seasonal/monthly temperatures/ relative humidity/rainfall are showing strong trends (some times increasing or decreasing). For the majority of the months, the change in the minimum temperature was more pronounced than the change in the maximum temperature. The overall increase in annual/monthly rainfall may be, therefore, largely attributed to an increase in the relative humidity. Adjusting planting date is one of the adaptation options used by the potato growers in the study villages. Appropriate planting date is important not only for using as an adaptation option for the changing climate but also it helps to avoid or escape blight defoliation to have occurred on the potato.

Respondents perceived that potato was affected by climate change either through pest-disease actors or through erratic nature of rainfall and rise in the heat or decrease in the moisture. Each potato producers adopted an appropriate adaptation options to cop up with weather vagaries . Most respondents were aware of meteorological information in their traditional languages, although they needed regular early warning information about climate change from metrological stations.

Farmers' intentions to adaptive behaviors are affected by socio-cognitive factors such as climate risk perception and perceived adaptation efficacy. This imply that the cognitive factors significantly influence the farmers' intention of some private adaptation behaviors. Therefore to enhance the farmers' adaptation capacity, relative policies should consider developing cognitive indicators to evaluate the farmers' adaptive responses. Further, the local governments should develop educational programs with integrated climate change risk information and management and the local elder figures can have a significant role in disseminating adaptation information. I may be important that local climate change policy try to balance adaptation and mitigation and create international networks to have exchange training programs so as to farmers themselves can share and learn from the experiences.

Accelerating intensification of cropping systems, increased climate change and variability, and deficient crop husbandry may be aggravating both native and invasive pests-diseases activity and crop variety susceptibility. Future efforts need to consolidate local capacity to tackle current (and future) pest , and diseases, boost detection capacity, devise locally-appropriate integrated pest management tactics, and transfer key concepts and technologies to farmers. Urgent action may be needed to mobilise regional as well as international scientific support, to effectively tackles phytosanitary emergencies and challenges and thus safeguarding the sustainability and profitability of agricultural commodities providing livelihood to farmers. Thus, improving people's adoption of climate-smart agriculture in the education system and training the people should be a prime concern (Adhikari et al. 2022) .

It is thus imperative to understand the effects of climate change on both the host and pathogen in order to ameliorate the negative effects and utilise the benefits thereof. The changes in climate are gradual and will thus give growers time to alter management practices and adapt to changes in disease and pest pressure. On-going research should focus on providing industry with crop protection tools such as cultivars with durable and innate resistance, knowledge of the mechanisms and expression of resistance genes under adverse weather conditions, efficacy of pesticides, adaptations of pathogens and pest insects to climate change and decision support systems (van der Waals et al.2013). Thus, improving people's adoption of climate-smart agriculture in the education system and training the people should be a prime concern (Adhikari et al. 2022) .

Persistent pests and diseases particularly potato bacterial wilt and late blight disease hampering potato productivity (Shimira et al. 2020).Soil erosion exacerbated by land fragmentation and use of steep land, and poor fertilization practices both in quantity and quality are secondary bottlenecks for potato production in Rwanda. Hence, active involvement of the private sector in seed production in conjunction with aeroponic systems and integrated pest and disease management is the promising future research path and most effective approach to be adopted for sustainable potato production and food security in Rwanda (Shimira et al. 2020). There is also a need to develop and evaluate adaptation of pest resistance and thermo-tolerant cultivars (Borus 2017).

Climatic change and absence of institutional instruments such as crop insurance, disaster payments make risk management strategies very critical for rural people in order to alleviate adverse impacts of climatic change. Thus policy makers should focus efforts on reducing production risks providing climatic information in order to increase the awareness of farmers and developing risk management institutions. Both climatic and non-climatic stressors have serious implications for farmer ' s livelihood sources in different agro-ecologies of the study area. Therefore, it is important to develop a holistic climate change adaptation strategy considering both climatic and non-climate stressors to minimize vulnerability and to increase the adaptive capacity of smallholder farmers.

The impact assessment study on different scenarios on potato under current climate change condition is need to be able to propose/provide early warning measures and suitable adaption options. Development of heat tolerant and pest and disease resistant varieties is one of the best adaptation mechanisms (Muthoni & Kabira 2015) that can be provided by research organization to both minimize impact of climate change and mitigate negative effect of pests and diseases on the yield. Smallholder farmers are encouraged to adopt effective climate variability adaptation strategies that can be upscaled to minimize the adverse risks associated with climate variability, and ensure sustainable agricultural development (Ankrah et al. 2023). The perceptions could indicate how farmers manage long-term changes associated with climate change and variability, which can be associated with their adaptive capacity (Kalungu et al.2013).

Therefore, since climate stress coupled with socio-economic and institutional stress has serious implications for farmer ' s livelihood sources, a holistic climate change adaptation strategy considering agro-ecological variation is required to sustain farm household livelihood (Dendir & Simane 2021). Agricultural policy makers should advocate and support farmers' in the use of adaptation mechanisms to enhance potato production and tackle food and nutrition security in the Kalehe territory.Any policy and development strategy that attempts to boost farmers' adaptation to the changing climate should be based on farmers' level of empirical evidence, assessment, identification, appreciation and handling potential drivers of yield loss.

The agricultural development policy should be advocating greater public-private engagement and to be benefit from farmers' inputs and opinions in the design of relevant policies. In the same light, non local based researchers and research institutions can draw on farmers' knowledge to create and accumulate knowledge on sustainable solutions to problems of low yields and low food production in Cameroon(Yengoh & Brogaard 2014). Local pattern of soil and environment conservation can serve as a stimulus for further promotion of technology adoption under climate risk. This implies that sector-level investments in extension, marketing pattern, and infrastructure that get a few farmers moving in the right direction will have a multiple effect in helping spread adoption of environmental friendly practices(Hakorimana & Akcaoz 2019). This study suggests that climatic change and absence of institutional instruments such as crop insurance, disaster payments make risk management strategies very critical for rural people especially farmers (Hakorimana & Akcaoz 2019).

Proven and sustainable practices like climate-smart agricultural practices need to be prioritized and promoted for uptake especially by the farmers to achieve sustainable development. These are capable of contributing to the realization of sustainable development goals through averting food and nutritional insecurity, increasing and sustaining yields that translate into increased incomes and later reduced poverty (Waaswa et al.2021). Farmers ' level of understanding of climate change, vulnerability and adaptation practices are likely to be improved by involving them in different organizations, such as climate field school and farmer associations. Such situation may accelerate the dissemination of agricultural adaptation practices among them to cope with adverse agricultural impacts of climate change (Hasan & Kumar 2019). Scientists should be effective in communicating with farmers concerning the rainfall onset and cessation dates, since flowering and bulking stages of potato are the most critical periods for the growth and development of the crop. It is important to allocate huge investment in the information delivery system; competitive institutional services and particular safeguarding of the resource-poor farmers to sustain livelihoods, food security and rural development (Faisal et al.2021).

Strategies to avoid maladaptation strategies should be studied by researchers. Extension services should provide need information to support farmers such as capital, training, and resilience technologies to consolidate the efforts they are making to adapt to climate change and remain producing potato for the people. Given the significance of climate change impacts on farming communities, large investments are made by research and development actors, including farmers themselves, to adapt agricultural systems. (Vandamme et al.2022). There is also a need to understand where climate change impacts are expected to be most severe, innovations strategies should be scaled-up to help farmers and enable uptake of socio-economic drivers of adoption of best climate smart adaptation technologies (Vandamme et al.2022) that can boost the food security while establishing sustainable farming systems resilient to climate change.

6. RECOMMENDATIONS

At this stage of the research, it may be recommended : (i) the increasing the adaptive capacity of farmers through providing integrated potato technology packages and trainings on climate risk management to reduce the negative impacts of climate variability and change., (ii)t provide early warning information's for the change in weather factors to help farmers implement best adaptation mechanisms ., (iii) to regularly communicated with farmers concerning the appropriate dates of onset and cessation to enhance crop production in the area., (iv) to develop center of excellencies for potato breeding, focusing on developing varieties that tolerant to various biotic and abiotic stresses including pests, diseases and climate variability., (v) to develop innovative potato modeling systems that can be used to strengthen the decision support system capability of research and development institutions with less cost and time required as compared to on-station and on-farm experiments.

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