EFFECT OF APHIDS AND APHID TRANSMITTED VIRUSES IN SEED POTATO *(Solanum tuberosum L.)* PRODUCTION BY SMALL SCALE FARMERS IN KENYA

BY

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DECLARATION

I declare that this is my original work and has not been presented for an award of a degree in any other University

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DEDICATION

To the Almighty Father in Heaven,

For giving me good health, resources, opportunity and the ability to study

To my wife Nicera Njoki and,

Children Hilda Kathomi, Breden Murimi and Angela Murugi,

For their emotional and financial support and encouragement during the course of my studies

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TABLE OF CONTENTS

Declaration ii

Dedication iii

Acknowledgement iv

Table of contents vi

List of tables ix

List of appendices xii

Abstract xiii

Chapter 1: Introduction 1

1.1 Background information 1

1.2 Problem statement/justification 2

1.3 Objectives 4

Chapter 2: Literature review 5

2.1 Potato production in Kenya 5

2.2 Seed potato production and marketing 8

2.3 Potato aphids 10

2.3.1 Species of aphids infesting the potato 10

2.3.2 Ecology and host range of potato aphids 13

2.3.3 Biology of potato aphids 15

2.3.4 Factors affecting aphid population 17

2.4 Potato virus diseases 19

2.5 Detection and quantification of potato viruses 27

2.6 Management of potato virus diseases 29

Chapter 3: Seed potato production and incidence of potato viruses among small scale potato farmers in Kiambu and Nyandarua districts 34

3.1 Introduction 34

3.2 Materials and methods 36

3.2.1 Experimental sites and administration of survey questionnaires 36

3.2.2 Determination of types and amounts of viruses in potato 36

3.2.3 Determination of farmers' knowledge on management of Potato viruses 38

3.2.4 Data analysis 39

3.3 Results 40

3.3.1 Seed potato production practices among small scale farms 40

3.3.2 Contamination of farmer-produced potato tubers with viruses 44

3.3.3 Farmers knowledge on management of potato virus diseases 48

3.4 Discussion 50

3.4.1 Seed potato production practices among small-scale farmers 50

3.4.2 Contamination of farmer-produced potato tubers with viruses 52

3.4.3 Farmers training in aphids and virus management 53

References 54

Chapter 4: Effect of aphid transmitted viruses on seed potato production among small sale farmers in Kiambu and Nyandarua districts 61

4.1 Introduction 61

4.2 Materials and methods 62

4.2.1 Experimental site, design and layout 62

4.2.2 Assessment of potato aphids population 63

4.2.3 Assessment of potato virus disease incidence 64

4.2.4 Determination of the effect of potato viruses on tuber yield 64

4.2.5 Data analysis 65

4.3 Results 66

4.3.1 Potato aphid population on leaves 66

4.3.2 Aphid population in water pan traps 69

4.3.3 Virus disease incidence 71

4.3.4 Effect of potato virus diseases on tuber yield 72

4.3.4.1 Effect of potato viruses on number of tubers 72

4.3.4.2 Effect of potato viruses on weight of tubers 73

4.3.5 Types and levels of viruses contaminating potato tubers 76

4.3.6 Relationship between aphid population, virus incidence and tuber yield ... 79

4.4 Discussion 82

4.4.1 Aphid population in seed-potato producing small-scale farms 82

4.4.2 Incidence of potato virus diseases and viruses in potato tubers 84

4.4.3 Effect of virus on tuber yield 87

References 88

Chapter 5: General discussion, conclusions and recommendations 96

5.1 General discussion 96

5.2 Conclusion and recommendations 98

References 100

Appendices 122

LIST OF CHARTS

4.1 Mean percentage change in weight of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons 76

LIST OF TABLES

2.1 Irish Potatoes Production 2005/2006 statistics in different provinces of Kenya 8

2.2 Summary of transmission of viruses infecting the Irish Potato 21

3.1 Chemical composition of buffers used in DAS-ELISA analysis 38

3.2 Percentage of farmers' with different sizes of whole farms and seed potato plot sizes measured in acres in Njabini and Limuru in 2007 41

3.3 Percentage of farmers' and their different seed potato sources in Njabini and Limuru in 2007 42

3.4 Percentage of farmers' growing different potato varieties in Njabini and Limuru in 2007 42

3.5 Percentage of farmers who used different potato production agronomic practices in Njabini and Limuru in 2007 43

3.6 Percentage of farmers' who used different pest and disease management methods in seed potato production in Njabini and Limuru in 2007 43

3.7 Percentage of farmers and their respective yield of Irish potatoes in 110 kg bags per acre in Njabini and Limuru in 2007 44

3.8 Percent incidence of different viruses in potato samples collected from farmers in Njabini and Limuru based on seed source 45

3.9 Mean virus titre in potato tuber samples that were harvested from seed potato from different sources in Njabini and Limuru 46

3.10 Mean virus titre in potato tuber samples from different agro-ecological zones in Njabini and Limuru 47

3.11 Pre-training and post-training questionnaires scores attained by farmers groups in Njabini and Limuru 49

4.1 Mean aphid species population per 3 leaves of a potato plant and per water pan trap in small-scale farms in Njabini and Limuru 68

4.2 Mean aphids' population per 3 leaves of a potato plant and per water pan trap in small-scale farms in Njabini and Limuru from the 3rd week after crop emergence 70

4.3 Mean % virus disease incidence in small scale seed potato farms during the short and long rain seasons from the 3rd week after crop emergence in Njabini and Limuru 72

4.4 Mean number of tubers per 10 plants for different potato grades harvested from healthy-looking and symptomatic plants from small scale farms in Njabini and Limuru during short and long rain seasons 74

4.5 Mean percentage change in number of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons 74

4.6 Mean weight of tubers per 10 plants in kg for different potato grades harvested from healthy-looking and symptomatic plants from small scale farms in Njabini and Limuru during short and long rain 75

4.7 Mean percentage change in weight of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons 75

4.8 Mean percent incidence of different viruses in potato samples harvested from healthy-looking and symptomatic plants in Njabini and Limuru 77

4.9 Mean titre of different potato viruses in tubers harvested from healthy-looking and symptomatic plants from small scale farmers during short and long rains in Njabini and Limuru 78

4.10 Correlation matrix among aphid population, disease incidence, virus titre and tuber yield for Njabini short rains 2006/07 and long rains 2007 80

4.11 Correlation matrix among aphid population, disease incidence, virus titre and tuber yield for Limuru long rains 2007 and short rains 2007/08 81

LIST OF APPENDICES

1 Weather data for Njabini during the experimental Period 122

2 Weather data for Limuru during the experimental Period 123

3 Agro-ecological zones in Njabini, Nyandarua district and Limuru, Kiambu district 124

4 Pre and post-training questionnaire and marking scheme used to determine farmers knowledge in training seed potato farmer groups in Njabini and Limuru 125

5 Procedure for carrying out double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) technique to detect potato viruses 127

6 Questionnaire for the field survey on management of aphids and aphid transmitted virus diseases in seed potato production in Njabini and Limuru..... 130

ABSTRACT

Small scale farmers contribute 99% of the seed potato produced and used in Kenya. Virus diseases cause degeneration of seed potatoes leading to low yields and low incomes to farmers. The study was carried out to determine the levels of aphids and viruses in farmer-produced seed potato system and to evaluate the associated yield losses. A survey was carried out to determine the seed potato practices among small scale farmers and the incidence of aphid transmitted potato aphid viruses in the farmer produced seed potato. Samples of potato tubers were collected from each farmer and analyzed for presence of viruses using DAS-ELISA test. On farm monitoring studies were carried out among farmer-based seed potato producers in Njabini and Limuru where 120 seed potato farmers from four seed potato producer groups were trained on identification and management of aphids and virus diseases in seed potato production.

Results of the study showed that 70% of farmers obtain seed potato from local markets and seed potato producing farmer groups. The main potato varieties grown in order of decreasing frequency in Njabini were Tigoni, Changi, Kimande and Mwezi Moja while in Limuru, Tigoni, Nyayo, Asante and Mwezi moja. Majority of the farm sizes are 1-5 acres and the area under potato was less than an acre per farmer. Most farmers applied fungicides for control of late blight but none had any knowledge of virus diseases and very few applied pesticides to manage insect pests. Only 22% of farmers in Njabini knew about existence of aphids in potato and none in Limuru. Most of the potato tuber samples were infected with potato leaf roll virus (PLRV) and potato virus S (PVS). Other potato viruses detected were potato virus M (PVM), potato virus X (PVX), potato virus Y (PVY) and potato virus A (PVA).

Aphid species identified were *Myzus persicae*, *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae* and *Rhopalosiphum maidis*. The most prevalent was *A. gossypii* and *M. euphorbiae*. Higher aphid population was detected using water traps.

Virus disease incidence was higher in Limuru than Njabini and the most prevalent virus was PVS followed by PLRV and PVM while the least prevalent was PVY. Healthy looking plants had a latent virus infection rate of 57.2% compared to 76.6% for plants showing virus symptoms. Healthy-looking plants yielded more and heavier tubers and virus infection reduced the number of tubers by between 10.0 to 35.5% while tuber weight was reduced by up to 63.0%. Training improved farmers' knowledge in management of aphids and potato viruses.

The results indicated that most farmers use virus-contaminated seed potato and that knowledge on potato aphids and virus diseases was non-existent. The results indicated high virus disease prevalence levels in the farmers' fields. Given that most farm holdings are less than 5 acres and that aphid management is not practiced, the spread of virus diseases among different farms could be very high. There is need to train farmers and agricultural extension staff in management of aphids and aphid transmitted viruses for increased potato yields. In addition, more studies on the rate of seed potato degeneration would be needed to determine the number of seasons a clean stock can be re-used for seed production without significant yield reduction.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Potato (*Solanum tuberosum* L) is the world's fourth important food crop after wheat, rice and maize (Gildermacher, 2006; FAO 2006). Potato is the second most important food crop after maize in Kenya (MOA, 2007; KARI 2007). There are approximately 500,000 growers in the country cultivating about 108,000 hectares (MOA, 2007). The annual production is over one million tons in two growing seasons. The Potato industry directly employs about 2.5 million people as market agents, transporters, processors, vendors, retailers and exporters (KARI 2007; MOA 2007). At the 2007 farm gate price of 25 shillings per kilogram, the farmers earned in excess of 25 billion Kenya shillings (MOA 2007).

There are 2 seed potato production systems in Kenya, formal and informal (MOA 2005, KARI 2007). The formal seed sector entails a certification process which was done under the ADC Seed Potato Project that had acquired equipments for grading (CIP, 2007). ADC was sole recipient of breeders' seed from Tigoni National Potato Research Centre for further multiplication to pre-basic and basic certified first and second generations (Anon, 1998; Anon, 2002; MOA 2007). Kenya Inspection Service which later converted to National Seed Quality Control Service and currently Kenya Plant Health Inspectorate Service is involved in all the stages of production by inspecting and certifying the seed. As a result of the programme, in 1982, there was increased production resulting in surpluses that rotted in the naturally ventilated seed potato stores (MOA 2005). In 1984, a severe drought led into serious seed potato shortage forcing the Agricultural Development Cooperation seed potato project to import seed to meet the short falls. To solve the problem of storing the surpluses, a cold storage complex was constructed at Molo in 1985 with a capacity of 2,250 tonnes to preserve seed potato prior to use (MOA, 2007). The highest capacity ever utilized amounted

to 1,500 tonnes per year compared to less than 100 tonnes per year in 2005 (MOA, 2007). Certified seed production distribution through KFA outlets went on until early 1990s when ADC farms were subdivided. As a result, the project started contracting out-growers.

In 1996 there was a failure of cooling systems of the cold store and all the potatoes stored worth about Kshs. 1.4 million rotted. ADC was unable to pay the out growers who then lost confidence in the project. To date the cooling system has not been repaired and the store has deteriorated (KARI, 2007). Some of the out growers have resorted to informal seed potato and ware potato production. Meanwhile the entire three ADC farms which were ADC Nyota, ADC Sirikwa and ADC Tall Trees located in Molo have all been hived off and subdivided leaving the project with only 300 acres from about 20,000 acres (MOA 2005). Similarly, KARI-Tigoni has also lost 180 acres from 240 acres in wrongful acquisition (MOA, 2005). KARI-Tigoni has now resulted to selling breeders seeds directly to the informal seed systems and a few in the formal sector. Those in the formal seed production sector register with KEPHIS for seed certification and constitute about one percent of the total seed potato suppliers in the country (KARI, 2007).

1.2 Problem statement and justification

Although the area under potatoes has been steadily increasing, production has not been increasing proportionately (MOA, 2007). Low productivity is reflected in low yields of less than 10 tonnes per hectare on average against a potential of 40 tonnes (Anon, 2002; MOA, 2007). This is attributed to inadequate certified seed and poor quality seed in the informal sub sector that contributes 99% of the seed in the country, pests and diseases and poor crop husbandry practices (Kinyae *et. al.*, 1994). The basic problem facing the potato industry is low productivity attributed to high losses due to pests and diseases, lack of adequate quantities of healthy planting materials, inadequate use of farm inputs, poor agronomic

practices, poor infrastructure, weak enforcement and regulatory mechanisms (Barton *et. al.*, 1997; KARI, 2006; MOA, 2007). Seed of most popular varieties has degenerated and need to be cleaned, multiplied and distributed to the industry (MOA, 2007). The quality of seed potato tubers is the most important yield-determining factor and also a major constraint to potato production in many potato-growing developing countries (Struik and Wiersema, 1999).

Other constraints in seed potato production include fluctuations in weather conditions particularly rainfall leading to seasonal oversupplies and shortages and inadequate irrigation infrastructure and limited access to investment capital (Semana, 2004). Others are inadequate land for rotation in research centres and in the seed production areas leading to high occurrence of diseases and pests especially bacterial wilt and viral diseases (Khurana, 2000; Kabira *et al* 2006). Low adoption of technology and poor farmer organization in production and marketing as well as depleted soil fertility are other constraints and challenges facing the seed potato industry. Inadequate replenishment of soil nutrients with appropriate fertilizers and soil amendments coupled with low level of public/private sector partnerships in research, extension and seed production add to the list of seed potato production constraints (MOA, 2007).

The informal seed potato production system is faced by lack of adequate and affordable certified seeds that are within the economic reach of small-scale farmers (Olubayo *et. al.*, 2004; KARI, 2006). Currently, a 50kg bag of seed potato costs ksh 1,950.00 at KARI-Tigoni and thus most small scale farmers cannot afford (Machangi 2003; MOA, 2007). Farmers therefore end up recycling the seed from previous harvests that is usually contaminated with diseases. This leads to further spread of seed borne viruses and other diseases contributing to low yields. This lack of awareness about the damage caused by aphids and aphid transmitted virus diseases in the informal seed potato production system contributes to low yields. The

capacity of farmers to manage aphids and seed potato virus diseases is very low (Kibaru, 2003, Olubayo *et. al.*, 2004). Most farmers are not even aware of these virus diseases that can cause yield losses of 10-100% (CIP, 2007).

1.3 Objectives of the study

The overall objective of the study was to determine the levels of aphids and viruses in farmer-produced seed potato system and to evaluate existing farmers' knowledge and the yield losses that occur due to these aphids and viruses.

The specific objectives were: -

i. To determine seed potato production practices among small-scale seed potato producers in Njabini and Limuru and to determine farmers' capacity to manage potato aphids and viruses and improve on it through training.

ii. To monitor the incidence of aphids and aphid transmitted virus diseases in small-scale seed potato production units and their effect on yield.

CHAPTER TWO

LITERATURE REVIEW

2.1 Potato production in Kenya

In Kenya Irish potato is the second most important food crop after maize (Ng'ang'a *et al.*, 1994; MOA, 2006). It was introduced during the late 19th century in Kiambu, Murang'a and Nyeri districts by European settler farmers initially for domestic consumption and later, for export (KARI, 2007). Indigenous Kenyan farmers started potato cultivation in 1920 and entered the export market in 1923. In 1963, the government of Kenya undertook to promote potato production in the country by introducing new varieties from Germany (KARI, 2007).

In 1967, a potato development programme was established to screen local varieties for yield and resistance to diseases and find solutions for potato production problems that were facing farmers. The programme was also expected to produce high quality seed of various varieties in sufficient quantities to satisfy the demand of farmers throughout the country (Walingo *et al.*, 2002). The government was also to support the programme with research facilities through establishment of a specific potato research station at Tigoni in Limuru with 3 sub-centres. These were Marimba in Meru North district, Marindas in Molo district and Njabini in Nyandarua district (MOA, 2006). In 1970, the area under potato cultivation was estimated at about 5,100 hectares with a production of 40,800 tonnes and an average yield of 8 tonnes per hectare (Were, 1996; Kabira *et.al.*, 2006; MOA, 2007).

In spite of these interventions, shortage of seed persisted because quantities of seed produced by the potato programme were small and did not reach all the farmers (Kabira 2006). At the same time, many farmers did not multiply the seed further but sold the harvested crop as ware

potatoes. To address the problem, the government established a commercial oriented seed potato production programme in 1979 under the Agricultural Development Cooperation (MOA, 2005). The sales activity was undertaken jointly with the Kenya Farmers Association (KFA). Promotion of the certified seed potatoes was done in collaboration with the extension service of the ministry of Agriculture while ADC operated naturally ventilated stores (MOA, 2006). Provision of disease-free seed tubers of high yielding varieties such as Tigoni, Kenya Baraka, Kerr's Pink, Nyayo, Asante, Dutch Robyn, Roslyn Tana, and Desiree is one of the major objectives of the seed research programme (KARI, 2007).

Irish potato is grown in Kenya highlands at altitude 1,500m – 3,000m above sea level where the annual rainfall is above 600 mm per annum with well-drained fertile soils with a pH of 5.5-6.0 and temperatures of 15-18°C (Kabira, *et. al.,* 2006; Gildemacher *et. al.,* 2006). The potato-growing areas include Meru, Kirinyaga Embu and parts of Laikipia. Other growing areas are Nyeri, Murang'a, Maragua, Thika, Kiambu and Nyandarua. Narok, Molo, Nakuru, Bomet, Uasin Gishu, Koibatek are other areas where potatoes are widely grown. In addition, South and North Nandi districts, Trans Nzoia, Mt. Elgon, Keiyo and Marakwet are popular areas of potato production in Kenya (MOA, 2007). Small acreages are cultivated in Kericho and Kisii highlands and isolated patches in the Taita hills of Taita districts (KARI, 2006; MOA, 2007).

According to the Ministry of Agriculture economic review, potato yields dropped from ten tons per hectare in 2003 to 8.1 tons per hectare in 2005 due to low quality seeds and widespread attack by bacterial wilt (MOA, 2006). In 2006, potato hectarage was 107,907 with a production of 984,596 tonnes and an average yield of 9.1 tonnes per hectare (MOA, 2007). This national average production level is therefore very low since it is possible to realize 40 tons/ha under research condition in the country (Kabira *et. al.,* 2006).

Potatoes are rich in carbohydrates, making them a good source of energy and have a protein content of approximately 2.1 percent on a fresh weight basis (Bradshaw *et. al.*, 1994). Potatoes have protein of fairly high quality, with an amino-acid pattern that is well matched to human requirements. They are also very rich in vitamin C - a single medium-sized potato contains about half the recommended daily intake (Horton, 1987). When compared on the basis of biological value, the nutritive value of potato is higher than that of maize, beans, soybean, peas and wheat (Bradshaw *et. al.*, 1994). Further, it can be profitably intercropped with most horticultural food crops grown in the highlands. Potatoes have a high production per unit of time because a farmer can grow three crops per year and a good rotation with barley, maize, wheat or cabbage (KARI, 2007). Potatoes require less energy, time, and are convenient to process into chips and crisps making it popular with both rural and urban inhabitants (Walingo *et al.*, 2004).

Irish potatoes play a major role in food security and the reduction of hunger (FAO 2006). The crop contributes to alleviation of poverty through income generation by providing employment opportunities in production, processing and marketing sectors. Being labour-intensive, the crop generates direct employment to 2.5 million people in production, marketing and processing sectors (KARI, 2007; MOA, 2007). Potato also has the potential as an industrial crop in the manufacture of starch, bar soap, alcohol and animal feeds. According to the 2005/06 annual report of the ministry of Agriculture, the production of Potatoes in Kenya is increasing due to the economic decline of competing crops such as maize, pyrethrum, and barley and an increased demand from Consumers, processors and exporters. The area under potatoes decreased by 11% during the year 2005/06 due to drought that prevailed in the first quarter. However production and value increased by 0.5% and 2.1% in the same period (Table 2.1). Prevalence of virus diseases and bacterial wilt in the smallholder farms negatively affected the production of the potato crop.

Table 2.1 Irish Potatoes Production 2005/2006 statistics in different provinces of Kenya

Province	Hectarage (Ha)		Production (MT)		Value (Kshs.)	
	2005	2006	2005	2006	2005	2006
Western	2,514	2,108	45,290	67,309	125,700	305,950,000
Central	59,720	39,728	331,772	275,764	2,171,600,000	2,146,840,000
Rift Valley	41,425	39,020	416,121	370,763	2,490,562,000	2,698,117,200
Coast	10	10	110	113	520,000	535,600
Eastern	27,116	21,451	187,123	230,802	857,581,245	918,415,000
Nairobi	25	505	247	700	4,360,000	9,000,000
Nyanza	1,220	2,086	19,650	39,145	6,679,342	632,500,000
Total	120,842	107,907	980,163	984,596	5,531,428,287	6,711,357,800

Source: Ministry of Agriculture, 2007.

2.2 Seed potato production and Marketing

There are two seed potato production systems in Kenya, formal and informal (MOA, 2006). Most small-scale farmers find it difficult to meet certification requirements due to the size of land required to economically meet the required three-year rotation (MOA, 2007). The same problem applies to potato breeding programme, which requires at least four years of rotation for breeders, pre-basic and basic seed production (KARI, 2007). The full implementation of the certification process involves registration, field inspection, lot inspection, sampling for pest control plots, labeling and sealing (Guyton, 1994; KARI, 2007).

The informal seed sector involves 'seed potato' production without going through the certification processes prescribed by the Seeds and Plant Varieties Act Chapter 326 (MOA, 2007_b). It includes unregistered growers and suppliers of seed mainly in their immediate localities. Following deficiencies in the formal systems, KARI improved on existing informal seed potato production system by providing breeders seed and advisory services for the small-scale farmers in the 1990s (MOA, 2007).

The informal seed system including farmer to farmer distribution supplies 99% of the estimated 300,000 tonnes required annually (Kinyae et. al., 1994; KARI, 2007). The informal seed production system encompasses seed production with involvement of Non Governmental Organizations (NGOs) and Community Based Organizations (CBOs). Other participants are private seed potato growers and individual farmers through seed plot technologies and positive selection (MOA, 2007). KEPHIS provides advisory services on high seed quality production practices on request (MOA, 2007). According to the Kenya gazette supplement no. 38 of 27th May 2005, the proportion of plants showing virus symptoms should not exceed 10%, 3% for bacterial wilt and 3% for nematodes in seed production (MOA, 2007$_b$). These current rules also set the standard weight of seed and ware potatoes of a specified variety to be 50 and 110Kg respectively as well as storage, transportation, processing and standards of crisps and chips that must be met by all the players in the potato industry (MOA, 2007b).

Potatoes are almost entirely marketed in the domestic market, which is liberalized with little government intervention (Walingo *et. al.,* 2004). Potato marketing chain is long and involves several players namely potato growers, transporters, wholesalers, processors, retailers and consumers (Ng'ang'a *et. al.,* 2002). The market information flow is controlled by brokers in urban markets and producing areas thus manipulating prices to the disadvantage of the grower (Walingo *et. al.,* 2004; MOA, 2006; KARI, 2007). Over 80% of commercially marketed potatoes go through brokers at both ends of the marketing channel. Potato supply normally follows the rainfall pattern and is a direct determinant of prices. Potato growers lack the ability to influence prices due to high perishability and lack of adequate storage facilities (MOA, 2007). The increasing demand for potatoes is linked to changes in consumption

habits, mainly in urban centres where chips production has become the major form of value addition for potatoes (Anton, 2004). The ministry of Agriculture disseminates market information particularly prices in major urban markets through the print media for ware potato but if farmers were encouraged to grow seed potato, the information can be captured and transmitted to other farmers as well (Anton, 2004).

In 2004, potato farmers in major growing areas started holding consultations and agreed to form a farmers association, Kenya National Potato Farmers Association (KENAPOFA; KARI, 2007). KENAPOFA is a member of the National Federation of Agricultural Producers (KENFAP). The priorities of association included underpayment for their potatoes due to lack of a standardized bag and shortage of certified seed potato. Other concerns were high incidences of diseases, poor infrastructure, and implicit multiple-taxation by local authorities and exploitation by brokers (MOA, 2007; KARI, 2007). The association has achieved some milestones which include review of the national policy on potato industry and development of an enforcement framework which culminated into a legal notice No. 44 as gazette supplement No.38 of 27th May, 2005 which provides rules and standards for seed and ware potatoes in regard to production, storage, grading, packaging, transportation, processing and inspection (KARI, 2007). The standard weight for seed potatoes of a specified variety shall be 50Kg and that for ware potatoes of a specified variety shall be 110Kg, (MOA, 2007$_b$).

2.3 Potato aphids

2.3.1 Importance of aphids' potato production

There are about 4,400 aphid species worldwide (Bernhard S. and Dixon F.G., 2005). The potato crop is susceptible to more than 300 pests and diseases (Horton, 1992). Important potato pests include aphids responsible for the spread of certain potato viruses including potato leaf roll virus spread by the green peach aphid, (*Myzus persicae)*, potato tuber moth

(*Phthorimaea operculella)* and root knot nematodes mainly (*Meloidogyne javanica)* and (*M. incognita)* (Bostan *et al.*, 2004). Important potato diseases include virus diseases, late blight disease caused by the fungus (*Phytophthora infestans)* and bacterial wilt caused by (*Pseudomonas solanacearum)* bacteria (Christine *et. al.*, 2001).

Aphids are the most economically important insect pests on potatoes worldwide (Anon, 2002, Braendle *et. al.*, 2006). Aphids infest the leaves, flowers, and sprouting tubers usually causing physical damage to the crop and also transmitting viral diseases. Aphids suck the hosts sap, weaken the plant and are efficient vectors of virus diseases (Kabira et. al., 2006). Aphids are the most important vectors of potato viruses (Erdal and Gulsen, 2005). Thirteen potato viruses are transmitted by aphids (Table 2.2) and especially by (*Myzus persicae)* (Robert and Bourdin, 2000). Aphids cause direct and indirect damage such as transmission of viruses to many crops, of which potato is the most important (Erdal and Gulsen, 2005). Since diseases caused by these viruses can be spread from season to season and from infected plants to healthy plants, control of aphids-borne viruses like PVY is difficult (KARI, 2007). Aphid colonies can easily be identified in the plants terminals and on the underside of leaves in the field (Kabira et. al., 2006). They also appear in tuber sprouts in storage where they transmit viruses to seed potatoes (Amir *et. al.*, 2003).

There are numerous types of aphids; their colours can vary for green to red. Aphids are a concern for commercial potato growers, but a bigger one for certified seed growers, since the diseases these pests transmit affect quality and yield (James and Bryce, 2006CIP, 2007; KARI, 2007).

The adult wingless form of the potato aphid (*Macrosiphum euphorbiae)* is large 1.7 - 3.6mm and an elongated pear shape. It ranges from light green, yellowish green to pinkish red. It often has a darker stripe down the centre of its back, especially in immature nymphs. This species has noticeably long legs and siphunculi at the rear end. The cauda is also long and finger shaped. The winged form is 1.7 - 3.4mm long, with a much less distinct central stripe. The antennae and siphunculi are darker than in the wingless forms.

The adult of the green peach aphid (*Myzus persicae)* is 1.0 - 2.1mm long, and varies considerably from yellow, through all shades of green, to pink, red and almost black. The siphunculi at the rear end of the abdomen are medium length and slightly swollen towards darkened tips. The winged form is 1.2 - 2.5mm long, with a black central abdominal patch on the upper surface, but a pale underside.

The cotton aphid (*Aphis gossypii)* has lateral abdominal tubercles on segments 1 and 7 well developed. Spiracles of abdominal segment 1 and 2 are widely separated and are placed on either side of the lateral abdominal tubercle. The body colour is usually green, olive, yellow, orange or black. The antennal tubercles are little developed or absent. The winged form has abdominal segments with more or less developed black transverse bars forming a black patch.

The black bean aphid (*Aphis fabae)* is 1.5 - 3.1mm long, usually sooty black or very dark olive green, with some individuals having distinct white waxy stripes on the upper surface of the abdomen. The siphunculi at the rear end are black, short and tapering slightly towards the tip. The cauda is black, blunt finger shaped and short. The antennae are about half the length of the body. The winged form is 1.3 - 2.6mm long, also very dark, with some barely discernible black cross-bars on the upper surface of the abdomen. *Aphis fabae* is known to transmit more than 30 viruses, mainly of the non-persistent variety (James and Bryce, 2006).

Large populations can cause significant secondary spread, even when it did not provide the initial primary infection. A by-product of such large colonies of aphid is contamination of the plant surface with sticky secretions, which promote the growth of sooty moulds. This superficial damage can reduce the sales value of the horticultural bean crops (MOA, 2007).

The corn leaf aphid (*Rhopalosiphum maidis)* is 1.0 - 2.5mm long and rather elongate with short antennae at adult stage. The body is usually blue-green to almost black, and sometimes appears dusted with wax. The siphunculi at the rear end are short and dark, and surrounded by a dark purple area at the base of each tube. The winged form is 0.9 - 2.4mm long and dark green in colour. The two tubes at the rear end are short and dark, and surrounded at their base by a ring of dark purple colour. There are no other major abdominal markings on the upper surface.

2.3.2 Ecology and host range of potato aphids

Aphid population is affected by both environmental and biological factors. Environmental factors include temperature, rainfall, nutrition and wind velocity. Biological factors include the fecundity of females, predation and whether the aphid colony is winged or not winged (Braendle *et. al.,* 2006). Aphid population is generally low in areas with low temperature, high rainfall and high wind velocity (Raman, 1985). Aphids exhibit complex life cycles. Approximately 10% of species alternate between a primary (usually woody) host plant and a secondary (herbaceous) host plant (Braendle *et. al.,* 2006). Non host-alternating species are usually monophagous but may feed on a range of related host plants (Hoffmann *et. al.,* 2001).

Aphid communities are subjected to predation by a broad range of specialist and generalist arthropod predators and parasitoids, whose number and variety fluctuate according to host plant species and phenology, season, and weather conditions. Natural enemies of aphids, such

as hoverflies (Gilbert, 2005), coccinellids, lacewings, (Verheggen *et al.*, 2007), midges, spiders (Lucas *et. al.*, 1998), and parasitoids are major components of the predatory guild associated with aphid colonies. Among these natural enemies, intraguild predation tends to be asymmetrical, with larger individuals acting as 'superpredators' and smaller individuals being the intraguild prey (Lucas *et. al.*, 1998). The effects of such interactions may lead to a stabilization of prey–predator populations (Verheggen *et al.*, 2007) or adversely affect foraging and oviposition performance of individual predators. The effect of predation by ladybird beetles on aphid population in potatoes has been evaluated (Birch *et. al.*, 1999).

Macrosiphum euphorbiae attacks over 200 plants including vegetable and ornamental crops as well as weeds. Cultivated food hosts include apple, bean, broccoli, burdock, cabbage, celery, Chinese broccoli, Chinese cabbage, corn, eggplant, ground cherry, lettuce, mustard cabbage, papaya, pea, pepper, potato, strawberry, sunflower, sweet potato, tomato, turnip, white mustard cabbage and zucchini (Francis *et. al.*, 2005; Alvarez and Srinivasan, 2005; Raki *et. al.*, 2008). Ornamental hosts are aster, Easter lily, gladiolus, iris and rose. Weed hosts, such as lamb's quarters, pigweed, ragweed, and shepherd's-purse serve as important reservoir hosts for the species (Nderitu, 1991; Saucke and Doring, 2004; Francis *et. al.*, 2005).

Green peach aphid (*Myzus persicae*) feeds on hundreds of host plants in over 40 plant families (Robert and Bourdin, 2000). However, it is only the viviparous (giving birth to living young) stages that feed so widely; the oviparous (egg producing) stages are much more restrictive in their diet choice (Flanders *et. al.*, 1991). Hosts include trees of the genus *Prunus*, particularly peach and peach hybrids, but also apricot and plum. Other hosts include vegetable crops in the families' solanaceae, chenopodiaceae, compositae, cruciferae, and cucurbitaceae (Flanders *et. al.*, 1991). Vegetables that are reported to support green peach

aphid include artichoke, asparagus, bean, beets, broccoli, Brussels sprouts, cabbage, carrot, cauliflower, cantaloupe, celery, corn, cucumber, fennel, kale, kohlrabi, turnip, eggplant, lettuce, mustard, okra, parsley, parsnip, pea, pepper, potato, radish, spinach, squash, tomato, turnip, watercress, and watermelon (Ming *et. al.*, 2007). Field crops such as tobacco, sugar beet, and sunflower also are attacked. Numerous flower crops and other ornamental plants are suitable for green peach aphid development. Stone fruit crops such as peach are sometimes damaged before the aphids leave for summer hosts (James and Bryce, 2006). Crops differ in their susceptibility to green peach aphid, but it is actively growing plants, or the youngest plant tissue, that most often harbours large aphid populations (CIP, 2006).

Aphis fabae has been recorded on almost 300 plant species (Raki *et. al.*, 2008). The principal commercial crops involved are field beans, broad beans and sugar beet, as well as most forms of garden bean. Some common summer wild hosts include docks, poppies, goosefoot and fat hen (Wyman *et al.* 1979). This species is a major pest on beans and sugar beet, occasionally at an epidemic scale, principally by causing direct feeding damage (Maren *et. al.*, 2002).

2.3.3 Biology of potato aphids

Aphids display a high reproductive rate due to three peculiarities of their reproductive biology (Verheggen *et al.*, 2007). First, during the spring and summer months, female aphids reproduce parthenogenetically, obviating the need for males. Second, during these parthenogenetic generations, the embryos initiate development immediately after the budding of the oocyte from the germarium and are born as fully developed first-instar nymphs. Third, the oldest embryos also contain embryos, so that adult parthenogenetic aphids carry not only their daughters but also some of their granddaughters within them. During the fall, declining daily photoperiod and temperature induce the development of sexual females and males.

These sexual aphids mate and females produce yolk-rich eggs that undergo diapause to survive the winter (Verheggen *et al.*, 2007).

Aphids characteristically have several parthenogenetic generations during summer, a single sexual generation in autumn, and overwinter as eggs. The parthenogenetic mode of reproduction in aphids is associated with the telescoping of generations, in which aphid embryos start developing in their grandmother and develop to an advanced stage inside their mother (Dixon 1998, Kindlmann & Dixon 2000), and results in rapid multiplication and facilitates the exploitation of short-lived resources. In addition, many species are highly polyphonic, with winged individuals specialized more for dispersal than reproduction and un-winged individuals more for reproduction than dispersal. That is, they show division of labor. Their prodigious rates of increase are unparalleled in other herbivorous insects.

Aphids feed on phloem sap, which is typically rich in sugars but low in nitrogen. As a consequence, aphids need to ingest large volumes of phloem sap—most of which is excreted as honeydew (Dixon 2000, Stadler *et al.* 1998; Blackman and Eastop, 2000). There is a clear North-South gradient in species richness, with relatively few species in the tropics (Hanafi, 2000). This geographic pattern is attributed to the small fat reserves, large investment in offspring, and high host-plant specificity of aphids. These life-history attributes greatly limit the amount of time aphids can spend searching for host plants. This in association with a high plant diversity in the tropics means that very few plants are abundant enough to host aphids (Hanafi, 2000).

Different species of aphid may exhibit wing dimorphism at various stages of the life cycle (Blackman and Eastop, 2000). The dimorphism could be environmentally induced dimorphism, known as polyphenism, or genetically determined dimorphism, known as polymorphism cycle (Blackman and Eastop, 2000). Wing polyphenism occurs primarily

among parthenogenetic females, while wing polymorphism has been found only in males (Blackman and Eastop, 2000). Most species of the Aphididae, however, produce both fully winged and completely wingless parthenogenetic females (Braendle *et. al.*, 2006). All potato-colonizing aphids have four nymphal instars. Their parthenogenetic lifestyle coupled by a rapid turnover of generations of seven to ten days allows for high population increases (Raman, 1985)

2.3.4 Factors affecting aphid population

Combinations of factors determine growth potential of an aphid population in a place (Salazar et. al., 2000). These factors include resources available which refers to the quantity and quality of the food, water, light, air, and space (Hazel *et. al.*, 2006). Climate or temperature affects aphids' population whether average, high and low, variation in temperature, wind velocity and direction and amount of rainfall (Nderitu, 1991; Braendle *et. al.*, 2006). Others include a situation whereby every organism is preyed upon by some others (James and Bryce, 206). Biological characteristics include birth rate, death rate, sex ratio of offspring, age of first reproduction and life span of individual insects (Salazar, 1996; Braendle et. al., 2006).

Aphid pests quickly adapt to changes in their environments by reducing different physical and biological forms (Ming *et. al.*, 2007). They produce winged forms which can be carried many miles by the wind to new food sources. They produce big fat fecund wingless females that give live birth to only female offspring, which in turn give birth to only female offspring, and on and on. They do this without males, by parthenogenesis. Once the food source dries up in the fall, they reproduce winged forms, this time male & female (Brunt, 2001; Braendle *et. al.*, 2006). These alates mate and females lay eggs that overwinter. Eggs may hatch in

spring into parthenogenetic females, the beginning of the new line, called "stem mothers" (Braedle *et. al.*, 2006).

The population of aphids is generally low in areas with low temperature, abundant rainfall and high wind velocity (Nderitu, 1983; Raman, 1985; Nderitu and Mueke, 1986; MOA, 2007). Host plant nutrition seems to affect the population of aphids. There has been considerable research on interactions between aphids and plant pathogens of economic interest (Christiansen *et. al.*, 2001). Winged *Myzus persicae* are more likely to be found on virus-infected sugar beet leaves than on healthy leaves because the nutritional quality of such infected plants appears to be increased (Christiansen & Hardie, 2000).

Although aphid-specific predators rapidly consume large proportions of aphids within a colony, a higher proportion of winged morphs may increase the probability of escaping from areas with high predator pressure (Francis *et. al.*, 2005). Only two studies have assessed the impact of ladybirds (*Coccinella septempunctata* and *Adalia bipunctata*) predation on wing induction in aphid colonies. Both studies showed that in the presence of ladybirds, pea aphid *A. fabae* colonies increased the production of winged morphs (Dixon & Agarwala, 1999) while such a response was not found for the often ant-tended *Aphis fabae* or the unpalatable *Megoura viciae* (Dixon & Agarwala, 1999). Wing morph production can thus be regarded, at least for pea aphids, as a predator-induced morphological defence of a colony (Christiansen *et. al.*, 2001). The mechanisms for such increases in wing induction are unclear but may be related to the physical contact between predators and aphids or between individual aphids arising from the release of alarm pheromone and disturbance caused by the predator (Christiansen *et. al.*, 2001).

Most species of aphid are attacked by hymenopteran parasitoids (Dixon & Agarwala, 1999). These parasitoids are solitary, endoparasitic, and attack young aphid instars. The parasitoids develop within the aphid, killing the host shortly before pupation. Such an intimate relationship involves the parasitoid larva interfering with the host's metabolism and physiology (Christiansen & Hardie, 2000; Brunt, 2001).

2.4 Potato virus diseases

Around 40 viruses have been reported to affect potato (Table 2.2) that can reduce yield and tuber quality by up to 100% (Mary and Zitter, 2005). Important virus diseases include Potato leaf roll virus (PLRV) transmitted in a persistent manner by the green peach aphid, *Myzus persicae* but also through infected seed tubers (X. Nie and Singh, 2001). Potato virus Y (PVY) transmitted in a non-persistent manner by the same aphid *Myzus persicae* as the most efficient vector as well as by other aphids such as *Aphis fabae, Macrosiphum euphorbiae* and *Rhopalosiphum insertum* (Saucke and Doring, 2004). Potato virus X (PVX) transmitted through infected tubers and by contact but not by aphids and Potato virus A (PVA) (Kabira. *et. al.*, 2006).

Virus diseases can often be diagnosed by mosaic patterns on leaves, stunting of the plant, leaf malformations, and tuber malformations (Nderitu, 1991; KARI, 2007). Symptoms are not always expressed due to interactions between the virus and the potato plant, growing conditions such as fertility and the weather, or the age of the plant when it is infected (Khurana, 2000; Mary and Zitter, 2005). A number of these viruses are spread by aphids and since the crop is vegetatively propagated, many pathogens including viruses such as potato leaf roll virus, potato virus X and potato virus Y, as well as potato spindle tuber viroid are disseminated in tubers (Khurana, 2000; Saucke and Doring, 2004). Some viruses like PVA,

may only have a minor effect on yield if they are the only infecting virus species and if a crop is newly infected in the field. However, if virus-infected seed tubers are used, the virus population will gradually build up during every crop cycle, both in number of co-infecting virus species and in amounts of infectious units per species (Rongai *et. al.*, 1998; Khurana 2000). This invariably leads to severely reduced plant vigour and a dramatic drop in yield. The important role that tubers play in virus and viroid spread is recognized by the strict requirements for certified seed potato production in many countries worldwide.

Some of these potato viruses have a wide adaptation and are efficiently transmitted through infected tubers such that they are found wherever potato is grown (Saucke and Doring, 2004). Most of such viruses are in the *Luteovirus, Potyvirus, Potexvirus* and *Carlavirus* groups, and constitute the most economically important viruses in potato production on a worldwide basis.

Table 2.2 Summary of transmission of viruses infecting the Irish Potato

Virus	Acronym	Group	Vector	transmission/spread
Potato virus A	PVA	Potyvirus	Aphids	Non persistent
Potato virus V	PVV	Potyvirus	Aphids	No persistent
Potato virus Y	PVY	Potyvirus	Aphids	Non persistent
Henbane mosaic virus	HeMV	Potyvirus	Aphids	Non persistent
Potato virus X	PVX	Potexvirus	Fungus	Mechanical contamination
Potato leafroll virus	PLRV	Luteovirus	Aphids	Persistent
Potato virus M	PVM	Carlavirus	Aphids	Non persistent
Potato virus S	PVS	Carlavirus	Aphids	Non persistent, contact
Potato virus T	PVT	Capillovirus	None reported	Infected tubers
Andean potato mottle virus	APMV	Comovirus	Beetles	Contact
Cucumber mosaic virus	CMV	Cucumovirus	Aphids	Non persistent
Potato mop-top virus	PMTV	Furovirus	Fungus	Fungal spores
Alfalfa mosaic virus	AMV	Alfalfa mosaic virus	Aphids	Non persistent
Tomato black ring virus	TBRV	Nepovirus	Nematodes	Contact
Potato black ring spot virus	PBRSV	Nepovirus	Nematodes	Contact
Tobacco rattle virus	TRV	Tobravirus	Nematodes	Contact
Beet curly top virus	BCTV	Geminivirus	Leaf hopper	Circulative
Potato yellow dwarf virus	PYDV	Rhabdovirus	Leaf hopper	Circulative
Solanum apical leaf curl virus	SALCV	Geminivirus	Leaf hopper	Circulative
Tobacco mosaic virus	TMV	Tobamovirus	Fungus	Contamination
Tobacco necrosis virus	TNV	Necrovirus	Fungus	Contamination
Tomato spotted wilt virus	TSWV	Necrovirus	Thrips	Propagative
Tobacco streak virus	TSV	Ilarvirus	Thrips	Propagative
Andean potato latent virus	APLV	Tymovirus	Beetles	Contact
Arracacha virus B	AVB	Rhabdovirus	None	Infected tubers
Egg plant mottled dwarf virus	EMDV	Rhabdovirus	None	Infected tubers
Potato aucuba mosaic virus	PAMV	Rhabdovirus	None	Infected tubers
Potato yellow vein virus	PYVV	Rhabdovirus	None	Infected tubers
Potato deforming mosaic virus	PDMV	Rhabdovirus	None	Infected tubers

Source: Mih and Atiri, 2000.

All potato viruses contain single-stranded RNA (Puurand *et. al.*, 1994). Depending upon the virus species, transmission can be mechanical through wounds, by a biological intermediary like aphids, or both. The most important vectors of potato viruses are aphids, and especially *M. persicae* (Syller, 2001). The most important virus diseases of potato are potato leaf roll virus (PLRV) and potato virus Y (PVY) both aphid transmitted (Were *et. al.*, 2003). Other aphid-transmitted viruses include potato virus A (PVA), potato virus M (PVM), and potato virus S (PVS) (Singh and Narwari, 1997; Syller, 2001; James and Bryce, 2006).

Potato viruses are transmitted either mechanically through implements, or through infected tubers or by aphids. Potato virus X and S are known to be transmitted mechanically. Tubers will transmit viruses to the next generation of the crop if they are infected (Nderitu *et. al.*, 1986; KARI, 2007). Transmission by aphids is either by non-persistent, semi-persistent or persistence manner (James and Bryce, 2006). Watson & Roberts (1939) coined the terms "nonpersistent viruses" and "persistent viruses" as a first attempt to categorize and understand plant virus vector transmission relationships (Watson & Roberts, 1939).

In the non-persistent transmission, acquisition and inoculation phases can be completed in a few minutes or seconds and there is no latent period (Salazaar, 1996). Viruses such as PVY, PVS and PVM are transmitted in this manner. The non-persistent viruses have very short retention times of 12 hours, which is the time the vector remained competent for virus transmission subsequent to acquisition (Forbes, 1977; Liu *et. al.*, 2002). For viruses that are transmitted to plants in nonpersistent and semipersistent manners, the vector mouthparts, in several cases, are the sites of virus retention (Backus, 1985; James and Bryce, 2006).

While in flight, aphids cannot distinguish and identify suitable host plants upon which they can feed and reproduce (Nault, 1977; Powel *et. al.*, 2006). Therefore, upon landing on a plant, aphids use their stylets to initiate several brief, shallow "sampling" probes that last for

a minute or less (Nault, 1977). The probes are mostly limited to the epidermal cells (Powel *et. al.*, 2006). During a period of brief probing on a virus-infected plant the epidermal cell plasma membranes can be punctured providing access of the stylets to cell contents and virions (Collar *et. al.*, 1997; Liu *et. al.*, 2002). Acquired virions can then be inoculated during subsequent probes on healthy plants (Powel *et. al.*, 2006). If after a few sampling probes the aphid determines that the plant is a non-host, it will leave the plant and repeat the process over and over until a suitable plant host is found. However, whether or not the plant is an aphid host is irrelevant in terms of virus transmission, for it is during the sampling probes that aphids can acquire and/or transmit viruses in a nonpersistent manner to plants (James and Bryce, 2006). Therefore, it is the non-colonizing aphids, probing and moving through non-aphid host plants, which are primarily responsible for the spread of non-persistently transmitted plant viruses (Collar *et. al.*, 1997; Syller, 2001; James and Bryce, 2006). Once a suitable host is detected, the aphid ultimately initiates longer probes in which stylets are directed toward a phloem sieve tube. Furthermore, if aphids select and stay on a host plant, they are less likely to move and probe, thereby reducing the amount of virus transmission (Powel *et. al.*, 2006).

Viruses transmitted in a nonpersistent manner include those in the genus Cucumovirus such as Cucumber mosaic cucumovirus (CMV) and Potyvirus such as PVY (Table 2.2). Viruses transmitted in a semi persistent manner include viruses such as Cauliflower mosaic caulimovirus (CaMV) and those in the family Closteroviridae such as Lettuce infectious yellows crinivirus (LIYV) (James and Bryce, 2006).

In persistent transmission, the virus is acquired and transmitted during feeding and the process of acquisition can take from 15 minutes to several hours (James and Bryce, 2006). After acquisition, aphids are unable to immediately transmit the virus; however, the aphid

remains infected for the rest of its life (Ballut *et. al.*, 2005). Persistently transmitted viruses are described as either persistently transmitted circulative or persistently transmitted propagative viruses (Nault, 1997). Persistently circulative viruses are those that remain in the gut of the vector but the virus particles do not multiply within the body of the insect (Gray and Gildow, 2003; Peiffer *et. al.*, 1997; Ballut et. al., 2005). For plant viruses that have persistent transmission relationships with their vectors, evidence suggests that virion release is indeed specific.

Viruses can be acquired and even circulate in aphids, but to be transmitted to plants they must be able to cross the selective barriers (basal lamina and basal plasmalemma) of the accessory salivary gland (Hogenhout *et. al.*, 2003). PLRV is the only virus in potato that is transmitted in a persistently circulative manner (Froissart *et. al.*, 2002).

Potato leaf roll virus (PLRV) is a member of the genus Luteovirus in the family Luteoviridae (Gildow and Gray, 1993; Salazar, 1996). PLRV is distinctive for its isometric particles of 25-30 nm in diameter, monopartite genome that is transmitted by aphids in a persistent manner. PLRV takes 10-30 minutes to be acquired and 24 to 48 hours to be transmitted by aphids but is mechanically non- transmissible (Hogenhout *et. al.*, 2003). In its host, the virus is restricted to the phloem tissue (Casper, 1988). The disease causes an abnormal accumulation of callose in the sieve tubes (Jonathan *et. al.*, 2008). The metabolic changes results in an inter-veinal chlorosis, rolled and leathery leaves and plant stunting. The severity of reaction of potato plants depends mainly on their varietal susceptibility and the effects of environmental conditions.

Other symptoms of PLRV include a characteristic upright character and rolling of the leaves, chlorosis or reddening, leaves with a leathery feel, phloem necrosis stunting of the plant, and net necrosis in tubers (Were *et. al.*, 2003; KARI, 2007; CIP, 2007). The severity of net

necrosis will vary depending on the variety and when the plant was infected, and may increase during storage (Hogenhout *et. al.*, 2003). The virus can reduce yield as well as quality of tubers by as much as 90% (Jonathan *et. al.*, 2008).

Potato virus Y (PVY) is one of the most prevalent and important viruses in potatoes. The worldwide distributed Potato virus Y family Potyviridae, genus Potyvirus is currently regarded as one of the main problems in seed potato production (Stevenson, 2001; Thomas et. al., 1997; Jonathan et. al., 2008). The virus consists of flexuous helically constructed particles 730x11nm. The virus has a thermal inactivation point of 55-60 °C, a dilution end point of 10^{-3} to 10^{-4} and longevity in vitro is 48-72 hours (Saucke and Doring, 2004). The virus is vectored non-persistently, mainly by alate aphids, with species dependent vector efficiency and most PVY vectors belonging to species that do not colonize potato (Thomas *et. al.*, 1997). Recently, strains of PVY which can cause necrosis have been discovered, creating more concern about this widespread virus (Jonathan et. al., 2008). It is transmitted by aphids in a non-persistent manner (Thomas *et. al.*, 1997). The virus can be acquired from the infected plant within seconds, and transmitted to a healthy plant just as fast. PVY can also be transmitted mechanically by machinery, tools, and damaging plants while walking through the field (Thomas *et. al.*, 1997). Several strains of PVY have been identified that differ by the symptoms they cause in potatoes and tobacco (Robert and Bourdin, 2000; Jonathan et. al., 2008).

Potato virus X (PVX), the type member of the Potexvirus group, is a flexuous rod-shaped virus of 13 nm by 510-520 nm in size. Viral capsid is composed of 25 kDa protein monomers that are packed in a helical array. Each virion contains a single-stranded, plus-stranded RNA genome of 6.4 kb (Huisman *et al.*, 1988). Though potexviruses are distributed worldwide and infect a wide range of host plants, PVX has a rather narrow host range (Kook, 2001).

It causes streak of tomato in combination with Tomato mosaic virus (Smith, 1972). Virus transmission occurs through mechanical contacts (Kook, 2001). PVX infection induces mosaic, necrosis, chlorosis, decreased leaf size, and necrotic lesions in tubers and or visible symptom depending on strains and host plant they infect (Lee *et al.*, 1977). When PVX is co-infected with Potato virus Y (PVY), it caused severe symptom development (Kook, 2001). PVX is transmitted mechanically and can cause losses of 10-15% (Salazar, 1996; Kook, 2001).

Potato virus S (PVS) is a Carlavirus, with straight to slightly curved filamentous particles of 12 x 650nm (De Bokx, 1981). Aphids, including Myzus persicae, the green peach aphid, non-persistently transmit it. It is also mechanically transmissible, and transmissible through tubers. (PVS) is of increasing importance in potato (Wenzl, 1980). Most potato cultivars are symptomless (Salazar, 1996). Some cultivars, if infected early in the season, will show a slight deepening of the veins, rough leaves, more open growth, mild mottling, bronzing, or tiny necrotic spots on the leaves. PVS can cause yield loss up to 20% (Wenzl, 1980).

Potato virus A is a Potyvirus and is one of the most widespread potato viruses and is found in most potato growing areas (Robert and Bourdin, 2000). Particles are flexuous filaments with normal length of 730 nm and diameter of 15 nm. Aphids transmit it in a non-persistent manner. Symptoms include a mild pattern of yellowish or light green patches alternating with patches of very dark green are present on most potato cultivars. The patches vary in size and can cross veins. The leaf surface is usually rougher than normal. Edges of infected leaflets may be slightly crinkled or wavy. Infected leaves usually look shiny (CIP, 2007). The stems of the plant bend outward, giving the plants an open look. Tubers are usually unaffected, except for a slight decrease in size. Sap-transmission without abrasive is usually difficult because of low virus concentration (Robert and Bourdin, 2000; Jari, 2001).

Potato spindle tuber viroid (PSTV) is not a virus. It is a viroid, which is essentially a self-replicating RNA, without a protein coat (Thomas *et. al.*, 1997). PSTV is an important disease in breeder stock, where it is often transmitted mechanically, as well as through pollen and true seed. It causes mild foliar symptoms including smaller leaves that curl downward, giving the plant a more upright growth habit. Plants can also be stunted, and leaves can be grey and distorted (Hogenhout *et. al.*, 2003). The stems are often more branched, with the branches having sharp angles on the stem. Tubers are narrow and spindle or oblong in shape, or more rounded than expected for a particular variety, and have prominent eyebrows. Tubers can also become cracked or develop knobs and swellings. PSTV can also infect tomato and nightshade (Syller, 2001; Jonathan *et. al.*, 2008). Farmers were found to have very little knowledge on virus management in seed potato production.

2.5 Detection and quantification of potato viruses

Accurate diagnosis of disease causing agents is an essential prerequisite for effective control. These methods include Indicator hosts, electron microscopy, enzyme-linked immunosorbent assay (ELISA), polymerase chain reaction (PCR), reverse transcription polymerase chain reaction (RT-PCR), nucleic acid hybridization, and bioassays (Kane *et. al.*, 2000; Boonham *et. al.*, 2003). When presented with a symptomatic plant with unknown aetiology, often a number of different methods are executed in parallel to reach a final diagnosis (Tan *et. al.*, 2000; Nie and Singh, 2001). Some 'multi target' generic assays have been used for plant virus diagnosis but most are suitable for a limited range of targets and each method has a number of drawbacks (Boonham *et. al.*, 2003).

Electron microscopy has been used for many years as a 'multi target' assay. Virus particles can be seen with the use of an electron microscope (EM). Plant sap containing virus particles

is prepared and put into an electron microscope and examined for virus particles (Thomas *et. al.*, 1998). There are several basic shapes that virus particles take which are diagnostic for the virus (Nie and Singh, 2001). However, although very useful for detecting and discriminating rod shaped particles, often the presence of spherical viruses is very difficult to confirm (Boonham *et. al.*, 2003). Detection of viral coat protein using methods such as Matrix Assisted Laser Dissorption Time of Flight (MALDI TOF) mass spectrometry have been reported for a number of viruses (Thomas *et. al.*, 1998) and can be described as a generic. However, both electron microscopy and matrix assisted laser dissorption are not suitable for viruses that do not have a protein target, for example viroids or NM isolates of *Tobacco rattle virus* (Nie and Singh, 2001), and both are useful only if the viruses are in a very high titre.

Microarray technology allows the detection of a large number of different viruses in a single generic assay (Boonham *et. al.*, 2003). Up to 30 000 DNA probes can be arrayed onto a single glass microscope slide, which forms the microarray. The DNA probes arrayed would be gene sequences from each of the viruses that need to be detected in a single assay. The microarray is then exposed to fluorescently labeled cDNA from the sample to be tested, and finally scanned using a microarray scanner to reveal if any of the targets were present in the sample (Boonham *et. al.*, 2003).

Assays based on infectivity can also be described as multi target, however, no 'universal' indicators exist for all viruses and many viruses are not transmissible mechanically (Kane *et. al.*, 2000). In addition, all of these methods have a basic drawback in common since each is based on a property that is common at the genus level for particle morphology, coat protein size or local lesion host (Tan *et. al.*, 2000). Diagnosis to species requires further testing with another method. A single 'multi target' method that could be used to test for a full range of

organisms in a totally generic format would streamline and standardize a significant portion of diagnostic testing currently carried out (Hoffmann *et. al.*, 2001).

Viruses can be purified and the purified virus injected into a mammal such as a rabbit (Borghesi and Milcarek, 2006). The inoculated animal will make antibodies to protein coat of this virus (CIP, 2007). The animal is bled and the serum (antiserum) that results can used to detect plant viruses. Serological tests and notably the enzyme-linked immunosorbent assay (ELISA) are used to detect and quantify potato viruses (CIP, 2007). ELISA test is carried out on a batch of individual samples (tubers or leaves) collected from the field in order to give an accurate estimation of the field plot infection level (KARI, 2007). This estimation, compared to a predetermined tolerance level, will lead to the acceptance or rejection of the field plot in the frame of the seed potato certification process (Chandelier *et. al.*, 2001).

2.6 Management of potato viruses

There are three general approaches to the management of potato viruses. These include eliminating the source of the virus, preventing aphids from spreading the virus, and using resistant varieties (Guyton *et. al.*, 1994; Were *et. al.*, 2003). Eliminating the source of the virus involves planting virus free seed and destroying volunteer potatoes and eliminating cull piles (KARI, 2007; CIP, 2007). Roguing early in the season by removing infected potato plants from the field before there is a risk of virus spread minimizes the risk of a virus infection in the field (Nderitu, 1983). Weed control measures should be addressed since weeds act as alternate hosts to potato viruses. Weeds such as wild rose, wild mustard and wild radish are hosts of aphids on which large populations can develop (Difonzo *et. al.*, 1995). For tuber transmitted viruses like PVX, there are no chemical control measures for these viruses. Unnecessary handling of plants and contact between disease-free tubers and those that are potentially carrying the disease should be avoided (James and Bryce, 2006).

The disease can also be spread by handling the plants and by tools such as planters and knives. Make sure that hand tools are cleaned frequently while working, and that equipment is cleaned thoroughly between different areas. For PVS infection, plants must be infected early in the season for the disease to occur, since most cultivars are naturally resistant as mature plants (Wenzl, 1980).

Preventing the aphids from spreading the virus is another approach to manage aphid-transmitted viruses such as PVY, PLRV, PVA and PVS (Were et. al., 1996). Cultural practices such as planting early to avoid heavy aphid times or planting in areas where aphid population is low (Woodford and Gordon, 1990). In most cases the control of aphids is an indirect management of these viruses that are transmitted by aphids (CIP, 2007). Control of aphids by insecticides has in some occasions led to reduced virus infections in potato production (Kabira et. al., 2006). Fast acting insecticides may be of use by rapidly reducing aphid populations thereby reducing within season spread. Chemical control is not always completely effective when viruses are transmitted in a non-persistent manner, as the aphids can infect many plants before the insecticide is able to kill them (Were, 1996; Hanafi, 2000). Over-reliance on insecticides has also been shown to cause insecticide resistance (Rongai *et. al.*, 1998). An oil spray can be used to prevent aphids from transmitting the virus while they feed (Pirone 1996; Powel *et.al.*, 1998; Kibaru, 2003).

The use of oil sprays may reduce the transmission of aphid-transmitted viruses from one plant to another by "washing" the stylet of probing aphids (Rongai *et. al.*, 1998). Planting seed certified through a recognized seed potato inspection program reduces viral spread (KARI, 2007). Field readings and post-harvest test results may be used as guides to select seed lots with the lowest virus levels (CIP, 2007). Other measures of preventing aphids from spreading the virus include avoiding planting seed potatoes downwind from commercial fields

(Harrewijn, 1989) and dehaulming early to prevent late-season virus infection (Hanafi, 2000; KARI, 2007; CIP, 2007).

The successes of chemical control methods depend on the ability of aphids to acquire resistance against insecticides (Were et. al., 1996). The spray programme should be timely and with different chemicals to reduce chances of aphids gaining resistance (Nderitu and Mueke, 1986, Rongai et. al., 1998). Seed potato plots should also not be located upwind of commercial potato plots as this would increase aphids being blown by the wind towards the seed plot (Raman, 1985). However, repeated applications of certain carbamate insecticides within intervals of a week or less deter aphid buildups (Nderitu, 1991; Maren *et. al.*, 2002).

Differences in susceptibility of some potato clones have been noted (Nderitu and Mueke, 1986; Were et. al., 1996; Luiza, 2006). However cultivars that have some degree of aphid resistance may be of little value. This is because frequent probing could be stimulated, which is unfavorable with regard to the dispersal of non- persistent viruses (Harrewijn, 1989).

Hairy nightshade, *Solanum sarrachoides*, is one of the preferred weed hosts for green peach aphid (Alvarez *et. al.*, 2005). With the use of double antibody sandwich enzyme-linked immunosorbent assay, it was confirmed that green peach aphid can transmit PLRV to hairy nightshade and that aphids can become viruliferous after feeding on infected hairy nightshade plants (Alvarez and Srinivasan, 2005). Transmission from hairy nightshade to potato is 4 times the rate of potato to potato or potato to hairy nightshade. The green peach aphid preferred hairy nightshade to potato plants and reproduced at a higher rate on hairy nightshade than on potato (Alvarez *et. al.*, 2005).

Virus diseases persistently transmitted by the green peach aphid require considerable time for acquisition and transmission; insecticides can be effective in preventing disease spread in

some crops. Research in Minnesota (Flanders *et al.* 1991) showed that potato leafroll virus was transmitted within the potato crop principally by wingless aphids moving from plant to plant. Infected seed potatoes are the principal source of leafroll in most potato crops, so planting disease-free seed is obviously an important step in minimizing the incidence of the disease. Growers commonly inspect fields for signs of disease, and remove and destroy infected and nearby plants, a process called "rouging." This procedure reduces the ability of aphids to spread disease from plant to plant. Insecticides may not keep winged aphids from alighting in a crop and quickly transmitting non-persistent virus, but they can certainly prevent the secondary spread of virus within a crop by colonizing aphids. As is the case with other aphids, however, insecticide resistance is a severe problem in many areas. Application of mineral oil (Lowery et al. 1991; Kibaru, 2003) and use of aluminum or white plastic mulch (Wyman *et al.* 1979) reduce virus transmission. Aphids that are not effectively repelled by reflective mulch seem to thrive on mulched crops and exhibit high rates of reproduction (Lowery *et al.*, 1991).

Coating the foliage with vegetable or mineral oil can sometimes reduce transmission of non-persistent viruses such as cucumber mosaic virus. Oil is postulated to inhibit virus acquisition and transmission by preventing virus attachment to the aphid's mouthparts, or to reduce probing behavior (Paola *et. al.*, 2005). Oil seems to be most effective when the amount of disease in an area that is available to be transmitted to a crop is at a low level. When disease inoculum or aphid densities are at high levels, oils may be inadequate protection (Paola *et. al.*, 2005).

With each successive planting, the quality of the seed stock degenerates until yields are so low that growers have to buy clean tubers (Erdal and Gulsen, 2005; Kabira *et. al.*, 2007). Infections can be avoided by planting healthy seeds and maintaining recommended field

sanitation practices such as rouging (Christine *et. al.*, 2001, Erik *et. al.*, 2006; KARI, 2007). Young plants are more susceptible to viral infections (Robert and Bourdin, 2000). It is recommended that seed potatoes be cultivated in areas where only a few aphids occur and keep the fields free of aphids particularly early in the season (Semana and Mwebesa, 2004)

CHAPTER THREE

SEED POTATO PRODUCTION AND INCIDENCE OF POTATO VIRUSES AMONG SMALL SCALE POTATO FARMES IN KIAMBU AND NYANDARUA DISTRICTS

3.1 Introduction

Irish potato is the second most important food crop after maize in Kenya (Ng'ang'a *et al.*, 2002; Anon, 2002; MOA, 2006). The formal seed potato supplies 1% of seed potato and informal system supplies 99% of seed (KARI, 2007). The formal seed potato system is focused mainly towards serving large-scale potato growers with little support the small-scale producers who are now the majority potato producers in the country (MOA, 2006).

The main problem of the informal seed system is lack of adequate and affordable certified seed potatoes within the reach of small-scale farmers (Kinyae *et.al.*, 1994; Were, 1996). The farmer based seed potato production is an attempt to alleviate the scarcity of good quality seed potato to the small-scale farmers (Olubayo *et. al.*, 2004). However, non-availability of quality seeds and inadequate production technologies for smaller holder farming has contributed to below potential potato production (Semana and Mwebesa, 2004; Salazar, 2004; MOA, 2006). This is due to the farmers' inability to manage aphids and aphid-transmitted virus diseases that reduce both the quality and yield of seed potato by as much as 70-90% (Khurana 2000, Kibaru *et. al.*, 2004). Important viruses include Potato leaf roll virus, Potato virus X, Potato virus M, Potato virus S, Potato virus A and Potato virus Y (Thackray *et. al.*, 2002; Grit *et. al.*, 2005).

Potato viruses cause both quantitative and qualitative losses (Khurana, 2000). PLRV and PVY have the potential to reduce yield by 60-80% while viruses like PVX, PVS and PVM depress yields by 10-30% (Bostan and Haliloglu, 2004). The quality of seed potato is reduced

when viruses latently infect it. Virus free seeds are also rapidly infected when planted in a field with infected volunteer plant and high aphid population Salazar, 1996). In mild infections exhibited by viruses such as PVX, PVA PVS and PVM, crop losses are apparent only when about 15% of the plants are infected (Khurana, 2000). If the seed stocks are not maintained well while in the field and during storage, virus infections may reach 100% in three to four successive crops (Kakuhenzire, 2000).

Potato farmers source their seed from local markets, neighbors, and farmer groups and from KARI (KARI, 2007; MOA, 2006). Most farmers are not able to buy clean seed from KARI (Walingo *et. al.,* 2004). Farmers therefore end up recycling the seed saved from previous harvest, which might be contaminated with viruses among other seed borne pathogens (Ng'ang'a *et. al.,* 2002).

Objectives

The main objective of this study was to determine the types and levels of viruses among small-scale seed potato farms and improve farmers' capacity to manage them.

The specific objectives were:

i. To survey for agronomic practices in seed potato production and management of aphid-transmitted viruses among small-scale seed potato producers in Njabini and Limuru.

ii. To determine farmers knowledge on management of aphids and potato virus diseases.

3.2 Materials and methods

3.2.1 Experimental sites and administration of survey questionnaires

Survey was carried out in two major seed potato growing districts of Nyandarua and Kiambu in the short rains 2006, long rains 2007 and short rain 2007. In each district, three different agro ecological zones were randomly selected. In south Kinangop division of Nyandarua south district the survey covered agro-ecological zones upper highland one (UH1), upper highland zone two (UH2) and upper highland zone three (UH3) while in Limuru the zones covered by the survey were upper highland one (UH1), lower highland one (LH1), and lower highland two (LH2) (Appendix V). Fourty small-scale seed potato farmers were selected from each district through the assistance of the agricultural extension officers. Structured questionnaires were administered to each of the eighty farmers in Njabini and Limuru. The information obtained included total farm acreage and the proportion of acreage under potato production, major sources of seed potato for the farmers, major varieties of potato grown in the two districts, types and amounts of manures and fertilizers used in seed potato production, viruses infecting the tubers and yield. One-kilogram sample of tubers from each farm was collected in a brown paper bag for virus testing.

3.2.2 Determination of types and amounts of viruses in seed potato tubers

DAS-ELISA kits were obtained from the International Potato Centre (CIP) and the DAS-ELISA analysis was carried out at the Kenya Agricultural Research Institute – National Agricultural Research Laboratories (KARI-NARL). A total of six viruses namely, potato leaf roll virus (PLRV), potato virus X (PVX), potato virus S (PVS), potato virus M (PVM), potato virus Y (PVY), and potato virus A (PVA) were assayed.

Three to five (or 0.5g) potato sprouts were taken from each sample of the tubers and put into a plastic bag. Four times the volume (or 2.0g) of the sample weight of extraction buffer was

added. The samples were then completely homogenized. Coating of each microtitre plate was done by mixing 35 µl of antibody (IgG) of the virus to be detected with 10 ml of coating buffer. To perform simultaneous detection of all the six viruses, 35 µl of each virus antibody was added to 10 ml of coating buffer. Then 100 µl of the coating solution was added to each well in the plate. The plates were incubated at 37°C for 3-4 hours.

The plates were then emptied and dried immediately with absorbent paper. The wells were then filled almost up to the top with PBS-T and then soaked for three minutes and drained. This procedure was repeated three times until the plates are completely clean.

Then 100 µl of the sample extract was added to each well with at least two wells being left as controls by adding 100 µl of extraction buffer alone. The plates were sealed and incubated at 4°C overnight. The plates were then washed with washing buffer three times. Then for each plate, 35 µl of each conjugate antiserum (IgG-AP) was mixed with 10 ml of conjugate buffer. The corresponding IgG-AP was used for the virus to be detected and whose IgG has been used to coat the plate. Then 90 µl of the conjugate solution was added to each well of the plate and incubated at 37°C for 3-4 hours (Table 3.1).

After incubation, the plates were washed using washing buffer three times. Then 80 µl of the substrate solution was added to each well and left for 30-60 minutes at room temperature. The positive reaction was observed as a yellow colour and the colour intensity was determined with a spectrophotometer (Elisa reader) at 405 nm wavelength. The amount of virus in each sample was determined according to the relationship $x \geq \bar{y} + 0.05$ where x = Positive sample, $\bar{y}$ = Average value of healthy controls and 0.05 = standard deviation (appendix VII).

Table 3.1 Chemical composition of buffers used in DAS-ELISA analysis

Buffer	Chemical composition
Coating buffer	0.2g Na_2CO_3, 0.44g $NaHCO_3$ 0.03g NaN_3 and 30.0 ml distilled water; pH 9.6
Phosphate Buffer Saline (PBS)	8.0g NaCl, 0.2g KH_2PO_4, 1.15g Na_2HPO_4, 0.2 KCl, 0.195g NaN_3, 1.0 litre distilled water
Tween	Tween 20
Washing buffer (PBS-T)	1 litre PBS + 0.5ml. Tween at pH 7.4
Extraction buffer	4.0g PVP-40,000, 2.0g egg albumin
Conjugate buffer	0.4g PVP-40,000, 0.04g egg albumin
Conjugate solution	Conjugate buffer + corresponding IgG
Substrate buffer	17.46 ml Diethanolamine, 9.6 ml distilled water and 2.4 ml HCl (37%)
Substrate solution	180 ml. substrate buffer + 18 substrate tablets

Source: International Potato Centre (CIP), 2006

3.2.3 Determination of farmers' knowledge on management of potato viruses

Training was conducted to 120 farmers belonging to four existing seed potato producer farmer groups in Nyandarua and Kiambu districts. Two of the four farmer groups were in Nyandarua district and the other two were in Kiambu district. The groups were selected with the help of extension staff of the Ministry of Agriculture and KARI. The groups were selected on the basis of active participation in seed potato production. Each farmer group was trained twice at early crop growth and at harvesting. The trainers included Ministry of Agriculture extension staff, technical staff from KARI and University of Nairobi and lecturers from the University of Nairobi. At the start of training in each group, a

questionnaire was administered to determine the level of knowledge on aphids and potato virus management before training was done. Each question was given a score such that the total maximum score was 20 (Appendix III). The same questionnaire was administered at the beginning of the second training to determine the level of improvement in farmers' knowledge on potato virus recognition and management. The first training was on recognition and management of potato aphids and viruses and the second training was on determination of the effect of virus diseases on tuber yield. The first training was carried out when the crop was at flowering stage.

The trainings were participatory and conducted on farms where there was a potato crop with visible virus symptoms. The farmers were trained on potato aphids' recognition, recognition of virus-infected plants, management of potato aphids and viruses and positive selection of potato plants for seed production. The effect of virus disease on yield was demonstrated by asking the farmers to mark 20 healthy and 20 virus infected plants at crop flowering. At harvest, each of the marked plants was harvested separately. The farmers determined the number and total weight of tubers.

3.2.4 Data analysis

The data was analyzed using GENSTAT computer programme by subjecting it to one way analysis of variance (ANOVA) for equal sample sizes as dictated by tests of normality homogeneity of variance. The separation of means was done using the Fisher's protected Least Significant Difference method (LSD) at 5% confidence interval. Correlation of data variables was analyzed by Pearson's Product Movement method at 5% significant level using the Statistical Package for Social Scientists (SPSS).

3.3 Results

3.3.1 Seed potato production practices among small scale farms

The farm sizes were established to be between 0.125 and 20 acres and the farmers in Njabini had bigger land sizes compared to their counterparts in Limuru (Table 3.2). More farmers in Njabini had bigger land acreage put under Irish potato production than Limuru. Majority of farmers in both Njabini and Limuru had between one and five acres of land and this was more prominent in Njabini at 75% compared to 57.5% of farmers in Limuru. The proportion of farmers with more than 10 acres of land was higher in Njabini at 7.5% than in Limuru at 5%. In addition majority of farmers had seed potato plots of less than one acre in both Njabini and Limuru while there was no farmer in either Njabini or Limuru with potato plots of more than six acres even where a farmer had as much as fourty acres of total land (Table 3.2).

The survey revealed that farmers sourced seed potato from KARI, local markets and farmer seed producer groups. Majority of farmers sourced their seed potato from local markets, which included their immediate neighbours. Farmers who sourced seeds from KARI and Farmers groups were equal in number but less than those who sourced seed potato from local markets (Table 3.3).

The potato varieties grown were Tigoni, Asante, Nyayo, Changi, Kimande, Mwezi moja and Desiree. The most common variety was Tigoni followed by Nyayo while the least grown was Desiree. More farmers in Limuru grew Asante, Nyayo, Desiree and Mwezi moja than those in Njabini. On the other hand more farmers in Njabini grew Kimande and Changi varieties compared to Limuru. All farmers were growing Tigoni variety while Desiree variety was not being grown in Njabini (Table 3.4).

Most farmers applied D.A.P fertilizer during planting and practiced crop rotation (Table 3.5). Farmers in Njabini planted potatoes throughout the year because there is always enough moisture to sustain the crop as opposed to farmers in Limuru who plant twice in a year during the long and short rains seasons. All farmers in Njabini practiced crop rotation but not all farmers in Limuru did the rotation. Most farmers in Limuru and Njabini applied fungicides to control late blight but very few farmers controlled virus diseases and applied pesticides to control aphids. No farmer had any knowledge of symptoms of virus infection in potato crop and very few had seen aphids on potato (Table 3.6). Potato yields in both areas surveyed averaged between 10 to 40 bags per acre (Table 3.7).

Table 3.2 Percentage of farmers' with different sizes of whole farms and seed potato plot sizes measured in acres in Njabini and Limuru in 2007

Farm acreage	Njabini	Limuru
<1	0.0	22.5
1 - 5	75.0	57.5
6 - 10	17.5	15.0
>10	7.5	5.0
Potato plot acreage	**Njabini**	**Limuru**
<1	70.0	87.5
1 - 5	30.0	12.5
6 - 10	0.0	0.0
>10	0.0	0.0
% land devoted to seed potato production	18.2	11.2

Table 3.3 Percentage of farmers' and their different seed potato sources in Njabini and Limuru in 2007

Seed potato source	Njabini	Limuru
KARI	32.5	30.0
Local market	37.5	40.0
Farmers seed potato producing group	30.0	30.0

Table 3.4 Percentage of farmers' growing different potato varieties in Njabini and Limuru in 2007

Variety	Njabini	Limuru
Tigoni	100.0	100.0
Asante	5.0	32.5
Nyayo	2.5	42.5
Changi	42.5	2.5
Kimande	37.5	2.5
Mwezi moja	7.5	25.0
Desiree	0.0	5.0

Table 3.5 Percentage of farmers who used different potato production agronomic practices in Njabini and Limuru in 2007

Activity	Njabini	Limuru
Use DAP fertilizer	92.5	52.5
Use cow manure	67.5	47.5
Use both cow manure and DAP	30.0	27.5
Use sheep manure	15.0	5.0
Use cow + sheep manure mixed	17.5	0.0
Use Chicken manure	0.0	15.0
Use cow + chicken manure mixed	0.0	17.5
Use foliar feed	12.5	0.0
Did not apply any manure or fertilizer	0.0	0.0
Dehaulm before harvest	27.5	50.0

Table 3.6 Percentage of farmers' who used different pest and disease control methods in seed potato production in Njabini and Limuru in 2007

Activity	Njabini	Limuru
Seen aphids in potato crop	22.5	0.0
Control aphids	2.5	0.0
Know virus symptoms	0.0	0.0
Apply insecticides	2.5	0.0
Control cutworms	0.0	2.5
Control potato tuber moth	0.0	5.0
Apply fungicides	85.0	57.5
Practice crop rotation	100.0	87.5
Know virus symptoms	0.0	0.0
Bacterial wilt present	57.5	27.5
Control late blight	85.0	57.5

Table 3.7 Percentage of farmers and their respective yield of Irish potatoes in tons per acre in Njabini and Limuru in 2007

Yield	Njabini	Limuru
< 1.65	7.5	15.0
1.65 – 3.30	72.5	62.5
3.41 – 4.40	20.0	20.0
> 4.40	0.0	2.5

3.3.2 Contamination of farmer-produced seed potato tubers with viruses

Tubers collected from farmers' stores during the survey in Njabini and Limuru were found to be contaminated with all the six viruses tested. These viruses were potato leaf roll virus (PLRV), potato virus X (PVX), potato virus S (PVS), potato virus M (PVM), potato virus Y (PVY), and potato virus A (PVA). The most encountered viruses were PVS and PLRV, (100% incidence), followed by PVX (Table 3.8). The least encountered potato virus was PVA and PVY with incidences of 39% and 49.7% respectively. The viruses were more prevalent in Njabini an average of 73.9% of the samples being positive compared with Limuru with average prevalence of 58.1%. Although the incidence of viruses was higher in Njabini than Limuru, the virus titre was higher in samples from Limuru (Table 3.9).

There were significant differences ($P \leq 0.05$) in the amount of potato virus Y between samples from Njabini and those from Limuru. However, potato samples from Njabini had significantly ($P \leq 0.05$) higher titre of PVM than samples from Limuru. There were no significant differences in virus titre of the different seed sources though samples in which seed potato was obtained from KARI had lower virus titre than for seed sourced from local

markets and seed farmer groups. The virus titre in samples from Limuru was more than that in samples from Njabini for farmers who had sourced seed potato from local markets (Table 3.9). There were no significant differences ($P \leq 0.05$) in the virus titre among samples from different agro-ecological zones for samples from Nyandarua and Kiambu districts (Table 3.10). However, there were significant difference in the mean of potato virus M (PVM) and potato virus Y (PVY) titre between samples from Njabini and Limuru

Table 3.8 Percent incidence of different viruses in potato samples collected from farmers in Njabini and Limuru based on seed source

Njabini						
Seed Source	PLRV	PVM	PVX	PVY	PVS	PVA
KARI	100.0	84.6	76.9	69.2	100.0	23.1
Local Market	100.0	80.0	86.7	60.0	100.0	33.3
Farmer group	100.0	75.0	83.3	41.6	100.0	16.7
Mean	100.0	79.9	82.3	56.9	100.0	24.4
Limuru						
Seed Source	PLRV	PVM	PVX	PVY	PVS	PVA
KARI	100.0	8.3	41.6	33.3	100.0	58.3
Local Market	100.0	25.0	25.0	43.8	100.0	68.8
Farmer group	100.0	0.0	58.3	50.0	100.0	33.3
Mean	100.0	11.1	41.6	42.4	100.0	53.5

PLRV = Potato Leaf Roll Virus, PVM = Potato Virus M, PVX = Potato Virus X, PVY = Potato Virus Y, PVS = Potato Virus S and PVA = Potato Virus A

Table 3.9 Mean virus titre in potato tuber samples that were harvested from seed potato from different sources in Njabini and Limuru

	Viruses in tuber samples						
Njabini	PLRV	PVM	PVX	PVY	PVS	PVA	Total
KARI	0.15	0.07	0.03	0.04	0.39	0.01	0.69
Local market	0.18	0.32	0.09	0.04	0.72	0.02	1.37
Seed farmer group	0.17	0.09	0.04	0.02	0.51	0.02	0.84
Lsd (treatment)	ns	ns	ns	ns	ns	ns	ns
Lsd (Njabini vs. Limuru)	ns	0.09	ns	0.02	ns	ns	ns
C.V. %	17.8	74.9	25.2	64.3	16.9	21.5	19.3
Limuru							
KARI	0.13	0.01	0.02	0.01	0.73	0.02	0.91
Local market	0.23	0.18	0.01	0.01	0.72	0.01	1.17
Seed farmer group	0.12	0	0.03	0.01	0.69	0	0.86
Lsd (treatment)	ns	ns	ns	ns	ns	ns	ns
Lsd (Njabini vs. Limuru)	ns	0.09	ns	0.02	ns	ns	ns
C.V. %	13.4	23.3	34.3	55.3	10.2	11.6	18.8

PLRV = Potato Leaf Roll Virus, PVM = Potato Virus M, PVX = Potato Virus X

PVY = Potato Virus Y, PVS = Potato Virus S and PVA = Potato Virus A

Table 3.10 Mean virus titre in potato tuber samples from different agro-ecological zones in Njabini and Limuru

Njabini							
AEZ	PLRV	PVM	PVX	PVY	PVS	PVA	Total
UH1	0.20	0.13	0.06	0.04	0.55	0.02	1.00
UH2	0.17	0.06	0.04	0.04	0.45	0.02	0.77
UH3	0.14	0.29	0.06	0.01	0.63	0.01	1.13
Mean	0.17	0.16	0.05	0.03	0.54	0.02	0.96
Lsd (AEZ)	ns	ns	ns	ns	ns	ns	ns
Lsd (Njabini vs. Limuru)	ns	0.09	ns	0.02	ns	ns	ns
C.V. %	20.4	25.9	31.0	18.4	13.7	14.0	15.2
Limuru							
AEZ	PLRV	PVM	PVX	PVY	PVS	PVA	Total
UH1	0.12	0.01	0.03	0.02	0.62	0.01	0.80
LH1	0.12	0.00	0.02	0.01	0.75	0.01	0.91
LH2	0.24	0.18	0.02	0.01	0.77	0.02	1.23
Mean	0.16	0.06	0.02	0.01	0.71	0.01	0.98
Lsd (AEZ)	ns	ns	ns	ns	ns	ns	ns
Lsd (Njabini vs. Limuru)	ns	0.09	ns	0.02	ns	ns	ns
C.V. %	22.0	111.2	31.0	18.4	38.8	14.0	26.4

PLRV = Potato Leaf Roll Virus, PVM = Potato Virus M, PVX = Potato Virus X, PVY = Potato Virus Y, PVS = Potato Virus S and PVA = Potato Virus A

3.3.3 Farmers knowledge on management of potato virus diseases

Farmers had very little knowledge on management of aphids and virus diseases in seed potato production. Very few (0% and 22.5% of farmers) in Limuru and Njabini respectively had seen aphids in potato crop (Table 3.11). In addition, the farmers could recognize virus symptoms in a potato crop both in Njabini and Limuru. The training significantly improved the farmers' knowledge on potato viruses and their management by 23%. The scores after the training were significantly higher ($P \leq 0.05$) than before the training. The highest score was on virus avoidance in which farmers significantly ($P \leq 0.05$) improved from 1.5 to 2.8 scores before and after the training respectively. However, there was no significant ($P \leq 0.05$) improvement on the aspect of virus transmission. The difference among farmer groups' scores was significant at $P \leq 0.05$ for potato pests' awareness before and after the training. The highest score before the training was achieved by Tharuni Farmers group while the lowest was Gatimu farmers group both in Kiambu district. Farmers in Njabini improved more than farmers in Limuru.

Table 3.11 Pre-training and post-training questionnaires scores (marks) attained by farmers groups in Njabini and Limuru

Pre-training

Farmer groups	Potato diseases	Potato pests	Virus symptoms	Virus avoidance	Virus transmission	Seed selection	Total
Ebenezer	1.2	0.9	0.5	1.0	1.0	1.1	5.6
Gatimu	1.3	0.6	1.1	1.9	1.6	1.3	7.8
Jersey	1.4	1.4	2.0	1.8	1.9	1.3	9.8
Tharuni	1.8	1.2	1.5	1.4	1.3	0.8	7.8
Mean	1.4	1.0	1.3	1.5	1.5	1.1	7.8
Lsd Group	ns	0.5	ns	ns	ns	ns	ns
Lsd Pre-training x Post-training	0.2	0.3	0.9	0.9	ns	0.3	1.6
C.V. % Groups	15.1	14.2	20.0	24.1	14.8	15.9	8.2
C.V% Pre-training x Post-training	6.3	11.4	21.1	18.3	15.9	9.6	8.2

Post-training

Farmer groups	Potato diseases	Potato pests	Virus symptoms	Virus avoidance	Virus transmission	Seed selection	Total
Ebenezer	2.3	1.5	2.8	2.9	2.0	2.0	13.4
Gatimu	1.5	0.8	2.1	2.4	1.8	1.1	9.6
Jersey	2.0	1.9	2.7	2.2	1.9	1.3	12.0
Tharuni	2.1	2.0	2.8	3.5	2.4	2.0	14.8
Mean	2.0	1.5	2.6	2.8	2.0	1.6	12.4
Lsd Groups	ns	0.7	ns	ns	ns	ns	ns
Lsd Pre-training x Post-training	0.2	0.3	0.9	0.9	ns	0.3	1.6
C.V. % Groups	14.9	17.3	24.5	25.5	19.7	18.3	8.4
C.V% Pre-training x Post-training	6.3	11.4	21.1	18.3	15.9	9.6	8.2

3.4 Discussion

3.4.1 Seed potato production practices among small-scale farmers

In Njabini no farmers had less than one acre of total land, which enabled individual farmers to allocate bigger land sizes to seed potato production compared to farmers in Limuru where 22.5% of the farmers had total land of less than one acre. The land acreage included area under homestead, which left very small parcels of land for cultivation in Limuru. The plots under seed potato production in Njabini were generally bigger in size than those in Limuru probably due to the corresponding bigger total land size for farmers in Njabini. Farmers were found to source their seed potato from KARI, local markets and seed farmer groups. Majority of the farmers sourced seed from local markets 40% and unaware of the seed borne diseases that may be infecting the seed (Kinyae *et. al.*, 1994; Machangi *et. al.*, 2004; Kibaru *et. al.*, 2004). The reason for their preferring to buy from local markets was reduced cost relative to the other two sources (Lung'aho *et. al.*, 1997; Anon, 2002). The seed from local markets was found to be more contaminated with viruses compared to seed from KARI and seed farmer groups. Since most of these small scale farmers are resource poor, and majority are not aware of the latent virus infections in seed potato, the little money they save in the cost of seed is lost through low yields due to these diseases (Hidayet *et. al.*, 2006).

The most preferred potato variety was Tigoni, which was being grown by all the farmers interviewed. Other varieties were varying in popularity depending on the location of the farmers. Changi and Kimande varieties were being grown by more farmers in Njabini than Limuru (40% and 2.5 respectively) while Asante and Nyayo were more popular with farmers in Limuru than Njabini (38% and 4% respectively). Most of these varieties are local and farmers prefer them due to good cooking abilities and for chips and crisps (ECAPAPA, 2004). Farmers' agronomic practices in seed potato production were found to be inadequate

for the realization of high yields. In Limuru 52.5% of the farmers used D.A.P fertilizer at planting compared to 92% of farmers in Njabini. Most of these farmers used less than the recommended 4 bags of 50kg per acre (Kabira *et. al.,* 2006; Gildermacher, 2006). All farmers in Njabini practiced crop rotation compared to 87.5% of farmers in Limuru. Given that crop rotation is important in management of soil fertility and insect pests' farmers in Limuru were at a comparative disadvantage (Powell and Hardie, 2006). The reason could probably be due to the small land acreages found in the area compared to Njabini (Walingo *et. al.,* 2004; Hidayet *et. al.,* 2006). The poor pest and disease management practices were responsible for the spread of virus diseases. Most farmers recycled their own seed from the previous crop that was contaminated with viruses among other seed borne diseases. This propagates the disease leading to poor yields (Lung'aho *et. al.,* 1997; Brunt, 2001; Roland, 2004).

More farmers in Njabini than Limuru carried out control measures against potato late blight probably because the disease was more dramatic in reducing yields as opposed to viruses that latently cause infection thereby reducing yields (Roland, 2004). Almost twice the numbers of farmers in Limuru dehaulm their potato crop two weeks before harvesting compared to farmers in Njabini. This practice not only leads to hardening the skin of the tuber but also reduces chances of viral disease transmission to the tubers from the upper parts of the plant (CIP, 2006). The practice of dehaulming also reduces the chances of aphids coming into contact with tubers and thereby further reducing chances of virus disease infection and spread (Gildermacher *et. al.,* 2006). Farmers in Limuru dehaulm the potato crop more than farmers in Njabini and this might explain why there was higher virus prevalence in Njabini.

Earlier studies found that farmers in Kenya recycled their own seed resulting in build up of tuber-transmitted diseases including viruses (Machangi *et. al.*, 2004; Kibaru *et. al.*, 2004). The reason for farmers recycling seed from previous harvest is because it is cheaper than buying certified seed (Walingo *et. al.*, 2004). The savings from buying poor quality seed might actually be less than if farmers spent a little more on clean seed and improved harvests (Yvon et. al., 2000). However, previous studies established that farmers prefer recycling their own seed due to the high cost and scarcity of certified seed (Barton *et. al.*, 1997), lack of an established seed potato market and lack of knowledge of seed borne pathogens (Kinyae *et. al.*, 1994; Barton *et. al.*, 1997). Farmers' yields were found to be very low with majority (67.5%) producing 15 to 30 bags per acre compared to an average of 100 bags per acre by KARI (Kabira et. al., 2006; KARI, 2007). This could be attributed to inadequate pest and disease control, poor agronomic practices and inadequate farm inputs for optimal seed potato production (Kariuki, 1999; Hanafi, 2000; Machangi *et. al.*, 2004).

3.4.2 Contamination of farmer-produced potato tubers with viruses

The study found that farmer produced seed potatoes were contaminated with viruses irrespective of the seed source. The tubers tested positive for all the six viruses assayed which were PLRV, PVY, PVA, PVS, PVM and PVX. Some of these viruses such as PLRV and PVY have been reported to reduce yield by 10-100% (Salazar, 2000; Were *et. al.*, 2003). Some of the viruses detected had earlier been detected earlier were PLRV, PVY, PVS and PVX (Machangi *et. al.*, 2004). Therefore, there is need to clean the seed potato held by farmers of viruses as reported in the 2006 KARI annual report (KARI, 2007). Tubers from Njabini had higher virus prevalence than Limuru at 73.9 and 58.1 percent respectively. The results of the survey agreed with a previous study done in the same area in 1998 concerning prevalence of some individual viruses (Kariuki, 1999). However a study done in 2002

showed that Limuru had higher virus prevalence than Njabini (Machangi *et. al.,* 2004). Given the fact that farmers' practices rarely manage aphids and viruses, aphid population levels are sorely controlled by natural forces (Syller, 2001). The most prevalent viruses were PVS and PLRV while in the previous study PVY and PLRV had been found to be the most prevalent (Machangi, 2003). Farmers who sourced seed potato from KARI had lowest contamination in their tubers suggests that farmers should be advised to plant clean seed as much as possible. The seed potato from farmers had high levels of virus contamination. This is probably because farmers have little or no knowledge in virus management. Co-occurrence of different viruses leads to higher yield reduction (Mih *et. al.*, 1995). Potato virus S had earlier been found to depress yield by between 10-30% (Khurana, 2000) and was readily spread by contact of foliage in the field. PVY and PLRV have the potential to reduce yields by 60-80% (Kook, 2001; Were *et. al.,* 2003).

3.4.3 Farmers training in aphids and virus management

Farmers in the four seed potato-producing groups were found to have little knowledge on aphid and potato virus management. The training significantly improved their ability to control aphids and potato viruses by 23%. During an evaluation before the training the average score of 41% improved to 62% through training. It is therefore possible to improve virus diseases management in farmer produced seed potato system by building capacity of farmers to manage virus and their aphid vectors (Nderitu, 1991; Kabira *et. al.,* 2006). This indicates that if farmers are trained, they can respond positively and manage these virus diseases (Semana and Mwebesa, 2004). More emphasis needs to be put in training farmers on virus management in the field and in storage. Virus infection continues during storage because aphids attack sprouts in the diffused light found stores (Kibaru *et. al.,* 2004).

Positive seed selection practices need to be emphasized as this practice of selecting healthy-looking plants can minimize transmission of potato viruses (KARI, 12007; Saucke and Doring, 2004). The Ministry of Agriculture, KARI, Universities and other development partners should foster close cooperation and train farmers in potato aphid and virus management. Since 99% of the seed potato in Kenya is produced by these small scale farmers, training them would greatly increase per capita production of potatoes in this country (MOA, 2007).

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CHAPTER FOUR

EFFECT OF APHID TRANSMITTED VIRUSES ON SEED POTATO PRODUCTION AMONG SMALL SCALE FARMES IN KIAMBU AND NYANDARUA DISTRICTS

4.1 Introduction

Irish potatoes are the second most important food crop in Kenya after maize and play a major role in food security and the reduction of hunger (MOA, 2007). The crop contributes to alleviation of poverty through income generation by providing employment opportunities in production, processing and marketing sectors (KARI, 2007). Potato production increased from 980,163 tons in 2005 to 984,596 tons in 2006 due to the economic decline of competing crops such as maize, pyrethrum, and barley and an increased demand from consumers, processors and exporters (Kabira *et. al.,* 2006). However, the acreage under potato production decreased by 11% over the same period from 120,842 ha to 107,907 ha, due to the drought that prevailed in July-September 2005 (MOA, 2007).

The basic problem facing seed potato production in the informal system in Kenya is low yields due to pests and diseases (Kinyae *et. al.,* 1994; Were *et. al.,* 2003; Kabira *et. al.,* 2006; MOA, 2007). Major pests include aphids (*Myzus spp., Macrosiphum spp., Aphis spp and Rhopalosiphum spp.*) potato tuber moth (*Pthorimaea operculella*) and cut worms (*Agrotis spp.*), (Nderitu, 1991; Thackray *et.al.*, 2002). The most common diseases include virus diseases (PLRV, PVY, PVX, PVM, PVS and PVA), late blight (*Phytophthora infestans)* and bacteria wilt (*Ralstonia solanacearum)* (Syller, 2001; Anton, 2004; KARI, 2007). Aphids are the main vectors of potato viruses and their control is therefore very important in reducing the spread of virus diseases (Ming *et. al.,* 2007). Aphids cause more damage by transmitting viruses than by feeding on the plants leading to crop degeneration (Raman, 1985; Ming *et. al.,* 2007). Small-scale farmers are the main seed producers and the problem of viruses in their farms seriously compromises their potential to produce clean seed (Walingo *et. al.,*

2004). Due to financial constraints, most small-scale farmers cannot afford to buy clean seed from KARI and therefore they resort to recycling the previous season seed whose yield and quality is usually low due to the effects of viruses among other seed-borne diseases (Hanafi, 2000; Olubayo *et. al.*, 2004). Most farmers do not control aphids either because they are not aware of their effect in virus diseases transmission in seed potato production (Olubayo *et. al.*, 2004). Therefore, potato production has continued to decline in terms of yield even as demand for potato products like chips increases (MOA, 2006). Viruses can reduce yields by up to 90% (Jonathan and Allison, 2008).

Therefore, this study was carried out to determine the levels of aphids and viruses in farmer-produced seed potato and to evaluate the yield losses that occur due to virus infection. The objectives were: -

i. To monitor the population of aphids in small-scale seed potato production units
ii. To determine the types and levels of viruses in small-scale farmer seed potato production system and the effect on yield

4.2 Materials and methods

4.2.1 Experimental site, design and layout

Eighteen seed potato producing small-scale farms in Nyandarua and Kiambu districts were selected for monitoring of aphids and virus diseases. Eight farms were in Njabini, Nyandarua district and ten farms were in Limuru division of Kiambu district. The study was carried out over two seasons in each site. Monitoring in Njabini was done during the 2006/2007 short rain and 2007 long rain seasons. Monitoring in Limuru was done in the 2007 long rain and 2007/2008 short rain seasons. Four farms were monitored in Njabini during the short rains and the other four farms in Njabini were monitored during the long rains. In Limuru, five

farms were monitored during the long rains and the other five farms during the short rains. In each farm a 0.25 hectare of potato crop plot was divided into four roughly equal portions, each portion acting as a replicate. Data collected included aphids population on leaves and in the water traps, virus disease incidence, virus types and titre in tubers and tuber yield. The design of the experiment was Randomized complete block design (RCBD) with split plot layout.

4.2.2 Assessment of potato aphid population

Aphid assessment was done using water traps and on potato leaves. In each 0.25 hectare potato plot, five water pan traps were placed equidistantly. The traps consisted of 40 cm diameter x 15cm height yellow colored basins placed on a one metre wooden stand. The basins were half-filled with clean water and a few drops of a liquid detergent were added to the water to break the surface tension so that insects sink to the bottom. The aphids were collected after every five days by draining the water through a fine sieve or fine cheese cloth. The insects were transferred to the universal bottles with 60% alcohol to preserve the insects. Sampling was done every week from the third week after crop emergence for up to eight weeks.

Aphid assessment on leaves was done by selecting ten plants at random in each farm and from each plant; three compound leaves were picked from the top, middle and bottom positions. Leaves from each plant were put in the same polythene bag and stored at 4°C until aphid counting was done. Sampling was done weekly for six weeks in Nyandarua district and weekly for eight weeks in Kiambu district starting from the third week after potato crop emergence. The aphids were counted and identified to species level under a dissecting microscope at x50 magnification. Aphids were distinguished on basis of lateral abdominal

tubercles/spiracles, shape of antennal tubercles, colour in life, shape of siphunculi, number of caudal hairs and dorsal abdominal pigmentation.

4.2.3 Assessment of potato virus disease incidence

Each of the 0.25-hectare potato plot was divided into four equal portions and in each portion, 100 plants were selected at random and observed for virus disease symptoms making a total of 400 plants. Virus symptoms observed included upright and rolling of the leaves, chlorosis or reddening, leaves with a leathery feel and stunting. The total number of plants showing virus symptoms was then expressed as a percentage of the total number of plants observed in the farm. The visual virus disease assessment was done from the 3rd week of crop emergence on a weekly basis in each farm for six weeks in Njabini and for eight weeks in Limuru over a period of two seasons.

4.2.4 Determination of the effect of potato viruses on tuber yield

In each farm, the potato plot of 0.25 ha was divided into four equal portions. At flowering, ten healthy looking and ten viruses infected plants were tagged in each portion. In total 40 healthy-looking plants and 40 symptomatic plants were tagged in each farm. At maturity, tubers from each tagged plant were harvested separately to determine the number and weight of tubers. Tubers were graded into ware (>55mm), seed (large 45-55mm, medium 35-45mm and small 25-35mm) and chats (<25mm) grades as recommended by the National Research Potato Centre (NPRC) Tigoni (Machangi *et. al.,* 2004; MOA, 2007b). The total weight and total number of tubers was obtained by adding together the weights of the ware, seed and chats grades for both the healthy-looking and symptomatic plants. The loss due to virus diseases was calculated as the percentage difference between the yield of the healthy-looking and symptomatic plants.

The types and levels of potato viruses titre was determined by DAS-ELISA as described in section 3.2.2

4.2.5 Data analysis

The data was analyzed using GENSTAT computer programme by subjecting it to one-way analysis of variance (ANOVA) for equal sample sizes as dictated by tests of normality homogeneity of variance. The separation of means was done using the Fisher's protected Least Significant Difference method (LSD) at 5% confidence interval. Correlation of data variables was analyzed by Pearson's Product Movement method at 5% significant level using the Statistical Package for Social Scientists (SPSS).

4.3 Results

4.3.1: Potato aphid population on leaves

Five species of aphids were found on potato leaves. These were *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae*, *Myzus persicae* and *Rhopalosiphum maidis*. The most abundant aphid species in both Njabini and Limuru was *A. gossypii* followed by *M. euphorbiae* while the least abundant was *R. maidis* (Table 4.1). *Rhopalosiphum maidis* was almost absent on the leaves during the short rains seasons both in Njabini and Limuru (Table 4.1). *Myzus persicae* population was highest in Limuru during the short rains season of 2007/08 and lowest in Njabini during the short rains season of 2006/07. Its population in Njabini was higher during the long rains season of 2007 compared to short rains season of 2006/07. There were no significant differences ($P \leq 0.05$) in the population of the different aphid species on leaves among farms in both seasons in both Njabini and in Limuru (Table 4.1).

There were significant differences ($P \leq 0.05$) in aphid population among the farms during the 3rd and 6th week after crop emergence in the short rains season of 2006/07 while there was no significant difference among farms in the long rains season of 2007 in Njabini (Table 4.1). In Limuru, significant difference in aphids' population on the leaves was noted only during the 3rd week after crop emergence in the long rains season of 2007 ($P<0.05$) while there was no significant differences among farms during the short rains season of 2007/08. The aphid population on leaves generally increased with growth of the crop then decreased as the crop matured. Aphid numbers were highest in the 6th to 8th week after crop emergence for both seasons in Njabini and Limuru (Table 4.2).

During the short rains season of 2006/07 in Njabini, there were significant differences ($P \leq 0.05$) between total aphids on leaves in the 3rd week and total aphids in the 7th and 8th week after crop emergence (Table 4.2). During the sort rains season of 2007/08 in Limuru, there were significant differences ($P \leq 0.05$) in aphid population among weeks with the 3rd week after emergence having the lowest population and the 9th week after crop emergence having the highest population (Table 4.2).

During the long rains season of 2007 there were significant differences ($P \leq 0.05$) in total aphid population on leaves among the sampling weeks compared to the 3rd week after emergence. The earliest significant difference in total aphid population on the leaves was between the 3rd week after crop emergence and the 7th week after the crop emergence both in Njabini and Limuru. In this season, total and mean aphids' population was higher in Limuru than Njabini (Table 4.2). The total aphid population on leaves in Kiambu district was higher than in Nyandarua district on all the seasons. There were significant differences ($P \leq 0.05$) in the population of aphids between seasons in Njabini and Limuru. Aphid population on leaves in Njabini was higher in the long rains season of 2007 than in the short rains season of 2006/2007. In Limuru the total population of aphids on leaves during the short rains season of 2007/2008 was lower than during the long rains of 2007 (Table 4.2).

Table 4.1 Mean aphid species population per 3 leaves of a potato plant and per water pan trap in small-scale farms in Njabini and Limuru

	Njabini					
	Me	Ag	Af	Mp	Rm	Total
Leaves short rains	3.3	1.0	0.6	0.3	0.0	5.2
Leaves long rains	2.4	6.5	0.7	1.3	0.5	11.4
Water pan short rains	9.3	0.4	0.5	14.9	0.7	25.8
Water pan long rains	7.0	3.5	0.3	14.0	4.6	29.5
LSD Leaves short rains	ns	2.7	0.9	0.3	ns	5.3
LSD Leaves long rains	ns	ns	ns	ns	ns	ns
LSD Water pan short rains	6.1	ns	0.8	12.7	ns	14.6
LSD Water pan long rains	5.0	2.7	ns	ns	ns	ns
	Limuru					
	Me	Ag	Af	Mp	Rm	Total
Leaves short rains	4.1	10.8	8.4	5.1	0.1	28.5
Leaves long rains	10.1	18.3	4.3	4.1	1.4	38.1
Water pan short rains	7.9	48.0	22.6	10.7	33.2	122.4
Water pan long rains	12.4	26.9	5.4	9.2	25.1	78.9
LSD Leaves short rains	ns	ns	ns	ns	ns	ns
LSD Leaves long rains	ns	ns	ns	ns	ns	ns
LSD Water pan short rains	ns	19.9	11.1	ns	17.7	36.1
LSD Water pan long rains	ns	19.9	11.1	ns	17.7	36.1

Me = *Macrosiphum euphorbiae;* Ag = *Aphis gossypii;* Af = *Aphis fabae;* Mp = *Myzus persicae;* Rm = *Rhopalosiphum maidis.*

4.3.2: Aphid population in water pan traps

The aphid species found in the water traps were similar species to those found on the leaves except that most were winged as opposed to the wingless aphids found on the leaves. These were *Macrosiphum euphorbiae*, *Aphis gossypii*, *Aphis fabae*, *Myzus persicae* and *Rhopalosiphum maidis*. Higher aphid population was detected using water traps, with a mean of 4.35 and 12.6 aphids per trap in Njabini and Limuru, respectively (Table 4.1). The most abundant aphid species in water pan traps was *A. gossypii* and the least population was *A. fabae* (Table 4.1). *Myzus persicae* population was higher in Njabini than in Limuru. The population of *M. persicae* was higher during short rain seasons compared to the long rains seasons in both areas. There were significant differences ($P \leq 0.05$) in the population of this aphid species among farms in Njabini during the short rain season and also in Limuru during the long rains season (Table 4.1). *Aphis gossypii* population in water traps was about twenty times higher in Limuru compared to Njabini. There were significant differences ($P \leq 0.05$) in the population of this aphid species among farms in Njabini during the long rain season and also in Limuru during the short rain season. *Aphis gossypii* was the most abundant aphid species in Limuru but also had the lowest population in Njabini during the short rain season (Table 4.1). The total aphid population was significantly different ($P \leq 0.05$) among farms during the two seasons both in Njabini and in Limuru except during the long rain season in Njabini. The population of aphids in Limuru during the short rain season was almost double that of the long rain season (Table 4.1).

Table 4.2 Mean aphids' population per 3 leaves of a potato plant and per water pan trap in small-scale farms in Njabini and Limuru from the 3rd week after crop emergence

Njabini

	Weeks after emergence						
	3	4	5	6	7	8	Mean
Leaves short rains	0.6	0.5	0.6	0.7	1.3	1.5	0.9
Leaves long rains	1.4	0.8	1.7	0.8	3.6	3.2	1.9
Water pan short rains	6.4	5.7	6.7	2.0	1.6	3.5	4.3
Water pan long rains	6.0	5.3	2.8	1.9	4.4	6.0	4.4

Limuru

	Weeks after emergence								
	3	4	5	6	7	8	9	10	Mean
Leaves short rains	5.7	1.8	5.9	4.7	2.1	1.7	4.2	2.4	3.6
Leaves long rains	6.2	7.3	3.5	9.1	3.2	3.1	2.8	3.1	4.8
Water pan short rains	15.7	18.4	14.4	25.7	19.9	18.1	7.0	3.3	15.3
Water pan long rains	9.2	10.3	9.4	7.6	9.1	12.0	11.7	9.7	9.9

Least Significant Differences among weeks

	Niabini		Limuru	
	Leaves	Water pans	Leaves	Water pans
LSD Short rains	0.7	2.8	1.9	5.7
LSD Long rains	1.7	2.2	2.0	ns

4.3.3 Virus disease incidence

Virus disease symptoms observed included rolling of leaves, erectness of the stem and leaves, chlorosis, bunchiness, mosaic and crinkling. The most common symptom in both Njabini and Limuru was leaf roll, plant becomes more erect and leaves look dry and brittle. Leaf mosaic was also common during both seasons in Njabini and Limuru. Light-green patches on the leaves of some potato plants were clearly visible under normal light conditions. Dwarfing was also observed in a small percentage both in Njabini and Limuru. The symptoms were observed from the third week of crop emergence in few plants and the number of infected plants increased as the crop matured (Table 4.3). The differences in the visual incidence among the farmers were significant ($P \leq 0.05$) in both Njabini and Limuru during the long and short rain seasons (Table 4.4).

The highest virus disease incidence in an individual farm was 78% in Njabini in the 8th week after crop emergence during long rain season. The lowest incidence was 0.8% also in Njabini during the short rain season. Disease incidence was higher during the long rain season than short rain in Njabini but the reverse was the case in Limuru. The difference in the visual virus incidence among different assessment times was significant ($P \leq 0.05$) in both Njabini and Limuru during short and long rains (Table 4.4). However, there were no significant differences in virus disease incidence among farms in Limuru at the ninth and tenth week after crop emergence during the short rain and in Njabini between the seventh and eighth week after crop emergence during the long rains. Overall there was higher visual virus disease incidence in Limuru compared to Njabini. However, Limuru had almost three times the virus disease incidence at 20.5% compared to 7.8% in Njabini during the short rain season.

Table 4.3 Mean % virus disease incidence in small scale seed potato farms during the short and long rain seasons from the 3rd week after crop emergence in Njabini and Limuru

	Weeks after emergence									
	3	4	5	6	7	8	9	10	Mean	LSD
Short rains Njabini	3.1	4.3	6.3	9.9	10.7	12.4	-	-	7.8	1.8
Long rains Njabini	5.4	8.1	12.2	16.8	26.9	28.0	-	-	16.2	1.9
Short rains Limuru	4.5	5.4	9.7	12.0	14.8	36.0	40.7	40.8	20.5	3.4
Long rains Limuru	3.8	11.5	12.2	12.3	13.8	16.4	21.9	26.6	14.8	4.8

4.3.4 Effect of potato virus diseases on tuber yield

4.3.4.1 Effect of potato viruses on number of tubers

Virus infection reduced the number of tubers by between 9.6 and 35.5%. The number of tubers from healthy-looking plants was significantly ($P \leq 0.05$) more than the number of tubers from symptomatic plants during the two seasons in both Njabini and in Limuru (Table 4.4). In Njabini, the reduction in number of potato tubers by 9.6% and 29.7% during the short and long rains respectively were significant ($P \leq 0.05$). In Limuru, reduction in number of potato tubers was also significant ($P \leq 0.05$) at 17.7% and 35.5% during the long 2007 and short rains respectively (Table 4.4). The reduction in the number of tubers was also significant ($P \leq 0.05$) among the potato grades during the two seasons. The reduction in number of tubers due to virus infection for ware grade in Njabini was significant at 67.7% and 66.0% during the short and long rains respectively while in Limuru reduction was 51.0% and 74.3% during the long and short rains respectively (Table 4.5). However, the reduction in the number of tubers for the seed grade was not significant ($P \leq 0.05$) in Njabini during the short rains season but it was significant ($P \leq 0.05$) at 28.7% and 17.4% during the long rains in Njabini and Limuru respectively. The reduction in the number of tubers for seed grade was also significant ($P \leq 0.05$) reduction of 40.9% in number of tubers during the short rain

season in Limuru was also significant ($P \leq 0.05$) at 40.9% in Limuru during the short rains. Virus infection resulted in a significant ($P \leq 0.05$) increase by 114% in the number of tubers for chats grade in the symptomatic plants (Table 4.4). There were significant differences ($P \leq 0.05$) among the farms in the number of tubers in both Njabini and Limuru. However, there was a higher reduction in the total number of tubers in Limuru (mean 26.6%) compared to Njabini (mean 19.7%) during the two seasons (Table 4.5).

4.3.4.2 Effect of potato viruses on weight of tubers

Virus infection resulted in significant ($P \leq 0.05$) reduction in weight of tubers by between 36.4% and 62.7% (Tables 4.6 and 4.7, Chart 1). Overall, virus infection reduced the weight of potato tubers by between 36.4 and 62.7 %. In Njabini, the reduction in weight of tubers was 46.7% and 42.2 % during the short and long rains respectively. In Limuru, reduction in total weight of tubers was 36.8% and 62.7% during the long and short rains respectively (Tables 4.6 and 4.7). The reduction in tuber weight among the different tuber grades in the two seasons in both Njabini and Limuru was also significant ($P \leq 0.05$). The highest reduction was in the ware grade at 65% and 47% in Njabini and 62.7% and 36.8% in Limuru during the short and long rains respectively.

However, symptomatic plants had higher weight of chats grade in both locations during the two rain seasons (Tables 4.6 and 4.7, Chart 1). Symptomatic plants yielded more chats that weighed more compared to healthy plants even where differences were not significant ($P \leq 0.05$). There were significant differences ($P < 0.05$) in the total weight of tubers among farms (Table 4.6). The loss in weight of ware grade among farms was higher in the short rain seasons compared to long rain seasons both in Njabini and in Limuru. The same case applied to the seed potato grade whereby higher losses were found in the short rain seasons compared

to the long rain season. There was a slightly higher total potato tuber weight loss in Limuru than Njabini over the two seasons where the mean loss was 49.8% and 44.5%in Limuru and Njabini, respectively (Table 4.7 and Chart 1).

Table 4.4 Mean number of tubers per 10 plants for different potato grades harvested from healthy-looking and symptomatic plants from small scale farms in Njabini and Limuru during short and long rain seasons

	Short rains				Long rains			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
Healthy-looking plants Njabini	23.8	62.1	8.4	94.2	25.1	100.2	33.9	159.2
symptomatic plants Njabini	9.0	51.1	22.6	82.7	13.8	69.4	29.3	112.5
LSD	3.1	ns	4.6	ns	11.1	9.3	ns	15.8
C.V. (%)	8.5	11.0	13.2	8.1	25.3	4.8	8.1	5.2
Healthy-looking plants Limuru	25.0	68.8	10.0	103.7	36.6	95.6	9.8	141.9
symptomatic plants Limuru	6.9	36.2	15.2	58.4	18.8	79.5	18.2	116.5
LSD	4.4	8.5	4.8	11.8	6.5	8.4	ns	9.2
C.V. (%)	12.2	7.2	17.1	6.4	10.5	4.3	30.4	3.2

Table 4.5 Mean percentage change in number of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons

	Ware	Seed	Chats	Overall change
Short rains Njabini	-62.7	-14.6	+ 398.3	-9.6
Long rains Njabini	-46.0	-28.7	+ 7.2	-29.7
Short rains Limuru	-74.3	-40.9	+ 114.0	-35.5
Long rains Limuru	-51.0	-17.4	+ 93.1	-17.7

Ware > 55mm; Seed 25-55mm; Chats < 25mm

Table 4.6 Mean weight of tubers per 10 plants in kg for different potato grades harvested from healthy-looking and symptomatic plants from small scale farms in Njabini and Limuru during short and long rain seasons

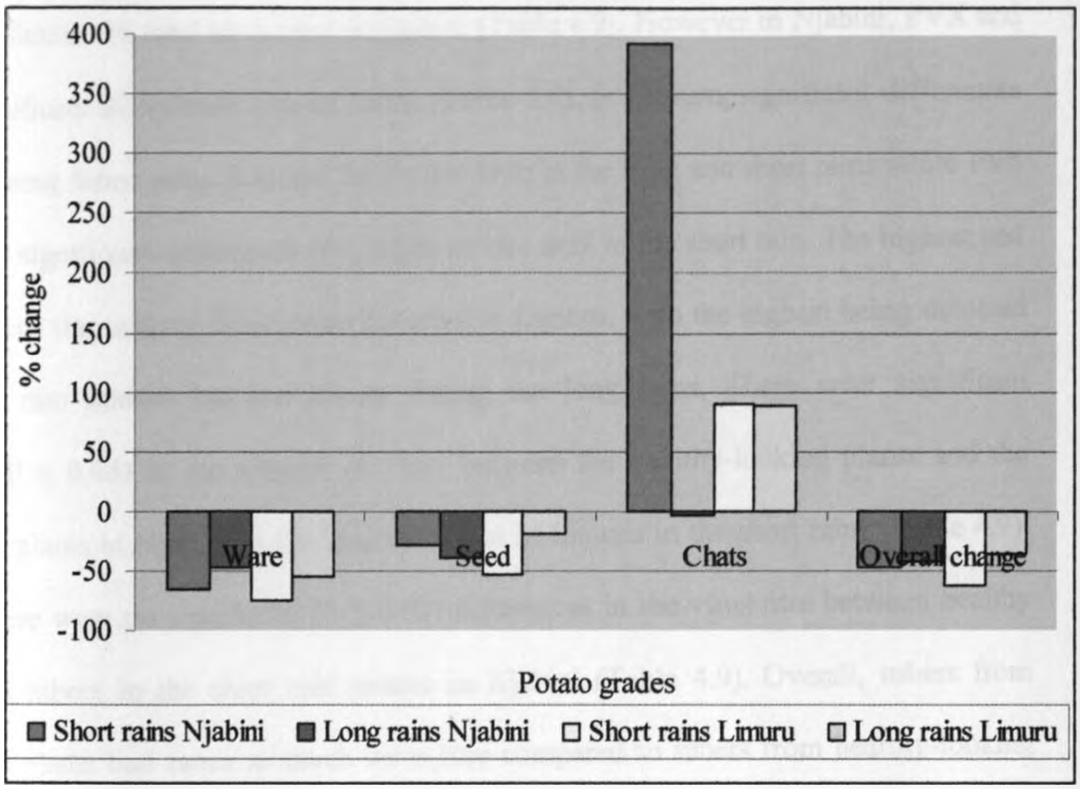
	Short rains				Long rains			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
Healthy-looking plants Njabini	3.82	3.50	0.08	7.40	3.91	5.36	0.42	9.69
symptomatic plants Njabini	1.37	2.36	0.19	3.94	2.11	3.20	0.27	5.57
LSD	0.58	0.44	0.04	0.74	1.70	0.41	ns	2.01
C.V. (%)	10.0	6.7	12.1	5.8	25.1	4.3	21.1	11.7
Healthy-looking plants Limuru	3.84	3.82	0.11	7.77	5.89	4.91	0.10	10.90
symptomatic plants Limuru	1.04	1.74	0.16	2.93	2.80	3.94	0.16	6.90
LSD	0.70	0.68	ns	1.34	1.41	0.42	ns	1.64
C.V. (%)	12.8	10.9	17.7	11.1	14.5	4.2	25.5	8.2

Table 4.7 Mean percentage change in weight of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons

	Ware	Seed	Chats	Overall change
Short rains Njabini	-65.0	-28.4	+ 392.0	-46.7
Long rains Njabini	-47.0	-38.6	-3.8	-42.2
Short rains Limuru	-75.1	-53.2	+ 90.5	-62.7
Long rains Limuru	-55.4	-18.3	+ 88.5	-36.8

Ware > 55mm; Seed 25-55mm; Chats < 25mm

Chart 4.1: Mean percentage change in weight of potato tubers due to virus infection in small-scale farms in Njabini and Limuru during short and long rain seasons



4.3.5 Types and levels of viruses contaminating potato tubers

Potato viruses detected in potato tubers from both Njabini and Limuru were potato leaf roll virus (PLRV), potato virus M (PVM), potato virus X (PVX), potato virus Y (PVY), potato virus S (PVS) and potato virus A (PVA). The most prevalent was PVS (100%) followed by PLRV (92.5%) and PVM (90.3%) while the least prevalent was PVY (16.9%) (Table 4.8). Healthy looking plants had a latent infection rate of 57.2% compared to 76.6% for plants showing virus symptoms. A higher amount of viruses was detected in tubers during the short rains (Table 4.9). Overall tubers from Njabini had higher virus titre in both the healthy and symptomatic tubers compared to Limuru. The viruses detected in highest amounts in both Njabini and Limuru were PVS, PVM and PLRV while PVY was detected in least amounts

over the two seasons (Tables 4.8 and 4.9). There were significant differences ($P \leq 0.05$) among farms in total virus titre in Limuru during the two seasons but there was no significant ($P \leq 0.05$) difference in total virus titre in Njabini (Table 4.9). However in Njabini, PVX and PVS had significant differences among farms (Table 4.9). In Limuru, significant differences ($P \leq 0.05$) among farms were detected for PLRV both in the long and short rains while PVS and PVA had significant differences ($P \leq 0.05$) in titre only in the short rain. The highest and the lowest virus titre among farms were detected in Limuru, with the highest being detected in the short rain season and the lowest during the long rains. There were significant differences ($P \leq 0.05$) in the amount of virus between the healthy-looking plants and the symptomatic plants in Njabini in the long rains and in Limuru in the short rains (Table 4.9). However, there were no significant ($P \leq 0.05$) differences in the virus titre between healthy and diseased tubers in the short rain season in Njabini (Table 4.9). Overall, tubers from symptomatic plants had twice as much virus titre compared to tubers from healthy-looking plants.

Table 4.8 Mean percent incidence of different viruses in potato samples harvested from healthy-looking and symptomatic plants in Njabini and Limuru

		Type of virus						
Condition	Site	PLRV	PVM	PVX	PVY	PVS	PVA	Mean
Healthy-looking	Njabini	100.0	93.8	68.8	12.5	100.0	18.8	65.6
Healthy-looking	Limuru	72.5	67.5	37.5	0.0	100.0	15.0	48.8
Symptomatic	Njabini	100.0	100.0	90.6	25.0	100.0	31.3	74.5
Symptomatic	Limuru	97.5	100.0	75.0	30.0	100.0	70.0	78.8
Mean		92.5	90.3	68.0	16.9	100.0	33.8	66.9

PLRV = Potato Leaf Roll Virus; PVM = Potato Virus M; PVX = Potato Virus X; PVY = Potato Virus Y; PVS = Potato Virus S and PVA = Potato Virus A

Table 4.9 Mean titre of different potato viruses in tubers harvested from healthy-looking and symptomatic plants from small scale farmers during short and long rains in Njabini and Limuru

	Njabini					
	PLRV	PVM	PVX	PVY	PVS	PVA
Healthy, Long rains	0.13	0.19	0.03	0.00	0.56	0.00
Symptomatic, Long rains	0.21	0.56	0.06	0.00	0.84	0.01
Healthy, Short rains	0.12	0.20	0.04	0.00	0.50	0.01
Symptomatic, Short rains	0.20	0.43	0.08	0.01	0.83	0.01
LSD, Long rains	0.05	0.28	ns	ns	ns	ns
LSD, Short rains	ns	ns	ns	ns	ns	ns
C.V. (%) Long rains	12.7	33.2	29.3	127.7	21.3	135.4
C.V. (%) Short rains	22.0	47.3	45.1	179.0	13.5	71.7
	Limuru					
	PLRV	PVM	PVX	PVY	PVS	PVA
Healthy, Long rains	0.15	0.12	0.01	0.00	0.66	0.00
Symptomatic, Long rains	0.24	0.35	0.02	0.00	0.77	0.02
Healthy, Short rains	0.04	0.04	0.01	0.00	0.69	0.00
Symptomatic, Short rains	0.17	0.07	0.06	0.01	1.19	0.05
LSD, Long rains	ns	ns	ns	ns	ns	ns
LSD, Short rains	0.06	0.03	0.03	ns	0.17	0.04
C.V. (%) Long rains	32.8	55.4	84.8	223.0	18.9	135.3
C.V. (%) Short rains	27.0	21.1	36.1	194.4	7.9	62.0

PLRV = Potato Leaf Roll Virus, PVM = Potato Virus M, PVX = Potato Virus X, PVY = Potato Virus Y, PVS = Potato Virus S and PVA = Potato Virus A

4.3.6 Relationship between aphid population, virus incidence and tuber yield

There was a significant ($P \leq 0.05$) positive correlation between the total number of aphids and the virus disease incidence both in Njabini and in Limuru (Table 4.10 and 4.11). The number of aphids on leaves had a significant ($P \leq 0.05$) positive correlation with the visual virus disease incidence in Limuru in the long rains but not during the short rains (Table 4.11). There was a significant ($P \leq 0.05$) negative correlation between the number of aphids on leaves and tuber yield both in Njabini and Limuru. Virus disease incidence had a significantly ($P \leq 0.05$) negative relationship with the number of tubers in Limuru during both the short and long rain seasons (Tables 4.10 and 4.11). The number of tubers had a significant ($P \leq 0.05$) negative correlation with the number of aphids on the leaves in Njabini both seasons while in Limuru there was a negative correlation in the long rains 2007 season and a significant ($P \leq 0.05$) positive correlation in the short rains season (Table 4.11). There was generally a negative correlation between the number of aphids in water traps and the number and weight of tubers both in Njabini and in Limuru during the two seasons. The number of aphids on the leaves and the virus titre were significantly ($P \leq 0.05$) positively correlated except in Njabini during the long rains and Limuru during the short rains where there was no correlation (Table 4.10 and 4.11). Virus titre had a positive correlation with disease incidence and the population of aphids in both Njabini and Limuru while it had a negative correlation with both the number of tubers and tuber weight.

Table 4.10 Correlation matrix among aphid population, disease incidence, virus titre and tuber yield for Njabini short rains 2006/07 and long rains 2007.

Short rains	Aphids on leaves	Aphids in water traps	Virus incidence	Virus titre	No. Tubers	Tuber weight
Aphids on leaves	1.000					
Aphids in water traps	0.628*	1.000				
Disease incidence	0.175	0.692*	1.000			
Virus titre	0.986*	0.658*	0.106	1.000		
No. Tubers	-0.459	-0.144	-0.497	-0.303	1.000	
Tuber weight	-0.798*	-0.553	-0.573	-0.693*	0.874*	1.000

Long rains	Aphids on leaves	Aphids in water traps	Virus incidence	Virus titre	No. Tubers	Tuber weight
Aphids on leaves	1.000					
Aphids in water traps	0.736*	1.000				
Disease incidence	0.117	0.554	1.000			
Virus titre	0.458	0.257	0.847*	1.000		
No. Tubers	-0.817*	-0.948*	-0.469	-0.042	1.000	
Tuber weight	-0.456	-0.121	-0.606	-0.383	0.011	1.000

* Correlation is significant at the 0.05 level

Table 4.11 Correlation matrix among aphid population, disease incidence, virus titre and tuber yield for Limuru long rains 2007 and short rains 2007/08

Long rains	Aphids on leaves	Aphids in water traps	Virus incidence	Virus titre	No. Tubers	Tuber weight
Aphids on leaves	1.000					
Aphids in water traps	0.571	1.000				
Disease incidence	0.937*	0.324	1.000			
Virus titre	0.610*	0.502	0.350	1.000		
No. Tubers	-0.635*	-0.434	-0.611*	-0.453	1.000	
Tuber weight	-0.648*	-0.384	-0.765*	-0.180	0.274	1.000

Short rains	Aphids on leaves	Aphids in water traps	Virus incidence	Virus titre	No. Tubers	Tuber weight
Aphids on leaves	1.000					
Aphids in water traps	0.621*	1.000				
Disease incidence	0.150	0.409	1.000			
Virus titre	0.416	0.254	0.341	1.000		
No. Tubers	-0.674*	-0.208	-0.763*	-0.234	1.000	
Tuber weight	-0.682*	-0.296	-0.743*	-0.129	0.975*	1.000

* Correlation is significant at the 0.05 level

4.4 Discussion

4.4.1 Aphid population in seed potato producing small-scale farms

The results of this study showed that aphids are prevalent in small-scale potato farms. Five aphid species were found in the small-scale farms producing seed potato. These included *M. persicae*, which is the most efficient vector of potato viruses (Hidayet *et. al.*, 2006). The population of this aphid was higher during the short rains than during the long rains both in Njabini and Limuru. According to previous studies, a similar trend had been observed (Nderitu and Mueke, 1988; Olubayo *et. al.*, 2004). The total aphid population was higher in Limuru than in Njabini where the climate was warmer (Appendices 1 and 2). Aphids prefer warmer conditions as opposed to cold areas as long as food is available (Hanafi, 2000; De Temmerman *et. al.*, 2002). Once the threshold for seed potato production of between 3 and 10 aphids per 100 leaves is reached, insecticides should be applied (Capinera, 2001; Thomas, 2002). The mean number of aphids on leaves in the study area was 1.4 and 4.2 aphids per three leaves in Njabini and Limuru, which translates to 46 and 140 aphids per 100 leaves respectively. This population was far much above the recommended economic threshold indicating high virus transmission rates in the seed production units (Capinera, 2001; Thomas, 2002).

Farmers must therefore take measures to control aphids in order to reduce virus spread in seed potato as reported previously in other studies elsewhere (Struik and Wiersema, 1999; Walingo *et. al.*, 2000). A combination of cultural and chemical control methods could be employed to reduce the population of aphids and thereby boost potato production (Olubayo *et. al.*, 2004). However, the most effective way to reduce late season spread of potato viruses is by rouging the vines as early as possible (Thomas, 2002). Farmers may be encouraged to incorporate insecticides during the fungicidal sprays. This may be combined with roguing of

infected plants early during the growing season and the use of barrier crops (Khurana S.M. 2000).

Aphid population was observed to peak between the sixth to the eighth week after germination when the crop is almost at flowering stage. According to earlier studies in the same area, the population of this aphid was lower than observed in this study (Nderitu 1983; Rongai *et. al.*, 1998; Machangi, *et. al.*, 2004). Factors affecting species population include weather conditions, nutrition and presence of predators (Handizi and Legorburu, 2002). The peak periods of aphid infestation were during the seventh and eighth week after crop emergence, which agrees with an earlier study by KARI (Kabira *et. al.*, 2006). The best time to start control measures is early in the season preferably three weeks after germination by rouging infected plants. Chemical control is applied when aphid population reaches economic threshold of between three to ten aphids per one hundred leaves irrespective of the stage of the crop after germination (Capinera, 2001; Thomas, 2002).

During the sixth to eighth week after germination, the rainfall is reduced and temperatures rise and there being plenty of food for the aphids, the numbers rise. The vegetation around the potato crop is also actively growing at this time and it is possible that this vegetation acts as a reservoir of aphids that later attack the potato in the field. This observation is consistent with the work done by Handizi and Legorburu (2002) who found that the first vegetation around seed potato plots play a critical and important role in aphid population dynamics. Radcliffe (1982) had earlier reported that temperatures of less than 17.8°C greatly restrict the number of *M. persicae* flights, which implies that temperature was not a limiting factor in population growth of this aphid species both in Njabini and in Limuru since day temperatures averaged 20°C. The observation is also in agreement with the findings by Thackray *et. al* (2002) and

his colleagues that rainfall promotes growth of weeds and pasture plants, which aphids can build on and acquire viruses before flying to the crops (Thackray *et. al.*, 2002). Aphid control measures should be enhanced at around the sixth to eighth week after germination, as this would have a big impact on the level of aphid-transmitted viruses to the potato crop. Scouting and spraying insecticides against aphids during this time of plant growth should be enhanced.

There was a significantly positive correlation between aphids' population and virus titre in tubers suggesting that aphids were indirectly responsible for the viruses found contaminating tubers (Powell *et. al.*, 2006). Aphid population, virus titre and visual disease incidence had significant positive correlation while aphid population had significantly negative correlation with number of tubers and tuber weight. There was a higher positive correlation between aphid population and aphids on leaves than aphid population and aphids in water traps. This observation concurs with studies done in England in 1999 that found apterae aphids transmitted more viruses into a potato plant than alate aphids (Yvon *et. al.*, 2000). This therefore suggests that by reducing aphid population the yield of seed potatoes would increase as reported in earlier studies (Were *et. al.*, 2003; Kabira *et. al.*, 2006; KARI, 2007, MOA, 2006). Higher aphid population leads to seed potato contamination with viruses thereby reducing yield and income to small-scale farmers (Nderitu and Mueke, 1988; De Temmerman *et. al.*, 2002; Verheggen, 2007).

4.4.2 Incidence of potato virus diseases and viruses in potato tubers

The study revealed high incidences of potato virus diseases in small-scale farms. Limuru had a higher disease incidence than Njabini and more aphid population than Njabini. Disease incidence is a measure of seed purity and is used in seed potato certification under the formal seed potato production system (MOA, 2007b). According to the Kenya gazette notice No. 38

of May 2005, the highest acceptable incidence in seed potato production is supposed to be 10% (MOA, 2006). The observed incidence was 12.4 and 17.7% in Njabini and Limuru respectively which is above the recommended maximum for seed potato production. This implies that seed potato quality has not been attained in the farmer-based production section. Previous studies in the same area had noted a similar high disease incidence (Nderitu and Mueke, 1986; Machangi *et. al.*, 2004).

The high incidence could be attributed to the fact that farmers do not take any measures to control the aphids. Farmers are not fully aware of the dangers posed by aphids in seed potato production (Kabira *et. al.*, 2006). Another explanation for the high disease incidence may be due to the recycling of infected seed (Paola *et. al.*, 2005). Infected seed potatoes transmit the viruses to the germinating plants and therefore the virus population continues to increase in successive generations until the yield is diminished (Syller, 2000).

The correlation between virus incidence and population of aphids was significantly positive indicating that farms with high aphid population had high virus infection levels. Therefore, reducing aphid population would have a direct effect of reducing virus infection and would increase potato yields (Walingo *et. al.*, 2004; Paola *et. al.*, 2005). Farms with low disease incidence had higher yields compared with farms that had high disease incidence. Disease incidence and both number and weight of tubers had a negative correlation. Therefore increased virus disease incidence reduces the incomes of the farmers and also makes market prices of tubers to increase since supply is reduced (Walingo *et. al.*, 2004; Olubayo *et. al.*, 2004). Correlation between virus titre and visual disease incidence was positive which agrees with earlier studies that viruses are transmitted to the tubers through infected plants (Verma *et. al.*, 1968; Ming *et. al.*, 2007).

Although the healthy-looking plants were found to be latently infected, they had low virus titre than symptomatic plants. The findings suggest that positive selection of healthy-looking plants can help reduce infections in seed tubers and increase potato yields in small-scale production system. Certified seed is expensive and sometimes unavailable which makes positive seed selection an important measure in clean seed potato production by small-scale farmers (Kinyae *et. al.*, 1994; KARI, 2007; CIP, 2007).

Healthy looking potato plants were found to be latently infected by viruses but the virus titre in tubers was lower than for symptomatic plants. The difference in virus titre between tubers from heathy-looking and symptomatic plants was significant ($P \leq 0.05$) for all the viruses except PVY. Farmers, therefore, could be advised to rogue symptomatic plants early after crop emergence to leave healthier plants and thereby increase production (Kabira *et. al.*, 2006). Similar studies have shown that virus titre from potato plants showing disease symptoms are higher than that of healthy plants (Raman, 1985; Birch *et. al.*, 1999; Jonathan and Alison, 2008). Study conducted in Hungary yearly between 1993 and 2000, linear regression analysis showed that total visual disease incidence and titre of PVY and PLRV was positive suggesting that a forecasting method based on cumulative vector intensity and disease incidence could be used to forecast virus threat to seed potato (Basky, 2002). Tubers from Njabini had a higher virus titre than Limuru and this corresponds to the higher population of *M. persicae* in Njabini. This aphid species is known to be the most efficient in virus transmission in potatoes (Difonzo, 1995; Zhukova and Timofeer, 1998; Brunt, 2001; Braedle, 2006; Ming *et. al.*, 2007).

4.4.3 Effect of virus on tuber yield

Potato viruses significantly reduced both the number and weight of tubers such that symptomatic plants produced fewer potato tubers that weighed less than healthy-looking plants. Losses of between 9.6% and 35.5% in the number of tubers and 36.8% and 62.7% in tuber weight were observed. Other studies have reported similar significant yield losses of up to 100% (Khurana, 2000; Saucke and Doring, 2004). Tubers from healthy-looking plants had lower virus titre compared to tubers from symptomatic plants. This is consistent with other studies done elsewhere (De Temmerman *at. al.*, 2002; Mary and Zitter, 2005; Hidayet, 2006). The results indicate that virus infection has a direct effect on potato yield and therefore the income the farmer would get from the crop. There is need to disseminate information on importance of using certified seed in farmer-based seed potato production systems. Farmers should be encouraged to buy certified seed from KARI and take control measures to minimize infection by viruses.

Virus infection reduced the number and weight of ware and seed grades but increased the yield of the chats grade. The chat grade has no economic benefit to the farmer both in terms of food or seed. This indicates that even with good agronomic practices, the farmers would not obtain desired yields unless management of virus diseases is incorporated in the production system. The findings seem to agree with the studies earlier conducted by KARI , 2006 and by Yvon (2002) where positive selection as a way of reducing the level of viruses in seed tubers was emphasized (Robert and Bourdin, 2000; Hoffmann *et. al.*, 2001; De Temmerman *et. al.*, 2002; Kabira et. al., 2006; KARI, 2007).

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CHAPTER FIVE

GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 General discussion

The results of this study indicate that potato-producing farmers have small farm holdings of between one and five acres in Nyandarua and Kiambu districts. The study found that farmers sourced their seed potato mainly from local markets. This indicates that crop rotation may not be feasible and that recycling of poor quality seed is highly prevalent. Crop rotation is one of cultural methods of pest and disease management when crops that are attacked by different pests and diseases are included in the programme (Nderitu and Mueke, 1986; Semana and Mebesa, 2004). Farmers were found to have little knowledge on management of viruses in seed potato production and therefore no farmers applied pesticides to control aphids. In addition, they could not recognize virus symptoms. Therefore, farmers should be trained in virus disease recognition and management to enable them increase yields (KARI, 2007, MOA, 2007b).

Most potato tuber samples were found to be contaminated with virus incidences of up to 100%. This indicates high levels of seed potato degeneration that farmers use. Quality of seed is the most important in determination of yield in the potato production and so attention should be directed towards enabling small-scale farmers' ability to produce clean seed (Nderitu, 1983; Hoffmann *et. al.*, 2002; Olubayo *et. al.*, 2004; KARI, 2006).

The training significantly improved the knowledge of farmers by 23% on potato viruses, aphids and their management. This indicates that training has great potential to improve the capacity of farmers in the management of aphids and viruses in the informal seed potato production system (Ng'ang'a *et. al.*, 2002; Semana and Mwebesa, 2004).

The results showed that high population of aphids is prevalent in small-scale potato farms. Five aphid species were found in the small-scale farms including *M. persicae*, which is the most efficient vector of potato viruses (Nderitu and Mueke, 1988; Olubayo *et. al.*, 2004; Kinyet *et. al.*, 2006). Higher populations were found in warmer areas, as aphids prefer warmer conditions (Hanafi, 2000). Water pan traps caught more aphids and therefore they could be used as a tool for forecasting virus disease infections by monitoring alate aphids. They could be used in combination with cultural and chemical control methods could be adapted to reduce the population of aphids and thereby boost potato production (Olubayo *et. al.* 2004; Roland, 2004). Aphid population was observed to peak when the crop was almost at flowering stage indicating that control measures should be effected at early stages of crop growth to minimize virus transmission to bare minimum (Radcliffe, 1982; Handizi and Legorburu, 2002; Thackray *et. al.*, 2002; De Temmerman *et. al.*, 2002; Verheggen, 2007).

Virus disease incidence is a measure of seed purity and is used in seed potato certification under the formal seed potato production system (Nderitu and Mueke, 1986; MOA, 2007b). The high virus incidence observed in the study could be attributed to the fact that farmers did not take any measures to control aphids (Kabira *et. al.*, 2006). Virus diseases lower the quality and quantity of farmers' yield (Walingo *et. al.*, 2004). Healthy-looking plants were found to yield more and heavier tubers with lower virus infection levels. Therefore, farmers should be advised to rogue symptomatic plants early after crop emergence to leave healthier plants and thereby increase production. Studies have shown that virus titre from potato plants showing disease symptoms are higher than that of healthy plants (Raman, 1985; Birch et. al., 1999; Kabira *et. al.*, 2006; Jonathan and Alison, 2008).

These findings indicate that there is need to create awareness on the dangers posed by aphids as has been suggested in other studies (Verma *et. al.*, 1968; Ming *et. al.*, 2007). Efforts geared towards reducing the population of aphids will greatly reduce virus contamination in farmers' seed potato. A combination of strategies such as use of clean certified seed, rouging of infected plants and application of insecticides to control aphids need to be employed. This will reduce the negative impact of viruses in this farming system that supplies 99% of the total seed used in the country.

5.2 Conclusion and recommendations

The results of this study indicate that small farm sizes restrict crop rotation programmes. The seed sourced from local markets coupled with recycling of degenerated seed potato from previous harvests results in low yields even with good agronomic practices. Training increases awareness and there is a potential to improve seed potato quality and yield through training of farmers. High aphid population indicates high virus transmission rates leading to increased infection levels and increased seed potato degeneration. Higher yields and low virus titre in healthy-looking plants indicates that positive selection combined with rouging has great potential in maintaining higher seed quality and higher yields.

Therefore, the following recommendations are proposed:-

1. Need for increased awareness creation on aphid control, virus symptoms recognition and use of certified seed among the potato growers
2. Farmers should be encouraged to carry out positive selection combined with rouging in the informal seed potato production system.

3. More studies on the rate of seed potato degeneration would be needed to determine the number of seasons a clean seed stock can be re-used for seed production without significant reduction in yield.
4. There is need to do an economic analysis of different aphid and virus management methods available to farmers in order to come up with the most cost effective.
5. There is need to strengthen research-extension-farmer linkage among the key stakeholders who include Universities, KARI, Ministry of Agriculture extension service and farmers. This would improve farmers capacity in management of aphids and virus diseases in the informal seed potato production system

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APPENDICES

Appendix 1: Weather data for Njabini during the experimental period

Month	Rainfall (mm)	No. rainy days	Maximum Temp. °C	Minimum temp. °C
September 2006	20.6	5	21.0	4.7
October	110.0	9	21.5	5.8
November	194.4	26	20.4	7.4
December	231.7	23	20.7	6.9
January 2007	109.0	16	22.5	5.5
February	86.0	16	23.4	5.5
March	68.2	12	23.5	6.7
April	188.2	13	22.2	7.7
May	158.5	20	21.9	6.7
June	156.1	19	20.9	5.6
July	63.8	12	19.5	6.3
August	100.8	19	19.4	6.3
September	66.8	13	20.8	4.8
October	182.2	12	21.3	5.5
November	41.6	15	20.8	7.5
December	30.5	8	20.9	6.8

Source: MOA, 2008.

Appendix 2: weather data for Limuru during the experimental period

Month	Rainfall (mm)	No. rainy days	Maximum Temp. °C	Minimum Temp. °C
January 2007	263.0	4	18.5	15.3
February	333.0	4	18.8	14.9
March	824.0	6	18.0	13.7
April	492.1	16	16.9	14.4
May	276.4	13	16.9	14.3
June	132.1	8	14.7	13.6
July	27.2	3	13.6	12.6
August	18.1	13	13.1	14.3
September	96.8	11	15.7	13.5
October	56.8	8	17.2	14.3
November	89.6	11	16.7	13.3
December	67.1	7	17.4	13.9
January 2008	62.1	11	17.8	14.4
February	85.5	7	17.9	14.6
March	304.1	15	19.2	14.4

Source: KARI, 2008.

Appendix 3: Agro-ecological zones in Njabini, Nyandarua district and Limuru, Kiambu district

Agro-ecological Zone	Altitude (m)	Mean Temperature (°C)	Rainfall (mm)	Length of growing season (Days)
UH 1 Sheep and Dairy Zone	2,280 – 3,000	10.0 - 14.6	1,150 - 2,000	350-360
UH 2 Pyrethrum-Wheat Zone	2,100 – 3,000	13.5 - 14.6	950 - 1,200	290-340
UH 3 Wheat-Barley Zone	370 - 2430	13.7 - 14.7	900 – 1,100	270-280
LH 1 Tea-Dairy Zone	1,820 – 2,280	15.2 – 18.0	1,300 – 1,500	340-365
LH 2 Wheat/Maize-Pyrethrum Zone	1,980 – 2,280	15.2 – 17.6	1,100 – 1,300	220-250

Source: Chris et. al., 2008

Appendix 4: Pre and post-training questionnaire and marking scheme used to determine farmers knowledge in training seed potato farmer groups in Njabini and Limuru

Farmer group _____ Location _____ Date _____

1. What are major diseases in potato production? (3 scores)

   A. _____

   B. _____

   C. _____

2. What are the major pests in seed potato production? (3 scores)

   A. _____

   B. _____

   C. _____

3. What are symptoms of virus disease in potato? (4 scores)

   × Wilting

   ✓ Leaf roll

   ✓ Yellow leaves

   ✓ Erect leaves

   ✓ Small tubers and low yields

4. How can viruses be avoided? (4 scores)

   ✓ Use of pesticides

   ✓ Use of healthy seed

   ✓ Timely weeding

   × Crop rotation

   ✓ Good storage

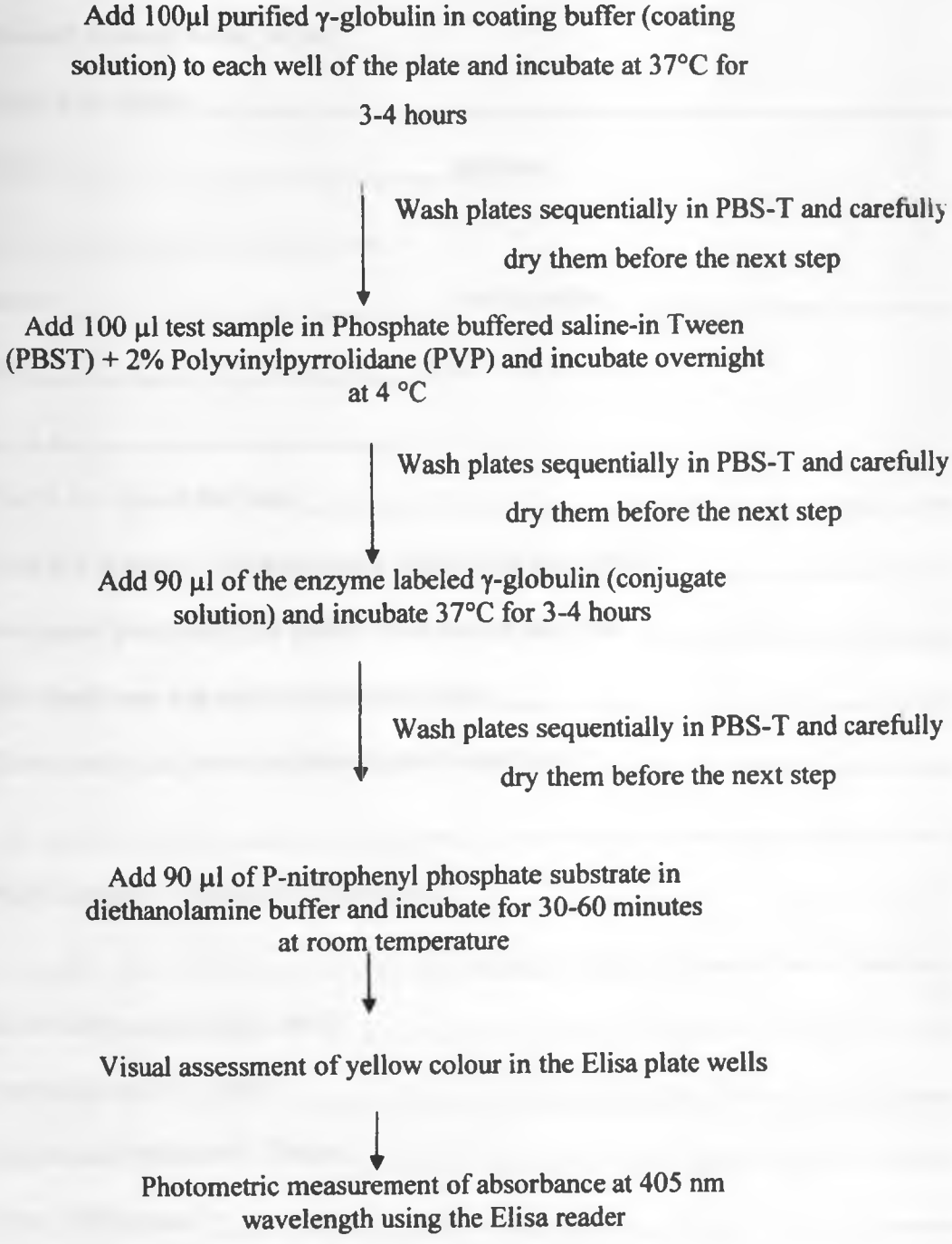
5. How are viruses transferred? (3 scores)

   - ✓ Through infected seed
   - × By wind
   - ✓ By contact
   - × By runoff water
   - ✓ By aphids

6. How do you select your seed potato? (3 scores)

   - ✓ Select the tubers immediately after harvest
   - × Select tubers after storage
   - ✓ Always buy seed tubers
   - ✓ Peg good looking plants at flowering and harvest separately for seed
   - × From the market

Appendix 5: Procedure for carrying out double antibody sandwich enzyme linked immunosorbent assay (DAS-ELISA) technique to detect potato viruses



Source: CIP, 2007.

Appendix 6: Questionnaire for the field survey on management of aphids and aphid transmitted virus diseases in seed potato production in Njabini and Limuru

✓ *Introduce yourself to the farmer*

1. Name of the farmer _____
2. District _____division

_____

Location _____ sub location _____

Village _____ AEZ

_____

3. What is the size of the farm _____
4. When did you open this land where potato seed was grown? _____
5. How many years have you planted potatoes on this plot? _____
6. How much area was under potato production _____
7. What crops/plants were neighboring the potato plot? _____

_____

8. Which variety of potatoes did you grow?

_____

9. Where did you get potato seed? _____
10. How much was the yield? _____
11. Did you use fertilizers? Yes/no _____
12. If yes, which ones? _____

_____

13. When did you apply? (at what stage of plant growth)

_____

14. How much fertilizer did you apply each time?

_____

15. Did you use manure? Yes/no

_____

16. If yes, which one? Cow/sheep etc.

_____

17. When did you apply? (at what stage of plant growth)

_____

18. How much manure did you apply each time?

_____

19. What other crops do you grow in the farm?

_____

20. In the plot where potato seed was planted, what had you planted the previous season?

_____

21. In the plot where potato seed was planted, what had you planted the previous to the previous season?

_____

22. What pests and diseases do you encounter in the course of potato seed farming?

Diseases Pests

_____

_____

_____

23. How do you control these pests and diseases?

Fungicides Pesticides

_____

_____

_____

24. When do you control these pests and diseases? (How many times?) _____

25. When do you weed the potato plot? _____

26. Do you encounter aphids (Ume) in potato farming? Yes/no

27. If encountered, is it a problem in potato farming? _____

28. Carry a sample of a healthy plant and a viral diseased plant. Ask the farmer what he/she thinks is the problem with the diseased plant? _____

29. Has the farmer ever seen such in the farm? _____

30. Do you remove potato tops before harvesting potatoes? _____

31. If yes, when? _____

32. How long do you store potato seed before planting? _____

✓ *Request for permission to take a sample of potato tubers from the current harvest*

☑ *Give a vote of thanks to the farmer*