RETURNS FROM INVESTMENT ON WHEAT RESEARCH, VARIETAL ADOPTION, TURNOVER RATES AND PRODUCTION RISKS

BY

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This thesis is my original work and has not been presented for an award of diploma or conferment of a degree in any other University or Institution of learning.

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To my Parents, Cyrus Gichangi and Rahab Nyawira and My children, Anthony Mbogo and Maureen Nyakeru.

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ABSTRACT

Appreciating the expanding significance of wheat in Kenya's food availability, remarkable research endeavors have been undertaken to breed for inflated yielding crop varieties to contribute to food availability in the country. This study investigated returns to wheat research, varietal adoption, turnover rates and production risks. There is much of public funds have been used in the investment into wheat research for many years in Kenya. The worry is if it is rewarding to pursue the investments. The hitch is there is limited facts on the returns to financing have been attained so far to give guidance to carry on with resources allocation to wheat research. A key prerequisite for the KALRO wheat research program to generate largescale impact is large-scale varietal adoption rates, high rates varietal turnover and minimization of production risks. There is a scarcity of information on the rates varietal adoption, turnover and the risk in wheat cultivation in Kenya. Hence, evidencing the breadth and depth of such adoption, varietal turnover and production risks is both of intrinsic interest and important for estimating returns. To address this problem, the objectives were to analyze a benefit-cost analysis of wheat research investment, Assess the speed of adoption of improved wheat varieties, examine the wheat varietal turnover rate and to investigate risks to wheat production in Nakuru and Narok counties. A multistage random sample of 344 wheat farmers was used. Primary data were collected using structured questionnaires in selected wheat producing Counties of Kenya, and also from secondary sources including government reports. The Benefit Cost Analysis (BCA) model was applied to approximate the returns to wheat research, in terms of three indicators: Benefit Cost Ratio (BCR), Net Present value (NPV) and Internal Rate of Return (IRR). Probit model was used to estimate wheat varietal adoption rates (VAR). The area weighted average variety age (WA or WAV) was used to estimate varietal turnover rate (VTR). The Five Point Likert scale model was used in assessing production risks. The results generated indicated a BCR of 1.47, a NPV of 23.31 million Kenya Shillings, and an IRR of 41%. The VAR was 42% and VTR was 15.65 years. The major production risks identified were Pests/diseases with a mean 3.24, output price fluctuations (2.38), lack of seed (3.10), and flood/high rainfall with mean and 2.18 in that order of ranking. The main conclusion from these results is that the return on investments in wheat research over the past years in Kenya is positive, even though relatively low, largely due to low varietal adoption and turnover rates and the prevalence of production risks. Therefore, it is recommended that in order to improve returns to wheat research in Kenya, varietal adoption and turnover rates should be improved, and wheat production risks should be minimized or eliminated. In addition, adequate policies and development programmes to promote new improved wheat varieties should be directed to pest and disease control, input and output delivery, seed multiplication and dissemination.

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ACRONYMS AND ABBREVIATIONS

AEZs	Agro Ecological Zones
ASRA	Agricultural Sector Risk Assessment
AVA	Average variety age
BCR	Benefit-Cost Ratio
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Improvement Center
DTVs	Drought tolerant varieties
FAO	Food and Agriculture Organization
GOK	Government of Kenya
IDRC	International Development Research Centre
IRR	Internal Rate of Return
JOOUST	Jaramogi Oginga Odinga University of Science and Technology
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KES	Kenya shillings
KNBS	Kenya National Bureau of Statistics
KSC	Kenya Seed Company
LPM	Linear probability model
LSF	Large scale farmers
m.a.s.l	Meters above sea level
MSF	Medium scale farmers
mm	Millimeters
NARS	National Agricultural Research System
NBS	National Breeding Station
NCIDP	Nakuru County Integrated Development Plan
NIWVs	New improved wheat varieties
NPV	Net Present Value
OECD	Organization de cooperation et de dévelopement

OIV	Old improved varieties
PVB	Present value of benefits accrued from the research program
PVC	Present value of Costs incurred in the research program
ReNAPRI	Regional Network of Agricultural Policy Research Institutes

DEFINITION OF TERMS

Rate of return to research: A rate of return is the gain or loss of an investment over a specified period of time, expressed as a percentage of the investment's cost.

Varietal adoption rate: It is the relative speed with which members of a social system adopt a new crop variety.

Varietal turnover rate: **V**arietal turnover is the average age in the seed production system for a variety adopted by a given farmer weighted by the area planted in each variety.

Weighted Average Age (WA): It is an index to be calculated and is an outcome variable to calculate wheat varietal turnover.

Wheat production risks: Risk is a loss due to a damaging event, which causes loss of wheat production and loss of income.

CHAPTER ONE

INTRODUCTION

1.1 Background

Wheat is a salient crop for food security in the world, with seven hundred and fifty million tons (MT) produced on about 220 million hectares (Mha) in 2017 and more than twenty-five million tons of produced in Africa (FAO, 2017).

The fast growing population, change in feeding habits and increasing rural - urban migration has emanated in the bulge for demand for wheat in Sub Saharan Africa. About 17 MT of wheat at an estimated cost of six billion USD from 2011 to 2013 was imported in SSA countries (FAO, 2017; OECD/FAO, 2019) (Figure 1).

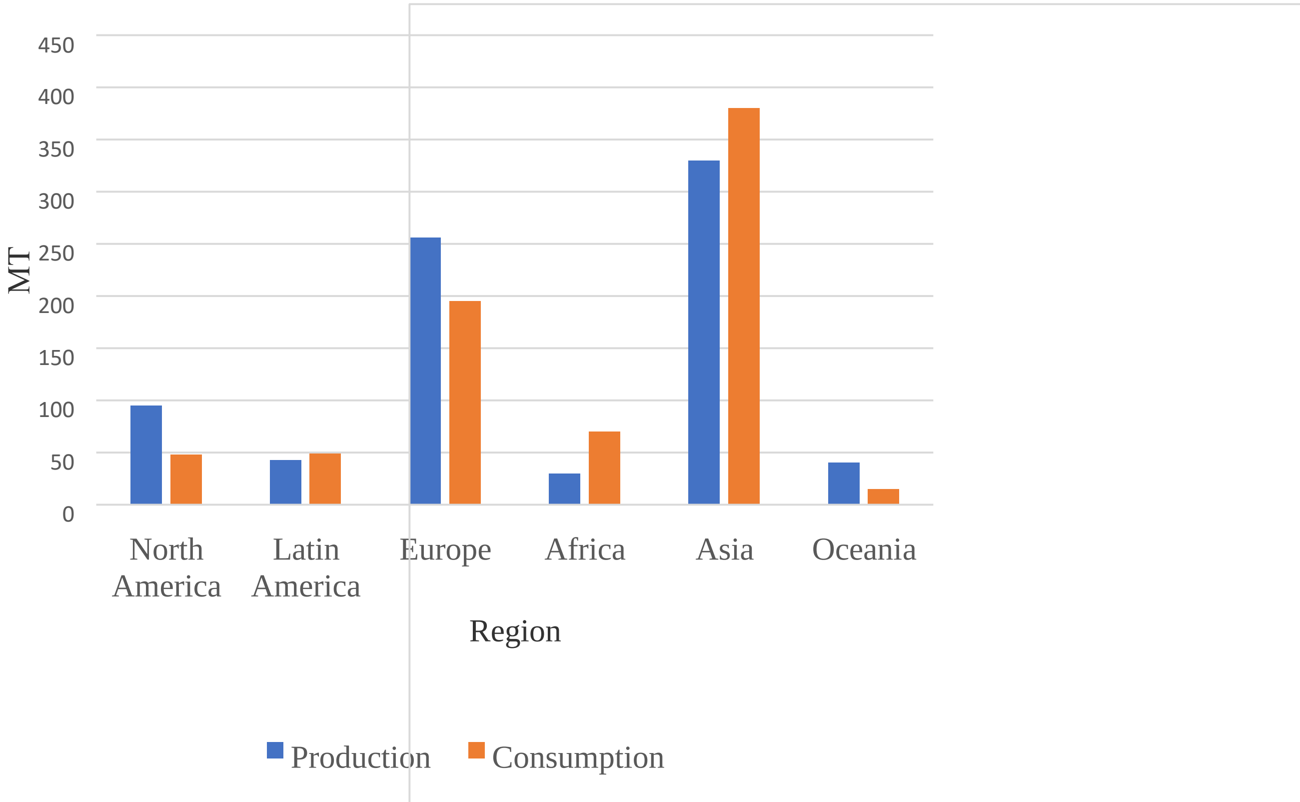

Figure 1: Average global wheat production and consumption [2016-2018]

Source: FAOSTAT, 2019

1.1.1 Wheat production in Kenya

The Current consumption of wheat in Kenya is at 44 kgs per an individual (KNBS, 2020). The enterprise has become a crucial family expense commodity accounting for a sizeable share of the primary monetary allocation, especially for city dwellers (Kiriti Nganga and Mugo, 2018). It is noted that the demand for wheat increased at a mean of about 5% annually
(FAO, 2015) driven by surging populace, rising earnings and changes in food preferences (Kiriti, Nganga and Mugo, 2018).

On average, Kenya's annual wheat production is about three hundred thousand metric tons on approximately one hundred and forty thousand hectares of land (KNBS, 2020). The rising difference between demand and production is mainly filled by importation of grain wheat. Presently, the country imports about 2 million metric tons of the grain, which more than five times its production (KNBS, 2020).

Narok, Uasin Gishu, Nakuru, Meru, Trans-Nzoia, and Laikipia are the major wheat producing counties in Kenya. Wheat production is majorly constrained by biotic and abiotic factors which are escalating in recurrence and intensity due to weather changes (Macharia *et al*., 2016). High cost of production is a major factor that has contributed to low wheat production, (Kiriti, Nganga and Mugo 2018).

1.1.2 Projected wheat area harvested and price

The medium and large-scale farmers dominate wheat production in Kenya and they account for approximately 75% of area cultivated (Meyer, *et al* 2016). In the past years, production has been marked by remarkable unstable, however a substantially surge has been apparent in the wheat cultivated area. Wheat production culminated in 2011 at 511100 tons, however, declining yields have been reported since 2013 while production reduced by about 27.9% relative to 2012, as a consequence of area depletion and low yields (Meyer, *et al* 2016).

Major constraints faced by wheat farmers, comprise of climate change, use of farmer recycled seed, competition from other high value crops and high production costs (ReNAPRI 2015). Historically, Kenya produces less than 35% of its national wheat demand hence it relies on imports to fill the gap (ReNAPRI 2015). Due to increasing population and rising levels of income, wheat demand is expected to rise by more than 50% over the subsequent years, approaching 2.8 million tons by 2025 as shown in Figure 2. As urbanization continues and rising levels of income are realized, families may diversify their consumption by replacing part of their maize menus with more suitable wheat products (ReNAPRI 2015), Figure 2.

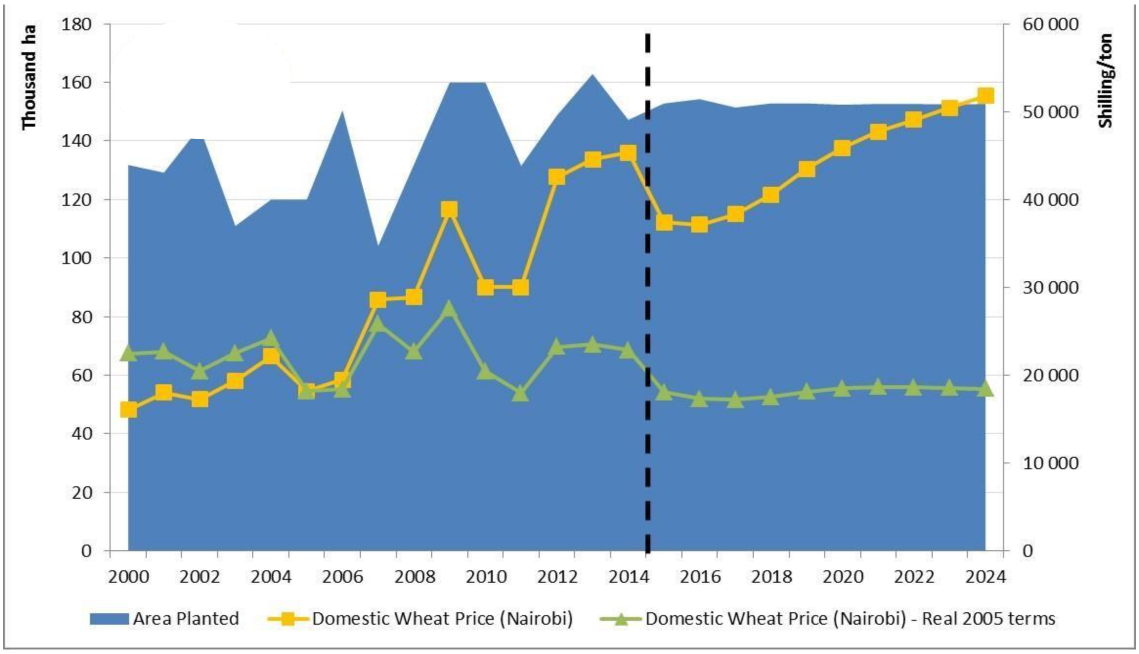

Figure 2: Kenya wheat area harvested and price

Source: Adopted from Meyer, *et al* 2016

1.1.3 Production, imports and apparent consumptions of wheat in Kenya (1960 to 2018)

The trends in production, imports and consumption of wheat products from 1960 to 2018 are shown in **(Figure 3)**. Consumption has been rising at an average of about 4 percent per year and there is no sign of slowing down. With a rising demand, the deficit was met by the elimination of exports in the early 1960s and a continuous increase in imports, (FAO, 2017). The Figure shows that the country imported substantial amount of wheat every year to meet the required demand. For example, in 2012, 2013, 2016 and 2018 the demand for wheat was 1750, 1800, 2000 and 2300 MT, respectively, while the imports were at 1139, 1473, 1774 and 2000 MT, respectively (FAO, 2019).

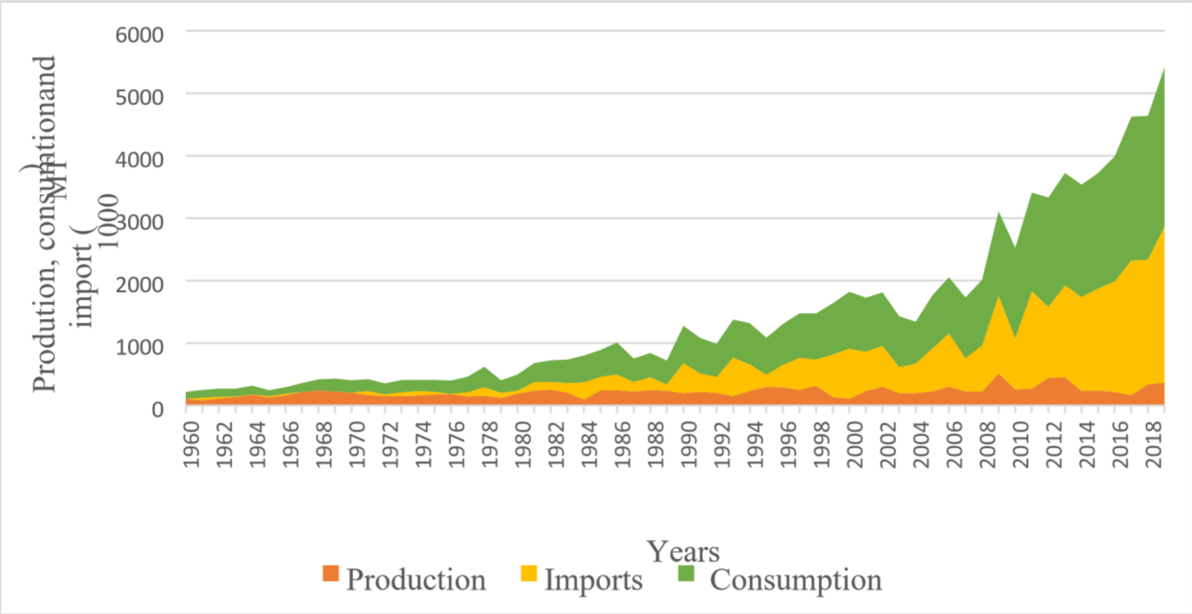

Figure 3 :Wheat production, consumption and import (1000MT) in Kenya (1960- 2016)

Source: FAO, 2017

1.1.4 Wheat varietal releases in Kenya

Many wheat varieties have been released by KALRO (Appendix-1). Nonetheless, a few of the varieties are adopted and extensively grown by farmers (KALRO, 2015). Examples of these varieties include: Kenya kingbird, Eagle10, Kenya Ibis, Kenya Hawk 12, Kenya Wren, and Kenya Tai. Varieties released between 2011 and 2012 (Table 1)

Table 1: wheat varieties released between 2011-2016

Commercial Name	Year of release	Attitude (m.a.s.l)	Maturity period(days)	Research Yield t/ha	Origin
Kenya Wren	2012	1800-2400	120-130	8.5	CIMMYT
Robin	2011	1800-2700	110-120	8.1	CIMMYT
Kenya Tai	2012	1800-2100	100-110	6.5	CIMMYT
Kenya Sunbird	2012	1800-2100	100-110	6.5	CIMMYT
Eagle10	2011	1800-2100	100-110	6.5	CIMMYT
Kenya Korongo	2012	2100-2400	120-130	8.5	CIMMYT
Kenya Kingbird	2012	1800-2400	90-110	6.0	CIMMYT

Source: KALRO (2015)

Unless sufficient quantity of seeds is produced, disseminated and availed to farmers, variety release solely not bring the expected returns. There exists a gap between use of certified seeds by farmers and wheat varietal release. This could mainly be due to the decreased multiplication rate, and the huge seed demand (Singh *et al*, 2015).

The character of the wheat's reproductive behaviour of self-pollination makes the seed distribution system remains a public sector function (de Roij (2020). The grain harvested from the field can be recycled in the subsequent seasons without significant yield reduction. This makes it difficult to ensure a strong intellectual property rights protection for the wheat seed-related transformation, the market discourage private sector investing in wheat varietal development but relies on the public research sector (Hassan., Mwangi, and Karanja, 2016).

1.1.5 Wheat Research in Kenya

KALRO's wheat breeding research centre under the umbrella of the food crop Institute was founded in the 1920‟s and has a national mandate of conducting research on wheat and oil crops. Plant breeding research centre has in many years conducted research in areas that of wheat breeding, quality enhancement and control, soil conservation, disease and pest control, among others since the 1920s. KALRO-Njoro wheat research program focuses on yield improvement, pest and disease and drought resistance among others. KALRO-Njoro has commercially released over 100 wheat varieties since its inception (Kamwaga *et al*, 2016).

The aim is to donate to improved food availability and development of the economy at agricultural, municipal and governmental levels. The purpose of the wheat development program spans geographical and world boundaries. Varietal development goals guiding the research agenda for long-term have included increased stable yields over time, tolerance to stresses such as drought, acidic soil, pest and diseases. To date, the wheat research program in Kenya has produced over 100 improved wheat varieties (Figure 4). A list of approved improved wheat varieties with key descriptors is included in Appendix 1.

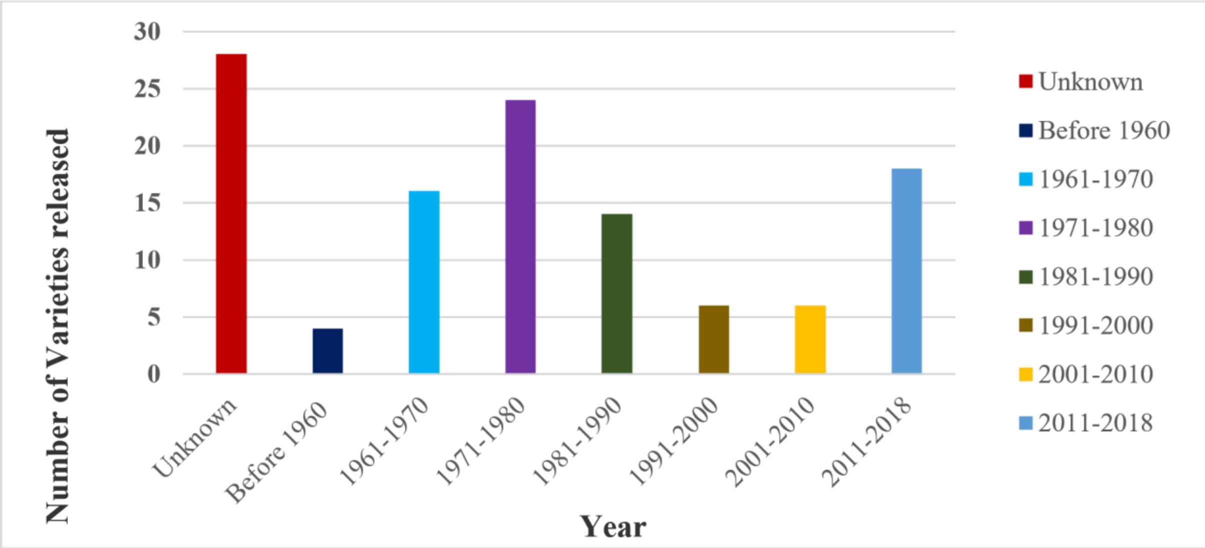

Figure 4 : Released improved wheat varieties up to 2018, Kenya

Source: KALRO, 2016

Examples of some outstanding varieties with exceptional characteristics that are favored by farmers are K. Wren and K. Korongo with a yield potential of about 9 tons/ha. Wheat cultivars such as K. Sunbird, Kwale Eagle10, K. Tai, K. Kingbird and Duma have an average potential of 6.0 to 7.5 tons/ha, Kamwaga, *et al*. (2016). According to Kamwaga, *et al.* (2016) Njoro BW2 and K. Wren are cultivars tolerant of acidic soil while K. Hawk12 can withstand pre-harvest storage and germination. Different wheat varieties have different moisture requirements and full growth periods. Depending on the time of year and geographic production location, Eagle10, K. Sunbird, K. Tai, K. Kingbird and K. Wren varieties are relatively resistant to stem rust. It was found that the Kenya Kingbird variety is highly resistant to yellow and stem rust.

Wheat farmers may need to consider these attributes when selecting varieties for commercial production as this will determine the niche market. Kenya Korongo is an excellent variety for confectionery and baked goods. This makes it a premium price point specifically for the high-end market, Kamwaga, *et al* (2016).

1.1.6 Characteristics of the new improved wheat varieties (2011-2012)

The development in the Kenya's wheat production is partly brought about by previous investments in wheat research, particularly the KALRO wheat breeding program. Eight wheat varieties were bred at KALRO-Njoro between 2011 and 2016 (Table 2). These are the cultivars designated as the new improved wheat cultivars in this study. Properties of the new improved wheat cultivars released by KALRO between 2011 and 2012 are shown in Table 2.

Table 2: Characteristics of eight wheat varieties released between 2011 and 2012

Commercial Name	Year of release	Attitude (m.a.s.l)	Maturity period(days)	Research Yield (tons/ha)
Kenya Wren	2012	1800-2400	120-130	8.5
Robin	2011	1800-2700	110-120	8.1
Kenya Tai	2012	1800-2100	100-110	6.5
Kenya Sunbird	2012	1800-2100	100-110	6.5
Eagle10	2011	1800-2100	100-110	6.5
Kenya Korongo	2012	2100-2400	120-130	8.5
Kenya Kingbird	2012	1800-2400	90-110	6.0
Kenya Hawk12	2012	2100-2400	120-130	8.0

Source: KALRO-Wheat Breeders (2017, 2018)

1.1.7 Funding for KALRO Wheat Research

The funding of the KALRO Wheat Research Program comes mainly from three sources: The Kenya Research Grant, external income (income from projects, R&D grants and trade in agricultural products) and other earnings such as short-term long-term investments interests. KALRO-Njoro annual report (2015/2016), gross earnings fell by 8.0%, due to lower government grant awarding from 2013 to 2015 and a slow private sector investment in agricultural R&D growth over the past decade. This cutting back in research finance is not limited to Kenya. Pardy *et al.* (2016) found that after adjusting for rising research costs, 40% of SSA spent less on public agricultural research and development in 2010 than in 1981.

The total area of wheat cultivated in Kenya has decreased by 18% from 2009 to 2017 (FAO, 2017); This transition is attributable to several factors. First, wheat prices in world markets have been historically low, in part due to high production in high-income countries (Coale, (2017)). Additionally, the cost of fertilizers, seeds and other inputs increased from 2010 to 2017 due to the devaluation of the Kenyan shilling. As a result, producers in Kenya are shifting away from wheat production towards more profitable crops such as corn and beans.

1.1.8 Return to wheat research

In the late early 1970s, lofty-yielding wheat cultivars (referred to as modern cultivars) developed in Mexico were initiated to a number of the globe's most famous less developed countries, including Kenya. When cultivated with more fertilizers and good water, modern cultivars performed better than earlier released cultivars, reading to high increases in wheat production and high incomes for many wheat farmers who embraced the new improved cultivars (Nalley *et al*, 2018).

When real budgets stopped expanding, research administrations in several countries were mandated to remunerate more attention to resource use efficiency (Lantican *et al*., 2016). Methods for setting research priorities have been largely modified by requirements that proposed research projects must undergo impact assessment with the aim of developing indicators to facilitate selection among alternative investment opportunities (Pardey *et al*., 2016). As Kenya's limited research funds are used to support a variety of research projects, it is important to establish that invested funds generate attractive returns to research compared to the opportunity costs.

1.1.9 Adoption Rates for Wheat Varieties

The benefits of new technologies in economic development can only be realized if the new technology is highly adopted by the farmers. If not, the transfer and production of agricultural technologies is not an end in itself. Unless farmers apply improved agricultural technologies emerging from research institutes, will not be realized.

System level impact of wheat research correlates positively with the degree of acceptance of the new improved wheat varieties produced. According to this model, if research and dissemination efforts for a particular new improved technology result in a high rate of adoption, then the overall return on research is expected to be high; but if there is no adoption, there will be no return, (Ngango & Hong, (2021).

Information about the adoption of improved wheat cultivars provides an important source of feedback for planning publicly funded research. Knowing the Adoption Rate of Wheat Research Results (cultivars) can also help guide follow-up research to uncover development implications when adoption rates are high. The outcome of the study will guide policy research and development of wheat.

1.1.10 Wheat varietal turnover rates

Replacing existing cultivars with new released varieties is an important means of continually improving yields and reducing losses from biotic and abiotic stress. especially for crops with low genetic diversity such as wheat (Singh *et al*., 2019).

The cultivar switching rate on the supply side is associated with lack of efficiencies in the distribution of new varieties and their superiority over the older varieties to be replaced (Tadesse, Bishaw, and Assefa, 2019). On the demand side, variety turnover is constrained by a complex set of economic, social and behavioral factors. Economic factors include the price of new improved seed and the transaction costs of securing the improved seed, opportunity costs associated with seed replacement, and the price of complementary inputs and output price of the product, access to information and credit (Karlan *et al*. 2014).

Many previous studies have tended to examine adoption as a choice between an old and a new technology, but few examine the process of technological change; for example, replacing an improved variety with a slightly newer one (Nazli and Smale 2014). As a result, the spatial genetic diversity of Kenyan wheat is limited and the production system may be at risk of biotic and abiotic stress, causing millions threatened by farmers and food-insecure consumers. While the relatively modest genetic gains associated with subsequent cultivar generations may partly account for this situation (Singh *et al*., 2019), a more thorough understanding of how the supply- and demand-side factors influence the rate of cultivar turnover and of area under new varieties in Kenyan wheat.

In this study, we focus on a major index for cultivar turnover by (Singh *et al.*, 2019), which is the average age of cultivars grown by farmers weighted with acreage to measure the rate of cultivar turnover. Research and development (R&D) in breeding of variety improved varieties is a necessary but not sufficient channel of bringing about technological change for a number of grounds. One, triumphant varietal development does not guarantee rapid uptake by willful users. Acceptance is dependent on the interrelationship between demand and supply factors for ancillary inputs, seeds, credit, and the produced commodity for consumption or sale, (Schleifer & Sun (2020).

1.1.11 Risks in wheat production

Farmers perform their functions in complicated environments created by natural environmental, market and social risks (Akhtar *et al*. 2018). The main obstacles to the agricultural production is that agriculture is under the impact of diverse risk factors that depend on distinct conditions (Hayran & Gl, 2015).

Agriculture is a risky business compared to other sectors because agricultural production is mostly affected by the natural and climatic conditions which include pests and diseases, rainfall fluctuations, drought, floods and storms (Hayran & Gl, 2015). The sector is also severely influenced by fluctuations and changes in market prices, (Akhtar *et al*, 2018). Therefore, in order for the agricultural sector to be developed the risk behaviour of farmers should be identified and proper risk management strategies developed. This would help in identification and understanding of the risky behaviour of farmers under the prevailing conditions, particularly for intervening institutions that ensure that agricultural development is achieved (Kabir *et al*., 2021).

Farmers need to invest time and capita to develop some management strategies to avoid many types of risk. Production risks include biological risks, market risks and social risks (McNeil *et al*., 2015; Ullah *et al*., 2015). Considering that agriculture is a variable source of income, farm households should to identify and manage risks (Ullah, Shivakoti and Ali (2015). Understanding the sources of risk can help farmers make wise decisions related to risk management and other adaptation measures (Ullah, Shivakoti & Ali (2015) According to Azadi, Yazdanpanah & Mahmoudi (2019), the main types of risk faced by wheat farmers include production risk (biological risk: biotic and abiotic risk), market risk, institutional risk and human risk.

1.2 Statement of the Problem

The Kenyan government funds the Agricultural Research organization, which conducts holistic technological improvement on crops and livestock. In Kenya, the average wheat area is 170,000 ha and annual production of 450,000 tons an estimated annual consumption of 1,200,000 tons. This makes Kenya a net importer of wheat, with annual imports of around about 60% of its total wheat requirements (FAO, 2017). Wheat consumption in Kenya has increased over the years due to population growth, rapid rural –urban migration, changes in dietary behaviour resulting in a large gap between wheat production and demand, which in turn makes the country to rely on imports. (FAO, 2017).

Nonetheless, despite Kenya's funding of wheat research and expansion over the past 90+ years, the Green Revolution has had little impact on Kenyan wheat production and yields. As a result, Kenyans and donors wrestle with questions about appropriate investment in wheat research and technological development. The literature on studies attempting to estimate genetic gains in Kenya's wheat breeding is sparse and to our knowledge there is no existing study using empirical data. There is no information on the returns achieved to date to guide and justify the further allocation of resources to wheat research.

This study is pertinent because research and development of agricultural projects must battle with other sector projects that could improve the lives of people in Kenya. In addition, the KALRO Annual Report 2014/2015 shows a decline in KALRO"s wheat breeding research since 2001. Without convincing evidence to measure the return on investment Kenya is making by funding the KALRO Wheat Research Program, the KALRO Wheat Research Program risks the possibility that competing funds will flow into other crops such as corn, oil crops and legumes.

To ensure future funding, the KALRO wheat program, the varieties released to improve wheat production, must have noticeable benefits referable to their new improved varieties. As Kenya continues to grapple with food insufficiency, this kind of research can provide lawmakers and academics with intuition into the way forward end food insufficiency. Without adopting the new improved wheat varieties, the returns to wheat breeding research cannot be realized. The rate of adoption of new improved varieties only gives part of the information about the impact to investments in crop research development.

The rate of cultivar turnover is a key end product, particularly in breeding research programs where breeding is continuous. Unless newer materials replace their earlier-generation counterparts, the return to genetic enhancement stalls. In Kenya, there are few credible databases on adoption, cultivar turnover rates and the impact of well-identified improved wheat cultivars. Risks affecting wheat production and thus wheat research were not documented for the study areas.

This study contributes to the bigger effort of developing feasible wheat production in Kenya. Realizing this objective in the countenance of reduced wheat acreage, climate change, reduced purchasing power, and population growth will require integrated approaches across all scientific disciplines. The results of this study can support this research.

1.3 Objectives

1.3.1 Overall Objective

To contribute knowledge and information on returns to wheat research, varietal adoption rates, varietal turnover rates, and wheat production risks.

1.3.2 Specific Objectives

1. To conduct a benefit-cost analysis of wheat research investment in Nakuru and Narok counties
2. To assess the rate of adoption of improved wheat varieties in Nakuru and Narok counties
3. To examine the wheat varietal turnover rate in Nakuru and Narok counties
4. To investigate risks to wheat production in Nakuru and Narok counties

1.4 Research Questions

1. What are the returns to investment on wheat research in Nakuru and Narok counties?
2. What is the rate of adoption of improved wheat varieties in Nakuru and Narok counties?
3. What is the wheat varietal turnover rate in Nakuru and Narok counties?
4. What are the risks that affect wheat production in Nakuru and Narok counties?

1.5 Significance of the Study

This study is important for several reasons. First, the information from the ROI analysis is needed by government and donor organizations to justify the continued allocation of resources. Second, the adoption rate is a necessary condition for agricultural research to be effective; Third, tracking cultivar turnover/replacement is an important source of information because the information can be used as an indicator of the economic impact of plant breeding and expansion programs. Finally, the information provided by the study would be important for farmers to take mitigation measures in managing wheat production risks in only two major wheat growing areas in Kenya. Therefore, the results cannot be generalized to the whole country.

This study was limited to varieties approved by KALRO but not to varieties approved by the private sector and universities. For research returns, the study only considered varieties released from 2011-2012. Varieties launched before 2011 are not included. It should be emphasized that there are many factors that affect the effectiveness of R&D.

These factors can be sociological, psychological, organizational/structural, managerial and economic in nature. This study focuses on the relationships between economic resource indicators and R&D effectiveness. Insofar as the study does not deal with the sociological and psychological factors influencing the effectiveness of R&D, the analysis presented here can therefore be regarded as incomplete, but nevertheless as an important contribution to measuring and understanding R&D productivity.

CHAPTER TWO

LITERATURE REVIEW

2.1 Approaches to Analysis of Returns to Wheat Research

Economic value analysis is the most common approach to analyzing the welfare effects of agricultural research in a partial equilibrium framework (Yigezu, *et al*., 2021). The economic added value model is used to assess the welfare effects of new technologies in agricultural research programs within a limited equilibrium framework (Rejesus *et al*., 2014; Sequeros *et al*., 2020).

There are several methods to use excess analysis for returns to research. Cost-benefit analysis was proposed for use by Timsina, (2019). Although this type of analysis usually used to complement surplus analysis), econometric models, and resource cost models. However, a mix of methods is often found in the literature. Both econometric and surplus methods were used to assess the economic impact of bean research in Honduras, Musimu, (2018). In their estimation, they found that investing in the bean breeding program was profitable.

To estimate the return on public investment in agricultural R&D in India, Alene (2010) used a simultaneous equation model. They found that agricultural research investment yielded the soaring return on productivity in recent years, with a BCR of 13.5. As reported in these studies an accumulation of the benefits showed that the respective research projects generated more than 90% of the total benefits of the CGIAR Centers.

Analysis by Malla and Gray (1999) using BCA shows a large influx of investment in agricultural research in the 80s and 90s was not accompanied by higher increases in crop yields. They found that an average IRR that initially exceeded 25% per year eventually approaching the level of market returns below 20% (CGIAR, 2011).

CIMMYT wheat research programs used a benefit-cost analysis (BCA) model to analyze wheat breeding returns and found a global per year investment in wheat development research of about $30 million, the per annum benefit of wheat development research in the period 1995-2015 ranged from US$2.3 to 3.2 billion, and a BCR of world wheat breeding research ranged from 73 to 103 (Byerlee and Dubin, 2010). Overall, this suggests that wheat breeding research programs have been successful.

Asadi *et al*. (2007) used the BCA model to analyze returns from wheat research. The results showed that BCR and IRR for 12 wheat varieties were 25.8 and 77.8%, respectively. Barkley *et al*. (2008) found from their work that the a BCR index of the CIMMYT wheat breeding program is 14.99, an IRR 55.5%, and NPV of 469200 and 415200 million Iranian rials respectively. The BCR for Shush, Narin, and Mehregan were 1.5, 7.7, and 4.6, respectively. The IRR for Shush, Narin, and Mehregan was 28.5%, 51.1%, and 47.5%, respectively. In this study, the economic analysis of the wheat breeding program in Kenya involved the determination of profitability indices, which included NPV, BCR and IRR by Asadi *et al* 2017.

2.2 Wheat Varietal Adoption Rates

Definition of adoption and choice of how to measure it depends on the technology used (Mwangi and Kariuki, 2015). For example, the adoption can be defined to consider the choice or perception of a technology by farmers, or the stage of an adopted research output (Singh, 2020). Adoption is defined as a binary or continuous variable in the studies on improved cultivar adoption. This measures a farmer's decision to accept an adoption or not (Jaleta, *et al*, 2018). The continuous variable, in turn, measures the rate of adoption (i.e., the percentage of land allocated to new improved plant varieties (NICVs), as well as which binary variables measure.

Many previous studies used an easy dichotomous adoption variable (Chandio and Yuansheng, 2018). A number of farmers grow more than one variety, in this case it is important to measure how much the improved cultivar is accepted, in addition to whether or not it is accepted, which means that the measurement for the binary variable does not contain enough therefore using a binary adoption variable is suitable for uptake of only one variety. Hence, the binary analysis is suitable in the case where farmers replace old improved varieties with new improved variety. As a measure of the continuous adoption variable, Bekuma (2018) proposed a proportion of land area under the new improved cultivar.

using part of the country in their corn and rice study, Ibitola *et al*. (2019) used an adoption indicator. The adoption indicator was calculated for each farmers as shown below:

$$ADOPTION_I = \frac{\sum_{i=1}^{n} p_i}{\sum_{i=1}^{n} T_i}$$

Where:

Total land area cultivated by Farmer i for cultivation. i = [1, n].

This study uses data from a farm-level household survey to measure adoption of the new improved wheat variety. This includes each household's acreage under new improved wheat cultivars and the aggregate area planted with wheat. Specifically, the gross area data includes the combination of the area of the old improved wheat varieties and the area of the new improved wheat varieties.

The adoption rate of the new improved wheat variety is calculated by averaging the area for the new improved wheat variety that was adopted by the aggregate area planted with wheat crop. Improved Wheat Varietal Adoption Rate

$$(\%) = \frac{Area\ for\ improved\ variety\ adopted}{Total\ area\ for\ \text{wheat (in hectares)}} \text{ X100}$$

Data were obtained from survey with the wheat growers**.** The estimated rate of adoption was based on the responses by farmers to the survey questions (see survey tool Appendix 2).

2.2.1 Factors influencing adoption of improved wheat varieties

To point out the explaining variables that influence the adoption of the new improved wheat varieties (NIWVs), along with their likely impact on farm household adoption decisions, a probit regression model was used due to its assumption of a normal distribution. About six binary independent and seven continuous variables were included in the probit model analysis.

2.2.1.1 Models used to examine adoption behaviour

Adoption is incorporation of a new research output into an existent system that usually involves a phase of trial and error and some degree of revamping (Ishola & Arumugam (2019). It is the relative speed with which growers adopt a new research output. Rate of adoption relate to the extent of utilization of a particular research output over a given duration (Yokamo, S. (2020). It is defined as a choice between two distinct alternatives, namely old improved technology and new improved technology. Farmers can choose to adopt one of the two technologies to maximize their utility. Most studies for example (Jaleta *et al.* 2018; Kurgat *et al*., 2020;) used a univariate and multivariate logit or probit model with binary variables (yes/no) to explain the adoption Coefficient interpretations of Tobit models can be due of information loss does not provide information on the intensity of the takeover, therefore the need to use steady takeover variable that detains the exhibit option ferocity is met, extension of the probit estimation methods was proposed and used (Gara, 2020; Lamichhane, 2017).

The probit model gives1) An estimation of the likelihood that a given farmer will become an adopter and 2) estimates of the degree of adoption that were not available in earlier studies (Lamichhane, 2017). The probit model is given as Equation (1), using an independent, normally distributed error term with zero mean and constant varianceσ 2 (Kumar, (2020).

$$Y^{*} = X\beta + \mu, Y_i = \begin{cases} \dfrac{Y_i^{*} \; if \; Y_i^{*} = X_i \beta + \mu > T}{0 \quad if \; Y_i^{*} = X_i \beta + \mu \leq T} \end{cases}$$

Where:

Y_i is the chance of technology adoption and the rate of use and $Y^{*}i$ is an unobservable hidden variable, and T is an unobservable entry point. If the $Y\,i$ is larger than T, notable variable Y_i becomes a steady function of the explaining variable, and 0, if not. the probit model uses all observations, those at the limit, usually zero (e.g. no acquisition). In addition, it captures the intensity of acceptance, thereby reducing information loss. Therefore, to examine farmer adoption of wheat varieties, this study will make use of the probit model.

2.2.2 Factors Influencing Farmers' Adoption Behaviour of Improved Varieties

Various technology uptake studies have been conducted on agricultural research output. Adoption Partial conservation is significantly influenced by access to credit , membership in various clubs and years of education (Dsouza and Mishra (2018). With secondary and tertiary education, household heads are more likely to adopt part of the preservation technologies compared to heads of households with primary education.

According to studies by Ghimire *et al*., (2015), the uptake of rice varieties is remarkably associated with extension-related variables. credit access, gender of head of the family, taking part in farmer trainings, distance to market and labor as major factors in rate of adoption of improved wheat varieties, Tesfaye Solomon *et al*. (2014).To increase rate of adoption, the above variables must be improved.

Adoption of improved maize varieties was positive and significant, and was influenced by the educational level of the household head and access to extension services, Mandate *et al*. (2016) .

Tufa and Tefera (2016) reported that age, agricultural experience of the head of household, , annual income and distance to the weather roads had significant influence to the adoption of improved barley varieties. According to Bentley *et al.*, 2017 and Wossen *et al*., 2017, adoption of improved crop varieties by producers varied according to the geographic location in which the households are located.

2.3 Wheat Varietal Turnover Rates

The main objective of breeding programs is to regularly release new improved varieties with a combination of increased yield, disease resistance, preferred quality and other traits of economic importance and avail them for farmers to adopt (Lantican *et al*. 2016). Farmers can only benefit from plant breeding if they change old improved varieties with newer improved cultivars when they are introduced to the market.

Unless varieties are continuously replaced in farmers' fields, they will not contribute significant returns to research even if breeding programs release new, improved cultivars and multi-locational trials are undertaken (Krishna *et al.,* 2014). Old improved varieties remain in production for very long for reasons that require additional investigation. Age of varieties can be used as a measure of introduction of new varieties, as has been in previous studies. The rate of varietal turnover, as measured by cultivar age, may vary from region to region. After reviewing previous works, it was noted that in developed countries, high varietal turnover rates resulted in low average ages compared to the developing countries where varieties were much older and farmers relinquished the significant benefits they could have derived from growing the new improved cultivars, Witcombe *et al*. (2016).

Farmers carry on producing cultivars that were released during the era of Green Revolution; this slow rate of varietal turnover is likely to contribute to yield stagnation that is reported in various parts of the world, Krishna *et al.*, (2014). Considering a few examples, Swarna, a cultivar that was released about 36 years ago is still grown on about 30% on the wet-season rice area of the South Asian (IRRI, unpublished paper).

According to Krishna *et al.*, (2014), the weighted age of wheat cultivars grown by in farmers' increased from 8.5 years in 1998 to 13 in 2008 in India. The duration taken to develop and release a wheat variety through pedigree breeding in India is about 10–14 years, this suggests that many farmers are using varieties selected over 19 years ago.

Singh *et al* (2020) reported that older variety ages on farms (low varietal turnover) is the cause of decline in yields, it also counteracts the positive returns to varietal development research. Research conducted under impacts of improved varieties studied cultivar replacement using area weighted average of 20 crops in 116 countries, it was found that the mean age was about 14 years, Walker and Alwang (2015). Cultivars must be replaced at the requisite rate, at which it is profitable for the growers to replace varieties depending on the cost - benefits of releasing new varieties (Spielman David J and Smale Melinda (2017).

In India, Witcombe *et al*,1998 estimated the weighted average age of several crop varieties as follows: rice-12.0, pearl millet-5.9, maize-16.7, sorghum-16.0, ground nut-15.0, chick pea19.8 and wheat-9.4. The rate of varietal turnover rate for wheat in India had declined from an average of 10 years in 2010 to 14 years in 2019, Krishna *et al* (2014).

Although many past studies used average weighted age of varieties, the weighted average age underrate the actual ages of cultivars described by the year of release, Witcombe *et al* (2016). Therefore, this study uses the real age of cultivars grown by the farmers and the years that a farmer takes to change varieties in the estimation of varietal turnover for wheat varieties.

Varietal turnover is an important mirror of returns to research of breeding programs. Farmers in India planted 5-7 years old improved wheat varieties in 1997, the average age of wheat varieties was about 7–9 years in 2014. This revealed that in Pakistan old varieties were not easily replaced.

A current assessment of wheat production in Pakistan showed that nearly 29% of wheat area was grown to varieties developed earlier than 1990s; four varieties covered about 69% of land area in 2014 (Javed *et al.* ,2015). This revealed that Inqalab-91 occupied about 49% of the total wheat area in hectares in 2008 season, later the area declined to less than 49% hectares after increasingly becoming susceptible to yellow rust.

Farmers replace seed to gain improved inherent traits in a new improved variety (Lantican *et al.*, 2016). Overtime, Varietal development researchers have stressed that the benefits of varietal replacement as a means of sustaining productivity gains and safeguard yield from the safeguard of plant disease in farming systems (Lantican *et al.*, 2016).

Brennan and Byerlee (1991) were the first to raise concern about the low varietal turnover of wheat varieties during and after the Green Revolution period. According to Heisey and Brennan, (1991), two factors are put into consideration in measuring the rate of varietal turnover: the average age of the variety grown by farmers, and the percentage area of the variety grown by the farmers in a certain duration.

The model of this study is drawn from a survey to evaluate the factors that determine uptake of new developed varieties at the farm level as by Heisey and Brennan (1991). Evaluation using the duration model, the weighted average age of the variety grown by farmers, and the area percentage of the variety grown in a certain period is done by estimating the varietal replacement as described in the literature review, where the mean age of a varietal adopted divided by the area planted in each variety weighted by number of farmers, as shown in this formula by asadi, *et al* 2020:

$$A_i = \sum_{j=1}^{i} A_{ij} \frac{L_{ij}}{\sum L_{ij}}$$

where:

A_i is the mean age of varieties grown by the i^{th} farmer,

A_{ij} are the number of years from the time the j^{th} variety was officially released, and L_{ij} is the area grown to the j^{th} variety on the i^{th} farmer's farm.

Duration model is uncomplicated and easy to derive and evades use of erratic descriptions of newer or older improved varieties in the seed dispensation structure (Atlin., Cairns., & Das (2017).

Even though it is measured at the farm, it apprehends two aspects of wheat seed dispensation system: the rate at which a new improved variety is adopted and a few years represents a highly adopted variety and the varietal turnover rate is also high. In this case, most farmers buy seed per annum to avoid planting own saved seeds.

The depiction of a particular cultivar as "new" and "old" can be unpredictable (Javed *et al*. 2015). Hence, several definitions that estimate varietal turnover rates have been proposed. For example, Area-weighted average variety age (WAVA), an indicator proposed by Brennan and Byerlee (1991), is computed as:

$$WAVA_t = \sum_i p_{it} R_{it}$$

Where:

p_{it} the percentage of the crop's area planted in variety i in year t, and R are the years at time t
from when the variety was released.

To estimate the WAVA, the researcher (1) selects a suitable geographical segment of observation and year for analysis; (2) documents all varieties planted and their ages since they were released; and (3) computes the total of all the varieties and the number of years since each variety was released and the area planted to the new varieties, for each geographical area.

There can be more successful policies that influence dispensation of cultivars in a given area in contrast to their mean varietal age. Hence, scientists have also used distinct assessments to contrast temporal and spatial postulation. i.e average variety age (AVA) stipulate the rate of varietal replacement without considering the area:

$$AVA_t = \sum_i R_{it}$$

where

AVA_t: is the average variety age of the i^{th} variety in year t

R_{it}: R is age of the variety at time t since the variety's release

In the environmental literature, spatial indicators such as the, Berger-Parker, Shannon, Simpson and Margalef indicators reveal concepts of percentages of comparative affluence, and are measured in terms of sizes of population and varieties counts (Atlin., Cairns., & Das. (2017). Similar indices can be used to seize varietal aggregation in a given market. For instance, the Herfindahl-Hirschman Index (HHI) is used to estimate the market share by firms operating in a given industry. The index is calculated as the aggregate sum of the market share squared of each variety in production for a given duration.

Initially, the HHI was given as:

$$AVAt = \sum iS2it$$

Where:

S_{it} designates the portion of the i^{th} variety of N varieties in production at time t.

Notably, all the varietal turnover rate measures have shortcomings. First, they depend on the rationality of the name of variety, date of release, and area estimates, and the entirety of the varietal register.

Secondly, computations relying on area means are achievable only if data used to compute variety-distinct areas under production are statistically illustrative and precisely reported. Even if the data are collected from governmental statistics, farm level surveys, or from expert opinion, inconsequential distress exist over imprecise reporting and other issues.

Thirdly, varietal turnover estimates based on production are practicable only if specific varietal seed production amounts are entirely and perfectly revealed which in a competitive market may constitute restricted information from a seed merchant's standpoint. This indicates that estimations may miss to capture the recycled seed varieties, insinuating the probability for downhill biasness in computing mean varietal age. However, production averages can inscribe the probable biasness brought about by missing responses to questions asked in farm surveys.

Fourthly, it is necessary to acknowledge that turnover rate computations are not proportionate across time, crop, and systems of cropping. Turnover rates measures are relevant only when viewed in the aggregate rate of adoption for new improved varieties in a given geographical location. But turnover rates computations have minimal relevance where there are low adoption rates because the computations contemplate the operations of a few farmers. Lack of significant varietal rate of adoption, example, if the federal cropped area grown with improved crop varieties is less than 10 percent, expediting varietal turnover rates is not likely to have very little impact federal production, Spielman and Smale (2017).

Finally, rates of varietal turnover computations should be looked at in the wider context of a new improved variety’s cycle, which consists of three phases with divergent cost and benefit designs. The release of a variety only includes the costs of investment in Research & Development and the costs of regulatory compliance associated with procedures of varietal release.

The first phase does not generate benefits, the second phase is the involves adoption of the released varieties, the lag phase which follows release of varieties in which there are no more investment costs and no benefits. The third phase is the time in the field the duration variety longevity when there are benefits but investment costs have stopped. Costs incurred in this phase include seed multiplication, breeder seed maintenance, seed quality assurance regulations costs, advertising. As reported by Brennan and Byerlee (1991) the mean weighted average age of varieties in growers" fields is an estimation of the on-farm varietal replacement rate.

Definitive measures of this crucial variables are scarce. Yield decline is likely to be contributed by the slow rate of varietal turnover as revealed in several countries globally (Ray *et al*. 2012). For instance, over 20% of the wet-season rice area in the South Asian is still grown to the cultivar Swarna, a variety that was released more than 30 years ago (IRRI, unpublished data).

The weighted mean age of wheat cultivars in growers' fields raised from nine years in 1998 to 12 in 2008 in India, Krishna *et al.*, (2014). The duration from development to releasing a wheat variety through pedigree breeding in India is between 10–14 years, this implies that many Indian growers are growing varieties released over 19 years ago.

Atlin., Cairns., & Das (2017), indicated that low varietal turnover rates were hampering the growth of wheat productivity in Punjab, India. This is the case all over the less developed world; Majority of growers grow older improved wheat varieties that are not developed for current's climate systems.

Based on the study of impacts of the world wheat survey by Asadi, *et al*, (2017), weighted average age of wheat varieties in Hungary, Lebanon, Czech Republic, Georgia, Argentina, Kenya, Spain, Ukraine are less than 6 years. However, in Rwanda, Ethiopia, Brazil,

Zimbabwe are between 6-9 years, in, China, Azerbaijan, Bangladesh, Italy, USA, Canada, West Australia, Iran, Japan, Zambia, Latvia, Nepal, Pakistan, Romania, Mexico, Tanzania, Uzbekistan are between 7-10 years, in Uganda, Egypt, Nigeria, Bolivia, Turkey, Switzerland is between 9 -12 years, and in India, Russia (Omsk), Israel, Serbia, Slovenia, Albania, is between 11-15 years (Crossa, *et al*, 2014). The average age of wheat varieties, in, Syria, Morocco, Sudan, Algeria Tunisia are more than 13 years (Asadi, *et al,* 2017).

Slow rate of varietal turnover in the developing countries and Southern Asia are probable due to lack of awareness about and access to new improved varieties on the portion of small scale farmers, Ray *et al*. (2012). It may be caused by collapse of new improved varieties to compliment with the old improved varieties in yield potential, resistance to pest and disease, among others (Atlin., Cairns., & Das (2017). How quickly varieties are replaced indicates how effectively the seeds of new varieties are supplied and taken up by farmers. Several factors determine the rate of varietal turnover; these includes: how varieties are popularized by government research institutions, how efficiently seed producers‟ market new varieties, and how superior the new improved varieties are to the old improved varieties.

For self-pollinated crops where growers can cultivate recycled own seed, the progression of aggressive seed outlets guiding expediting varietal turnover is slow due to absence of a business plan to dispense adequate proceeds to seed growers to support crop development programs (Krishna *et al.,* (2014).

In majority of these cropping structures, the development and dissemination of new improved varieties will consequently remain a public sector control for many years in the future. An essential element in slow varietal turnover rates is the level of commercialization of the cropping structure (Spielman and Smale, 2016). Farmers will rapidly replace old improved varieties when there is a constant supply of new released superior varieties.

Variety replacement rate is, accordingly, a good indicator of successful crop breeding programmes in developing and releasing new improved varieties and the extension services in advertising and disseminating new crop varieties. For a sizeable percentage of the wheat crop in sub-Saharan African countries, the major questions are related not to early adoption of improved wheat varieties but to growers‟ decisions to gradually replacing the old improved wheat varieties with new improved varieties. Varietal turnover rate is an important index of the adoption rate of growers of second and third generation improved wheat varieties and of farm-household level demand for improved varieties.

Diverse measures have been suggested in the literature to evaluate variety turnover rate, for example, Brennan and Byerlee, (1991), among others. Of the several approaches to analyzing the varietal replacement rate. For this study we have chosen to use the model proposed by Brennan and Byerlee (1991). They proposed the area-weighted average age of cultivars in growers‟ fields as an estimate of the on-farm varietal turnover rate. The choice of this approach was because it is simple to make interpretations and does not require time series data that farmers have a problem of remembering mainly the farmers who don't keep records.

2.4 Risks in Wheat Production

2.4.1 Methodologies Employed in Analysis of Wheat Production Risks

Goerlandt, & Reniers (2018 developed the concept to define risk in quantitative terms. The definition of risk can be delineated by answering three questions; "What can happen?", "How likely is it?", "What are the consequences?" The term risk is demonstrated as follows (Goerlandt, & Reniers (2018).):

$$R = \{S_i P_i(\phi_i), P_i(X_i)\}$$

Where:

R is the risk definition,

S_i is the risk scenario, P_i ($\square_i$) is the probability and P_i (X_i) is the outcome.

Uncertainty as a condition when the decision maker lacks perfect information as pointed out by Haines (2019). The researchers revealed how diverse consequences to risk might be visualized with the likelihood dispensation of each consequence. Lavik, Lien, Korsaeth & Hardaker (2020). Made an attempt to explain the perplexity in the definition of risks by proposing three usual elucidation of risk, which included “the chance of bad outcome”, “the variability of outcomes” as well as “the uncertainty of outcomes”.

Agricultural production risks are complex, hence can be termed as a risky venture (Iqbal, *et al*, 2018). Farmers are confronted by production risks which include a variation of yields, fluctuating input and output prices and absolute changes in production technology. These lead to the unstable in farm profitability after a long time (Atta (2018).

Descriptions of price or market risk is the variation in the price of farming inputs and outputs caused by supply and demand in the competitive markets. For instance, new limitations regarding the use of chemicals on farms that will raise the cost of production (Reinhardt, Hoevenaars & Joyce (2019). According to Mena, Melnyk, Baghersad & Zobel (2020). the interviewees were asked to define and rank risks, sources and management strategies based on Likert five-point scale. The results showed that precipitation variation, pests and diseases, and price variations ranked as the most important sources of risk for agricultural production. Climatic irregularity, diseases and price were viewed as important sources of risk for animal production.

Using a survey of beef producers in Texas and Nebraska, Iqbal, Ullah, Abbas, Afil & Sadaf
(2018), used 5-point Likert scale to examine farmers‟ insight of sources of risk and usefulness of several risk management tools. Growers were asked to rank sources of risk on the bases of their insights about impact of a every risk on farm revenue.

Porsch, Gandorfer, & Bitsch (2018), used 5-point Likert scale to measure insights of risk and their management. A one (1) meant high disagreement and a five (5) meant high agreement with a specific source of risk. 1) financing risks; 2) production risks; 3); social risks 4); environmental risks and 5) market risks were the five Sources of risk that were identified. Shabanali, & Bagheri (2018). investigated how mussel producers in Denmark viewed sources of risk on profitable performance and the importance of several risk management strategies in tackling risks using a Likert scale from 1(not important) to 5(very important). Producers viewed poor weather conditions, unpredictable future demand and prices, and likely changes in statutes as the worst unreliability. Alternatively, farmers identified liquidity and solvency, cost reduction techniques and engaging peer farmers in production and marketing strategies to be the most effective risk management techniques. The 5-point Likert Scale was used in this study to assess risks associated with wheat production in Kenya.

2.5 Conceptual Framework

Research impact occurs when improved varieties or production practices are adopted by farmers, resulting in lower costs and/or increased output. To identify factors that might block this from happening, it is helpful to look at the causal chain of events involved in technology development, transfer, adoption, varietal turnover and production risks (Figure 5).

Cost-Benefit-Analysis (CBA) assess and makes comparisons to all the costs and benefits of the social, environmental and economic effective and cynical impacts of the approaches to revamping which are expressed in fiscal terms based on its general information. In this study wheat improvement expenditures include capital expenditures (land, buildings, and equipment) operating expenditures (staff salaries and benefits, staff trainings, office operations.

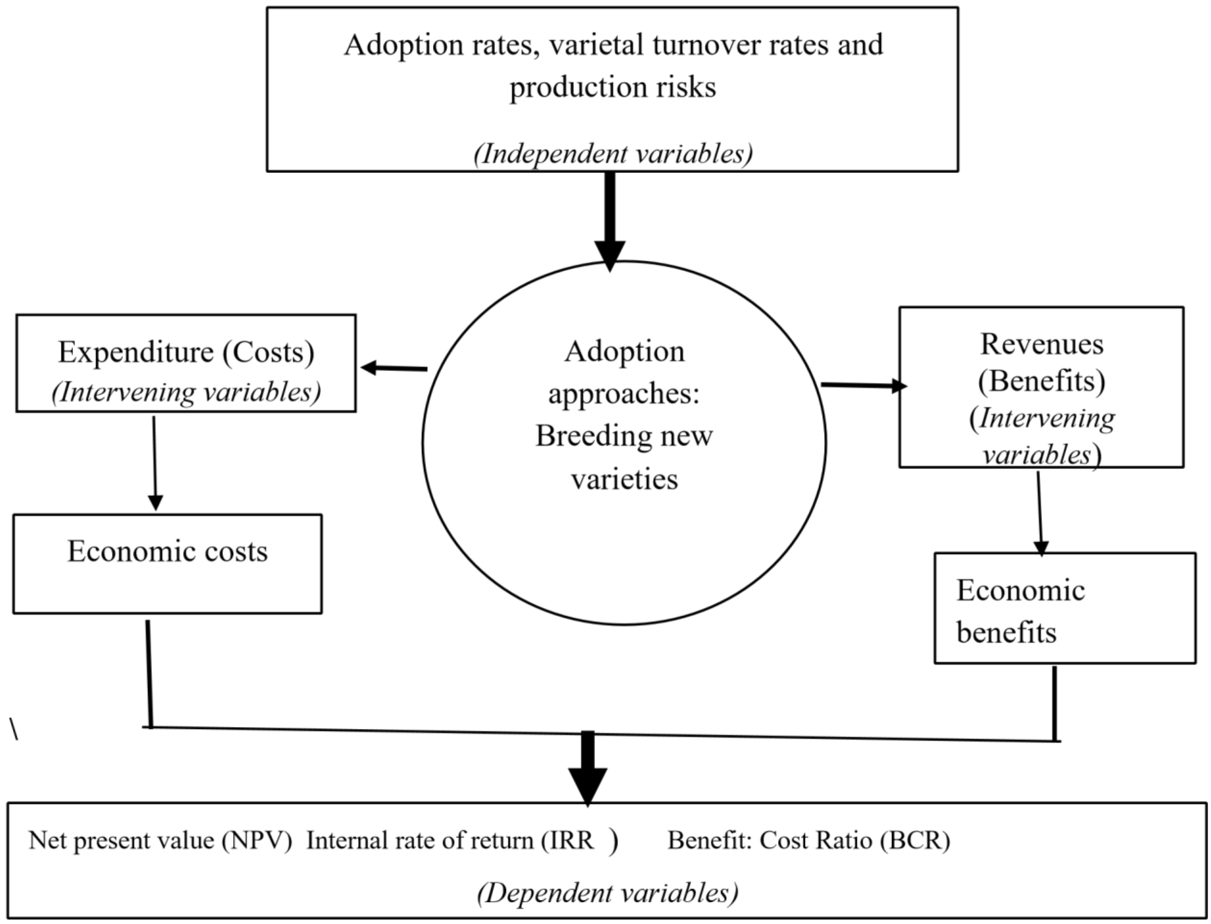

Figure 5 : Conceptual framework Source: Authors own compilation

Rates of return to wheat research depend very much on the magnitude of associated adoption rates, varietal turnover and associated production risks

CHAPTER THREE
RESEARCH METHODOLOGY

3.1 Scope of the study

Primary data was collected within two counties namely: Narok and Nakuru during the months of May-July 2018. The farmers were categorized into scale of production- small scale (<20ha), Medium (20-50 ha) and large scale (>50 ha) farmers. The households were asked about the varieties of wheat that they grew, adoption of new varieties, number of times that they changed varieties, the risks that they faced in wheat farming among others.

3.1.1 Design and Sampling Procedures

The study used survey design. The design incorporated the use of observation, interviews using -structured questionnaire and schedules as methods of data collection. In order to compute the economic analysis, data on expenditures for the wheat breeding research obtained from the KALRO wheat breeding program-Njoro for 2001 to 2011.

3.1.2 Sampling Procedure

A multi-stage random sampling technique was used to identify respondents from whom data were collected. Stage one involved the purposive selection of Counties identified for wheat production. Based on information obtained from the wheat breeding Centre, KALRO-Njoro, over eighty percent of Kenya's wheat is grown in Narok, Laikipia, Nakuru, and Uasin-Gishu Counties (Figure6), KALRO (2015). However, given the resources and time available for this research, the survey was confined to two Counties (Narok and Nakuru). Narok County was purposively selected because large-scale wheat farming predominates in the County, while Nakuru County was purposively selected because small-scale farming predominates in the County and it hosts the wheat breeding research Centre, KALRO-Njoro.

In Stage two, Sub-counties in each of the selected Counties were purposively selected. These included Rongai and Njoro Sub Counties of Nakuru County; Narok North and Narok South sub-Counties for Narok County. A list of households growing wheat was obtained from the cereal growers‟ association (CGA) office records and finally 344 farm wheat farmers were selected by use of proportional random sampling method. The farmers were stratified by scale of the wheat production, i.e. into small farms having less than 20ha; medium farms with 20–50ha; and large farms having more than 50ha. From the list, farmers were randomly selected from each stratum (Figure 6).

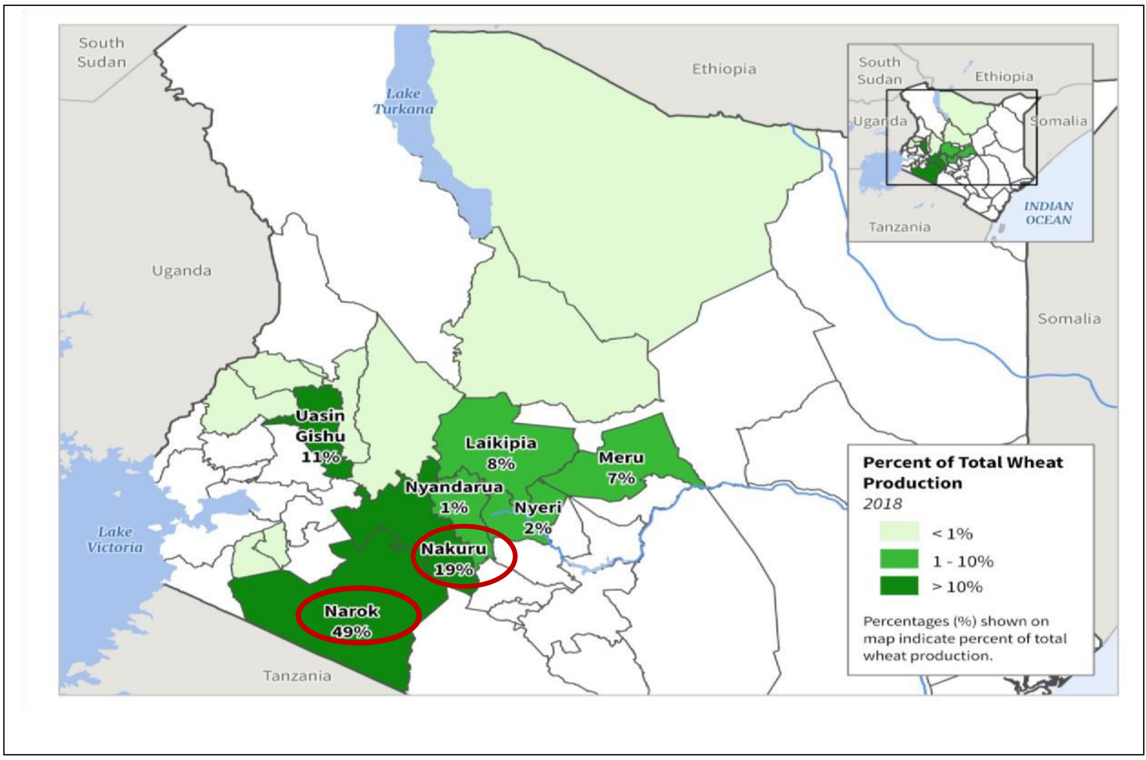

Figure 6: Wheat growing areas in Kenya

Key: The green shaded Counties represent the wheat producing areas

The red circled Counties are the study Counties

Source: Kenya Ministry of agriculture, Wheat Production 2018

3.1.3 Study Area

Cross sectional survey approach and Multi- stage sampling procedure was used in the selection of the sample. Nakuru and Narok counties were the counties idenfied for this study (Figure 1) purposively because of their potential for wheat production. Three sub – counties were selected from each county to form strata, Njoro and Rongai sub - counties from Nakuru County and Narok North and Narok South from Narok County.

The sub - counties were included in this study because of their geographical location, levels of wheat production, and the extent of small-scale, medium, and large-scale wheat production. The study used structured questionnaire and key informants to collect data from the selected wheat farmers.

3.1.3.1 Description of Nakuru County

Nakuru County covers an area of about 7,495.1 km^2 and has a bimodal precipitation pattern with a high precipitation of 1800mm and a low rainfall of 500mm. The county covers an area of 7,495.2 km^2. Temperatures in the county ranges from 29.0^oC between December, January, February, and part of March to low temperatures of up to 12.0 ^oC in the month of June and July, NCIDP, (2013). The County is one the major wheat growing counties in Kenya as well as the wheat research centre in the country. Over 70% of the total County land is agriculturally productive, KNBS, (2018) (Figure 7).

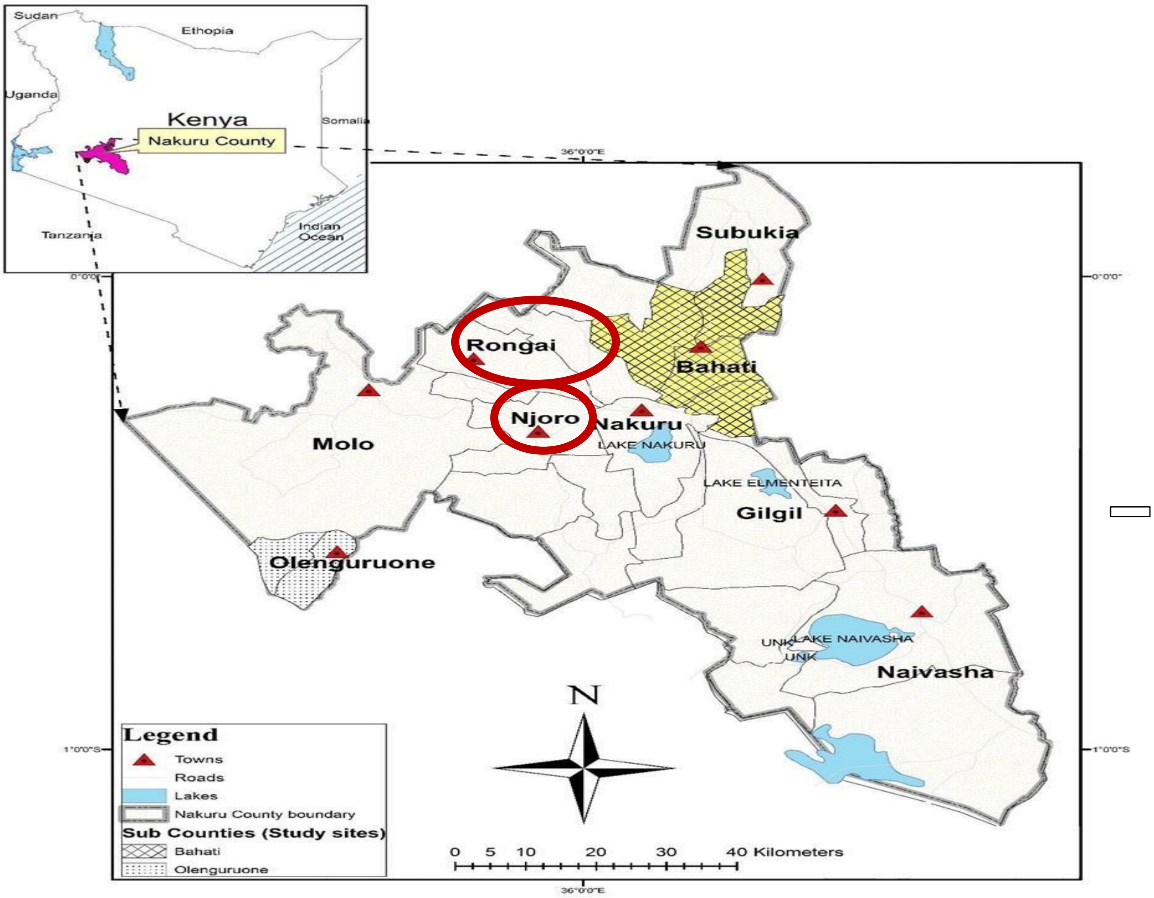

Figure 7: Map of the study area in Nakuru County

Key: Red circled sub-counties represent the study counties

Source: Nakuru County Integrated Development Plan, 2013

3.1.3.2 Narok County

Narok County (Figure 8) lies between latitudes 0° 50´ and 1° 50´ South and longitude 35^{o} 28´ and 36^{o} 25´ East. It borders the Tanzania to the South, Migori, Kisii, Bomet and Nyamira counties to the West, Kajiado County to the East and Nakuru County to the North. It covers approximately 17,933 km^{2} with a total population of 1,157,873 people, KNBS, (2013). The county is divided into four sub-counties namely, Narok South; Narok North, Trans Mara East and Trans Mara West. Narok South covering an area of about 10,412 km^{2} is enormous with five wards, 28 locations, 52 sub-locations and 62,412 households. followed by Narok North, while the smallest is Trans Mara East with an area of 275.4 Km^{2} comprising of two divisions, six locations, 12 sub-locations and 15,098 households (Figure 8). Temperatures range from 20^{0}C in January- March to 10^{0}C in June- September with an average of 18^{0}C.

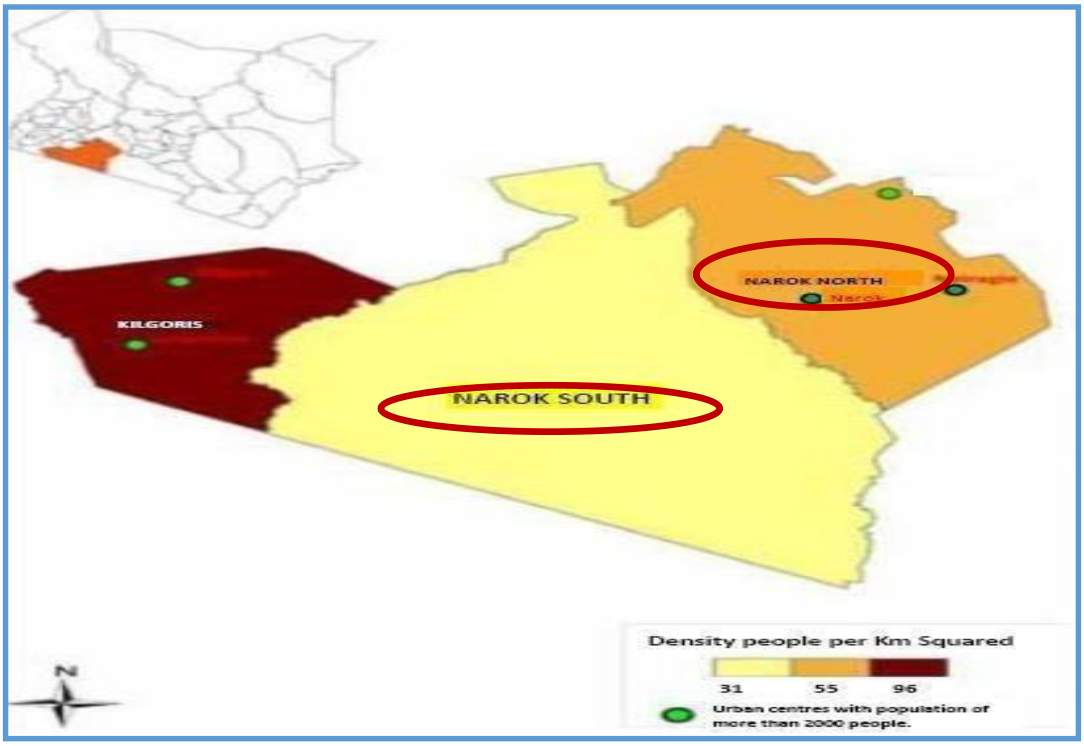

Figure 8: Map of Narok County

Key: Red circled represents the study sub-counties

Source: Government of Kenya, 2016

3.2 Study Design

Research study design is a set of methods for data collection and analysis on specified variables in a specific research problem. The study adopted a survey methodology for field data collection to investigate the returns to wheat research, adoption, varietal turnover rates and risks faced by wheat producers in Narok and Nakuru Counties.

The survey methods were considered appropriate because of its great advantage in facilitating quantitative analysis of data for enabling complete generalization of the results to the entire population. Surveys are also designed to reach a large number of respondents and as such were found suitable for studies related to perceptions of rural households.

3.2.1 Target Population

The target population is the set of individuals that the researcher intends to conduct research in and bring-out conclusions from (Bloomfield& Fisher (2019). Facets of the target population should be described clearly in the cost-benefit analysis.

The sample population was drawn from two Counties (Narok and Nakuru) and four Sub- Counties, Rongai and Njoro in Nakuru County, and Narok North and Narok South in Narok County. The Counties and sub-counties are selected because they are typical of wheat growing areas in Kenya.

3.2.2 Sample Design

A sample design is the road map, that serves as the basis for the selection of a sample for the survey. It refers to the research techniques that allow the investigator to use people with the required information in to respect to the objectives of the study (Mwita & Tefurukwa (2018).

A95% confidence interval and a sampling error of 5% were used to determine the sample size required for the survey (Mwita & Tefurukwa (2018). It was calculated using the equation developed for large populations to yield a representative sample population (Krejcie and Morgan, 1970).

$n = X^2NP(1-P)/d^2(N-1) + X^2P(1-P)$.

Where: s = required sample size.

X^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level (1.962 or 3.841 for 95% confidence).

N = Number of registered wheat farmers (185 +428=613 for Nakuru and Narok Counties).

P = the proportion of population (assumed to be 0.50 since this would provide the maximum sample size). d = the degree of accuracy expressed as a proportion/ is the desired level of precision (0.055).

$$s = \frac{\chi^2 NP(1-P)}{d^2(N-1) + \chi^2 p(1-p)}$$

Using this formula, the sample size at 5% is:

$$S = \frac{1.962 \times 613 \times 0.5\,(1-0.5)}{0.05^2\,(613-1) + 1.962 \times 0.5\,(1-0.5)} = 344$$

Table 3: Distribution of sample size by County, Sub- County and scale of Production

Sampling stage	Sampling frame	Multi-stage sampling			
		Selected units			
Stage I		**Counties**			
		Nakuru		**Narok**	
Select counties	List of all major wheat growing counties	158		186	
Stage II			**Sub-Counties**		
Selection of Sub- Counties	List of all major wheat growing Sub- Counties	Rongai		Narok North	
		Njoro		Narok South	
Stage III		Location	Sub-County	Location	Sub-County
Selection of locations	List of all major wheat producing locations	Mossop	Rongai	Nkareta (N.South)	
		Okilgei	,,	Melelo	,,
		Ngata	,,	Naisoya	;;
		Rikia	Njoro	Osupuko (N. North)	
		Njoro	,,	Suswa	,,
		M-Narok	,,	Loroito	,,
Stage IV		**Scale of production**	**Nakuru**	**Narok**	**Total**
Selection of farmers	List of farmers from selected locations	Large- scale	27	62	89
		Medium– Scale	43	48	91
		Small – scale	88	76	164
		Total	**158**	**186**	**344**

Source: Own compilation, 2018

Key: Farm size (Acres): Small scale farms<20ha; Medium scale farms 20– 50ha; Large scale farms >50ha

The Organogram (Figure 9) shows the hierarchical structure of sampling across the study counties of Narok and Nakuru.

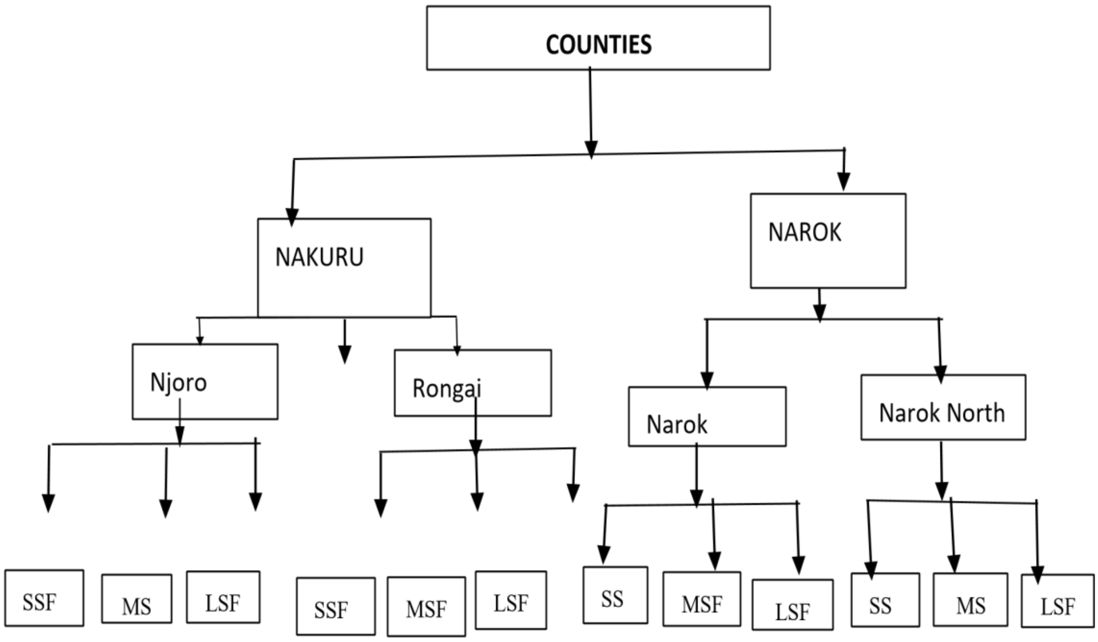

Figure 9: Sample Organogram for the sample derivation

Key: Small scale farmers= SSF Medium scale farmers= MSF Large scale farmers= LSF

3.2.3 Data Collection

Data were collected by use of a structured questionnaire. Appendix 1 shows a structured study questionnaire used to interview the 344 (Nakuru- 158 and Narok-186) households followed by key informant interviews (experts) (Appendix 3). The data collected were: household head characteristics, the farm characteristics, adoption and dis-adoption of newer improved varieties, varietal turnover rates, and risks in wheat production, Agricultural extension service, marketing and credit, income and expenditure.

Varieties released by KALRO overtime shown in appendix 2, wheat expenditure and revenues (appendix 4), donor funds used in wheat research to cover staff salaries and other direct costs (appendix 5), Government expenditure on wheat research (appendix 6) and annual wheat producer price (appendix 7) provided data for analysis of returns to wheat research by KALRO.

3.3 Methods of Data Analysis

3.3.1 Models' specification

3.3.1.1 Benefit Cost Analysis of Investments in Wheat Research

The BCA model used by, Asadi *et al* (2017), was applied in estimation of returns to wheat research, in terms of the three indicators: Benefit Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR). Following Asadi *et al* (2017), the aggregate welfare of wheat research in Kenya (B_t), change of genetic development per year of variety due to breeding research (kt), and fixed and variable costs of wheat breeding (TC) are estimated as:

$$Bt = Pt^* Qt^* Kt$$

$$Kt = \sum Vit^*gt$$

$$TC = CsS + Cvt$$

where:

$B_{t:}$ the gross benefit of wheat research in Kenya P_t: Grain Price of wheat in year t

Q_t: Quantity of wheat produced in year t Vit: percentage of area planted variety in year t gi: Genetic enhancement for variety i

S: Number of full-time breeders and technicians in the breeding program

$C_{s:}$ The costs accrued to breeders and technicians in year t

$K_{t:}$ annual change of genetic improvement of variety due to breeding program

$C_{vt:}$ Fixed and variable research costs in year t

TC: fixed and variable costs of wheat breeding research

The CBA is built on the theory of cash flows that are discounted. The assumption that a dollar earned today is worth less than a dollar earned in the future because its interest-earning prospective is lost in the for the moment. In research estimation, the time-evaluated of research costs are contrasted to the time-evaluated research benefits (Asche *et al* 2018).

Estimate used in the CBA as elucidate by (Mishan & Quah (2020) are:

NPV calculated by deducting the entire discounted costs from the entire discounted benefits.

$$NPV_t = \sum_{t=0}^{n} \frac{\beta_{(t)}}{(1+r)^t} - \sum_{t=0}^{n} \frac{TC_{(t)}}{(1+r)^t}$$

where: β : Net cash inflow TC: Net cash outflow t: Number of time period r: Discount rate

$$NPV = PVB_t = \sum_{t=0}^{n} \frac{B_{(t)}}{(1+r)^n} - PVC_t = \sum_{t=0}^{n} \frac{TC_{(t)}}{(1+r)^n}$$

Where:

PVB: Present value of benefits accrued from the research program PVC: Present value of Costs incurred in the research program r: Discount rate n: period

Benefit Cost Ratio (BCR) was estimated by dividing the total discounted value of the benefits by the total discounted value of the costs incurred in the wheat research program

$$BCR_t = \sum_{t=0}^{n} \frac{\beta_{(t)}}{(1+r)^t} \Big/ \sum_{t=0}^{n} \frac{TC_{(t)}}{(1+r)^t}$$

Where:

β: Net cash inflow

TC: Net cash outflow

t: Number of time period

r: Discount rate

IRR is a metric used in accounting to approximate the lucrativeness, of prospective financing. IRR is a rate that makes the NPV of entire cash flows equated to zero in analysis of cash flow that is discounted. In its calculation, the net present value of entire cash flows (both positive and negative) equal zero.

$$IRR = NPV_t = \sum_{t=0}^{n} \frac{\beta_{(t)}}{(1+r)^n} - \sum_{t=0}^{n} \frac{TC_{(t)}}{(1+r)^n} = 0$$

Where:

β: Net cash inflow

TC: Net cash outflow

t: Number of time period

r: Discount rate

Table 4: Economic returns parameters calculated for KALRO wheat research program

BCR	**IRR**	**NPV**
Calculated by dividing the total discounted value of the benefits by the total discounted value of the costs	Calculated in a way that the net present value of all the cash flows (both positive and negative) from the project equal zero	Calculated by subtracting the present values of cash outflows from the present values of cash inflows, over a period of time.

Note: The data on the stream of costs (expenditures) and benefits (revenues) used for this analysis is presented in Appendix 4).

3.3.1.2 Wheat Varietal Adoption Rate

This study uses an adoption index by Verma, Bajpai & Shrivastava (2017). The index of adoption was evaluated for discrete farmers as follows:

$$ADOPTION_I = \frac{\sum_{i=1}^{n} p_i}{\sum_{i=1}^{n} T_i}$$

Where:

$ADOPTION_v$ = Rate of adoption for a particular new variety by farmer i,

P_i = Proportion of Land under a new variety by farmer i,

T_i = Entire land area planted to wheat by farmer i. i = [1, n]

To measure adoption of the new wheat variety, this study uses data from a farm level survey, which contained every household's farm portion for new wheat variety as well as the entire land planted to wheat. The entire area data in contained addition of old wheat variety's portion and new wheat variety's portion. The new improved wheat variety rate of adoption is analysed by dividing the portion planted with new wheat variety by the entire area planted to wheat, that is between zero to 100.

$$\text{Rate of adoption (\%)} = \frac{Area\ for\ improved\ variety\ adopted}{Total\ area\ for\ \text{wheat}} \times 100$$

3.3.1.2.1 Probit regression models

To investigate farmers' etiquette to adoption, this study utilized the probit model for it expresses both decision to adopt improved varieties or not and the rate. The adoption probit regression model is specified as a function of variables as:

Equation (1) where μi is a normally, independently, distributed error term with zero mean and constant variance σ 2 (Wooldridge, 2010):

$$Y^* = X\beta + \mu, Y_i = \begin{cases} Y_i^* & if\, Y_i^* = X_i\beta + \mu > T \\ 0 & if\, Y_i^* = X_i\beta + \mu \le T \end{cases}$$

Where:

Y_i is the likelihood to adoption and the magnitude of use

Y^*_i is a non-detectable dormant variable; and T is a non-detectable threshold level.

If the Y^*_i is greater than T, observed variable Y_i becomes a steady function of the explanatory variables, and 0 otherwise (i.e., no adoption) (Banjade *et al* (2017).

According to Paltasingh, Goyari, & Tochkov (2017). the model makes use of the entire considerations, zero being at the limit (e.g., no adoption), other than frameworks that use observations over the limit value. More so, it seizes the velocity of adoption, that minimizes the losing information (Paltasingh, Goyari, & Tochkov (2017).

Depending on the previously mentioned exposition and past research experiences, the unconstrained variables were chosen, defined and fitted into a probit model as follows:

$$A_i = y_0 + y_1 X_1 + y_2 X_2 + \ldots y_n X_n + \mu_i$$

Where:

A_i represents the rate of adoption new wheat varieties

X_1 to X_n, are the unconstrained factors fitted in the model y_0 to y_n, represent variables to be evaluated,

μ_i constitute disturbance term

Table 5 shows the expected sign of explanatory variables on the adoption of improved wheat variety.

Table 5: Interpretation of the explaining variables

Variables	Description	Measurement	sign
Gender	Sex of the head of household	1 if male and 0 otherwise	+
Education	household head's education level	Years of schooling	+
Family size	Number of household members	Number	+
Experience	Head of Household's farming experience	Years	+
Non/Offfarm income	Household head participation in nonfarm activities or not	1 if yes and 0 otherwise	+
Extension	head household contact the extension officer within the production season	Number	+
Farm size	Portion of farming land that a household own	Hectare	+
Distance market	The remoteness of the household to the closest market	Kilometer	-
Perceptions on yield	Whether farmers have positive perception on the improved wheat variety or not	1 if positive and 0 otherwise	+
Perception Cost	Whether farmer" perception is inexpensive to cost of new wheat variety or not	1 if cheap and 0 otherwise	+
Variety information	Whether farmer acquired new wheat variety information or not	1 if accessed and 0 otherwise	+
Credit	Whether farmers acquired credit or not	1 if accessed and 0 otherwise	+

3.3.1.3 Varietal Turnover Rate

Varietal turnover rate was estimated using the duration model by (Atlin, Cairns & Das, (2017). This model estimates varietal turnover rate of a new improved wheat variety in relation to age and percent area planted to that articular variety. Number of years since variety release lessened from the year under production was used to calculate the age of a variety.

The varietal turnover rate at a period „t" was estimated as the mean age of the planted varieties weighted by the portion of area under production. As first proposed by (Atlin, Cairns & Das, (2017), weighted average age of a variety is estimated as follows:

$$VRI_i = \varepsilon_i(A_{it}\, X\ W_{it})$$

$$A_{it} = (Year_{it} - Year_{ir})$$

$$W_{it} = \left({S_{it}}/{ST_{it}} \right)$$

where:

VRI_i: Average weighted age of the variety in year t

A_{it}: varietal Age

$Year_{ir}$: year of release of the variety i

W_{it}: percentage of certified seed of the new variety: total certified seed in year *it*

S_{it}: certified seed of the new variety i in year t

S_{Tt}: entire certified seed in year t

3.3.1.4 Wheat Production Risks

This study uses descriptive statistics, which include mean, standard deviations and frequencies, to investigate and classify sources of risks based on farmers‟ insights to examine risks influencing the production of new improved wheat varieties in Kenya. Moreover, a Likert scale with responses on a 1-5 scale represented by 1st =no/negligible risk, 2nd =low, 3rd =medium, 4th =high and 5th =extremely high risk, was used in ranking the risks in order of importance to the wheat farmers.

To rank the various risk sources of, the mean of the five Likert scales was used. This study also focused on the measurement of farm revenue risk in wheat production in Nakuru and Narok Counties. To determine farmers‟ risk insights, farmers were asked to rate risks according to their own discernment of risk in relation to the five-point Likert scale of totally Agree, Agree, averagely Agree, Disagree and totally Disagree with appointing a weight of 5,
4, 3, 2 and 1 for all items.

CHAPTER FOUR
RESULTS AND DISCUSSIONS

4.1 Cost Benefit Analysis of Investments in Wheat Research

Under the Operating Expenditure, total costs of research scientists and technical staff were estimated as KES 9,077,527 million, while the Capital Expenditure which included land, buildings and machinery was estimated at *KES*. 3,533,200 (see Appendix4)

The results obtained by the application of the BCA model in terms of NPV, BCR and IRR are KES 23.31 million, 1. 41 and 41.0 %, respectively (Table 6). The IRR for the wheat-breeding program was 41%. Thus, on average, a one-shilling investment in the research returned KES 0.41 per year over the investment period. This is the return for investing in the improved research activities by the Government of Kenya and all the donors.

The NPV of the program for the period 2010 to 2016, with an assumed discount rate of 10%, was KES 23.31 million. Based on these results, the investments in the KALRO breeding program can be justified.

Table 6: Summary economic analysis of returns to wheat research for KALRO varieties

Measures of economic viability	Parameter level
Discount Rate	10%
Present Value of Benefits (Ksh)	80,302,690
Present Value of Costs (Ksh)	56,989,662
Net Present Value (Ksh)	23,313,028
Benefit: Cost Ratio (BCR)	1.41
Internal Rate of Return (IRR)	41%

Source: Author's Research Data (2018), Appendix 6

4.2 Adoption rates of improved wheat varieties

Generally, the mean area planted with the new improved wheat varieties (NIWV) is 42% of the entire wheat area (Table 7). accordingly, about 58% of the area planted with wheat is still under old improved wheat varieties. The percentage of farmers who had adopted the NIWV is 56%, which is more than the percentage area planted with the NIWV. This is an indication that several farmers cultivate the NIWV in only a portion of their entire wheat area.

Table 7: Adoption rate of new improved wheat varieties (NIWVs)

County	Sub-County	Location	Percentage of Households Adopting NIWV (%)	Percentage of NIWV Area to wheat Area (%)
Nakuru	Rongai	Mossop	50	44
		Okilgei	27	12
		Ngata	15	13
	Njoro	Rikia	91	26
		Njoro	38	27
		M-Narok	76	58
Narok	Narok South	Nkareta	78	59
		Melelo	87	74
		Naisoya	76	71
	Narok North	Osupuko	59	53
		Suswa	34	26
		Loroito	44	41
Total			56	42

Source: Author's Research Data (2018)

4.2.1 Improved wheat varieties planted by sampled farmers (2018-2019).

Farmers were asked which improved wheat varieties they had grown on their land. They mentioned about six improved wheat varieties that they had grown. However, more that 10% of interviewed farmers were not aware the names of the improved cultivars they planted. The most commonly and K. Kingbird, varieties released after 2010). It is evident from the results known and mentioned variety by the farmers were Njoro BWII and Kwale which were released in 2001 and 1987, respectively. K. Korongo, Eagle 10, K. Hawk Figure 10 that farmers were still cultivating varieties released over 10 years ago. According to respondents, the two varieties, Njoro BWII and Kwale varieties released in are high yielding and less susceptible to the stem rust disease.

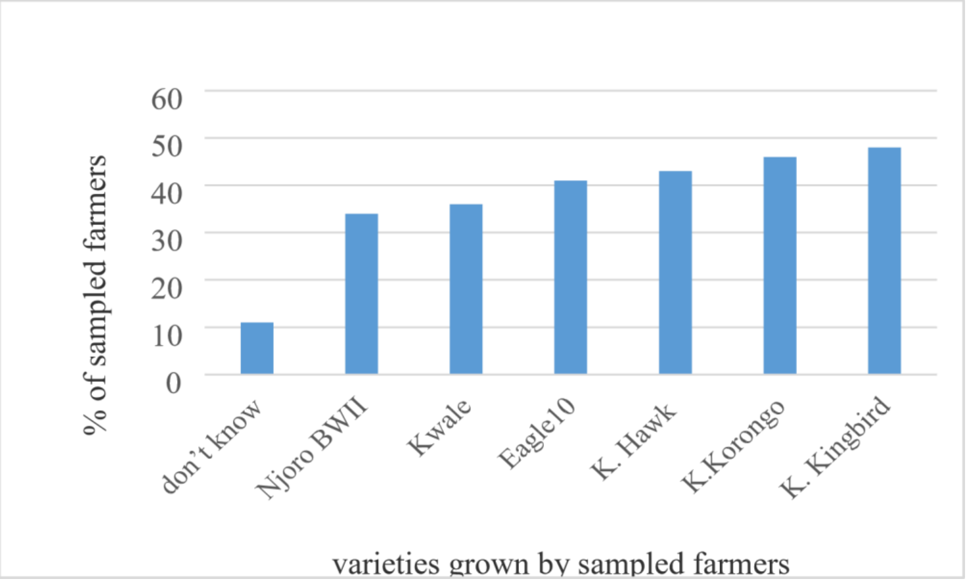

Figure 10: Improved Wheat varieties cultivated by interviewed farmers in %.
Source: Author's Research Data (2018)

4.2.2 Percentage farmers recycling the improved wheat seeds

Farmer recycling seed is common in most parts of wheat growing areas of Kenya. Results Figure 11, reveals that more than 30% of the sampled farmers rely on recycled seeds while 15% bought new seeds. Figure 11 also indicates that nearly 33% of interviewed farmers recycled seeds 5 seasons at most while 30% recycled wheat seeds at most two seasons.

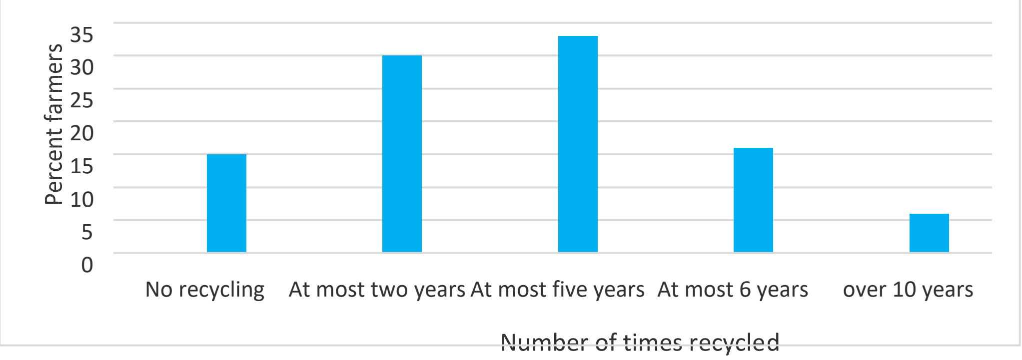

Figure 11: Percentage wheat growers reported recycling seeds Source: Author's Research Data (2018)

4.2.3 Share of area of improved wheat varieties by sub-counties and scale of production in 2018, Kenya

From the results shown Table 8, the estimated area share of the old improved varieties was higher than the share of area of the newer improved wheat varieties in the Nakuru and Narok north sub-Counties with 61% and 58% respectively. The new improved wheat varieties were higher in Rongai (55%) and Narok South (84%). This might have been contributed by the dominance scale of production in the different sub-counties. Narok South and Rongai sub counties are dominated by large scale farmers while Njoro and Narok North are dominated by small scale farmers.

Table 8: Area Share (percent) of improved wheat varieties by sub-counties and scale of production in 2018, Kenya

Counties	Sub- Counties	New Improved wheat varieties	Old improved wheat varieties
Nakuru	Njoro	39.0	61.0
	Rongai	54.9	45.1
Narok	Narok South	84.0	16.0
	Narok North	42.3	57.7

*Improved wheat varieties with recycled seed use for more than 5 seasons were considered as old improved.

Source: Author's Research Data (2018)

4.2.4 Popular wheat varieties cultivated by the farmers in the study area

Table 9 shows the different wheat varieties cultivated by the producers in the study counties. In the 2017-2018 season, the wheat varieties cultivated by farmers in the selected counties were Njoro BW2, K. Heroe Mwamba, , Kwale,Eagle10, Robin, K. Korongo, Duma, K. Kingbird, and K. Hawk. Njoro BWII was the most popular variety and accounted 30.4% % of farmers with the different varieties, followed by Kwale (10.4%), K. Korongo (10.3%), Eagle 10 (6.2%), and K. Kingbird (5.2%). These five varieties together accounted for 56.2% of the entire varieties grown by farmers. Njoro

BWII a variety released in 2001 is still popular among the famers. Njoro BWII and Kwale varieties released in 2001 and 1987 were the most widely cultivated varieties in the two study counties.

Table 9:: Wheat varieties grown across scale of production and Counties (%)

Characteristics	Njoro BWII	Kwale	Korongo	Eagle 10	K. Kingbird	Others	Total	Varietal age in years)
Scale of Production								
Largescale	21.25	10.12	6.73	2.08	12.41	53.31	4.71	26.3
Medium scale	23.56	14.31	9.63	3.29	9.60	45.48	11.59	28.04
Small scale	24.57	12.19	11.41	3.69	5.89	48.04	25.51	28.88
Counties								
Nakuru	28.73	24.68	1.93	2.01	8.41	39.51	39.41	24.71
Narok	45.56	1.88	3.52	14.8	1.72	38.91	32.69	33.32
Sub-Counties								
Rongai	22.77	9.37	17.37	4.82	6.89	49.49	36.17	35.13
Njoro	29.24	12.09	8.50	7.34	4.31	44.61	22.71	30.31
Narok South	46.75	7.28	3.9	14.48	6.96	26.71	26.72	30.72
Narok North	10.07	12.92	7.6	5.29	5.14	45.24	29.82	28.91

(Percentage of farmers growing the different varieties)

Key: Large scale (n= 89); Medium scale (n= 91); Small scale (n= 164)

Farm size (HA): small scale farms<20ha; medium scale farms 20–50ha; large scale farms >50ha

Source: Author's Research Data (2018)

4.2.5 Characteristics of the sampled wheat farmers

From results Table 10, All the continuous variables were significant at 1% and four variables (education, farm size, extension and experience) positively influenced adoption of the improved wheat varieties. Two continuous variables (family size distance to market) negatively influenced adoption. While for the six variables there were no significant differences between the two counties apart form for sex variable.

Table 10: Characteristics of the sampled wheat farmers

Continuous independent variables	Nakuru (N = 158)	Narok (N= 86)		
	Mean	Mean	Mean difference/test	t- value
Education	9.81	8.93	2.43***	5.13
Family size	7.32	7.97	-1.14***	-2.62
Farm size	5.07	3.86	0.93***	3.22
Distance from market	3.58	5.31	-1.14***	3.48
Extension	12.24	7.16	4.87***	6.73
Experience	28.92	24.82	4.18**	2.43

Binary explanatory Variables	Description	Nakuru (N = 158)		Narok (N= 86)		
		No.	%	Mean	%	X- value
Sex	Male	91	0.97	56	0.97	0.06
Variety information	Accessed	50	0.53	16	0.27	9.681 *
Non/Off -farm income	Participated	91	0.92	13	0.22	81.482
Perceptions towards yield	Positive	32	0.31	12	0.21	1.441
Perception on cost	Cheap	54	0.61	24	0.36	2.925*
Credit	Accessed	53	0.61	7	0.21	29.225

4.2.6 Factors that Influence Adoption of Improved Wheat Varieties

A probit regression model was used to identify the variables that influence adoption of the released wheat varieties (NIWVs) and their probability outcome on decisions to adopt by farmers. Twelve variables, 6 continuous and 6 binary independent variables were fitted in the approximation of the model.

From the results, Wald test (LR chi2) of the model was remarkable at 1% level (Table 11), this indicated that the entire independent variables fitted in the model collectively had significant impact on farmers‟ likelihood to adoption of new wheat varieties. The results revealed that the education level of the head of household, access to information, distance to product market, off-farm income, rate of contact to extension and credit access were scientifically significant (Table 11). Level of education (EDUCLEVEL) positively influenced adoption of new wheat varieties and was significant at 1% with a marginal effect of 0.087. This implied that an increase in level of education by the head household by a year, probability of adoption is increased by 8.7%, *Ceteris Paribus* (Table 11).

Concerning information to varietal access (AVAINFO), it was positive and significant at the 5% level of significance (Table 11) with a marginal effect of 0.332 which signifies that the probability was 33.2% higher than those households who had no access to information in adoption of NIWVs, all other things held constant.

Off-farm income (NOFFI) influenced adoption of NIWVs positively and significantly at 1% significance level (Table 11). The minimal influence of Off-farm earnings of 0.638 reveals that the likelihood of the farm households who were involved in off-farm activities was 63.8% more than for those who didn't get involved in off-farm activities in the adoption of new varieties (NIWVs), holding everything else constant.

Distance to from produce market (DISMKRT) negatively but significantly influence adoption at at 5% significance level with marginal effect of -0.083, this implies that with the increase in distance to the output market by a km, the likelihood of farmers adopting of improved wheat varieties drops by 8.3%, *holding* all other things constant (Table 11).

Acquisition to credit (ACREDIT) Influenced adoption positively and significantly at significance level 5% (Table 11) with a marginal effect of 0.47. This indicates that the likelihood of adoption was 47% higher than those households who did not acquire credit, other things held constant.

Table 11: Binary probit model Results (n=344)

Independent Variables	Coef.	Marginal Effect	Std. Err.	z	P>z
SEX	-2.003	-0.230	1.320	1.620	0.122
EDUCLEVEL	0.308|***	0.087	0.123	2.670	0.013
FAREXP	0.026	0.008	0.034	1.130	0.283
AVAINFO	1.245**	0.332	0.515	2.530	0.01
FAMSIZE	-0.144	-0.041	0.110	-1.360	0.221
NOFFI	2.080***	0.638	0.444	4.740	0.001
FARMSIZE	0.054	0.016	0.135	0.540	0.713
DISOMRT	-0.262**	-0.083	0.128	-2.120	0.046
ACREDIT	2.006**	0.470	0.770	2.511	0.022
PERYIELD	0.222	0.062	0.519	0.520	0.644
PERCOST	-0.675	-0.212	0.551	-1.190	0.221
MEMGP	-0.003	0.002	0.121	-0.130	0.953

*, ** and *** significant at 10, 5 and 1%, respectively.
Source: Author's Research Data (2018)

Number of observations	344.00
LR chi^2 (14)	148.19***
Prob > chi^2	0.000
Pseudo R^2	0.7502
Log likelihood	-26.982749

4.3 Wheat Varietal Turnover Rate

This section provides and discusses results of the varietal turnover rate of the improved varieties of wheat grown by the farmers as generated by area weighted average variety age (WA or WAV) following the model by De Groote and Omondi (2021). The age of varieties was estimated by subtracting the year of release of the variety from the survey year (which was 2018). Results in (Figure 12) show that the mean age of the varieties was about 27 years, the least being for medium scale and large-scale farmers (15 years) for farmers who cultivated new improved varieties compared to small-scale farmers with old varieties (27 years) (Figure 12).

Considering the sub-counties, farmers in Rongai sub-county cultivated older varieties (23 years) when compared to those of Njoro (21years), Narok South (9 years) and Narok North (18 years). Across counties, the mean age of cultivars was lower for Narok (14 years). It is also evident that despite Nakuru County being the home of a well-established wheat research station, (KALRO-Njoro), farmers still cultivated older improved varieties (28 years old).

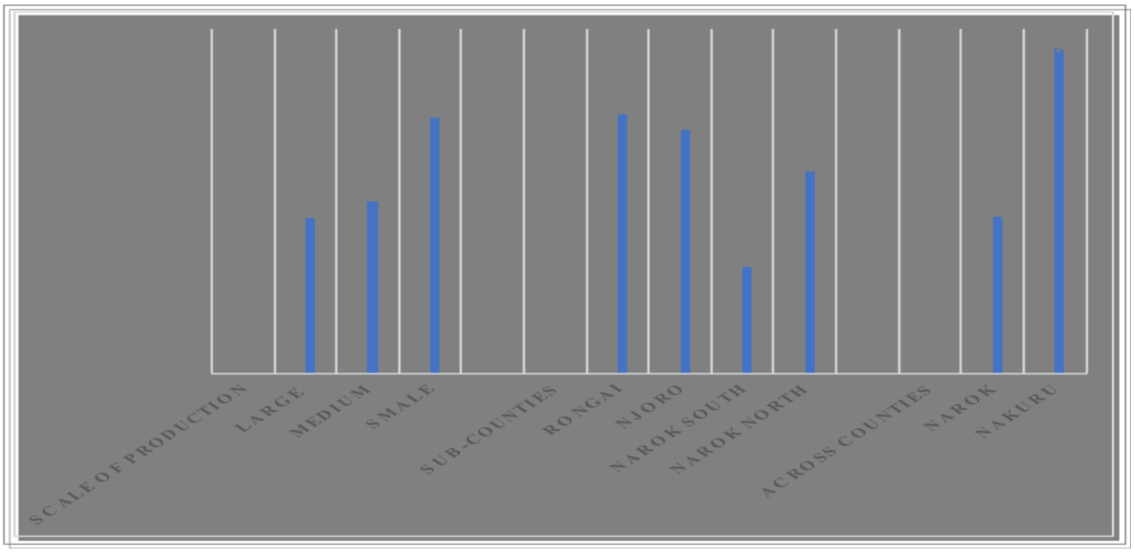

Figure 12: The varietal age (yrs.) by scale of production, Sub- County and within the counties

Key: Large scale (n= 89); Medium scale (n= 91) ; Small scale (n= 164)

Category of Farm (Acres): small scale farms<20ha; medium scale farms 20–50ha; large scale farms >50ha

Source: Author’s Research Data (2018)

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4.3.1 Varieties of Wheat Grown in Kenya

The rate of varietal replacement of the older varieties by newer ones is a key index of varietal turnover. As indicated in the previous section, 20-30 year varieties are still grown by farmers (Table 12). The most aged wheat varieties still planted by farmers were, Kwale (year release 1980s and Njoro BWII, a variety released in the year 2001 (Table 12).

Kumar *et al.* (2018), reported similar to results of a study. He noted that growers continued to plant 15-20 years old varieties. Wheat varieties that were released in the 1980s and 1990s were still under cultivation although they were not presented because they were not among the top 5 varieties (Table 12). Thus, from the results, it is apparent farmers continued to grow wheat varieties that were 15-30 years old.

Table 12 : More than 15 years' wheat varieties cultivated in Kenya: 2018-19

Variety name/code	Breeder	Year of Release	Age (year) (2018-2019)
Pasa	KARI	1989	29
Kwale	KARI	1987	31
Ngamia	KARI	1998	20
Kenya Heroe	KARI	1999	19
KS Mwamba	KSC	2001	17
Duma	KARI	1998	20

Source: Author's estimates based on expert elicitation meetings

4.3.2 Average age of wheat varieties cultivated in Kenya: 2017-18

From the results, the average age of the top five (5) wheat varieties was more than the mean age of the entire number of varieties under production in Narok and Nakuru Counties. This implied that the percentage of area under the aged improved varieties was high in the study Counties. Therefore, in these Counties, the new varieties have not gotten go the farmers as would be anticipated.

The rate of variety turnover, as estimated by the average weighted age of the varieties under cultivation is shown in Figure 12 The range of the rate of variety turnover was about nine (9) years in Narok South to about 20 years in Narok North Sub-counties.

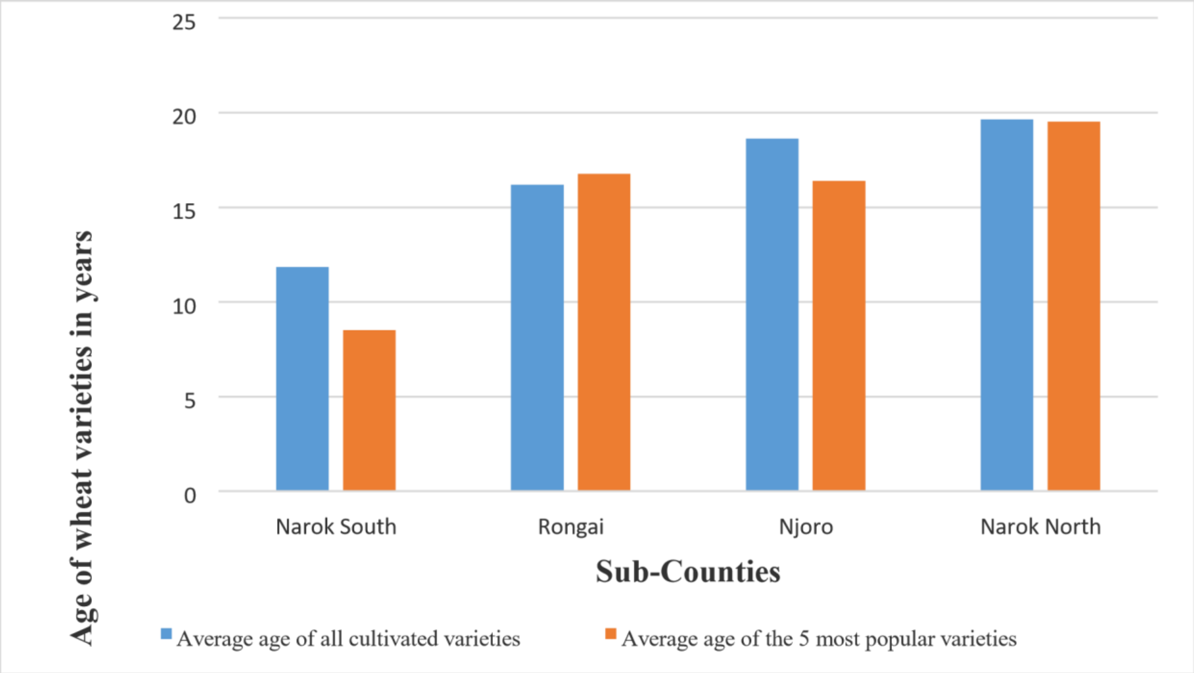

Figure 13: Mean age of cultivated wheat varieties in Kenya: 2017-18

Source: Author's estimations based on the survey and release data

4.3.2 Wheat farmers who cultivated different types of seed by scale of production in the Sub-Counties and Counties

Table 13 shows the percentage of farmers by scale of production, sub-county and county who used different types of wheat seeds. From the results, about 88% and 79% of large and medium scale farmers respectively were cultivating the new varieties as compared to small scale farmers (about 39%). From the results, it is apparent that the mean years for varietal turnover increases as the scale of production decreases. Large-scale farmers grew newer varieties, compared to the small-scale farmers. Small scale farmers replaced the improved varieties that they were growing with aged varieties that have preference for.

Based on sub-county results (Table 13), Rongai Sub- County farmers grew both new and old improved varieties with about 59 and 54 percent, respectively, with about 50% of the farmers indicating they used recycled seed. Majority of farmers (68%) in Njoro sub-county cultivated more of the old improved as compared to the new improved wheat varieties at 48%. (Table 13) shows that 63% of the sampled wheat farmers used recycled seed. Narok County had majority (79%) of the sampled farmers using the new improved varieties while few farmers (34%) used recycled seed. This may due to the certainty that most of the farmers in the sub county are large scale farmers. This illustrates why the adoption rates are low because a high percentage of farmers recycle seed.

Table 13: Wheat farmers who cultivated different types of seed by scale of production; Sub- Counties and Counties

Scale of Production	Varietal turnover (%, n=344)			
	New improved wheat varieties	Old improved wheat varieties)	Recycled (Farmer seed)	Unidentified
Large scale	89.78	48.89	2.28	0.00
Medium scale	79.10	44.19	33.49	1.21
Small scale	39.17	65.72	75.71	15.22
Counties				
Nakuru	65.51	45.28	64.58	14.89
Narok	78.91	37.67	33.59	5.49
Sub-Counties				
Rongai	58.91	54.48	50.11	5.88
Njoro	47.82	68.07	63.33	3.84
Narok South	67.49	37.57	22.38	0.00
Narok North	57.28	58.23	52.82	4.86

Key: Large scale (n= 89); Medium scale (n= 91); Small scale (n= 164)
Farm size (Acres): small scale farms<20ha; medium scale farms 20–50ha; large scale farms >50ha
Source: own compilation

4.4 Wheat Production risks

Farmers" perceptions on risks of what production in Nakuru and Narok Counties

Lack of seed which ranked as 2nd risk was the cited as the most significant risk perceived in Nakuru and Narok counties with average scores of 4.30 and 3.98 respectively, Table 14. For this category of risk, medium scale farmers had an average score of 4.27 while the large farmers had average score of 4.46. Risk 1 caused by natural occurrences were considered, important/very important in Nakuru and in Narok counties with average scores of 3.98 and 3.84 respectively. Small farmers had an average score of 3.79, while large farms had mean score of 3.86 while for the medium scale farms the risk was reported as slightly exceeding the
"very important" threshold.

Low market prices risk 3, was pondered principal in Narok (mean score 3.55) and average score 3.43 by small-holder farmers. However, market risks were not pondered as important to farmers in Nakuru and for the medium and large scale farms. The magnitude of significance attributable to risk 3 declined with expanding farm size with 3.43, 2.74 and 2.67, for small, medium and large farms, respectively. The magnitude of importance risk 5 attributable to access/availability to inputs was 3.16, 2.75 and 2.63 for small, medium and large scale farms, respectively.

In addition, risk 4 - high costs of inputs ranked very highly as reported by the interviewed farmers. In Narok County, it was the second cited risk with average score of 3.92 and the highest score among small scale farmers with average score of 3.78. It is worth noting that cost of credit which ranked 6th was not an important risk in Nakuru County with an average score 1.93 and in Narok with an average score 2.69 , nor by the various farm size groups.

Table 14: Average level of importance of production and market risks county and farm size (n=344)

Type of risk		By county			By farm size		
		All	Nakuru	Narok	Small	Medium	Large
1	Drought, hail floods and other natural risks	3.85* (1.01)[1]	3.98* (0.99)	3.84* (1.02)	3.79* (1.11)	4.13* (0.96)	3.86* (0.91)
2	Lack of seed of new improved varieties	4.04* (0.93)	4.30* (0.94)	3.98* (0.94)	3.71* (1.04)	4.27* (0.91)	4.46* (0.75)
3	Low output prices	2.85* (1.26)	2.24 (1.03)	3.55* (1.18)	3.43* (1.27)	2.74* (1.25)	2.67* (1.23)
4	High costs of input price	3.87* (0.88)	3.83* (0.85)	3.92* (0.91)	3.78* (0.99)	3.92* (0.83)	3.97* (0.74)
5	Access/availability to inputs	2.76* (1.21)	2.23* (0.95)	3.25* (1.22)	3.16* (1.22)	2.74* (1.24)	2.63* (1.13)
6	Cost of credit	2.30* (1.23)	1.93* (0.96)	2.69* (1.34)	2.42* (1.29)	2.16* (1.25)	2.32* (1.13)

Significance level: 1, "not at all important"; 2, "somewhat important"; 3, "important"; 4, "very important"; 5, "extremely important".
*Statistically different with p-value<10%; standard deviations in. Farm size (Acres): small farms<20ha; medium farms 20–50ha; large farms >50ha. Figures in parenthesis are standard deviations (SD)

4.4.1 Average scores and ranking of main wheat production risk sources

In order to assess the uncertainties in wheat farming, Sources of risks were grouped into different categories. Categorization included financial, institutional, market, social and technical risks. The risks were also analyzed to find out their sequence of importance. To determine their significance, analysis of the mean scores and standard deviations (SD) in the farmers‟ interviews was undertaken.

The insight of growers on risks affecting wheat production was evaluated by use of the five point Likert scale; with one (1), indicating no risk and five (5) indicating risks that are very high. This model of evaluation is in line with other researches (e.g. Ali and Kapoor, 2008). From the outcome presented in Table 15, it is evident that wheat producers were at a risk of weather related conditions such as droughts and variations in rainfalls. From the interviews, Pests and disease were cited as important sources of risks in the study areas according to the farmers responses. Pests/diseases, with a mean

3.24, was reported to be among the very highly cited sources of technical risks by the sampled wheat farmers, followed by Lack of seed and flood/high rainfall with mean 3.10 and 2.18, respectively.

A few respondents (about 5.3% of the respondents) cited drought as a major risk affecting wheat production in the study areas. Output price fluctuation had a mean of 2.38 and was cited as the most prominent trade risk followed by inflated inputs costs which had a mean of 2.34. Economic risk occurs when cost of using capital fund is higher than the enterprise profitability (rate of return) (Cao, *et al*, 2011). However, from the results of this study, cost of credit was found to be very low with a mean of 1.19. Pest and diseases with high ranking (mean 3.24 on a five-point Likert-scale) was cited as the most important risk by the interviewed farmers. Lack of seed (average 3.11) was reported as the second most important source of risk. Therefore, production and marketing risks were found to be the major sources of wheat cultivation risks among the growers in the study areas and this is a reflection of the other wheat producing Counties.

Table 15:Mean scores and rank of major wheat production risk sources (n=344)

ources of	Percentage response risks					Mean	SD	Rank
	1st	2nd	3rd	4th	5th			
Seed not available	10.9	20.9	21.6	41.6	5.3	3.10	1.127	2
Drought	19.3	10.9	50.1	17.9	3.2	2.84	1.054	3
Flood/high rainfall	34.7	30.9	22.4	7.8	4.7	2.18	1.129	5
Pests/ Diseases	10.1	21.6	23.2	26.3	19.3	3.24	1.268	1
Output price fluctuation	32	22.4	31.6	13.2	3.2	2.38	1.136	4
High costs of inputs	53.9	29.3	10.9	3.9	2.34	1.74	0.968	6
Weeds	64.8	23.5	6.4	6.3	2.4	1.63	1.017	7
High cost of credit	89.4	4.7	4.8	1.6	1	1.19	0.582	9

Source: Research data (2018)

Note: 1st =no risk, 2nd =low risk, 3rd =medium risk, 4th =high risk, 5th =very high risk

4.5 DISCUSSIONS

In using cost –benefit analysis, all the projects with a Net Present Value of zero or more, a BCR of one or more, or IRR more than the target rate of interest should be continued or accepted (Asche, 2018). In this regard, BCA, adoption and varietal turnover rates which are considered as the most important gainful indicators, were applied. Total costs of researchers and technicians were estimated KES 9,077,527 million while the Capital Expenditure which included land, buildings and machinery was estimated at KES. 3,533,200.

The three economic indices, NPV, BCR and IRR of the wheat varietal research were reported as KES 23.31 million. 1. 41 and 41.0 %, respectively. The IRR for the wheat-breeding program was 41%. Thus, on average, a one-shilling investment in the research returned KES 0.41 per year over the investment period. This is the return for investing in the improved research activities by the Government of Kenya and all the donors.

The NPV of the program for the period 2010 to 2016, with an assumed discount rate of 10%, was KES 23.31 million. Based on these results, the investments in the KALRO breeding program can be justified. The three measures demonstrate that returns to funding in wheat research have been positive and worthwhile.

The Present value of cash inflow exceeds the present value of cash out flows by KES 23.31 million which means that the project earns yield in excess of 10%. Hence the KALRO wheat breeding project is profitable and worthwhile.

Based on these results, the investments in the KALRO breeding program can be justified. The three measures demonstrate that returns to investments in wheat research have been positive and worthwhile. Although they may be lower than expected. The return to research is low due to the low rates of adoption, low varietal turnover rates and the high production risks.

Due to the risks and uncertainties, it can take several years for producers to adopt the new disseminated varieties, largely the small-holder farmers, Wang *et al* 2010. Thus, these farmers typically grow the newer improved varieties originally in a portion of land but they later expand as they gain confidence with the suitability of the new improved varieties. There are substantial contrasts in the adoption of the new improved wheat varieties across the study counties. The rate of adoption is close to 99% in Narok South sub-County. Equally, the contrast between the percentage of farmers adopting improved varieties and the percentage area planted with the new improved varieties is divergent across the study areas, indicating substantial variability in adoption patterns.

Factors apart from research funding impacting the adoption of a new improved varieties. The results suggest that most of the producers had basic education. Education prayers great role in the decision to adopt improved varieties. Farmers who are educated easily look for new agricultural information and pass it to other unknowledgeable farmers. Ghimire, *et al*, (2015) argued that educated farmers adopt innovations faster than un-educated farmers. Ghimire, *et al*, (2015) reported that education had positive impact on adoption of improved rice varieties in Central Nepal. This implied that education strengthen farmer's understanding of the new improved technologies such as the improved varieties.

Statistical influence of education on adoption of improved seeds was reported by Thomson, Gelson, and Elias (2014). They reported that education level was associated with human capital and the ability for farmers to faster to new technologies and market conditions.

Access to varietal information influence on adoption of the new improved varieties is similar to results reported by Shiferaw *et al* (2011). The results revealed that access to variety information positively and significantly influenced producers‟ decision to adopt new improved varieties. Hence having varietal information prior to planting time makes farmers aware of the advantage of NIWVs so better chances to adopt NIWVs.

The main source of varietal information was from the public agricultural research and extension systems. Their potency in the influence to adoption of new improved wheat varieties are dependent to the robustness of the linkages between them. However, poor linkages, and little incentive for research scientists or extension agents to work with poor households. Poverty-stricken farming households lack information through networks such as participation in farmer field days, demonstrations, field schools among others.

Olalekan and Simeon, (2015) reported similar findings on how off -farm activities effect the uptake of the improved cultivars. Their study found out that participation in off-farm activities had a positive impact on the adoption of new varieties. This may be because the households involved in the off-farm activities may have additional income to purchase farm inputs. Hence participation in non/off-farm activities enhanced the adoption of new improved wheat varieties.

This finding of proximity to out-put market effect on uptake of the new improved cultivars is similar to findings by (Kudama (2021). This implies that farmers who are near the output market easily sale of their produce and hence minimizes marketing costs.

This finding of contact with extension influence on uptake of the new improved cultivars is similar to results of a study by Yemane, (2014). Producers with frequent exposure to extension staff were more expected to adopt NIWVs than those who had no contact to extension. This is because contact with extension agents helps farmers be aware of benefits of NIWVs.

Access to credit can be expounded by the certainty that farmers who had access to credit were better endowed with adequate funds to by required production inputs hence increase production and increase adoption rates.

Small-holder producers used the old varieties because they were less risk bearing and were not market oriented. They also have less contact with the extension agents and hence less likely to adopt new improved wheat varieties. This also explains why in Narok had varieties with low age as compared to Nakuru county where farmers still cultivated older improved varieties.

These results are same as those reported by Krishna *et al*., (2014) He established that the mean age of wheat varieties in farmers' fields in India raised from nine (9) years in 1998 to thirteen years in 2008. This was due to the lag period between development and release of wheat varieties through line breeding which was 10–15 years in Punjab, India. This meant that Indian growers used varieties released more than 20 years. Slow varietal replacement was slowing down wheat productivity growth in, India (Smale *et al.* (2008).

In their study, Witcombe *et al*. (2016) reported that in Nepal, the mean age of rice varieties adopted was about 20 years. They concluded that the production of aged varieties was a wide practice in the under-developed countries.

The demand for seed is met through recycled seeds from own seed or farmer- to-farmer seed exchange. This implies that the gains of new varieties from wheat improvement research are don't benefit the wheat farmers. Adoption of the new improved varieties and varietal turnover rates are key tackling crop losses. A slow turnover rate has a negative effect to productivity (Smale *et al*., 2008).

As suggested by Brennan and Byerlee (1991), the average weighted age of seven (7) years was considered more appropriate in terms of varietal replacement and in combating the emergence of new races of pests and diseases. Nonetheless, a varietal replacement of more than 10 years is an indication of a delay in the dissemination of the wheat breeding research efforts. Furthermore, it mirrors on the mislaying of genetic achievements emanating from the crop improvement (Witcombe *et al*.,1998).

The mean an age of varietal turnover goes up as scale of production decreases. Large farmers grew newer varieties compared to small farmers. Small farmers replaced the aged varieties they were growing with aged cultivars which they already had detailed information about. The findings by Krishna *et al*, (2014) indicated that large scale farmers are able to observe, and eventually adopt, the newly released wheat varieties. This is because it is affordable for them to buy new seeds annually compared to the small scale farmers.

Economic-based risk sources were found to be the major sources of risks faced by wheat producers. This is might be because the two sources of risk are beyond the growers‟ control and they directly influence their revenues. Similar results were realized in studies conducted in other countries (Hayr an, 2019.; Akhtar *et al*., 2018; Hayran *et al*., 2015; Hayran & Gül, 2015; Gebreegziabher and Tadesse, 2014). The fluctuating prices of wheat grain because the are dependent to the forces of demand and supply from local and international markets. This finding is consistent with those of Thompson, Bir, & Widmar (2019). and Bell, Moore & Thomas (2021). They reported that risks related to the unstable input and output prices were major sources of risk as reported by interviewed farmers.

Exploring the risk sources and designing the risk management strategies to combat agricultural risks are very useful for not only making production decisions but also for marketing decisions (Gunduz *et al* 2016). The results for natural factors such as drought affecting wheat production are similar to the previous research (Ullah., Shivakoti, and Ali, 2016; Shannon and Motha,2015). Drought is one of the major source of risk that has been mentioned in many studies. It‟s one of the most important natural disasters that has many economic, social, and environmental costs. Drought is a natural and recurring phenomenon of climate change.

Although weather related factors are considered to be the main cause of risks, other factors should also be considered, these includes water resources management, tree cutting, land degeneration, etc. drought is a constant that almost all farmers must contend with (Shannon and Motha, 2015).

The pests and diseases results which are biological factors are the same as previous research by Riwthong *et al*, 2016; Ullah., Shivakoti, and Ali, (2016). At the same time, findings of this study reveals that the major sources of risk to wheat farmers were floods and heavy rains. This results are similar to those by Ullah *et al*. (2016), who reported that these risks were major causes of weather related wheat production risks.

CHAPTER FIVE
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

To ensure food security and poverty eradication in Kenya, improved wheat varieties are crucial. Insufficient wheat supplies caused by increased population and Change of dietary inclination to wheat-based foods which is associated with urbanized lifestyle, has been a notable element propelling increase in wheat demand. The rising gap between demand and production is mainly met by way of wheat imports.

Presently, Kenya imports almost two million metric tons of wheat, which is about six times its production. The problem calls for intervention to tackle it and increase wheat production. A lot of wheat research has been undertaken by KALRO and many varieties have been released and distributed to the farmers. However, there is little evidence about the returns to wheat research, adoption rates and varietal turnover rates in Kenya especially in Nakuru and Narok Counties. Production Risks affecting wheat production consequently returns to wheat research in Kenya are not documented.

Therefore, this study focused in examining the returns to wheat research, varietal adoption and turnover rates and the wheat production risks in Nakuru and Narok Counties. Four specific objectives guided this study: to analyze a benefit-cost analysis of wheat research investment, assess the rate of adoption of improved wheat varieties, examine the wheat varietal turnover rate and investigate risks to wheat production in Nakuru and Narok counties.

The study used the Benefit Cost Analysis (BCA) model to estimate the returns to wheat research, in terms of three indicators: BCR, NPV and IRR. Probit model was used to estimate wheat varietal adoption rates (VAR). The area average mean variety age (WA or WAV) duration model was used to estimate varietal turnover rate (VTR). The Five Point Likert scale model was used in assessing production risks. The study used a multistage random sampling procedure to draw a sample size of 344 respondents and a structured questionnaire was used to collect primary data.

The results generated indicated a BCR of 1.41, a NPV of 23.31 million Kenya Shillings, and an IRR of 41%. The VAR was 42% and VTR was 15.65 years. The major production risks identified were Pests/diseases with a mean 3.24, output price fluctuations (2.38), lack of seed (3.10), and flood/high rainfall with mean and 2.18 in that order of ranking.

5.2 Conclusions

Providing a comparative estimate of return on investment is important for donors to assess whether to continue funding research to improve wheat varieties. These estimates of research returns act as a guide for future research investments. The results indicate that the return on investment in wheat research in Kenya in recent years is positive, albeit relatively low, mainly due to low cultivar acceptance and turnover rates, and the prevalence of production risks. Based on these results, however, the investments in the KALRO breeding program can be justified. The three actions show that the returns from investments in wheat research have been positive and worthwhile. Therefore, continuous wheat breeding research is required, both to increase output per unit area and to for minimization of abiotic and biotic stress, lessen yield unevenness and contribute in reducing food insecurity in the future

The mean area under NIWV is 42% of the entire wheat area, while the percentage of growers adopting the NIWV is 56%. This is more than the percentage of the portion of area under the NIWV, the high percentage of farmers, that adopted new varieties versus the low area percentage among the new varieties is an indication that many farmers only plant the NIWV on a portion of their total wheat acreage to test its performance before full introduction. It should be eminent that given the quantity of wheat cultivars released in Kenya, the number of cultivars grown by specific farmers was small. In addition, a few varieties occupied most of the area apportioned to wheat and were also planted by majority farmers. The accessibility of released varieties alone would not imply a varietal turnover if they were not availed and grown by farmers.

In 2018, the WA estimated for wheat revealed a low varietal replacement of 27 years. These number shows that while Kenyan farmers are planting improved wheat varieties, they are slow to switch to new varieties that have come onto the market in current years, or are struggling to get rapid access to the new variety seeds. This shows that farmers have a long seed storage time, which negatively impact the introduction of new varieties and thus enhanced the WA of the varieties on the farm.

Economic-based risk sources were found to be the most dominant sources of risks faced by wheat growers in the study areas. This is might be because both sources of risk are beyond the farmers‟ control but directly affect their farm earnings

5.3 Recommendations

The following recommendations are made based on the conclusion.

1. To improve economic achievement to wheat research in Kenya, varietal adoption and turnover rates should be improved, and wheat production risks should be minimized or eliminated.
2. In addition, adequate policies and development programmes to promote new improved wheat varieties should be directed to pest and disease control, input and output delivery, seed multiplication and dissemination
3. Development of strategies that encourage commercial seed markets should be developed
4. Efforts and resources should be directed towards enhancing adoption of the new improved wheat varieties besides creating awareness through information flow. Hence government actors such as KALRO and non-governmental organizations such as the cereal growers‟ association (CGA) should strive to link wheat growers to the various sources of information to access quality improved seed to accelerate the rates of adoption and varietal turnover.
5. The government should direct resources through the public research such as KALRO towards breeding of more varieties that drought, pest and diseases resistant. The seeds should be available to the stakeholders at low cost price.

5.4 Suggestions for further research

1. Estimate the proportion of the increases in yield in the Kenya Agricultural and Livestock Research Organization’s released wheat varieties attributable to genetic improvements.
2. An Identify improved sources of climate resilience in untapped genetic resources to broaden the wheat gene pool in terms of abiotic stress adaptation.

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APPENDICES

Appendix 1 : List of wheat varieties released by different breeding institutions over time in Kenya

Variety name/code	Breeder	Year of Release	Variety name/ Code	Breeder	Year of release	Variety name/ Code	Breeder	Year of Release
1061.K.1	NBS	Unknown	Kenya8	NBS	Unknown	Lenana	NBS	1963
1061.K.4	NBS	Unknown	KenyaB-256-G	NBS	Unknown	Menco	NBS	1963
1200.M	NBS	Unknown	Kenya cheetah	NBS	Unknown	Fanfare	NBS	1964
291J.1.I.1	NBS	Unknown	KenyaFL.1.158	NBS	Unknown	Fury	NBS	1964
BF236 C1L	NBS	Unknown	Equator	NBS	1920	Gem	NBS	1964
EgyptianNa95	NBS	Unknown	K. Governor	NBS	1925	Kenya Hunter	NBS	1964
FLI Kenya	NBS	Unknown	Kenya	NBS	1929	Kenya Plume	NBS	1965
H441	NBS	Unknown	K. Standard	NBS	1930	Bailey	NBS	1966
K-360-H	NBS	Unknown	K.Plowman	NBS	1950	Bonny	NBS	1966
K.291 J.1.I.1	NBS	Unknown	338AA1A2	NBS	1951	Bounty	NBS	1966
Kenya-117A	NBS	Unknown	Kenya-184-P	NBS	1951	Brewster	NBS	1966
Kenya 117C	NBS	Unknown	Kenya Farmer	NBS	1954	Kenya civet	NBS	1966

Kenya-122	NBS	Unknown	K-362-B-1A	NBS	1956	Kenya Grange	NBS	1966
Kenya-131	NBS	Unknown	321BT11B1	NBS	1960	Kenya Jay	NBS	1966
Kenya 155	NBS	Unknown	Africa Mayo	NBS	1960	Kenya Kudu	NBS	1966
K-294-B-2A-3	NBS	Unknown	Equator1	NBS	1960	Kenya Leopard	NBS	1966
K-318.O.3B.2	NBS	Unknown	Kentana Yaqui	NBS	1960	Goblet	NBS	1967
K-318-AJ-4A-1	NBS	Unknown	Kenya-5	NBS	1960	Mentor	NBS	1967
Kenya-358-AC	NBS	Unknown	Kenya-1	NBS	1961	Beacon-Ken	NBS	1968
Kenya501	NBS	Unknown	Kenya Mamba	NBS	1962	1010AM2 (L)	NBS	1969
Kenya-58	NBS	Unknown	Catche	NBS	1963	1010F3SEL.13	NBS	1969
Kenya-6297-2	NBS	Unknown	Front hatch	NBS	1963	1010F3SEL.4	NBS	1969
Kenya6820	NBS	Unknown	Gabrino	NBS	1963	1010F3SEL.7	NBS	1969
Kenya7	NBS	Unknown	Kenya page	NBS	1963	1012B.1 (L)	NBS	1969
1016.P.2	NBS	1969	Kenya Kanga	NBS	1977	Njoro BW1	KARI	2001
1016P.1	NBS	1969	Kenya Kifaru	NBS	1977	Njoro BWII	KARI	2001
1076.D.7	NBS	1969	Kenya Ngiri	NBS	1979	KS-Simba	KSC	2007

688F4SEL3	NBS	1969	K.Nyangumi	NBS	1979	KS-Chui	KSC	2008
690F4SEL.D.1	NBS	1969	Kenya Paa	NBS	1981	Kenya Ibis	KARI	2011
K.Sungura	NBS	1969	Kenya Kanga	NBS	1977	Robin	KARI	2011
Kenya Swara	NBS	1971	Kenya Kifaru	NBS	1977	Eagle10	KARI	2011
Kenya Nyati	NBS	1972	Kenya Ngiri	NBS	1979	Kenya Hawk 12	KARI	2012
K. Mbweha	NBS	1973	K.Nyangumi	NBS	1979	Kenya Tai	KARI	2012
Kenya Nungu	NBS	1974	Kenya Zabadi	NBS	1979	Kenya SunBird	KARI	2012
Kenya Nyoka	NBS	1975	Kenya Paa	KARI	1981	Kenya Wren	KARI	2012
Kenya Paka	NBS	1975	Kenya Popo	KARI	1982	Kenya Kingbird	KARI	2012
Kenya Kanga	NBS	1977	Mbuni	KARI	1987	Eldo Baraka	UoE	2014
Kenya Kifaru	NBS	1977	Kenya Chiriku	KARI	1989	Eldo Mavuno	UoE	2014
Kenya Ngiri	NBS	1979	Pasa	KARI	1989	Kenya Hornbill	KALRO	2016
K.Nyangumi	NBS	1979	Duma	KARI	1998	Kenya Peacock	KALRO	2016
Kenya Zabadi	NBS	1979	Mbega	KARI	1998	Kenya Songbird	KALRO	2016
Kenya Tembo	KARI	1975	K.Nyumbu	KARI	1982			
Kenya Kongoni	KARI	1975	Kenya Tumbil	KARI	1984	KS-Kanga	KSC	2013
Kenya Fahari	KARI	1977	Kwale	KARI	1987	KS Nyota	KSC	2013

Kenya Paa	KARI	1981	Chozi	KARI	1998	Kenya Pelican	KALRO	2016
Kenya Popo	KARI	1982	Ngamia	KARI	1998	Kenya Falcon	KALRO	2016
Kenya Nyumbu	KARI	1982	Kenya Heroe	KARI	1999	Kenya Deer	KALRO	2016
Kenya Tumbili	KARI	1984	Kenya Yombi	KARI	1999	K.Weaverbird	KALRI	2016
Kwale	KARI	1987	KS Mwamba	KSC	2001			

Breeder refers to institution under which the variety was developed and is maintained: National breeding station **(NBS),** later became KARI Kenya agricultural research institute) and currently it is known as KALRO (Kenya agricultural and livestock research Organization); KSC (Kenya seed company); and UoE (University of Eldoret)

Source: Adopted and modified from Godwin Macharia* and Bernice Ngina, (2017)

Appendix 2 Interview questionnaire   Introductory statement

I am (*Name of the Enumerator*) collecting data on behalf of Anne Wanjogu Gichangi, a student at Jaramogi Oginga Odinga University of Science and Technology (JOOUST). She is carrying out this survey as her PhD degree thesis research. The objective of this survey is to evaluate the adoption and impact of new improved wheat varieties and the risks faced by farmers in adopting the new improved wheat varieties on households‟ livelihoods and derive recommendations for planning dissemination and out-scaling the released varieties**.** You were randomly selected and your participation is voluntary, but it is very important because you represent many other people in this County. There are no wrong and right answers to these questions. I would like to assure you that your answers will be handled with strict confidentiality. The interview will take about 1½- 2 hours. I would be happy if you would allow me to continue with the interview.

SECTION 1: INTRODUCTION Enumerator information and study sites

Name of Enumerator: ___________________________________

Date of interview: ______________________________________

Start time of interview: __________________________________

Name of Supervisor: _____________________________________

GPS Readings: ____

County ____________________________________

Sub county____

Location ____

Village____

SECTION 2: HOUSEHOLD CHARACTERISTICS

Name of the respondent _______________________________

Are you the household head? 1 = Yes, 0 = No

If no, what is your relationship with the household head 1= Household head, 2= Spouse, 3= Son/daughter, 4= Parent, 5= Son/daughter in-law, 6= Hired worker, 7= other, specify

What is the name of the household head (If not the respondent) ______________________________?

Sex of the household head 1= Male, 0= Female

Age of the household head (years) ____________________

Education level of the household head 1= No formal education, 2= Adult education, 3= Primary school, 4= Secondary school – 4 years, 5= Secondary school – 6 years, 6= post-secondary school____

Main occupation of the household head 1= Farming (crop + livestock), 2= Salaried employment, 3= Self-employed off-farm, 4= Casual laborer on-farm, 5= other, specify

Farming experience of the household head (years) _________________

What is current Household size? _______________

Is the household head currently a member of any farmers" groups? 1= Yes; 0= No

If yes, do you belong to a wheat producer/marketing group 1= Yes; 0= No

What is your current land size (*acres*)___________________

Land ownership (*Tick one*)1 = Freehold with title, 2 = Freehold without title, 3 = Rented from other individual, 4 = Communal, 5 = Informal (roadside), 6 = Others (Specify)........

Main land uses (*tick appropriately*) 1 = Crop production, 2 = Fodder/pasture production, 3 = Dairy farming, 4 = Kitchen garden, 5 = Woodlot/forestry, 6. Others (Specify)..........

Do you have livestock? 1= Yes; 0= No :

If yes, how many _________________________________

Distance to the nearest main market in km/hr___________________________ 28.

Involvement of the household in off-farm activities: 0. No ______ 1. Yes______

If yes, who participates in off-farm activity?

What is the type of off-farm activity in which the household is involved in?

Paid daily labour _______

Petty trade ________

Handcraft ________

Other, specify ________________

31. Please fill the following table about land holdings during 2016/17 planting season in Acres

Land ownership	Total Area (Acres)	Cultivated land (Acres)	Rented in(Acres)	Rented out(Acres)	Shared out Acres)	Other, specify**
. Own						
. Rented in						
. Shared in						
. Total						

**Specification……………………………………………………………………

Do you think that shortage of land is the major production constraint for you in wheat prod? 0) No 1)Yes

Do you think that Poor quality of land is the most important problem currently faced by the household in wheat production 0) No 1)Yes

Do you think that shortage of labour is the major production constrain for wheat production? 0) No 1)Yes

If yes, for what specific activities do you encounter labour shortage?

1= Cultivation of land 2= Weeding/logging 5=management

3= Crop harvest 4 = Threshing 6= others (Specify)

If yes, how did you overcome this labour shortage?

1. Hiring labour 2. Mechanization 3. Others, specify_____________

Do you think that Poor extension, input supply, and farm implements are the most important production constraint 0) No 1)Yes

Do you think that natural factors (pests, disease, weather, and drought) as a production constraint 0) No 1)Yes

The number of times the household faces drought problems during the last ten years?

The number of years the HH expects potential pest/ disease problems during the future 10 years?

. SECTION 2: FARM CHARACTERISTICS 45. Characteristics of all plots (cultivated or fallow) in the 2016/17 planting season

Plot code number starting from nearest plot to house)	Plot size (Acres/ha)	Plot ownership **Code A**	Soil fertility **Code B**	Soil type **Code C**	Soil slope **Code D**	Soilwater conservation **(0=no; 1=yes)**	Water logging on plot **(0=no; 1=yes)**
1.							
2.							
3.							

Code A	**Code B**	**Code C**	**Code D**
Owned Rented in Shared in Shared out Other, specify….	1. Poor 2.Medium 3.Good	Black (loam) Brown (sandy) Red Grey (clay) Other, specify	Gently slope (flat) Medium slope Steep slope ____________

46. Do you practice dairy farming? 0) No 1) Yes

47. If yes, Number of dairy cattle kept on-farm

SECTION 3: Adoption of New Improved Wheat Varieties

Have you heard of the new improved varieties? 0) No 1) Yes

Key: Kenya Ibis; Robin; Eagle10; Kenya Hawk 12;Kenya Tai; Kenya Sun Bird; Kenya Wren; Kenya Korongo

If yes to Q44, have you ever used one or all of them? 0) No 1) Yes

If you ever used the varieties, when did you start using? ________ year.

If no to Q46, reason for not using the new improved wheat varieties?

_______________2. __________3. __________

From the cultivated land holding:

1. Crop land___________in acres 2. New improved wheat varieties

(NIWV)___________in acres

Old improved wheat varieties (OIWV) ___________in acres

Did you use any of the new improved wheat variety during 2016/17 cropping season?

0) No 1) Yes

If yes, NIWV ____in acres in 2016/17 If no, OIWV _____in acres

If yes, what was the size of area under NIWV and OIWV last season?

	Area planted in acres
New Improved wheat varieties(NIWV)	
Kenya Korongo	
Kenya Ibis	
Eagle10	
Robin	
Kenya Hawk	
Kenya Tai	
Kenya Sunbird	
Kenya Wren	
Old Improved wheat varieties (OIWV)	
Njoro Bw2 Duma Kwale Kenya Ibis Kenya Mwamba Kenya Heroe Kenya Yombi Others (Specify)	

If you have ever used these the new varieties and stopped, what are the reasons?

New Improved varieties	***Reasons for not using the new improved wheat varieties*** 1= Cost of seed 2. Unavailability of seed 3= Susceptible to disease 4 = Preference of old varieties 5= Poor yields, 6 Preference for alternative enterprises 7= Others, Specify__________
Kenya Korongo	
Kenya Ibis	
Eagle10	
Robin	
Kenya Hawk	
Kenya Tai	
Kenya Sunbird	
Kenya Wren	

Please answer questions in the table below on discontinuation of use of new improved wheat varieties.

New improved wheat variety	Year first adopted	Source of recommendation	Whether farmer has ever discontinued adoption of variety 1=Yes 2=No	Main reason for discontinuation	Main reason for continuation
Kenya Ibis					
Robin					
Eagle10					
Kenya Hawk 12					
Kenya Tai					
Kenya Sun Bird					
Kenya Wren					
Kenya Korongo					

SECTION 4: Rate of Varietal Turnover

Do you cultivate the OIWV? 0= Yes 1=No,

If yes, which varieties do you grow?

Old varieties released before 2009	Did you grow: (Tick)		For each of the variety grown, what was area under production in :- (acres)			If the acreage has increased for the last 5 year, give reasons? 1=Demand for the variety 2= High Yielding 3= Disease resistance 4=Drought Tolerant 5= Seed availability 6=Others(Specify) (multiple reply)			
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Njoro Bw2									
Duma									
Kwale									
Kenya Ibis									
Kenya Mwamba									
Kenya Heroe									
Kenya Yombi									
Others (Specify)									

Are there any varieties which you are no longer growing? 0= Yes 1=No,

Do you think that the improved wheat varieties are better than OIWV?

What is the most preferred trait in the OIWV for your household?

1. Yield capacity 2. Climate adaptability

Disease resistance 4. Marketability 5. Grain quality

Give priority order of the traits you consider

1. ____________________________ 2. _____________________________

3. ____________________________ 4. _____________________________

From where did you get improved NIWV seeds?

1. MOA __________ 2. Research centre ______ 3. Own __________

Market _________ 5. Neighbors______ 6. NGO ________7. Others, specify ________

Do you think that there is risk associated to the use of NIWV?

0) No 1) Yes

If yes, what are the risks associated to the use of new NIWV?

1 _____________________________2.____________________3. __________________

What was the change in the area under wheat on your farm in the last five years?

1 constant 2 increasing 3 decreasing

Please give the two most important reasons for your answer in 73 *(if area is constant skip to 76)* 1) ________________________________ 2)

. If *area is increasing:* What are the crops/enterprise replaced by increased wheat area? (1) -------------------- (2) --------------------- (3) -------------------------- *If area is decreasing* what are the crops/enterprise replacing wheat?

a. (1) -------------------- (2) --------------------- (3) --------------------------

What is production trend of improved wheat varieties (IWV)?

Year	**Quantity harvested kg**	
2018		
2017		
2016		
2015		
2014		
2013		
2012		
2011		
2010		

SECTION 5: AGRICULTURAL EXTENSION SERVICE

Do you have access to extension services? [ ] 1= Yes 0= No

How often did you access agricultural extension services in the last growing season?

Frequency of service (code A)

What is the source of extension service (code B)

Code A: Frequency of extension service	Code B: Source of extension service
1=Once a week	1=Government extension officers
2=Once in a fortnight	2=NGO extension officers
3= once a month	3=News paper
4= Once a year	4=TV
5=Cannot remember	5= Farmer to farmer
6=Never	6=Other (specify)................
7= Other (specify)...................	

SECTION 6: Marketing and Credit

What are the major constraints in purchasing seed, please rank the first two important (do *not read out the reasons assign the farmers' answers to the given categories)?*

Lack of information about recommended variety ---------

Non-availability of seed of required variety --------

(c). High seed price ---------

(d). Need to travel long distances ----------------------- (e) Credit facility not available ------------------------ (f) Low seed quality --------------------------

Others (specify) ------------------------

Did you sell wheat grain 2016/17 cropping season? 0) No 1) Yes

If yes where is your output marketed?

1. Farm gate _______2. Local market______ 3. District market _____ 4. Other, specify

If yes, to whom did you sell your wheat grain in the 2016/17?

Traders (Retailers, Whole sellers)

Millers 3. Others(specify)___________

If no, why not?

1. Reserved for seed 2. Market far /transportation cost large 3. Others specify

Which are months of higher prices of wheat grain?

Which were months of lower prices of wheat grain? _____________________________

What type of storage method do you use for wheat grain? _________________

For how long do you store your wheat grain? ___________________________

Do you have Access to credit 0) No 1) Yes

If yes, did you receive credit during 2016/17 cropping season? 0) No 1) Yes

If yes, which category? 1. Cash ________ 2. Kind _______

What was the purpose of credit? ____

If yes to Q. 98 what are the preconditions for getting credit? ________________

SECTION 5: INCOME AND EXPENDITURE

90. Wheat grain income from sales of NIWV during 2016/17

New improved wheat variety	Unit (90kg/bag)	Quantity sold	Price per unit (90kg/bag)	Total
Kenya Ibis				
Robin				
Eagle10				
Kenya Hawk 12				
Kenya Tai				
Kenya Sun Bird				
Kenya Wren				
Kenya Korongo				
Total				

91. Wheat grain income from sales of NIWV during 2016/17

Old improved wheat variety	Unit (90kg/bag)	Quantity sold	Price per unit (90kg/bag)	Total
Kenya Ibis				
Robin				
Eagle10				
Kenya Hawk 12				
Kenya Tai				
Kenya Sun Bird				
Kenya Wren				
Kenya Korongo				
Total				

Cordially thank the respondent!

Appendix 3: A Tool Expert Elicitation Method

In your opinion, what is the estimate of area planted was planted with NIWV and OIWV last season
(2016-2017) by wheat farmers in your area?

Varieties	**Area planted in acres**
New Improved wheat varieties(NIWV)	
Kenya Korongo	
Kenya Ibis	
Eagle10	
Robin	
Kenya Hawk	
Kenya Tai	
Kenya Sunbird	
Kenya Wren	
Old Improved wheat varieties (OIWV)	
Njoro Bw2 Duma Kwale Kenya Ibis Kenya Mwamba Kenya Heroe Kenya Yombi Others (Specify)	

For the farmers who grow this varieties, in your opinion estimate the following:

Old varieties released before 2009	Did you grow: (Tick)		For each of the variety grown, what was area under production in :- (acres)			If the acreage has increased for the last 5 year, give reasons? 1=Demand for the variety 2= High Yielding 3= Disease resistance 4=Drought Tolerant 5= Seed availability 6=Others(Specify) (multiple reply)			
	2015	2016	2017	2015	2016	2017	2015	2016	2017
Njoro Bw2									
Duma									
Kwale									
Kenya Ibis									
Kenya Mwamba									
Kenya Heroe									
Kenya Yombi									
Others (Specify)									

In your opinion, are there varieties which farmers are no longer growing apart from the varieties in question 2 above? [ ]   1= Yes   No=2

If yes which are this varieties?; For how long did the farmers grow them?

Why did they stop growing them?

In your opinion are the NIWV better than OIWV? In which way?

In your opinion what are the most preferred traits in the OIWV?

Give priority order of the traits you consider most important

1. ____________________________   2. ____________________________

3. ____________________________   4. ____________________________

What was the source of improved NIWV seeds?

1. __________   2. _______ 3. __________   _________ 5. ______   6. ________7.

In your opinion are there risks associated to the use of NIWV?

0) No   1) Yes

If yes, what are the risks associated to the use of new NIWV?

1________________________2.____________________3. _________________

Appendix 4: Expenditures and Revenues from Wheat Research (20102018)										
Item	Unit	2010	2011	2012	2013	2014	2015	2016	2017	2018
WHEAT EXPENDITURES AND REVENUE										
Government budget allocation to wheat research	Ksh	8,004,780	4865232	11361336	8764416	9804072	8869872	3106260	6398616	7921116
Donor funding for wheat research	Ksh	115,147.00	4,320,123. 54	(84,645.07)	3,073,1 2. 60 0	2,833,432.00	2,337,330. 0 0	2,181,267. 20	6,438,886.20	6,689,611. 0 0
Sub -total budget	**Ksh**	**8,119,927. 0**	**9,185,355. 5**	**11276690.9**	**11837578**	**12637504**	**11,207,202 . 00**	**5,287,527. 20**	**12,837,502.2 0**	**14,610,727 . 00**
Capital Expenditure	Ksh									
Land	Ksh	60,500.00	1,163,000	1,163,000	1,227,800	1,294,700	1,294,700	1,175,500	2,689,200	2,552,200
Buildings	Ksh	500,000	515,000	515,000	530,450	546,364	562,754	600,000	618,000	639,000
Equipment	Ksh	306,000	324,000	318,000	355,636	375,305	375,305	375,305	321,000	342,000
Sub-total Capital Expenditure	Ksh	866,500	2,002,000	1,996,000	2,113,886	2,216,369	2,232,759	2,150,805	3,628,200	3,533,200
Operating Expenditure										

Staff Salaries & Benefits	Ksh	6,619,910.00	2,619,910.00	1,779,899.00	1,923,103.00	1,068,040.00	5,223,080.00	(1,324,680.00)	(6,767,600.00)	2,986,990.00
Training	Ksh		0	0	0	0	0	1,015,000	1,015,500	1,015,000
Office operations	Ksh	500,000	-					50,000	565,000	536,000
Other	Ksh	133,517	4,563,446	8,500,792	8,800,589	9,353,095	3,751,363	3,396,402	5,396,402	4,539,537
Sub-total Operating Expenditure	Ksh	7,119,910	7,183,356	10,280,691	10,723,692	10,421,135	8,974,443	3,136,722	209,302	9,077,527
Grand Total Expenditure	**Ksh**	**8,119,927. 00**	**9,185,355.54**	**12,276,690.93**	**12,837,578.00**	**12,637,504.00**	**11,207,202.00**	**5,287,527.20**	**3,837,502.20**	**12,610,727.00**
Revenue from Wheat Production										
Hectares („000 ha)	Ha	130	132	142	149	163	147	120	153	150
Yield per ha („000 t)	Ton	2.5	2.5	2.5	2.5	2.5	2.5	2.9	2.6	2.9
Total Wheat production	ton	325	330	355	373	408	368	348	398	435
Average price per ton	Ksh	36,770	33,980	42,850	43,480	39,750	36,280	36,630	36,630	36,630

Total Gross Revenue	**Ksh**	**11,950,250**	**11,213,400**	**15,211,750**	**16,196,300**	**16,198,125**	**13,332,900**	**12,747,240**	**14,571,414**	**15,934,050**
Net revenue (Loss/ Profit)	**Ksh**	**3,830,323**	**2,028,044**	**2,935,059**	**3,358,722**	**3,560,621**	**2,125,698**	**7,459,713**	**10,733,912**	**3,323,323**
YEAR	Y	2010	2011	2012	2013	2014	2015	2016	2017	2018
Economic Analysis:										
Measures of Economic Viability		-								

Discount Rate	10%									
Present Value of Benefits, Ksh	80,302,690									
Present Value of of Costs, Ksh	56,989,662									
Net Present Value (NPV), Ksh	23,313,028									
Benefit: Cost Ratio (BCR)	1.41									
Internal Rate of Return (IRR)	41%									

Source: Own Calculation from Appendix 4, 5, 6

Appendix 5: Donor Funds (2010-2018)

Expenses per Task Order	**Year 1 Expenses (2010)**	**Year 2 Expenses (2011)**	**Year 3 Funding (2012)**	**Year 4 Funding (2013)**	**Year 5 Funding (2014)**	**Year 6 Funding (2015)**	**Year 7 Funding (2016)**	**Year 8 Funding (2017)**	**Year 9 Funding (2018)**
Phenotyping Platforms									
Personnel									
SPRO	607,318.00	407,300.00	325,500.00	244,200.00	263,600.00	683,500.00	625,600.00	0.00	0.00
PRO	989,000.00	389,000.00	10,186.00	204,900.00	208,000.00	411,131.00	705,600.00	181,720.00	226,100.00
PRO1	805,300.00	405,300.00	329,400.00	354,300.00	379,900.00	506,300.00	176,400.00	181,720.00	267,300.00
PRO2	584,200.00	304,200.00	301,700.00	319,700.00	338,300.00	457,500.00	414,600.00	181,720.00	267,300.00
Breeder	587,300.00	477,300.00	304,900.00	323,000.00	341,700.00	361,000.00	468,790.00	203,860.00	771,400.00
Senior Pathologist	805,300.00	505,300.0000	429459.00	354343.00	479973.00	906,372.00	438,750.00	378,930.00	395,690.00
Senior Tech Assistant	1000000.00	0.0000	0.00	0.00	0.00	400,000.00	430,000.00	224,000.00	464,200.00
T. A Field/Greenhouse/	160083.00	160,083.0000	164885.00	269800.00	174927.00	280,175.00	286,580.00	267,750.00	332,100.00
Tech Officer Breeding	193809.00	193,809.0000	199623.00	205612.00	211780.00	218,134.00	290,000.00	294,700.00	742,600.00
Tech Assistant Pathology	387600.00	387,618.0000	399246.00	316848.00	323560.00	436,268.00	400,000.00	318,000.00	636,600.00
T A Farm Management	0.00	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	332,100.0

									0
Lab Assistant							0.00	0.00	551,600.0 0
Office support officer	0.00	0.0000	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Interns	500000.00	390,000.00 00	315000.00	330400.00	346,300.0 0	562,700.0 0	439,000.00		

Expenses per Task Order	**Year 1 Expenses (2010)**	**Year 2 Expenses (2011)**	**Year 3 Funding (2012)**	**Year 4 Funding (2013)**	**Year 5 Funding (2014)**	**Year 6 Funding (2015)**	**Year 7 Funding (2016)**	**Year 8 Funding (2017)**	**Year 9 Funding (2018)**
Total	**6,619,910.0 0**	**3,619,910.0 0**	**2,779,899. 00**	**2,923,103. 00**	**3,068,040 . 00**	**5,223,080. 00**	**4,675,320. 00**	**2,232,400 . 00**	**4,986,990 . 00**
Travel									
Local Transport for Research & Farm Visits		1,200,000.0 0	1,236,000. 00	1,273,080. 00	1,311,272 . 00	1,350,611. 00	500,000.0 0	515,000.0 0	515,000.0 0
Conferences		1,100,000.00	0	0	0	0	0	0	0
Total		**2,300,000.0 0**	**1,236,000. 00**	**1,273,080. 00**	**1,311,272 . 00**	**1,350,611. 00**	**500,000.0 0**	**515,000.0 0**	**515,000.0 0**
Other Direct Costs									
Pathology Support		500,000.00	500,000.00	500,000.00	500,000.0 0	500,000.0 0	500,000.0 0	500,000.0 0	0

Seed Handling		200,000.00	215,000.00	230,450.00	246,364.00	262,754.00	200,000.00	2,618,000.00	0
Maintenance of Equipment		300,000.00	318,000.00	334,540.00	355,636.00	375,305.00	300,000.00	321,000.00	342,000.00
Utilities		500,000.00	515,000.00	530,450.00	546,364.00	562,754.00	600,000.00	621,000.00	642,000.00
Seed Room Storage		500,000.00	515,000.00	530,450.00	546,364.00	562,754.00	600,000.00	618,000.00	639,000.00
Land Charge - (3ha)		0	0	0	0	0	3,000,000.00	3,090,000.00	3,111,000.00
Land Charge - (5ha)		-	2,163,000.00	2,227,800.00	2,294,700.00	2,356,500.00	2,400,000.00	2,472,000.00	2,493,000.00
Land Charge - 8 ha		1,050,000.00	0	0	0	0	1,774,000.00	1,827,200.00	1,848,200.00
Land Leveling Irrigation and Supplies		0	0	0	0	0	469,800.00	0	0
Computer/Printer (for Assistants & Field Books)		500,000.00	-	-	-	-	0	515,000.00	536,000.00
Supplies		1,050,000.0	1,081,500.	1,113,945.	1,147,363.	1,181,784.	1,000,000.	1,000,000.	1,021,000.

Expenses per Task Order	**Year 1 Expenses (2010)**	**Year 2 Expenses (2011)**	**Year 3 Funding (2012)**	**Year 4 Funding (2013)**	**Year 5 Funding (2014)**	**Year 6 Funding (2015)**	**Year 7 Funding (2016)**	**Year 8 Funding (2017)**	**Year 9 Funding (2018)**
		0	00	00	00	00	00	00	00
Total		**5,700,000.00**	**6,437,500.00**	**6,596,090.00**	**6,763,655.00**	**6,927,067.00**	**10,823,800.00**	**11,182,600.00**	**11,032,200.00**
Equipment									

Breeding Pipeline									
Travel									
Farmers Trainings	-	-	-	-	-	-	15,000.00	15,500.00	15,000.00
NPT Visits by Stakeholders	-	-	-	-	-	-	1,000.00	1,200.00	-
Total							**16,000.00**	**16,700.00**	**15,000.00**
Other Direct Costs									
Field Chemicals, Fertilizers, Dispensing Paper Bags, etc.	-	10,000.00	-	-	-	-	4,000.00	400,000.00	400,000.00
Experimental Land Hire and Preparation	-	10,500.00	-	-	-	-	1,500.00	300,000.00	100,000.00
Natural Resources Management Research	-	-	-	-	-	-	2,000.00	100,000.00	100,000.00
KEPHIS Charges: Seed Certification	-	-	-	-	-	-	500	100,000.00	100,000.00
Lab Equipment Repair (Milling Machine)	-	6,000.00	-	-	-	-	1,500.00	-	-
Vehicle Servicing	-	0	-	-	-	-	30000	30000	30000
Cereal Breeding LAB Upgrading	-	0	-	-	-	-	100,000.00	-	-
Crossing Block Repair (Irrigation)	-	0	-	-	-	-	100,000.00	-	-
Data Sharing and Publications	-	0	-	-	-	-	50000	50000	50000

Expenses per Task Order	Year 1 Expenses (2010)	Year 2 Expenses (2011)	Year 3 Funding (2012)	Year 4 Funding (2013)	Year 5 Funding (2014)	Year 6 Funding (2015)	Year 7 Funding (2016)	Year 8 Funding (2017)	Year 9 Funding (2018)
KEPHIS Charges: NPT and DUS	-	0	-	-	-	-	-	5,400.00	5,400.00
IDC (15%)		27,428.54					80,445.00	108,097.20	8,505.00
Total		**47,928.54**					**616,745.00**	**828,745.20**	**65,207.00**
Surveillance							1,000,000	2,000,000	2,000,000
IDC (15%)							150,000	300,000	2,000,000
Surveillance Total							**1,150,000**	**2,300,000**	**4,000,000**
Talent Pipeline									
Students	96,000.00	96,000.00	96,000.00	96,000.00	96,000.00	96,000.00	96,000.00	96,000.00	96,000.00
Graduate Student Stipends -	0	0	0	0			150,240.00	154,752.00	119,556.00
IDC (15%)							16,908	17,412	17,928
Sub-Total							**10,799.00**	**11,123.00**	**11,457.00**
Grand Total	**8,119,927.00**	**16,167,855.54**	**16,282,690.93**	**16,799,942.00**	**17,620,642.00**	**16,302,500.00**	**25,517,135.00**	**26,837,502.20**	**21,613,727.00**

Source: KALRO Annual Reports 2010- 2018

Appendix 6*: Government expenditures for wheat research (2010- 2018)*

	2010				**2011**					
Cadre	**No**	**Annual Salary**	**Annual H/Allowance**	**Commuter Annual**	**Cadre**	**No**	**Annual Salary**	**Annual H/Allowance**	**Annual Commuter**	**Total**
PRO	1	1076976	240000	-	PRO	1	1130820	240000	31188	
SRO	1	765384	204000	-	SRO	1	803652	204000	300000	
ROII	2	1029048	360000	-	ROII	3	1543572	540000	72000	
ARO	1	514524	180000	-	ARO	1	-	-		
TA.III	1	423264	96000	-	TA.III	0	-	-	-	
STA	6	2539584	576000	-	STA		-			
Total		**6348780**	**1656000**	-	**Total**		**3478044**	**984000**	**403188**	**12870012**
		2012			**2013**					
PRO	1	1187364	240000	168000	PRO	1	1187364	240000	168000	
SRO	1	1187364	240000	168000	PRO1	1	1025688	240000	168000	
ROII	3	1187364	240000	168000	RO1	1	595632	180000	96000	
STA	6	3796920	576000	432000	RO2	3	1269792	540000	288000	
RO1		595632	180000	96000	STA	4	1693200	384000	288000	
TA1		383952	54000	60000	TAII	1	**310740**	**42000**	**48000**	

TAII		310740	42000	48000						
Total		**8649336**	**1572000**	**1140000**	**Total**		**6082416**	**1626000**	**1056000**	**20125752**

		2014			**2015**					
PRO	1	1187364	240000	168000	PRO	1	1187688	240000	168000	
PRO1	1	1025688	240000	168000	PRO1	1	1130820	240000	168000	
RO 1	1	595632	180000	96000	RO1	1	595632	180000	96000	
ROII	3	1543572	540000	288000	ROII	3	1269792	540000	288000	
TOII	1	490020	180000	96000	STA	4	1693200	384000	288000	
STA	4	1693056	384000	288000	TAII	1	310740	42000	48000	
TAII	1	310740	42000	48000						
Total		**6846072**	**1806000**	**1152000**	**total**		**6187872**	**1626000**	**1056000**	**18673944**
		2016			**2017**					
PRO	1	1187364	252000	168000	PRO	1	1329852	240000	168000	
RO 1	1	595632	216000	96000	RO1	1	684972	180000	96000	
ROII	1	595632	180000	96000	RO2	2	1183416	360000	192000	
STA	3	423264	96000	72000	STA	3	1460376	288000	216000	
Total		**2206260**	**564000**	**336000**	**Total**		**4658616**	**1068000**	**672000**	**9504876**
2018										
PRO	1	1329852	240000	168000						
RO 1	1	684972	180000	96000						
ROII (3)	3	1775124	540000	288000						

STA (4)	4	1947168	384000	288000						
Total		**5737116**	**1344000**	**840000**						**7921116**
Grand Total										**69095700**

Source : KALRO Annual Reports 2010- 2018

Appendix 7*:* Annual wheat Producer Price (USD/ton) 2009 - 2018

Domain	Element	Item	Year	Unit	Value	Flag Description
Producer Prices - Annual	Producer Price (USD/tonne)	Wheat	2009	USD	379.7	Official data
Producer Prices - Annual	Producer Price (USD/tonne)	Wheat	2010	USD	367.7	Official data
Producer Prices - Annual	Producer Price (USD/tonne)	Wheat	2011	USD	339.8	Official data
Producer Prices - Annual	Producer Price (USD/tonne)	Wheat	2012	USD	428.5	Official data
Producer Prices – Annual	Producer Price (USD/tonne)	Wheat	2013	USD	434.8	Official data
Producer Prices – Annual	Producer Price (USD/tonne)	Wheat	2014	USD	397.5	Official data