Biological innovation in South African Agriculture: Economics of wheat varietal change, 1950-2012

By

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DECLARATION

I declare that this thesis I hereby submit for the degree of PhD in Agricultural Economics at the University of Pretoria is entirely my own work and has not been submitted anywhere else for the award of the degree or otherwise.

Parts of the thesis have been published and submitted for publication in journals.

Any errors in thinking and omissions are entirely my own responsibility.

Signed: ………………………………………………………..

Name: Charity Ruramai Nhemachena

2017

DEDICATION

To my loving husband Charles, son Blessings and daughters Blessed and Blessing.

We say “Ebenezer”

Thus far the Lord has taken us

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Degree:	PhD Agricultural Economics
Supervisor:	Professor J.F. Kirsten
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ABSTRACT

In the wake of increasing private investment in crop breeding research and the release of new varieties by global biotech companies such as Monsanto, there is rightfully a question related to the benefits from wheat varietal improvement research funded by the public sector. It is therefore critical to understand the economic benefits generated from public investments in wheat varietal innovations. Since private and public institutions and funding sources are sometime jointly involved in developing and commercialising new varieties, a related problem is how to estimate benefits from wheat varietal innovations and apportion credit to the different institutions, both public and private, which contributed to the research that developed new wheat varieties across different time frames. Addressing this problem helps generate important information for decision makers that includes: ideas to inform further support for more research and balancing local varietal improvement support (including mix of research support across different crops) and getting technologies developed from other contexts such as international sources.

The main research problem addressed in this study was the estimation of benefits from wheat varietal improvement research and their attribution to the Agricultural Research Council-Small Grains Institute and various sources of wheat research investments that contributed to varietal changes in South Africa. The findings contribute to generating information that is important in guiding decision-making on wheat varietal improvement investments, including national policy planning, to support wheat varietal innovations in South Africa. The empirical analyses used data on market shares of wheat varieties planted by farmers (used a measure of adoption rate of the varieties) and estimates of proportional yield gains, annual wheat farmer prices in South Africa and annual quantity of wheat produced across different wheat production areas in South Africa, namely dryland summer areas, dryland winter areas, and irrigation areas.

A vintage regression model was applied to estimate the proportional yield gain from wheat varietal improvement in South Africa. The results indicated that the rate of yield gain due to release of new wheat varieties (varietal improvement) was 0.8% per year (equivalent to 19.84 kg/ha/year) for dryland summer varieties and 0.5% for both irrigation (equivalent to 32.20 kg/ha/year) and dryland winter varieties (equivalent to

16.65 kg/ha/year). The estimated aggregate economic benefits over the analysis period 1985-2015 amounted to R22.81 billion from all sources, which is an average of R0.76 billion per year. About R7.52 billion (33%) of the aggregate economic benefits from wheat variety research programmes in South Africa were from varieties developed in the pre-1985 period.

The results using the geometric rule to attribute economic benefits among different institutional sources showed that local wheat research programmes have been relying on breeding efforts from CIMMYT and other sources. The results confirm that not accounting for attribution of benefits by source and time period results in an overestimation of benefits to any specific research programme. In addition, comparison of benefits between ARC-SGI and local private sector actors, mainly Sensako, before and after deregulation of the wheat sector showed that benefits to the ARC-SGI decreased after deregulation while the benefits to Sensako increased.

The results highlight the impact of the drop in public funding for wheat variety improvement research after deregulation. Given the importance of wheat as a main cereal crop (second after maize) in South Africa, public funding for variety improvement remains critical for the country. An analysis of ARC-SGI partnerships and pedigree analysis of selected dominant varieties demonstrated that wheat varietal improvement research relies on efforts of other institutions and previous research. The results illustrated the need for attribution of benefits from wheat varietal improvements to avoid overestimation of benefits allocated to any institution. Further research would be be required to assess complementarity and substitution effects of the changing roles and how best public and private wheat varietal improvements in the country can be further stimulated to enhance productivity.

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ACRONYMS

ANOVA	Analysis of Variance
ARC-SGI	Agricultural Research Council Small Grains Institute
CEC	Crop Estimation Committee
CGIAR	Consultative Group for International Agricultural Research
CIMMYT	International Maize and Wheat Management Centre
DAFF	Department of Agriculture, Forestry and Fisheries
GARB	Gross Annual Research Benefit
IPRs	Intellectual Property Rights
NARIs	National Agricultural Research Institutes
NARS	National Agricultural Research Systems
PVP	Plant Variety Protection
R&D	Research and Development
PBR	Plant Breeder's Rights
SAGIS	South African Grain Information Service
SAGL	South African Grain Laboratory
SGC	Small Grain Centre
TRIPS	Agreement on Trade-Related Aspects of Intellectual Property Rights
UPOV	International Union for the Protection of New Varieties of Plants
VIF	Variance Inflation Factors

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Biological innovations in agriculture, especially crop varietal changes, have substantially contributed to improvements in yield and earnings growth in agriculture over the years (Pardey et al., 2004). The main objectives of investments in biological innovations include the need to: (a) improve yield potential, (b) increase resistance to biotic and/or abiotic stresses, and (c) improve other characteristics such as processing and nutrition quality (Atack et al., 2009, Lantican et al., 2005). Investments in agricultural research and development (R&D), particularly biological innovations, are necessary to increase and sustain agricultural productivity as well as address challenges such as poverty, food security and responding to natural changes such as climate change and changes in agricultural crop growing conditions (Nhemachena et al., 2016a, Department of Agriculture Forestry and Fisheries, 2010).

Agricultural innovations can be classified under different forms such as mechanical innovations (e.g. tractors); innovations in chemicals (fertilisers and pesticides), innovations in new management practices (agronomic), innovations in biotechnology and information using computer-based technologies and biological innovations (new seed varieties) (Sunding and Zilberman, 2001). These classifications of innovations in agriculture help in determining research questions on policy and understanding of driving factors that contribute to investments and adoption of new agricultural innovations. For example, biological innovations may positively improve productivity of crops. This study focusses on biological innovations (new seed varieties) for wheat in South Africa with particular emphasis on innovations in wheat varietal improvements.

The need for assessment of economic returns to biological innovations in agriculture and agricultural research investments in general is motivated by the increasingly scarce public funding and greater accountability. Given that agricultural research competes for investment funds with other alternatives, there is a need for strong and clear evidence of economic returns to such investments. Despite recent shifts in the South African government funding to the country's main agricultural research agency, the Agricultural Research Council (ARC), government contributions remain the primary funding source for agricultural Research and Development (R&D). In the current climate of declining agricultural funding, it is critical to demonstrate to government and the public the positive payoffs to biological innovations in wheat and other agricultural research investments. In addition, policy and decision-makers need information on research payoffs in order to make informed decisions on alternative allocations of public funds and priority setting within the wheat research programs.

Innovations generated from agricultural research are outputs of cumulative and in many cases, collaborative investments by various institutions and individuals. Biological innovations in new crop varieties often draw directly on earlier developments on breeding lines and commercial varieties and are based on collaborative efforts of various institutions (public and private) (Maredia et al., 2010, Pardey et al., 2006). The main research challenge is how to apportion benefits from investments in biological innovations (such as development of new varieties) across different institutions and time frames (Maredia et al., 2010, Pardey et al., 2006).

A number of studies (Brennan and Quade, 2004, Heisey et al., 2002, Lantican et al., 2016, Lantican et al., 2005, Maredia et al., 2010, Pardey et al., 2006) have made efforts to estimate economic benefits from crop varietal improvement and attribute the benefits to different institutions that were actively involved. However, similar estimation and attribution of research benefits have not been done for wheat varietal improvement research in South Africa. As discussed above, the need for empirical work that addresses these attribution problems in biological innovations on wheat varietal improvement research in South Africa cannot be underestimated.

1.2 Problem statement

Given the competing needs for public resources and current changing political climate where public funding for research and development has been decreasing (Pardey et al., 2016a, Pardey et al., 2016b, Pal, 2011, Maredia and Byerlee, 2000), further support for wheat varietal research depends on the benefits to the public from the investments. For example, despite the widely accepted contribution of the Agricultural Research Council in improving performance of the agricultural sector in South Africa (Liebenberg, 2013), in real terms, public funding through the Parliamentary Grant to the ARC has been declining over the recent years (Dlamini et al., 2015). This affects research activities of the ARC, including crop breeding programmes, which would have to compete for the declining resources for their continued operations (Dlamini and Liebenberg, 2015, Dlamini et al., 2015). The reality of declining public funding emphasises the need for the different research programmes to demonstrate their returns to public investments to prove their worth for continued funding etc. Estimation of empirical benefits from wheat varietal improvement research provides an important source of information that decision-makers could use to make informed decisions on prioritisation and allocation of public funding for wheat varietal research and other research needs.

In the wake of increasing private investment in crop breeding research and the release of new varieties by global biotech companies such as Monsanto, there is rightfully a question related to the benefits from wheat varietal improvement research funded by the public sector. It is therefore critical to understand the economic benefits generated from public investments in wheat varietal innovations. Since private and public institutions and funding sources are sometimes jointly involved in developing and commercialising new varieties, a related problem is how to estimate benefits from wheat varietal innovations and apportion credit to the different institutions, both public and private, that contributed to the research that developed new wheat varieties across different time frames. Addressing this problem helps generate important information for decision-makers that include: ideas to inform further support for more research and balancing local varietal improvement support (including mix of research support across different crops) and getting technologies developed from other contexts (such as international sources).

The challenge in estimating rates of returns of research expenditure is to identify the research investments/ expenditures responsible for specific productivity increases or which part of productivity increases can be attributed to a specific research investment (Alston and Pardey, 2001). The main challenges in estimating the benefits of plant breeding programmes are:

- challenges in measuring adoption of modern varieties (especially area planted to modern varieties;
- challenges in evaluating benefits associated with adoption/ attribution over time (such as measurement of farm-level gains; separating benefits from improved crop management practices and non-yield benefits; imagining counterfactuals etc.); and
- challenges in attribution of credit to different sources of plant breeding programmes/ matching benefits and costs (e.g. accounting for spill overs between different programmes etc.) (Alston and Pardey, 2001, Alston et al., 2009, Morris and Heisey, 2003).

1.3 Objectives of the study

In the context of the problem statement, it is evident that investments in agricultural research are faced with stiff competition for limited government funds emanating from the increasing fiscal demands and pressure from other sectors. Therefore, disaggregated studies focusing on individual crops such as wheat, inform decision-makers on investments decisions to support further research and development of varietal improvements. Furthermore, biological innovation studies on crop-specific estimates based on public research investments that address the above issues are usually non-existent in developing countries including South Africa.

For the above reason, the main objective addressed in this study was to assess economic value of biological innovation in South African agriculture focusing on wheat varietal change from 1950 to 2012. The specific objectives were to:

1. Assess the sources and use of wheat varietal innovations in South African agriculture from 1819 to 2012.
2. Assess the changing public and private roles in wheat varietal rights in South African agriculture.

3. Analyse the effects of strengthening wheat variety intellectual protection on wheat productivity and varietal improvement (release of new improved varieties).
4. Estimate the benefits from wheat varietal innovations in South African agriculture.

1.4 Benefits from investments in crop varieties and hypotheses of the study

Innovations in varietal changes including crossing, testing and selection of new varieties draw from earlier breeding lines and commercial varieties and involve collaborations among all actors namely the public, private, local and international (Maredia et al., 2010, Pardey et al., 2006, Lantican et al., 2016). Despite the widespread understanding of the impact of agricultural research and development, little is known about the origins or sources of relevant varietal innovations that contributed to yield and productivity growth for specific crops in particular countries or changes of these sources over time. There is a lack of knowledge on whether benefits from research investments are attributed to local or foreign sources or whether the benefits are attributed to farmer innovations as well as public or private sector investments and how these have changed over time (Alston and Pardey, 2001, Alston et al., 2009, Pardey et al., 2006). The following hypotheses are formulated based on this literature review:

H_1: *Public investment has been the main source of wheat varietal innovations in South African agriculture.*

H_2: *After the abolishment of the wheat marketing board, the private sector share of wheat varieties is more than that of the public sector.*

The developments and changes in Intellectual Property Rights (IPRs) systems for agricultural innovations (such as varietal improvements) are one of the institutional factors[1] expected to impact on the productivity of agricultural systems (Campi, 2017).

[1] Other factors that affect agricultural productivity include: capital, land, labour, environmental and climatic factors, technological capabilities (Campi, 2017)

Despite arguments for stronger plant IPRs, empirical research on their effects on agricultural innovations and productivity have produced mixed results. For example, Campi (2017) found significant and positive relationship between stronger IPRs and cereal productivity in high-and low-income countries while the relationship was negative and insignificant in middle-income countries. In a separate study Naseem et al., (2005) found that plant variety protection (PVP) contributed to development of more varieties and positively impacted on cotton yields in the United States. On the negative side, plant IPRs have been argued to affect innovations and availability of new plant varieties, increasing input market concentration and impact on productivity is either insignificant or negative (Dutfield, 2009).

Based on this review of literature the following hypotheses are proposed:

> ***H_3:*** Strengthening Plant Breeders' Rights in South Africa increased investments and release of improved wheat varieties.
>
> ***H_4:*** Strengthening Plant Breeders' Rights in South Africa positively and significantly impacted on wheat productivity.

As stated above, the challenge in estimating rates of returns of research expenditure is to identify the research investments/ expenditure responsible for specific productivity increases or which part of productivity increases can be attributed to a specific research investment (Alston and Pardey, 2001). The main challenges in estimating the benefits of crop varietal breeding programmes include:

1. Challenges in measuring adoption of modern varieties especially area planted to new improved varieties.
2. Challenges in evaluating benefits associated with adoption/ attribution over time such as measurement of farm-level gains.
3. Separating benefits from improvements in management practices and benefits; imagining counterfactuals.
4. Challenges in attribution of credit to different sources of plant breeding programmes/ matching benefits and costs (for example, accounting for

spillovers between different programmes etc.) (Alston and Pardey, 2001, Alston et al., 2009, Morris and Heisey, 2003).

Failure to address attribution challenges such as the ones mentioned above leads to overestimation of benefits and rates of return from agricultural research expenditure. A review of published studies by Alston and Pardey (2001) found that many studies fail to adequately address attribution problems and reported high rates of return. Other factors such as improved management contribute to increases in wheat yields and productivity in addition to varietal improvements. Therefore, the effects of improved management such as changes in input use and/ or efficiency, should be carefully measured in estimating benefits of varietal improvement research. The development of a variety depends of previous breeding programmes both of the institution releasing the variety as well as other institutions. It is therefore important to carefully measure and attribute the benefits from varietal breeding to different institutions.

Economic impact studies estimating benefits from crop varietal improvements such as (Brennan and Quade, 2004, Heisey et al., 2002, Lantican et al., 2016, Lantican et al., 2005, Maredia et al., 2010, Pardey et al., 2006) demonstrated that investments in new crop varieties contribute to positive yield and economic benefits. Furthermore, these studies demonstrated that attributing the economic benefits across the different institutions involved and across different time frames reduces the overestimation of benefits to any specific research institution. The empirical results from these studies demonstrates that applying geometric attribution rules to research benefits reduces the benefits that are apportioned to a specific research institution. This is in contrast to cases where all benefits are credited to a specific institution. The following hypotheses are derived based on this literature review:

H_5: *Wheat varietal improvement investments by the ARC-SGI generated positive economic benefits for the period 1985 – 2012.*

H_6: *The benefits from public research investments significantly decreased since the deregulation of the wheat sub-sector in 1997.*

1.5 Contributions of the study

Based on the above discussion, the measurement of benefits from agricultural research and development has been an area of concern for agricultural policy-makers for decades. There is growing need for accountability and competition for public financial resources requiring publicly funded investments such as varietal innovations to demonstrate the benefits from these programmes. However, empirical work that addresses estimation of economic benefits and the attribution challenges in biological innovations, particularly in wheat varietal improvement research, is lacking. In addition, there is a lack of comprehensive analyses of the sources and uses of wheat varietal improvements as well as evolution of wheat plant breeders' rights in South Africa. The current study attempts to address this empirical gap in the South African agriculture sector by making efforts to identify institutional origins of the benefits of wheat varietal improvement research with particular attention on research done by the ARC.

Also, there is no empirical work that has assessed how strengthening wheat variety IPRs have affected the wheat sector variety improvement landscape and seed industry. The empirical analyses from this research contributes to the knowledge and debate on the effects of Plant Breeders' Rights and or strengthening of IPRs on plant varieties on agricultural productivity, the release of improved varieties and changing roles of public and private sector R&D investments in agriculture.

In addition, this study attempts to estimate and attribute the economic benefits generated from investments in wheat varietal research in South Africa across different institutional sources and across different time frames. To achieve this, the study also contributes to generating detailed databases of wheat varietal research in South Africa. Currently, there is no single source of wheat varietal research in the country and, to this end, the databases used in the current study provide an important source of data for future research in wheat varietal improvement.

The data generated include sources of wheat varietal releases from 1890 to 2015, evolution of wheat plant breeders' rights in South Africa and wheat experimental data (experimental yields and shares of varieties in national crop). Therefore, by using these unique datasets, the study demonstrates application of methods to estimate and attribute economic benefits of wheat varietal improvement research from investments by the ARC-SGI and other institutions. In addition, the datasets generated from this study can be used for further research and analysis that could not be addressed in the current study.

1.6 Approach and methods of the study

This study comprises of four analytical chapters, excluding the introduction and conclusion, with a common subject of biological innovations in South African agriculture focusing on improvement in wheat varieties. Each individual chapter, excluding the introduction and conclusion, addresses each of the specific objectives using different methods.

To assess the sources and use of wheat varietal improvement, the current study analysed historical evolution of wheat varietal improvement research and production in South Africa. This chapter used generated detailed information on history of wheat varietal improvement to attribute the research to different institutions, particularly the ARC. The main objective of this chapter was to provide a historical evolution of wheat varietal improvement in South Africa. Compared to previous studies, the assessment extends the period of analysis from 1891 to 2013. Efforts were made to understand how policy changes in the wheat sector have affected wheat varietal improvement in the country over time.

The empirical analysis is based on the critical review of information from policies, the varieties bred and their breeders, the years when those varieties were bred, and pedigree information gathered from the journal "*Farming in South Africa*", sourced from the National Library of South Africa, CIMMYT database and many other sources of literature like journal papers. A database of the sources and uses of wheat varietal innovations in South Africa was developed using information from the above sources. The data was analysed using trend and graphical analysis, indicating that from the 1800s, wheat varietal improvement in the country focused on addressing the following: adaptability to the production area, yield potential and stability and agronomic characteristics

To assess the changing public and private roles in varietal rights, this study developed a database of Plant Breeders' Rights (PBRs) for wheat from 1979 to 2012 focusing on applications and the granting of the PBRs. The data on applications and the granting of PBRs for wheat varietal improvement in South Africa was collected from Plant Breeders' Rights journals from the South African Department of Agriculture, Forestry and Fisheries and South African National library. Descriptive statistics was used to analyse trends and ownership of wheat varietal improvement PBRs.

The other objective was to analyze the effects of strengthening wheat variety intellectual (IP) protection on wheat productivity and release of new varieties. The strength of IPR systems was measured using an IP protection index, plant variety protection legislation and the number of Plant Breeders' Rights granted for wheat varieties. The empirical analyses were based on correlation and multiple regression analyses.

The main objective of the fourth chapter was to estimate the benefits of wheat varietal innovations over the period 1978-2015 and attribute them to the Agricultural Research Council's Small Grains Institute and the various sources of wheat research investments that contributed to varietal changes in South Africa. The findings contribute to generating information that is important in guiding priority decision-making on wheat varietal improvement investments, including national policy planning, to support wheat varietal innovations in South Africa.

1.7 Organisation of study

Chapter 1 presented the introduction of the study. The next chapter presents the assessment of the sources and use of wheat varietal innovations in South African agriculture from 1819 to 2012. Chapter 3 presents the analysis of the changing public and private roles in wheat varietal rights in South African agriculture. Chapter 4 analyses the effects of Plant Breeders' Rights on wheat productivity and variety improvement in South Africa. Chapter 5 presents the estimation and attribution of benefits from wheat varietal innovations in the same sector. Finally, Chapter 6 presents the conclusion and recommendations of the study.

CHAPTER 2

A HISTORICAL ASSESSMENT OF THE SOURCES AND USES OF WHEAT VARIETAL INNOVATIONS IN SOUTH AFRICAN AGRICULTURE

2.1 Introduction

The driving factors for investment in crop varietal innovations include the need to: (a) improve yield potential, (b) increase resistance to biotic and/ or abiotic stresses, and (c) improve other characteristics such as processing and nutrition quality (Atack et al., 2009, Lantican et al., 2005). Investments in agricultural research and development (R&D), particularly biological innovations are necessary to increase and sustain agricultural productivity as well as address challenges such as poverty, food security and responding to natural changes such as climate change as well as changes in agricultural crop growing conditions (Nhemachena et al., 2016a, Department of Agriculture Forestry and Fisheries, 2010). The World Bank Development Report (2008) argues that productivity gains through innovations that address increasing scarcities of land and water remain the main drivers of growth in agriculture and of increased production of food and agricultural products to feed the increasing demand. Innovations such as those in crop varietal improvements need to focus beyond raising productivity and address additional challenges such as water, risk reduction, improved product quality and environmental protection.

Du Plessis (1933) reports that wheat was first produced in South Africa in the winter of 1652 when Jan van Riebeeck planted the first winter wheat. This development in the 1600s was the foundation of wheat production and subsequent breeding programmes to date. Despite the first production of wheat taking place in the 1600s, wheat varietal breeding was reported to have been established more than two centuries later in 1891 (Smit et al., 2010). The focus of wheat varietal improvements in South Africa addresses the following cultivar characteristics: adaptability to the production area; yield potential and stability; and agronomic characteristics (e.g. tolerance to diseases, pests and aluminium toxicity). The wheat varietal improvement sector consists of three main actors namely the ARC-SGI (established in 1976 as the then Small Grains Centre), Sensako which was established in the mid-1960s (becoming autonomous in 1999 after functioning as part of Monsanto) and Pannar (entering the wheat breeding sector in the 1990s) (Smit et al., 2010).

Periodic assessment of plant breeding is required to determine the benefits of on-going investment to allow (a) temporary constraints that could permanently hinder the identification of crop varietal improvements to be addressed and (b) desirable characteristics to be identified and prioritised, such as quality, quantity, environmental impact (Chigeza et al., 2012). The main objective of this chapter is to undertake a historical assessment of the sources and uses of wheat varietal innovations in South African agriculture. Specifically, the chapter focuses on the historical evolution of wheat varietal improvements in the country, including the identification of popular varieties, their history, sources and uses, between 1891 and 2013. This assessment complements earlier efforts by Van Niekerk (2001), De Villiers and Le Roux (2003); Smit et al., (2010) and Stander (2012), firstly by extending the period of analysis from early breeding periods in the early 1900s to 2013. Furthermore, the current empirical analysis is critical in helping to identify popular wheat varieties that have been bred and grown for long periods of time, particularly among current varieties in the market. These varieties form the basis for analysing the attribution of wheat varietal improvement in South Africa, which is the focus of chapter 5. Further analysis in the next chapter looks at the parental history of the selected varieties from the current analysis, and develops an empirical model for the attribution of benefits of wheat varietal improvement in South Africa

2.2 Review of commercial wheat production in South Africa

2.2.1 Wheat production in South Africa

The Department of Agriculture, Forestry and Fisheries (2010) reports that the precise origin of wheat is not known, but there is evidence that the crop evolved from wild grasses somewhere in the Near East. Wheat is reported to have likely originated from the Fertile Crescent in the upper reaches of the Tigris-Euphrates drainage basin. Wheat production in South African started in 1652 with varieties brought by the Dutch traders to Cape Town (then the Cape of Good Hope). After maize, wheat is the second most important grain crop produced in South Africa. In South Africa, the main uses of wheat are for human consumption (especially for making flour for the bread industry), industrial use (for making alcoholic beverages, starch and straw), and animal feed (bran from flour milling as an important source of livestock feed, grain as animal feed, etc.) (Department of Agriculture Forestry and Fisheries, 2010).

Two types of wheat are produced in South Africa, namely, durum wheat (*Triticum turgidum*) and bread wheat (*Triticum aestivum*). Both types of wheat are used to make various food products. For example, in developed countries, durum wheat is used to manufacture pasta while in developing countries it is mainly used for bread, couscous and bulgur. On the contrary, bread wheat is used to make bread, biscuits, cookies and noodles. There are two growth habitats for wheat which are the winter-habitat wheat and the spring-habit wheat. Winter wheat requires a period of cold temperatures (vernalisation) before flowering while spring wheat does not require the same (Lantican et al., 2005).

Wheat is produced in 32 of South Africa's 36 crop production regions. The main wheat-producing provinces in South Africa are Western Cape (winter rainfall), Free State (summer rainfall) and Northern Cape (irrigation). Limpopo (irrigation) and North West (mainly irrigation) are also important producing provinces (Southern African Grain Laboratory, 2012). Wheat production in South Africa occurs in both summer and winter rainfall regions. Figures 2.1 and 2.2 below present the distribution of the dryland and irrigation wheat production areas respectively. Most of the production (at least 50%) happens under dryland conditions and at least 30% of the total harvest is produced under irrigation (Pannar, 2009).

Irrigation production has a higher yield potential compared to dryland wheat production. Dryland productivity in South Africa is very low compared to major wheat-producing countries in the world. Pannar (2009) attributes the slower than anticipated progress in yield increases of local breeding programmes to stringent quality requirements for new varieties, as well as variable climatic conditions (including dry, warm winters); low soil fertility, new diseases such as yellow/stripe rust (*Puccinia striiformis*) in 1996, and the emergence of new pathotypes, the introduction of the Russian wheat aphid in 1978, and a new biotype in 2005. These developments caused wheat-breeding programmes to discontinue many promising germplasm lines despite their highly promising yield potential, as they were susceptible to new diseases and pests (Pannar, 2009). Consequently, the focus in wheat breeding shifted to producing varieties resistant in terms of specific agronomic characteristics (e.g. pest and disease resistance) and of good quality, as opposed to high-yielding varieties (Pannar, 2009).

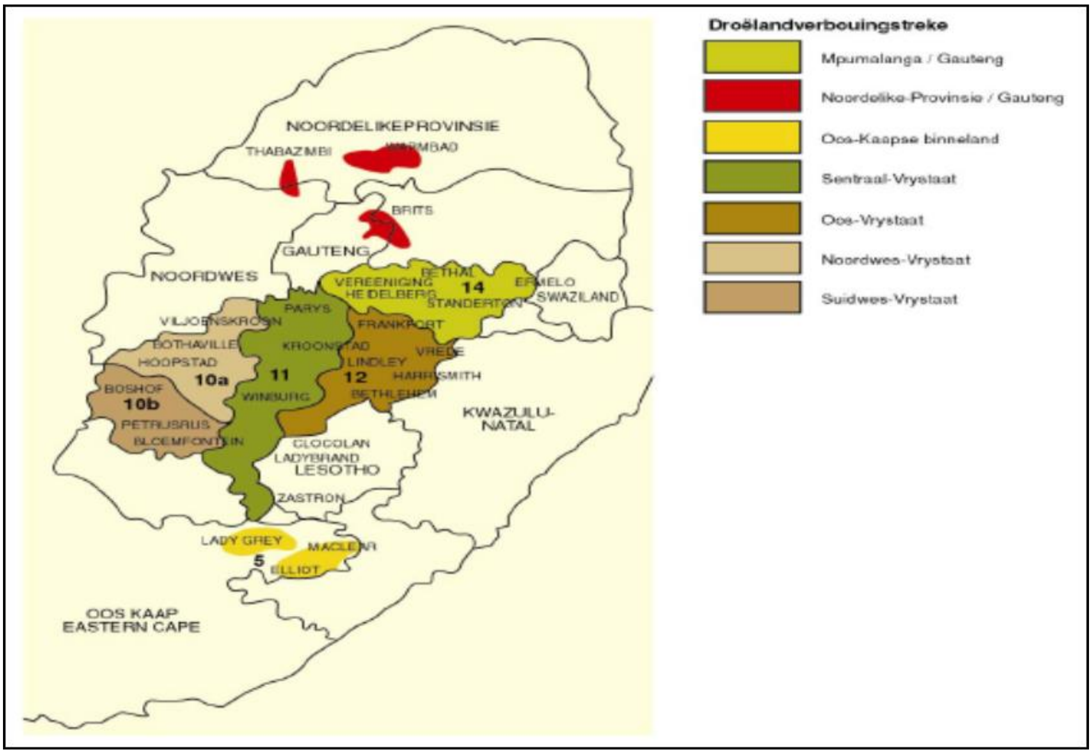


Figure 2.1: Distribution of various dryland wheat production areas

Source: Pannar (2009)

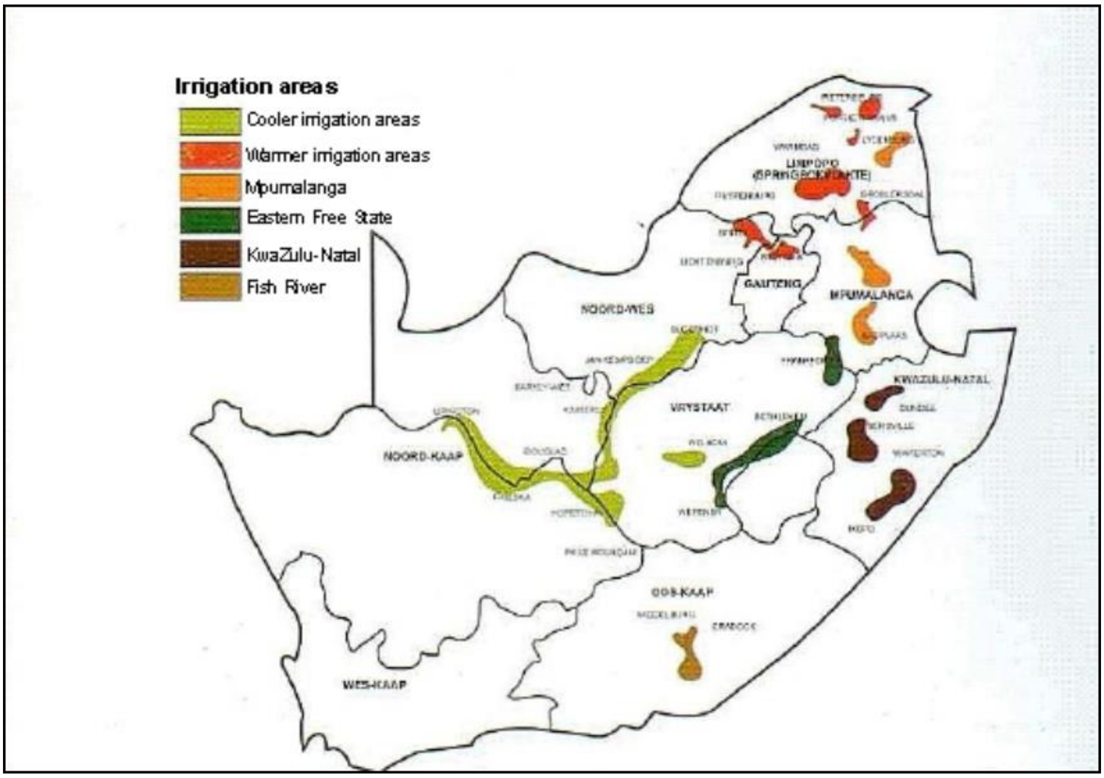


Figure 2.2: Introduction of wheat production regions under irrigation

Source: Pannar (2009)

Figure 2.3 presents wheat area, production and productivity trends in South Africa from 1917 to 2015. The overall trends show that wheat area and production increased until the early 1990s. The late 1990s show a downward trend in both wheat area and production. Before the establishment of the Wheat Board, from 1917 to 1934, production was below area of production and yield. This was as a result of limited research and innovation in the wheat sector. From 1935, area of production, production and yield increased more than the area planted because the Wheat Board was collecting a small fee to be used as research money from farmers. Because of this, the Wheat Board was funding some research work on wheat to control diseases and pests resulting in an increase in production. Since the deregulation of the Wheat Board there, has been a gradual decrease in both area of production and production.

Productivity trends have generally increased over time in South Africa. Smit et al., (2010) argue that efficiency, productivity and quality in wheat production have increased over time and they identify some of the contributing factors which include research efforts from various disciplines such as plant breeding, agronomy, crop physiology and crop protection. For example, the productivity levels for wheat have increased from less than 0.5 tonnes per hectare in 1936 to more than 3.5 tonnes per hectare in 2015 (Figure 2.3). A study by Lill and Purchase (1995) reports a yield improvement of 87% while baking quality improved by 20% between 1930 and 1990.

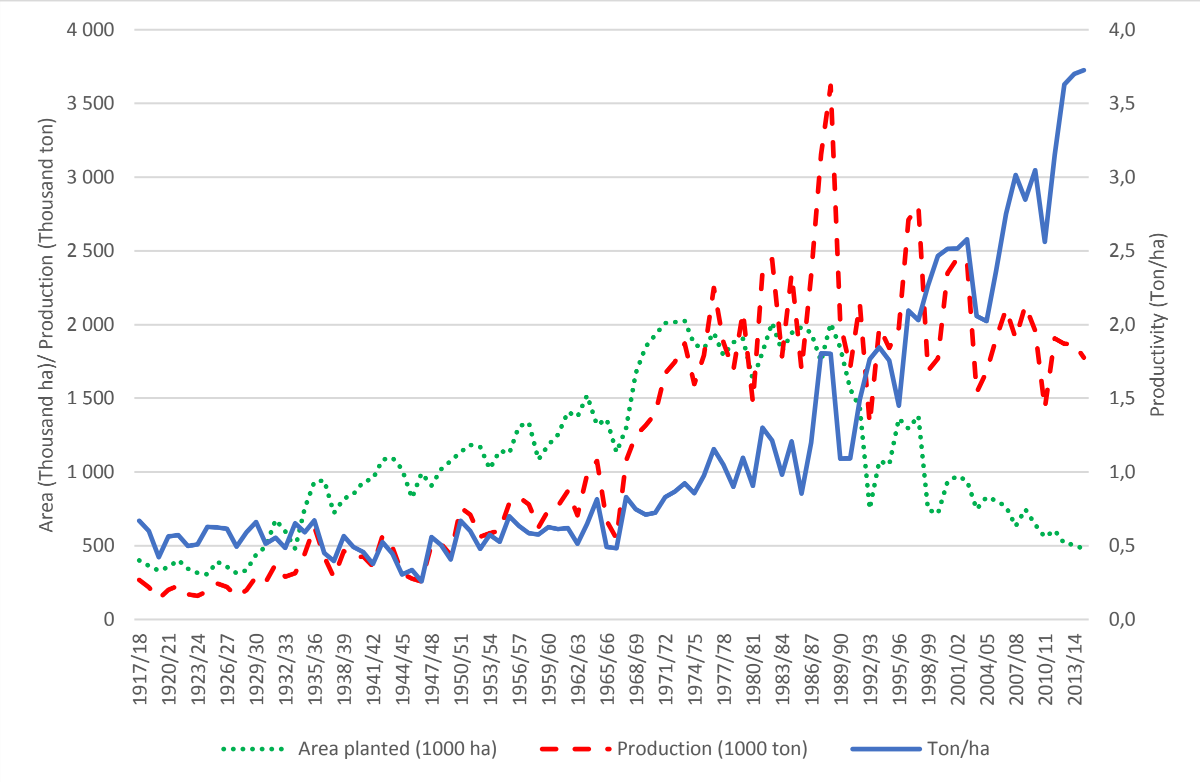


Figure 2.3 Commercial wheat area, production and productivity in South Africa, 1917 – 2015

Source: Authors' own calculations based on data from http://www.sagis.org.za/. Accessed 6 March 2015

Figure 2.4 shows trends in wheat imports, exports and net exports in South Africa over the period 1961 to 2012. Overall, South Africa had been a net importer of wheat but trends show that the country exported more wheat than it imported for the period between 1972 and 1980 and in 1990. However, from the year 2000 to 2015, South African wheat imports increased while the net exports declined. The Figure shows that South Africa relies mostly on wheat imports to support the local wheat dependent industries. More effort is required to support local production, including ensuring that there are wheat varietal improvements and innovations that are highly productive and adapted to local environments.

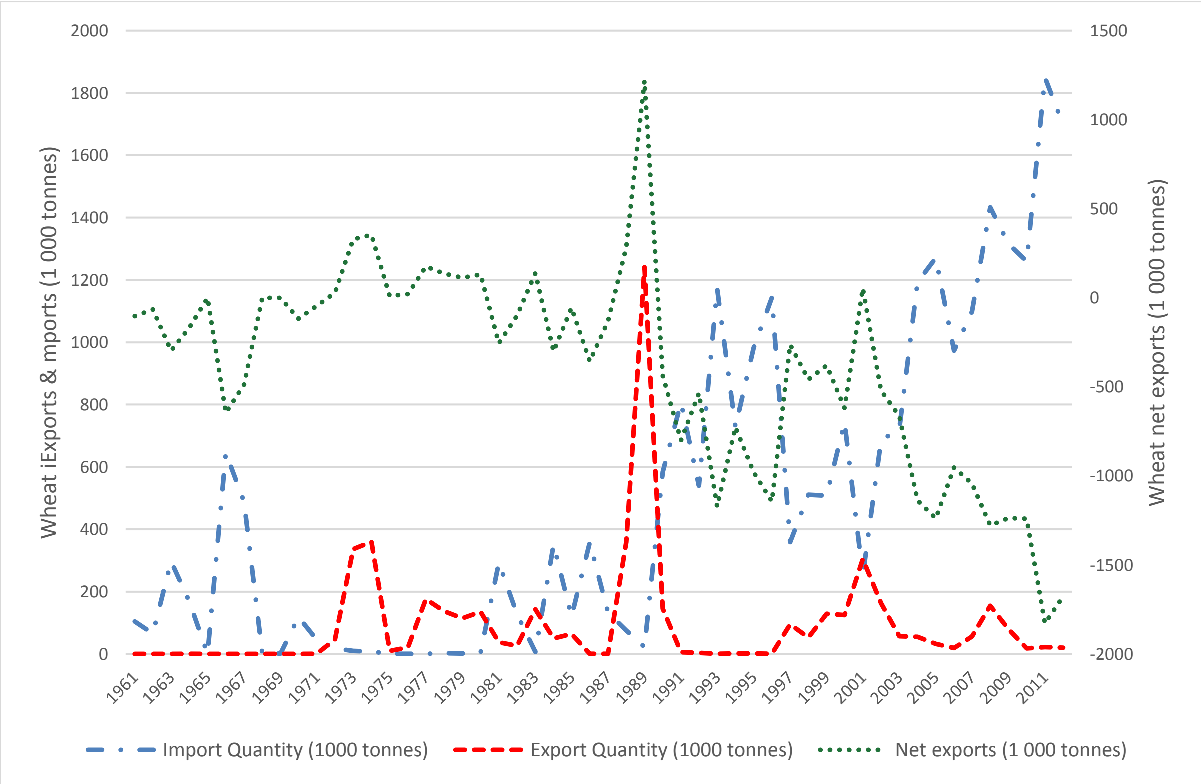


Figure 2.4: South Africa wheat imports, exports and net exports, 1961 – 2012

Source: Authors' own calculations based on data from FAO Statistics, 2015. Accessed 25 August 2015

2.3 Empirical studies analysing the evolution of crop production and breeding in agriculture

Various studies have reviewed the historical changes and evolution of crop production and breeding. Examples of these include Byerlee and Moya (1993), Heisey et al., (2002), Grace and Van Staden (2003), This et al., (2006) and Chigeza et al., (2012). This section reviews these studies in order to understand the approaches used and some of the major findings and their implications for this study.

In a study focusing on analysing the impact of international wheat-breeding research in the developing world between 1966 and 1990, Byerlee and Moya (1993) analysed the origins and trends of new varieties released by National Agricultural Research Systems (NARS) from 38 collaborating countries. The analysis of wheat varieties released by NARS included the listing of over 1300 varieties, information of their pedigrees, ecological niches and area planted to specific varieties. The information was used to estimate the benefits of wheat breeding on genetic yield and changes in traits such as disease resistance and quality. Byerlee and Moya (1993) found an increasing proportion (84% by 1986 – 90) of spring bread wheat varieties originating directly from CIMMYT or having a CIMMYT parent, especially among small NARS. The study also found that larger NARS used their own crosses to develop more than half of the varieties released. The analysis of wheat releases by NARS regarding type of variety (winter bread wheat and durum wheat) and growth habit was also done once every five years between the period 1966 and 1990. The current study follows a similar approach to develop a comprehensive database of wheat varietal improvements in South Africa.

Smit et al., (2010) summarised wheat cultivars released in South Africa between 1983 and 2008. The current study extends the analytical period to date back from 1891 to 2013. In addition, the current study builds on these earlier efforts to develop a comprehensive database that forms the basis for estimating the benefits attributed to wheat varietal improvements in South Africa. Another addition from the study is that Smit et al., (2010) did not provide the institutional evolution of wheat breeding as presented in the study Furthermore, the focus of Smit et al., (2010) was agronomic, while the current chapter focuses more on the economics side of wheat-breeding developments over the study period. Also, despite listing varieties released from 1983 to 2008, Smit et al., (2010) do not provide a detailed historical evolution of wheat varietal improvements in the country dating back from 1891 to 2013, as addressed in this chapter.

2.4 Data and research methods

The empirical analysis is based on the critical review of information from policies, varieties bred and their breeders, years when varieties were bred, and pedigree information, as gathered from the journal “*Farming in South Africa*”, sourced from the National Library of South Africa, the CIMMYT database, and many other sources of literature. The focus was to identify the sources such as the history of wheat varietal improvement innovations – institutions and individuals, where the innovations were used (areas where the wheat varieties were grown and factors driving the innovations and the types of wheat varietal innovations. The study analysed the wheat varieties released in and/or introduced to the South African agriculture during the period 1891 to 2013. A database of sources and uses of wheat varietal innovations in South Africa was developed using information from the above sources. The database shows that the breeding history of wheat in South Africa has remained a subject of breeding endeavours for more than two centuries, and wheat varietal improvement has rapidly expanded, particularly in the past four decades.

Learning from some of the reviewed studies above, for example Byerlee and Moya (1993), Heisey et al., (2002), Grace and Van Staden (2003), This et al., (2006) and Chigeza et al., (2012), the data was analysed using trend and graphical analysis. The results and discussion of the historical assessment of the sources and uses of wheat varietal innovations in South Africa's agriculture are structured as follows: The first part discusses the key developments (institutional and policy) and the evolution of wheat breeding from early wheat production periods in the country to the 1970s. The analysis is also done by geographic region/ area, as well as wheat type and growth habit. In addition, the analysis discusses varietal improvements by wheat-breeding structural/policy shifts, particularly prior to the establishment of the ARC-SGI. , after the establishment of the ARC-SGI, before deregulation of the wheat sector in 1996, and during the post-deregulation period of 1997 – 2013. Furthermore, the historical evolution of the ARC-SGI wheat-breeding programme is discussed in detail.

Liebenberg and Pardey (2011) discuss the historical evolution in order to document and describe the most important developments in the agricultural sector over the 20th and early 21st centuries and the changing policy and institutional environment of public support for agricultural R&D in South Africa. The article by Liebenberg and Pardey (2011) analysed the historical and policy context and changes in public agricultural R&D investments between 1880 and 2007. This chapter uses the same approach by Liebenberg and Pardey to discuss historical changes in the wheat sector and how they have shaped varietal improvements over the years. Although the database is incomplete and undoubtedly not completely accurate, it was thoroughly reviewed during the preparation of this chapter and is by far the most recent comprehensive database available on the history of wheat varietal improvement in South Africa. As indicated above, this database forms the basis for further analysis focusing on the attribution of wheat varietal improvement benefits and costs in South Africa.

2.5 Results and discussion

2.5.1 Key developments and early history of wheat varietal improvements in South Africa

Wheat production was first initiated in South Africa by Jan van Riebeeck during the winter of 1652 at the Cape of Good Hope (Du Plessis, 1933). Production subsequently expanded and by 1684, there were some exports to India (Van Niekerk, 2001). The original cultivars produced at that time had originated from Europe and the East Indies, brought by the early settlers and trading vessels. The selection criteria for the new varieties then focused on their adaptability to the new environment, such as their resistance to stem rust, periodic droughts and wind damage. Table 2.1 summarises the key developments (institutional and policy) throughout the history of wheat varietal improvements in South Africa from the 1600s.

Table 2.1: Key developments in the history of wheat varietal improvements in South Africa

Historical event	Year	Description
Planting of first wheat crop by Jan van Riebeeck	1652	First wheat crop was planted in South Africa in the winter of 1652.
First report of wheat breeding	1891	Overman (Principal of Agricultural School, Somerset East) reported first wheat-breeding programme at an agricultural institution.
Breeding at original Stellenbosch Agricultural School	1892	Blersch (Principal of original Stellenbosch Agricultural School) reported on wheat variety tests at Stellenbosch.
Opening of Elsenburg School of Agriculture	1898	Considerable amount of research was conducted on wheat grain growing; unfortunately, all records of experimental work up until 1915 are missing.

Historical event	Year	Description
Establishment of Department of Agriculture	1911	Despite undergoing various structural changes over the years, overall it supported and provided an institutional framework for plant-breeding research (including wheat breeding, etc.).
Governing of agricultural education	1913	Three agricultural colleges were established (Cedara, Potchefstroom and Grootfontein).
Wheat breeding at Elsenburg Research Station	1913	First wheat-breeding programme was established at Elsenburg Research station.
Establishment of Glen Agricultural College	1919	Glen Agricultural College was established.
Establishment of Langgewens Cereal Station	1928	From 1929, experiments on wheat varietal improvements were done at the Jongensklip Experimental Plot in Caledon, and from then on intensive research has been conducted on wheat varieties.
Establishment of Stellenbosch Glasshouse and Laboratory	1930	The glasshouse was used for intensive rust studies, with funding from the Wheat Industry Control Board. This was extended in 1950.
Establishment of Wheat Industry Control Board	1935	The Wheat Industry Control Board was established to regulate the wheat industry (including oats, rye and barley) following poor-quality wheat production in 1935.
Division of Department of Agriculture into Department of Agricultural Economics and Marketing, and Department of Agricultural Technical Services	1958	Research function was given to the Department of Agricultural Technical Services, which continued to finance research at universities.
Establishment of PANNAR Seeds Pty Ltd	1958	Although established in 1958, PANNAR started being involved in wheat varietal improvements in the 1990s and remains one of the three main actors in wheat breeding in South Africa.

Historical event	Year	Description
Establishment of Sensako	Mid 1960s	Sensako was purchased by Monsanto in 1999 and then became a private South African company in 2008. It remains the main actor in wheat breeding in South Africa.
Establishment of Small Grains Centre (SGC)	1975	The SGC was established as a Research Centre of the Highveld Region of the Department of Agriculture. The main objective of the SGI (then SGC) was to help improve production of small grains, including addressing production challenges, investigating new production possibilities and transfer of information to strategic points.
Establishment of Agricultural Research Council	1992	The establishment of the ARC in 1992 centralised all national agricultural research functions, including the mandate to serve historically segregated homeland areas.
Deregulation of wheat sector	1996	Marketing of Agricultural Products Act, Act 47 of 1996, which led to the deregulation of the wheat sector, has had a significant impact on both wheat research and the industry.

Source: Author from various sources

The first programme of wheat breeding was reported to have started in 1891 in the Western Cape Province (Neethling, 1932). The initial series of artificial crosses between varieties were conducted in 1902 and 1904 to retain the successful resistance of Rieti wheat while replacing its poor milling quality and tendency to shed grain prior to harvesting (Van Niekerk, 2001). This marked the beginning of modern wheat breeding in South Africa. The early crosses were reported to have procured only three varieties of value, which formed the basis for the first cultivars namely, Union, Darlvan and Nobbs, bred in South Africa. These developments preceded Neethling's first wheat-breeding efforts in 1913 at the Elsenburg Research Station near Stellenbosch. The wheat-breeding research efforts at the Elsenburg Research Station led to the release of at least 26 wheat varieties, which remained dominant between 1914 and 1961. Examples of the varieties released during that time include

Unie17, Unie28, Unie31, Unie52 and Unie81 (all released in 1914), with Unie52 dominating between 1917 and 1927 (Van Niekerk, 2001).

The next release of an early wheat variety, namely Kleintrou, which was a selection from Potchefstroom Agricultural College, occurred in 1916. Between 1933 and 1958, Kleintrou was directly used as a parent in at least six wheat varieties including Farrertrou, Koalisie, Stirling, Sonop and Eleksie. The wheat varieties known as Bobriet and Gluretty (retaining Rieti wheat as one of the parents), which were released in 1925, were cultivars created from crosses after this period of testing and reselection. The Gluretty variety dominated, replacing Unie52 before succumbing to rust infection and being replaced by six new varieties released in 1933. Of these, Pelgrim, Stirling and Koalisie were successful. The post-1933 breeding period included the first use of interspecific crosses, including Medeah, a *Triticum durum* wheat with excellent rust resistance which has been used in South Africa since ± 1850, and McFadden which originated from the USA, using Marquis and Jaroslav Emmer to produce the famous Hope and H44 wheat varieties. Long-used and adapted varieties such as Nobbs, Van Niekerk, Florence and Kleintrou, were also consistently used in the new releases. Of all the varieties released, Stirling had the greatest impact on wheat production in the Western Cape, due to its resistance to stem rust (inherited from Rieti and Medeah), as well as its adaptation abilities and quality (inherited from Comeback). Stirling remained dominant until the release of Hoopvol in 1948 (Van Niekerk, 2001).

The Wheat Industry Control Board was established in 1935 to regulate the wheat industry in the wake of extremely poor-quality yields, despite record production levels in 1935. Among the varieties available at the time, none were of bread-wheat quality. Following the establishment of the Wheat Industry Control Board, seven new varieties were released in the 1940s, with only two making an impact, namely Sonop (Kleintrou/Pelgrim) and Hoopvol (Kleintrou/Gluys Early/Spring Early), which became the most popular. Sonop was the first true bread wheat from the Elsenburg College of Agriculture (Van Niekerk, 2001). Between 1950 and 1959, four wheat varieties were released, with only two, namely, Daeraad (Unie52A/Kruger) and Dromedaris (Hope/Gluretty) making an impact on the wheat industry. Neethling's retirement and the resultant break in continuity, coupled with increased interest from his successors in terms of using wide crosses, is arguably the reason for the limited activity in terms of varietal releases during this period.

After taking over from Neethling as head of the Department of Genetics at the University of Stellenbosch in 1950, F.X. Laubscher introduced a completely new era in wheat breeding in the country. In 1952, he ushered in an era of extensive international co-operation with the introduction of the International Rust Nursery, in collaboration with Dr Bayless of the United States Department of Agriculture. The new releases during the 1960s were based on completely new parents, combining good yield, excellent quality and disease resistance, thus surpassing the existing varieties at the time. One of the first varieties released during this period was Flameks (Mentana-Kenya-Supremo/Florence Aurore) (Van Niekerk, 2001) and in addition, five new varieties were released between 1960 and 1970 but they did not have the same impact on the wheat industry. New avenues in local wheat breeding were opened following the singular success of short-strawed varieties from Borlaug and CIMMYT. In the Northern Province of South Africa, St Clair Caporn initiated wheat breeding at Potchefstroom in 1918 while Pieper started winter wheat breeding in Bethlehem in the Free State in 1954 and Schneider started irrigation-type spring wheat breeding at Losperfontein (Van Niekerk, 2001).

The discussion above indicates that wheat varietal improvements in the early years of wheat breeding were specific to the production area, with little or no movement from one area to another. This situation has changed over time and wheat-breeding companies – although focusing on wheat varieties specific to the different wheat-growing regions of the country – aim at producing breeds that are adaptable across the country. According to the World Bank (2008), there was little movement of genetic improvement technologies in the 1950s and 1960s, especially from the temperate North to the tropical South. Their report further argues that the focus on adapting improved varieties to subtropical and tropical regions since the 1960s has generated high payoffs and pro-poor impact, which are expected to continue to grow with rapid advances in biological and informational sciences. Byerlee and Moya (1993) also found that the initial focus on CIMMYT wheat-breeding activities was on specific environments, particularly irrigated areas in Mexico and South Asia and this was later expanded to incorporate resistance in rain-fed areas to diseases such as septoria (Septoria spp) and stripe rust (Puccinia striiformis f. sp. tritici) into CIMMYT germplasm. The further incidence of pests and diseases challenged CIMMYT to widen the focus on resistance to pests and diseases in different environments. Similarly, in

South Africa, structural changes in the agricultural sector and the liberalisation of the wheat sector have also opened up the rapid growth of wheat-breeding improvements that transcend beyond original regional production areas.

2.5.2 Establishment of ARC Small Grains Institute and wheat varietal improvements

The Agricultural Research Council Small Grains Institute (ARC-SGI) was established in 1975 as the Small Grains Centre (SGC). The SGI aimed at harnessing the impact of the then fragmented research efforts especially small grain breeding programmes in the Cape Province, and the then Transvaal and Orange Free State provinces, into an organisation running along the lines of CIMMYT. This initiative followed the recommendation by Dr Borlaug to the Department of Agriculture (De Villiers and Le Roux, 2003, Liebenberg and Pardey, 2011, Van Niekerk, 2001). The SGC was established as a research centre of the Highveld Region of the Department of Agriculture. The main objective of the SGI (then SGC) was to help improve the production of small grains, including addressing production challenges, investigating new production possibilities and transferring information to strategic points. The SGI became an autonomous institute on 1 April 1995.

The Wheat Board, through motivations by Dr Jos de Kock, provided funding for a new Research Building for the centre in 1989. De Villiers and Le Roux (2003) report that 90% of the infrastructure at the ARC-SGI was funded by the Wheat Board and indirectly by wheat farmers. In an effort to harness fragmented research efforts, the SGI, since its establishment in 1975, has managed to initiate the following: national seed multiplication scheme, national cultivar evaluation scheme, and breeding of cultivars that are nationally co-ordinated from Bethlehem. SGI supplied at least 65% of all nationally bred cultivars up to the 1996s (e Villiers and Le Roux, (2003). The wheat variety improvements released by the ARC-SGI were started in 1975; its contribution to wheat breeding remains very important to South Africa. The World Bank (2008) argues that in areas where markets fail and it is difficult to appropriate benefits, public investments such as wheat varietal improvements are required in agricultural R&D. The following section discusses wheat varietal releases by the ARC-SGI.

2.5.3 Wheat varietal releases, sources and uses

The results and discussion of the sources and uses of wheat varietal innovations are presented by geographic region/area and wheat growth habit. In addition, the analysis discusses varietal improvements by wheat breeding structural/policy shifts during three specific periods, namely, before the establishment of the ARC-SGI, after the establishment of ARC-SGI to deregulate the wheat sector in 1996 and post-deregulation (1997 – 2013).

Figure 2.5 shows the main wheat varietal improvement breeders for the period 1891 to 2013. Sensako has the highest number of varieties, with 102 varieties since mid-1960s. The ARC is the second highest with 51 varieties, and the third highest is Pannar with 41 varieties. This is followed by Monsanto with 20 varieties. Professor J.H. Neethling has released 16 varieties, making it one of the highest individually released wheat varieties used to develop many South African varieties. Most of the wheat innovation in South Africa should be credited to him and his team. The analysis of the wheat varietal improvement breeders in Figure 2.6 below is structured according to organisation type (local private companies such as Sensako, Pannar, local public organisations such as the ARC-SGI and universities; local individuals; foreign private companies and foreign public organisations). The results show that the local private sector, with a total of 171 wheat varieties, has the highest share of varieties released in South Africa for the period under study. Local public organisations, which include the ARC-SGI and universities, trail with 72 wheat varieties – less than half that of the local private sector. Results from Figures 2.5 and 2.6 clearly show that the private sector dominates wheat varietal improvements in the country. The current funding challenges in the public sector mean that the private sector will continue to dominate wheat varietal improvements. However, more effort would be required to support research that caters for all types of farmers, especially the emerging farmers who would want to grow wheat. This means that the public sector has a critical role to play in this area, in addition to releasing varietal innovations to large commercial farmers.

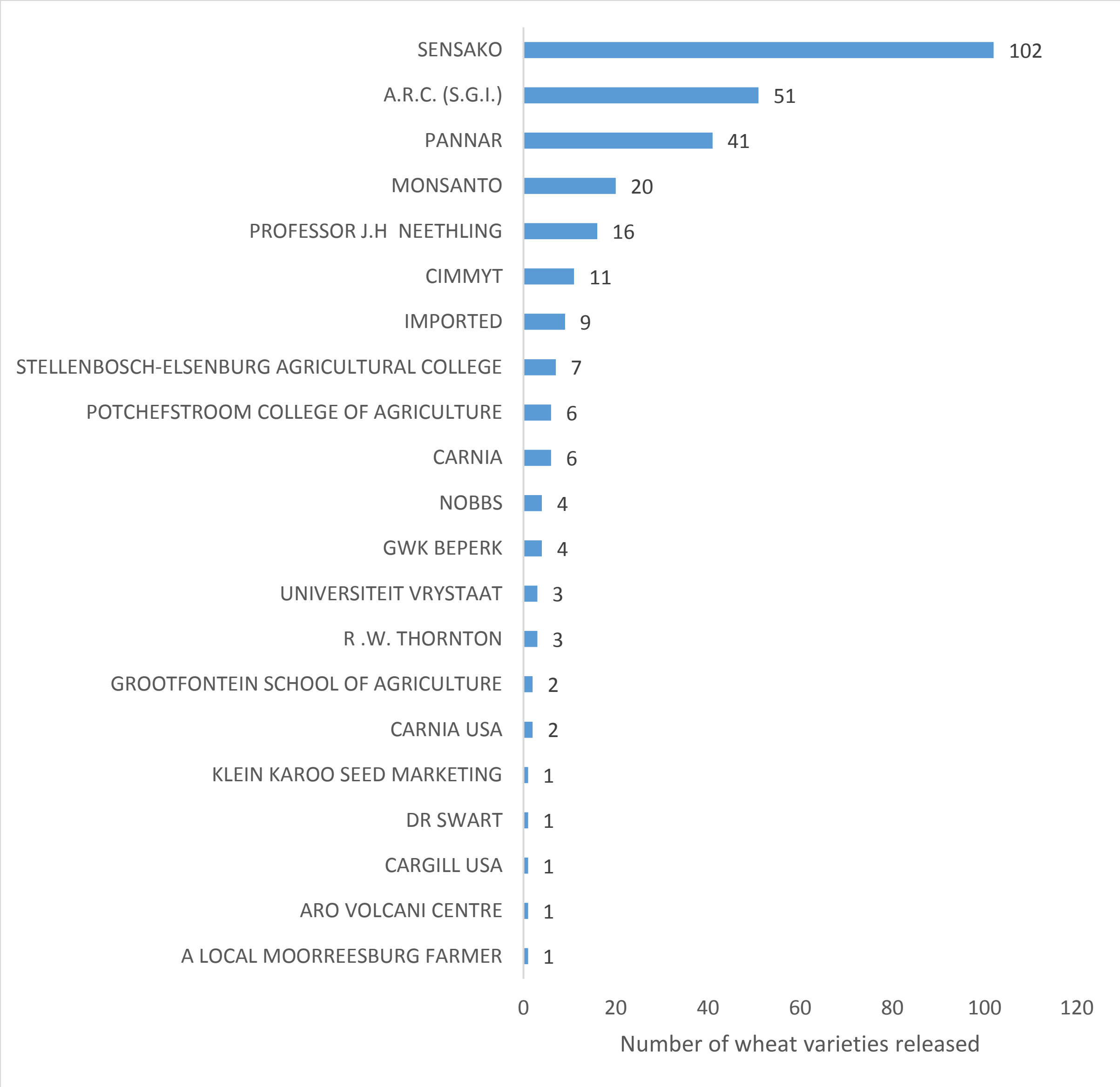


Figure 2.5: Wheat varietal breeders in South Africa, 1891 – 2013

Source: Author's own calculations from various sources of literature

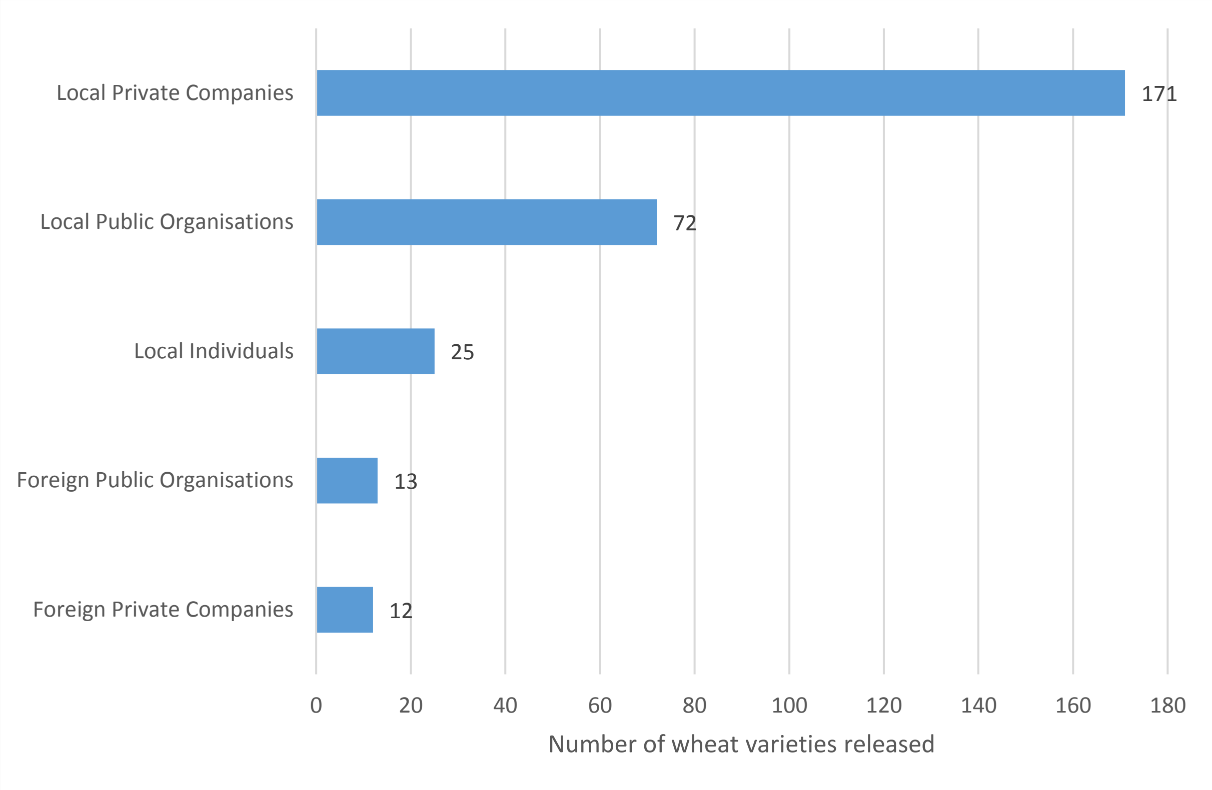


Figure 2.6: Classification of wheat varietal breeders in South Africa, 1891 – 2013

Source: Author's own calculations from various sources of literature

Figure 2.7 below presents rates of varietal releases from 1880 to 2013 in South Africa. The Figure shows that wheat varietal innovations have evolved over time, from early breeding in the early 1880s to 2013. The distinct period of interest in wheat varietal improvement history in South Africa includes pre-establishment of the Wheat Control Board in 1936; 1936 – 1976, when the Small Grains Centre was established, 1976 – 1996 when the Wheat Market was deregulated, and 1997 – present. Prior to 1936, wheat varietal improvements and the release of varieties were driven by individual researchers and colleges of agriculture. When the Wheat Control Board was established in 1935, it started to promote research in wheat varietal innovations in the country. During these early years, funding from the Wheat Control Board was the main source of wheat varietal innovation research. The consolidation of research efforts from the then colleges of agriculture provided an important way of harnessing the synergies from the comparatively limited research capacity scattered across these colleges (Liebenberg and Pardey, 2011).

The low rate of wheat varietal release in the late 1970s and early 1980s could have been driven by reduced government funding for all non-security departments to support increased demands for military support (Liebenberg and Pardey, 2011). The introduction of the Marketing of Agricultural Products Act in 1996 led to the dissolving of the Wheat Board, affecting the funding originally provided by the Board to wheat varietal improvements in the country. The establishment of the ARC in 1992 centralised all national agricultural research functions, including the mandate to serve historically segregated homeland areas.

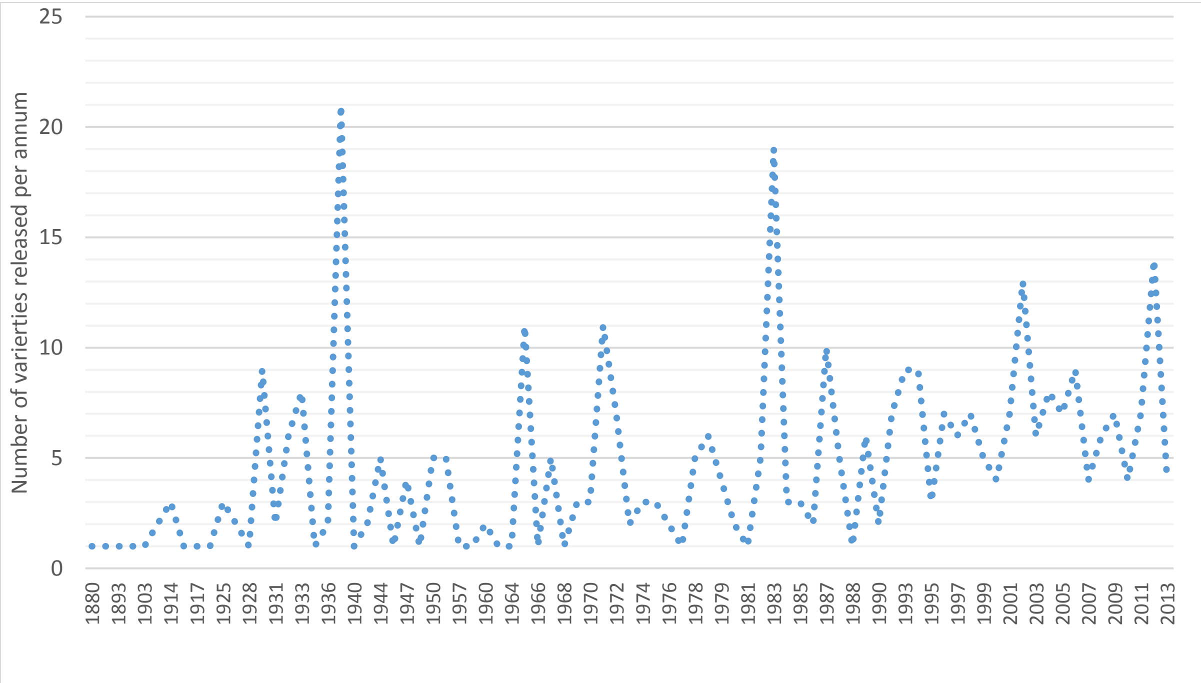


Figure 2.7: Annual Rates of varietal releases from 1891 to 2013 in South Africa

Source: Author's own calculations from various sources of literature

The varieties were also analysed by the geographical area for which they were released. Table 2.2 presents proportions of varieties released in South Africa for each geographic region. Initial wheat varietal breeding in South Africa focused on specific environments and this has expanded over time, especially since deregulation in 1996. Since the deregulation of the South African wheat sector, the ARC-SGI budget for wheat has steadily declined, reflecting reduced funding for wheat varietal improvement by the government.

Table 2.2: Shares of varieties released in South Africa for each geographical region

Region	Total number of varieties released (percentage)		
	1891 – 1975	**1976 – 1996**	**1997 – 2013**
Western Cape	50 (30.30)	9 (5.45)	10 (6.06)
Free State	26 (15.75)	9 (5.45)	6 (3.64)
Limpopo	11 (6.67)	7 (4.24)	1 (0.61)
Eastern Cape	6 (3.64)	-	-
Kwazulu-Natal	1 (0.61)	3 (1.81)	-
Mpumalanga	8 (4.85)	1 (0.61)	3 (1.82)
North West	8 (4.85)	-	-
Northern Cape	2 (1.21)	4 (2.42)	-
Total	**112 (67.88)**	**33 (20.00)**	**20 (12.12)**

Source: Author's own calculations from various sources of literature

Table 2.3 below presents the distribution of wheat varieties released by growth habit. In the period 1891 to 1975, most of the wheat varietal releases focused on spring (13.80%); irrigation (9.85%) and winter (8.87%) growth habits. Spring (17.24%) and facultative growth habits dominated wheat varietal improvements in the period 1976 and 1996. Since the deregulation of the wheat market in 1996, spring, winter and facultative growth habits dominated wheat varietal improvement research in South Africa. Liebenberg and Pardey, (2011), argue that initial agricultural R&D was decentralised and focused on specific environments and patterns of agricultural production. Specifically, the five agricultural colleges then focused their efforts on the main farming enterprises within their relevant agro-ecological regions. For example, Elsenburg focused on winter grains. However, this was greatly transformed over time, and public agricultural R&D is now more nationally centralised that before and has been experiencing a declining trend in recent years, at least since the deregulation of the wheat sector.

Table 2.3: Wheat varieties released in South Africa by growth habit

Growth habit	Total number of varieties released (percentage)		
	1891 – 1975	1976 – 1996	1997 – 2013
Spring	28 (13.80)	35 (17.24)	26 (12.81)
Winter	18 (8.87)	7 (3.45)	11 (5.42)
Facultative	7 (3.45)	30 (14.78)	14 (6.90)
Irrigation	20 (9.85)	3 (1.48)	4 (1.98)
Total	**73 (35.96)**	**75 (36.95)**	**55 (27.10)**

Source: Author's own calculations from various sources of literature

The analysis of wheat varietal releases was further divided into three distinct periods: the first one focussed on improved wheat varieties prior to the establishment of the ARC-SGI; the second traced the development from the establishment of the ARC-SGI to the deregulation period of the wheat sector and the third period gave attention to the post-deregulation period (1997 to 2013). Appendix 1 presents a summary of the wheat varieties released in the country, including information on their release years, breeders, pedigrees, area suitable for planting the variety, and growth habits. The most popular ARC-SGI varieties identified for further analysis of the attribution of costs and benefits of wheat varietal improvements were Tugela DN, Limpopo, Gariep, Caledon, Betta, and Betta DN. These varieties performed well in the commercial market due to their good baking qualities and resistance to rust.

Smit et al., (2010) argue that the establishment of the Wheat Board through the Agricultural Marketing Act, (Act 59 of 1968) and the subsequent deregulation of the wheat sector in 1996 after the enactment of the Marketing of Agricultural Products Act, (Act 47 of 1996) have had a significant impact on both wheat research and the industry. For example, during the time of the Agricultural Marketing Act, the Wheat Board, in addition to regulating the wheat industry, also collected levies that were used to contribute to the funding of wheat research and varietal improvements. The deregulation of the wheat sector led to a shift in focus in that most research activities aimed at lowering input costs and risks while increasing the profitability of wheat production to farmers.

2.6 Summary and recommendations

Wheat varietal innovations are important in agriculture, as they help to improve crop productivity, adaptability and resistance to diseases and pests, and also help to protect the environment. Wheat was first produced in South Africa in the 1600s, and the first wheat varietal improvements were reported two centuries later in 1891. The main objective of this chapter was to examine the historical evolution of wheat varietal improvements in the country as well as the identification of popular varieties, and their history, sources and uses from 1891 to 2013. Firstly, this assessment extends the period of analysis from early breeding periods in the early 1900s up until 2013. Furthermore, the current analysis identifies popular wheat varieties, particularly among current varieties in the market. These varieties form the basis for analysing the attribution of improved wheat varieties in South Africa, which is the focus of the next empirical chapter emanating from this study.

Previous studies on this subject did not fulfil this purpose. Moreover, an effort was made through this chapter to understand how policy changes in the wheat sector have affected wheat varietal improvements in the country over time. The empirical analysis is based on the critical review of information from policies, varieties bred and their breeders, years when varieties were bred, as well as pedigree information, as gathered from the journal "Farming in South Africa", sourced from the National Library of South Africa, the CIMMYT database, and several other sources of literature. A database of the sources and uses of wheat varietal innovations in South Africa was developed using information from the above resources. The data was analysed using trend and graphical analysis.

The analysis of wheat releases for the period 1891 to 2013 indicates that about 501 varieties were released from wheat varietal innovations in South Africa. From the 1800s, wheat varietal improvements in the country focused on addressing the following variety characteristics: adaptability to production area, yield potential and stability and agronomic characteristics, for instance tolerance to diseases, pests and aluminium toxicity. The main sources of wheat varietal improvements in South Africa are Sensako, ARC-SGI and Pannar. In terms of growth habits, most wheat varietal improvements have focused on spring, winter and facultative wheat varieties grown mostly under dryland conditions. Analysis by geographic area indicates that most of the wheat varieties released between 1891 and 2013 were from the Western Cape and Free State provinces, which are the major wheat-producing areas in the country. Wheat varietal improvements in the early years of wheat breeding were decentralised and specific to the production area, with little or no movement from area to area. The structural changes that have occurred in the agricultural sector, particularly the establishment of the ARC-SGI and the deregulation of the wheat sector, have contributed to the effort to harness the impact of the existing fragmented research efforts, especially small-grain breeding programmes in the Cape Province and the former Transvaal and Orange Free State provinces.

An analysis of the sources of wheat varietal improvements during the different periods indicates that initially, wheat breeding was driven by individual breeders and agricultural colleges. Since its establishment, Sensako has been the main source of wheat varietal improvements, followed by the ARC-SGI and Pannar. Some of the most popular varieties identified for further analysis in terms of the attribution of costs and benefits of wheat varietal improvements include Elrina, Gariep, Caledon, Elands, and Duzi. The findings from this chapter form the basis for chapter 5 which focuses on the estimation of benefits from wheat varietal investments in South Africa.

CHAPTER 3

THE EVOLVING LANDSCAPE OF PLANT BREEDERS' RIGHTS FOR WHEAT VARIETAL IMPROVEMENTS IN SOUTH AFRICA

3.1 Introduction

Integrated agricultural innovations in areas such as seeds, biotechnology, crop protection mechanical innovations such as tractors, chemical innovations in the form of fertilisers and pesticides, agronomic innovations as evident in new management practices and biotechnological innovations are critical to help address global challenges facing agriculture. The most noticeable of these challenges are climate change and decreasing availability of water and farmland, increasing food demand due to increasing population and high demand for food crops for other uses such as biofuels (Kock and Gould, 2013, Thiele-Wittig and Claus, 2003). For example, varietal innovations that are high yielding and drought resistant are required if farmers are aiming to produce more with less inputs. However, investments in varietal improvements are expensive in terms of skills, labour, material, resources and take time (10-15 years in the case of many plant species). In addition, the resulting seed products face the risk of being reproduced and "copied' by competitors, necessitating the need for some forms of enforceable commercial protection for plant breeders (Kock and Gould, 2013, Louwaars et al., 2009, Thiele-Wittig and Claus, 2003). For decades developing countries relied on national and international public investments for plant varietal improvements (Evenson and Gollin, 2003, Louwaars et al., 2009).

The above observation was mainly driven by collaborations between national agricultural research institutes and the International Agricultural Research Centres of the Consultative Group on International Agricultural Research such as CIMMYT, Mexico and IRRI, Manila (Evenson and Gollin, 2003). However, the increasing funding challenges facing public research institutions meant that the private sector could start to play a larger role in plant variety improvement, especially in the developing world, which has been dominated by the public sector. Contrary, the private sector requires economic incentives provided by Intellectual Property Rights (IPRs) to invest in plant variety innovations (Srinivasan, 2003). At the same time, the publicly funded research outputs should be protected, utilised and commercialised for the benefit of the funding country. All of this points to the importance of plant variety protection being critical in stimulating plant breeding innovations and their dissemination (Lesser, 1990).

Pardey et al., (2012) and Pardey et al., (2013) argue that plant varietal rights are subject to controversy and ongoing public policy scrutiny and debate. In order to inform these policy debates, there is a need to understand the evolution of varietal rights and the extent of the varietal rights granted. In addition, it is also important to understand changes of the rights on offer overtime such as the changing ownership of the rights (including comparison between public and private as well as domestic and foreign breeders) and the impact of plant variety protection on varietal development.

This chapter analyses the evolving landscape of plant breeders' rights for wheat varietal improvements in South Africa. Earlier efforts by Stander (2012) to undertake a similar exercise were limited by the few years of relevant observations but this current study extended the period of analysis to start from 1890s to 2015. In addition, we do not know the implications of plant variety protection on public and private investments on wheat varietal improvements in South Africa or whether granting of plant breeders rights enhanced, slowed or changed the nature of genetic improvement. The chapter therefore specifically focuses on the following research questions: Which trends can be observed in the wheat varietal improvements subsector in South Africa? How have plant breeders' rights for wheat varietal improvements evolved? Who are the main plant breeders' rights holders in the wheat sector? What are the effects of these developments for diversity and competition in South African wheat breeding industry? Which measures can be taken by the South African government to restrict or reverse possible negative impacts of these trends in light of relevant policy objectives?

3.2 International experiences in plant variety protection

The protection of IP rights of plant breeders was recognised in the 19th century. The International Union for the Protection of New Varieties of Plants (UPOV) established in 1961 seeks to harmonise plant variety protection (PVP) laws and standards of protection across member countries (UPOV, 1961). Plant variety protection was almost exclusively the protection granted for plant-related innovations until 25 years ago (Kock and Gould, 2013). Plant variety protection also referred to as plant breeder's rights is defined as an independent *sui generis* form of protection of new plant varieties for essential features (usually phenotypical) (Thiele-Wittig and Claus, 2003). Plant breeders' rights is a form of intellectual property right that grants the breeder of a new plant variety with exclusive rights to benefit from his/her variety. In addition, innovations in plant breeding are driven by the need to acquire and/or increase market share (Louwaars et al., 2009). Plant breeders' rights provide legal protection for the plant breeder to exclude others from commercialisation of the protected variety for a specified number of years granted by the registrar in the Department of Agriculture, Forestry and Fisheries (DAFF). This gives protection against unauthorised copying (propagation) of the protected variety for commercial uses by farmers and competitors. During the first five years after the granting of PBRs, the breeder will be the sole user of the variety material after which the breeder can issue licences for use to anyone interested with any material of the variety at a stipulated fee.

Countries are required by the Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS) of the World Trade Organisation to provide plant varietal protection "either by patents or by an effective *sui generis* system or a combination thereof (TRIPS Article 27(3)(b)" (Kock and Gould, 2013). In addition to the obligation under the TRIPS Agreement for countries to introduce plant variety protection systems, other benefits include providing a system of incentives for individuals and entities be they state, private and foreign, that are engaged in plant breeding in order to increase the quantity or effectiveness of plant breeding. Plant variety protection contributes to increasing genetic diversity, improving food security through production of high quality and higher yielding varieties, sustaining agriculture by promoting the use of national resources and inputs and protecting the environment through pest and disease resistant varieties that need less chemicals (pesticides) (Thiele-Wittig and Claus, 2003).

The standard argument for implementing PVP is that they would stimulate and drive investments in plant breeding research and development of the domestic seed sector (Tripp et al., 2007). Although PVP provide some incentives for increased plant breeding, findings from some empirical studies reveal mixed results with some scholars, for instance (Alston and Venner, 2002, Eaton et al., 2006, Srinivasan and Thirtle, 2003, Tripp et al., 2007) arguing that they might not be strong enough to encourage plant breeding investments. For example, Tripp et al., (2007) studied the potential of PVP to provide incentives for plant breeding in developing countries such as China, India, Colombia, Kenya and Uganda. Their findings show that development of PVP systems in developing countries should be framed as part of a broader strategy for seed system development as PVP may not be adequate to initiate commercial seed development. In a separate study, Alston and Venner (2002) found that introduction of the PVP Act of 1970 in the US increased public investments only (with no change on private investments) and did not affect experimental and commercial wheat yields.

Srinivasan (2003) explored the levels in the ownership of IPR over plant varieties based on data from 30 UPOV member-countries. He argues that the combination of ownership of plant variety rights and growing plant variety protection systems in the developing world would have significant influence on future plant innovations and distribution of market power between companies. This has implications for the structure of the domestic seed industries and access to protected varieties and associated plant breeding technologies. Diez (2002) analysed the impact of plant variety rights on the public and private research sector in Spain, focusing on the role of PVR in altering research incentives and understanding intersectoral differences. The study showed that there were positive incentives particularly for the private sector for increased investments in plant breeding driven by higher appropriability conditions.

Wright and Pardey (2006a) argue that with the exception of a few, many public agricultural research institutions in developing countries have made little progress in developing and commercialising their innovations. Consonant with this view, Alston and Venner (2002) contend that although plant variety protection is meant to provide some exclusive rights to the plant breeder, sometimes high enforcement costs, difficulties in monitoring the area in which a crop such as wheat is planted and determining the source of seed make it difficult to exclude farmers and seed companies from freely using protected varieties.

3.3 Plant variety protection in South Africa

South Africa became a member of the International Union for the Protection of New Varieties of Plants (UPOV) in 1978. According to Moephuli et al., (2012), until 1996, the country had not acceded to UPOV 1991. In 1976, South African enacted the Plant Breeders' Rights Act (Act 15 of 1976). This was later amended in 1996 to conform to the constitution as well as to align and comply with the UPOV 1991. Plant variety protection in South Africa is also guided by the Plant Improvement Act 1976 (Act 53 of 1976). Granted PBRs are listed in a variety listing and are usually granted for 20 years for all crops and 25 years for trees and vines. However, the national authority may expropriate rights for national interest, such as food security needs. The granted PBRs automatically expire at the end of the prescribed period (Moephuli et al., 2012).

The PBR provides the owner of the variety the opportunity to obtain financial reward from the investments put in breeding and development of the new variety, in order to recover the costs incurred. Since the 1930s, Plant Breeders' Rights have evolved when crop improvements became an applied form of genetics practised by specialised institutions and seed companies (Department of Agriculture Forestry and Fisheries, 2011).The owner of a PBR has the privilege of a sole right period of 5 years meaning that the owner is the only one who can use the materials of the variety. In this period, the owner does not award licences thereby providing a chance to get returns on investments on plant varietal improvements. After the 5-year period, the owner of a PBR can allow for licences through an attorney and the contract should show how royalties are paid. These licenses allow the owner to receive payments on any material that is used by other breeders from the variety. In the case where the holder of the right refuses to issue licenses to other persons who wish to use (propagate and breed material) and market the material, the Registrar from the Department of Agriculture, Forestry and Fisheries (DAFF) may issue a compulsory licence (De Bruyn, personal communication, 2013). After the expiry of the full period of the Plant Breeders' Rights the variety becomes public property and anyone may propagate and sell it.

The holder of a plant breeder's right is required to maintain the reproductive material during the period of the right. It is however not clear what happens to the said material after the period of the right has expired. There is a test on the distinctness of the candidate variety; it should be compared to other varieties of the same kind of plant of which their existence on that date is a matter of common knowledge. The holder is not entitled to make available plant material after the right has expired. This poses a problem as such that material will then not be available for comparison purposes with the others that would have joined the market. The Department of Agriculture, Forestry and Fisheries does not have facilities to maintain all the plant material of varieties which have been granted plant breeders' rights therefore they are sent to the gene bank at the Agricultural Research Council Small Grains Institute (ARC-SGI).

In South Africa, 60% of Plant Breeders' Rights holders on most of the crops are foreigners who are largely based in Europe and North America. This asymmetry is not unique to South Africa as a developing country (Department of Agriculture Forestry and Fisheries, 2011). Although the Plant Breeders' Rights in South Africa give the holder a limited exclusive right to the variety, traditional farmer practices such as re-sowing and saving protected varieties may constitute infringement of that right because in the Act, the farmers are permitted to re-sow their seeds. The Plant Breeder's Right Act (Act No, 15 of 1976) allows a farmer to use (re-sow) protected material on his or her own holding. This expression of farmer rights is known as farmer privileges (Department of Agriculture Forestry and Fisheries, 2011).

3.4 Research methods and data

Plant Breeders' Rights (PBR) in South Africa were analysed to assess the sources of intellectual property rights in wheat varietal improvements in South Africa. The chapter used secondary information collected from various sources on wheat varietal improvement policies and changes in wheat plant breeders' rights. Other studies that have analysed changes in plant variety protection focusing on trends and changes in plant variety protection policies include (Diez, 2002, Louwaars et al., 2009, Pardey et al., 2013, Pardey et al., 2012, Srinivasan, 2003). In these studies, trends were analysed to understand the evolution of plant varietal protection. This chapter applies the same approach in order to understand changes that have shaped the South African wheat varietal improvement landscape to date and to allow a comparison with other countries at a later stage.

A detailed and novel count and attribute database of wheat varietal innovations in South Africa from 1979 – 2013 was compiled. Consultations were made with key informants from the Department of Agriculture Forestry and Fisheries, ARC and the South African National Library during development of the database. The database provides information to assess changing amounts and forms of wheat plant breeders' rights as well as changes in the types and pool of the applicants of the rights. The database gathered data on applications, granting, rejections and surrendering of the PBRs. Additional information captured in the database includes; plant variety name, alias name, applicant name, applicant type, application date of PBR, grant date of PBR, withdrawal date of PBR, date end of sole right of PBR, end of sole right month and date of termination of PBR.

Data on wheat variety rights were manually compiled from information on wheat plant breeders' rights applications and granting obtained from the Plant Variety Journal of the South African Department of Agriculture Forestry and Fisheries. Additional data were gathered from the South African National Library and the ARC. These different sources of data were used to backfill the data series in order to come up with a complete database. The data series included a total of 134 applicants of wheat variety rights lodged between January 1979 and December 2013. The empirical analyses were based on descriptive statistics, trend analysis and graphical representation of trends and ownership of wheat varietal improvements by PBRs.

3.5 Results and discussion

3.5.1 Evolution of Plant Breeders Rights legislations in South Africa

This section summarises the chronology of relevant legislations and legal developments affecting wheat Plant Breeders Rights. Plant-breeding research was established in South Africa and the first Gene bank was established in 1960. In 1964, the legislation on Plant Breeders' Rights was passed and in 1966, the legislation was put in place (Njubi-Mbuli Undated). Since then, a number of Acts and amendments have been developed on PBRs over the years. Figure 3.1 below presents the evolution of PBRs legislations in South Africa.

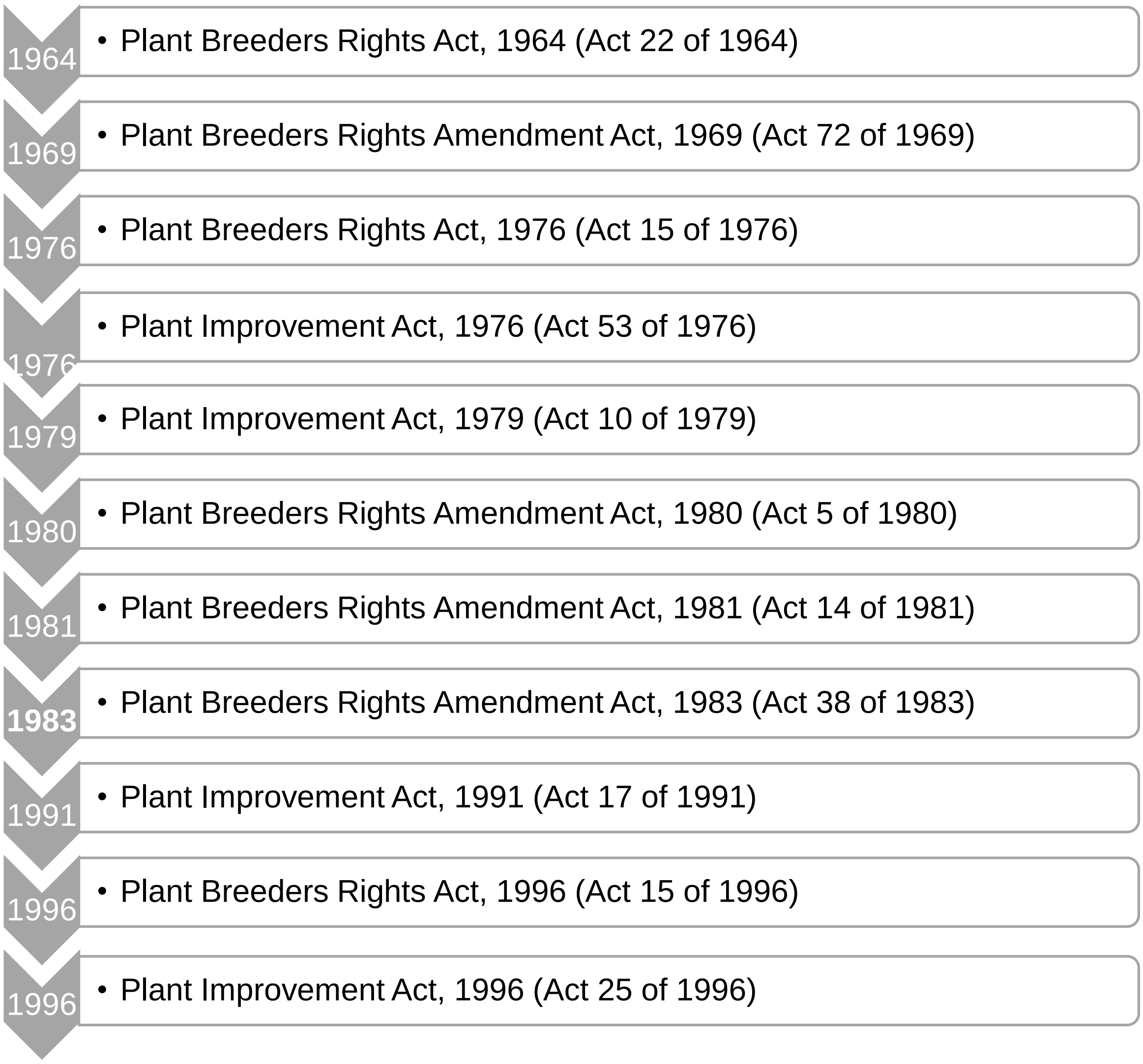


Figure 3.1: Evolution of Plant Breeders' Rights legislations in South Africa

Source: Author's own compilation from different Acts

Below details of each of the Acts on Plant Breeders in Figure 3.1 are provided:

- *Plant Breeders' Rights Act, 1964 (Act 22 of 1964)*: The Act provided for the registration of plant breeders' rights in respect of new plants which originated in the Republic and for the protection of the rights of persons who register such rights. As an amendment of the Patents Act, 1952, it also provided for other incidental matters.

- *Plant Breeders' Rights Amendment Act, 1969 (Act 72 of 1969)*: The Act amended the provisions of the Plant Breeders' Rights Act, 1964, relating to the rights of a holder of final plant breeders' rights. It provided for the granting of plant breeders' rights also in respect of new plants which did not originate from the Republic.
- *Plant Breeders Rights Act, 1976 (Act 15 of 1976):* The act provided for a system where under the plant breeders' rights, rights relating to varieties of certain kinds of plants may be granted and registered. It also made provision for the requirements which have to be complied with for the granting of such rights and for the protection of such rights and the granting of licences in respect of the exercise thereof in addition to providing for incidental matters.
- *Plant improvement Act, 1976 (Act 53 of 1976):* The Plant Improvement Act 53 of 1976 (PIA), as amended, complements the Plant Breeders' Rights Act by providing a regulatory regime for the distribution and sale of certain plants and propagation material. The PIA appoints a Registrar of Plant Improvement who is the required inter alia, to register premises from which plant material is sold, and to compile and maintain a varietal list. The PIA also provides for various administrative and enforcement measures. The significance of the PIA is that it provides control measures for import and export of plant varieties and therefore indirectly protects biodiversity (Barron and Couzens, 2004).
- *Plant improvement Act, 1979 (Act 10 of 1979):* The act amended the Plant Improvement Act, 1976, so as to insert a definition of "business", and to substitute the definitions of the concepts "owner or occupier", "nursery" and "establishment"; to provide that the particulars of an establishment which have been entered in the register of establishments shall be cancelled upon the termination or expiry of the registration of the establishment; to provide that if any business is conducted on premises which are separated from one another, as such premises shall be registered in terms of this Act; to authorize the Minister to exempt certain businesses from the provisions of this Act; to provide for a denomination under which the varieties of certain plants may be sold; to determine who shall bear the costs involved in obtaining certain results; to provide that certain persons and bodies who perform functions in connection

with the application of a scheme shall perform such functions subject to the directions of the Registrar of Plant Improvement; to grant to the said registrar certain powers in connection with the taking of samples; to make punishable the furnishing of false particulars in connection with any plant or propagating material; and to indemnify certain persons in respect of certain acts performed bona fide under a provision of this Act or any scheme; and to plant or propagating material; and to indemnify certain persons.

- *Plant Breeders Rights Amendment Act, 1980 (Act 5 of 1980):* The act amended the provisions of the Plant Breeders' Rights Act, 1976, relating to the definitions; the application of the Act; entries in the register of plant breeders' rights; the persons who may apply for plant breeders' rights; applications for plant breeders' rights; priority of applications; the description and samples of new varieties; the designation of new varieties; the rejection of applications; the termination of provisional protection; objections to the granting of plant breeders' rights; the consideration and examination of applications; the period of plant breeders' rights; the rights of holders of plant breeders' rights; the maintenance of reproductive material; the granting of licences by the holders of plant breeders' rights; applications for compulsory licences; the rights of joint holders of plant breeders' rights; the taking over of plant breeders' rights by the State; the alteration of the denomination of a variety; the termination of a plant breeder's right; the marking of labels or containers; secrecy and to provide for incidental matters.
- *Plant Breeders' Rights Amendment Act, 1981 (Act 14 of 1981):* The act amended the Plant Breeders' Rights Act, 1976, so as to redefine the expressions "department" and "Minister"; and to limit applications for a plant breeder's right to certain persons as well as provide for incidental matters.
- *Plant Breeders Rights 1983 Amendment Act, 1983 (Act 38 of 1983):* The act amended the Plant Breeders' Rights Act, 1976, so as to substitute certain definitions; to authorize the entering into of certain agreements in connection with the exchange of the results of tests and trials with new varieties; to further regulate the consideration and examination of applications for plant breeders' rights; to make the payment of certain fees a prerequisite for the granting of

plant breeders' rights; to further regulate the prohibition of the disclosure of certain information; and to provide for incidental matters.

- *Plant improvement Act, 1991 (Act 17 of 1991):* The Act amended the Plant Improvement Act, 1976, so as to define or further define certain expressions, to further regulate certain applications in terms of the Act, and to extend the reservations regarding certain propagating material and the matters in respect of which certification schemes may provide. Other amendments included making different provision for powers of entry upon and inspection of premises to which the Act applies, further regulating the circumstances under which plants and propagating material may be imported and exported, effecting a change in relation to offences and penalties and to providing for matters connected therewith.
- *Plant Breeders Rights Act, 1996 (Act 15 of 1996):* The Act amended the Plant Breeders' Rights Act for 1976 so that there is insertion of certain definitions and to substitute or deletes others. The act further regulates the delegation of functions by the Registrar of Plant Breeder's Rights. It also made provisions for denomination of varieties and to make further provision for the rejection of applications for PBR. The act made further provisions for the hearing of an objection to the grant of PBR and to make further provisions for the consideration and examination of an application for a PBR. The act prescribes anew of the period for which a PBR shall be granted, to further regulate the rights of a holder of PBR and defines the infringement of a PBR to further regulate the termination of a PBR. In the act, there is also provision for secrecy of certain information, regulation of appeal against a decision of the registrar, further regulation of offences and increase penalties.
- *Plant Improvement Act, 1996, (Act 25 of 1996):* The Act amended the Plant Improvement Act, 1976, so as to alter, insert or delete certain definitions; to prohibit the conducting of business on unregistered premises; to further regulate the registration of premises; to make further provision for the term of registration; to further regulate the renewal of registration; to make further provision for exemption from registration; to further regulate the provisions relating to the varietal list; to further regulate the recognition and evaluation of

varieties of plants; to provide for inspection for quality control; to adjust penalties; and to make further provision for presumptions in criminal proceedings; to provide that the Plant Improvement Act, 1976, shall apply throughout the Republic; to repeal certain laws; and to provide for matters connected therewith.

3.5.2 Trends of wheat varietal improvements Plant Breeders Rights

Figure 3.2 below shows the trends of annual applications of Plant Breeders Rights for wheat varietal improvements lodged in South Africa. The total number of PBRs lodged for wheat varietal innovations were 134 during the period from 1979 to 2013, an average of 6 applications per year. Data on the number of wheat varietal improvements PBRs lodged since 1979 show changes over time, with some years having a high number of applications while others recorded very low applications. For example, the year 2012 received the highest number of wheat varietal improvements PBRs with 14 applications and the year 2004 recorded only 1 application. A possible explanation of the uneven trend in wheat PBRs applications could be that some breeders chose to apply for their new varieties to be included on the national variety list and did not apply for varietal protection. The variety may be included on the national variety list for it to be listed and known by millers and bakers, but if the owner does not go further to apply for PBR's anyone can use any material on the variety without paying the owner for IPRs. Another explanation could be that the development of new varieties is the result of long term breeding programs. It follows that one could not expect the same number of varieties reaching market readiness every year. Furthermore, an outbreak of pests or diseases can trigger more investments in wheat varietal improvements in some years compared to others. For example, in 2012, the outbreak of new strains of wheat rust in North Africa which then spread to the rest of the world, could have triggered more investments in wheat varietal improvements, leading to a high number of PBRs applications. Generally, the main triggers of wheat varietal improvements in South Africa include outbreak of pests and diseases such as wheat rust, septoria, Russian wheat aphid and different environmental and climatic conditions.

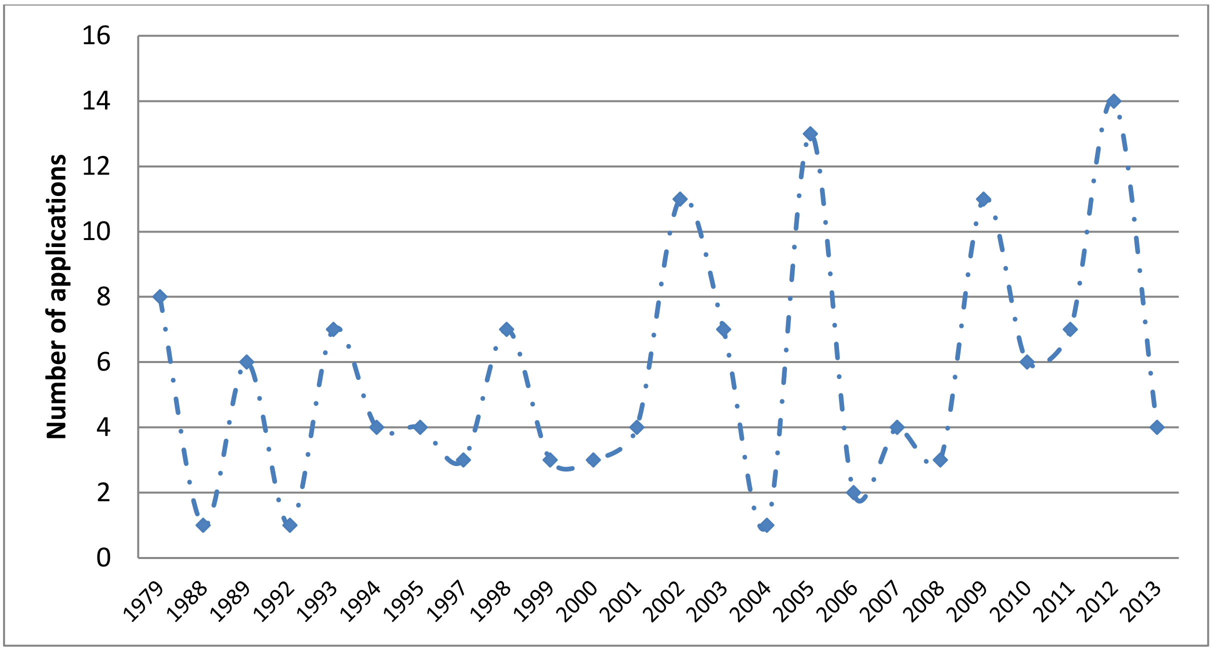


Figure 3.2: Annual applications of wheat varietal improvements by PBRs, 1979 – 2013

Source: Author's own data compilation from Plant Variety Journals

It is also important to understand the effects of the abolishment of the Wheat Board in 1996 and establishment of the ARC-SGI in 1991 on the number of applications of PBRs for wheat varietal improvements. Analysis by time periods of before and after abolishment of the Wheat Board shows that 77% of the applications lodged were between 1998 and 2013 (after the abolishment of the Wheat Board). The number of PBR applications for wheat variety innovations increased faster than before after the abolishment of the Wheat Board with an average of 6 applications per year compared to 4 applications per year for the time period 1979 – 1997. In addition, in recent years, the number of wheat variety PBR has substantially increased compared to the previous years. From the results, liberalisation of the wheat sector can be argued to have opened competition in wheat varietal improvements and stimulated increase in applications of PBRs on wheat varietal innovations. Further analysis by time period before and after the establishment of the ARC-SGI shows that only 15 applications of PBRs for wheat varietal innovations were lodged before 1991. The rest, 89%, were lodged when the ARC-SGI was established from 1992 to 2013. The rate of applications per year was 6 after the establishment of the ARC-SGI, compared to 5 applications per year before the ARC-SGI was established. The decreasing funding for agricultural research might be contributing to the ARC-SGI seeking revenue from their research outputs.

Figures 3.3 and 3.4 below present an analysis of the plant breeders' rights for wheat varietal improvements and grant lags. Figure 3.3 plots PBRs applications and grants in each year and Figure 3.4 tracks the lag, in days between the application and grant dates of each PBR that was eventually granted a certificate. The average waiting time between application and granting of protection is around 336 days for the overall period of study. Analysis of the grant lags by pre and post deregulation time periods indicates that before 1997, which was the pre-deregulation period, the grant lag was 451 days. This reduced to 374 days in the post deregulation period. Elna de Bruyn, a Plant Variety Registration officer at DAFF informed the researcher that the whole application process from application to granting the process should not take less than 84 days because the average growing season of wheat is 130 to 190 days.

When the application process starts, the sample seeds and application papers are taken and inspected then sent for trails at ARC. If the variety is found to be distinct, uniform and stable for two seasons, it is granted the PBRs. This explains why it takes more than 300 days to be granted the rights. If the trials are unstable, it takes a bit longer to be granted the rights because the irregularities have to be checked and rectified. The grant lags are short after the abolishment of the Wheat Board as well as after the establishment of the ARC-SGI. This can be considered to be efficient in comparison with the US were the average grant lag ranged from 500 days to 1449 days. On this issue, Pardey et al (2012) explain that administrative delays substantially lengthen the lags in the processing of applications. The results show that recently, the administrative delays in granting PBR applications have been substantially reduced after the abolishment of the Wheat Board. This indicates increased efficiency in the processing of PBRs, which is associated with the removal of controls since the abolishment of the Wheat Board in 1997.

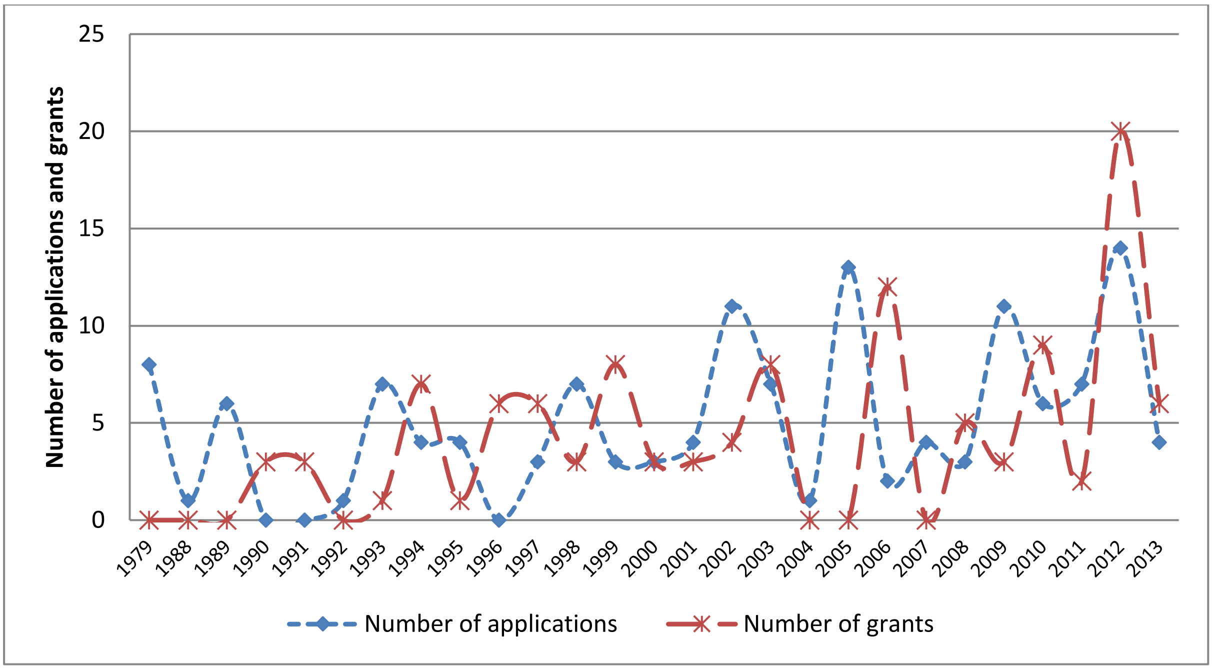


Figure 3.3: Wheat varietal improvements regarding PBRs applications and grants, 1979 -2013

Source: Author's own data compiled from Plant Variety Journals

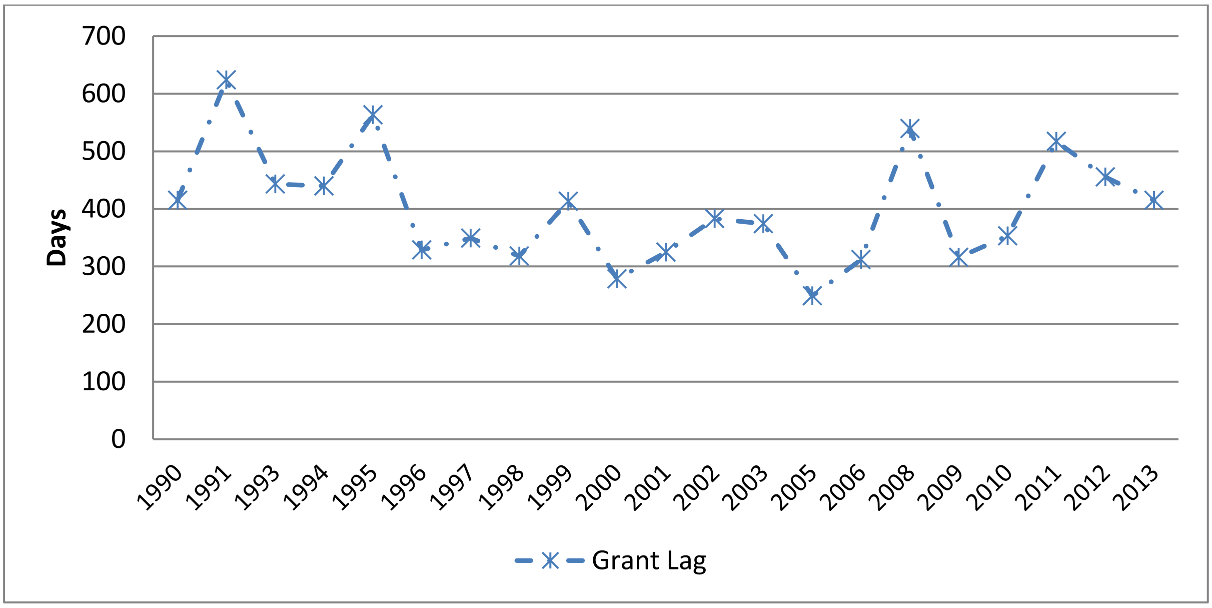


Figure 3.4: Wheat varietal improvements in relation to PBRs grant lags, 1979 - 2013

Source: Author's own data compilation and calculation from Plant Variety Journals

The plant variety rights applications can at any time be granted, abandoned or withdrawn by the applicant, deemed ineligible – such as in cases of incomplete applications, denied by the office or still pending examination (Pardey et al., 2012). In the South African context, applications for PBRs may be (a) granted if they meet the required standard set by DAFF (b) surrendered if there is need to do so if the applicant no longer needs protection and also due to the completion of the right to be protected after 20 years in the case of wheat (c) rejected if the application is incomplete and does not meet the required standards and (d) terminated if the Registrar sees it necessary in the event of some irregularities (De Bruyn, personal communication, 2013).

Table 3.1 shows the changing status of wheat varietal improvements PBRs overtime. For the period under review, of the wheat variety rights applications that were lodged between 1990 and 2013 were 113 were granted, while 33 (25%) of the applications were surrendered and 15 (11%) were deleted. The results show that only 3 cases were rejected from 1990 to 2013. Analysis of the granted PBR for wheat varietal innovations by decade shows an average grant rate of 4 PBRs/year; 5 PBRs/year and 9 PBRs/year for the periods 1990 - 1999; 2000 - 2009; and 2010 - 2013 respectively. Further analysis by pre and post deregulation of the wheat sector shows that the grant rate increased from 4 grants/ year before abolishment of the wheat board to an average on 7 grants/year from 1998 to 2013. In addition, from 2003 to 2013, the number of granted PBRs for wheat varietal improvements was relatively high compared to other years with the highest number (a total of 20 PBRs) being recorded in 2012. These results indicate that plant breeders are increasingly seeking protection of their innovations.

Table 3.1: Changing disposition of PBR applications

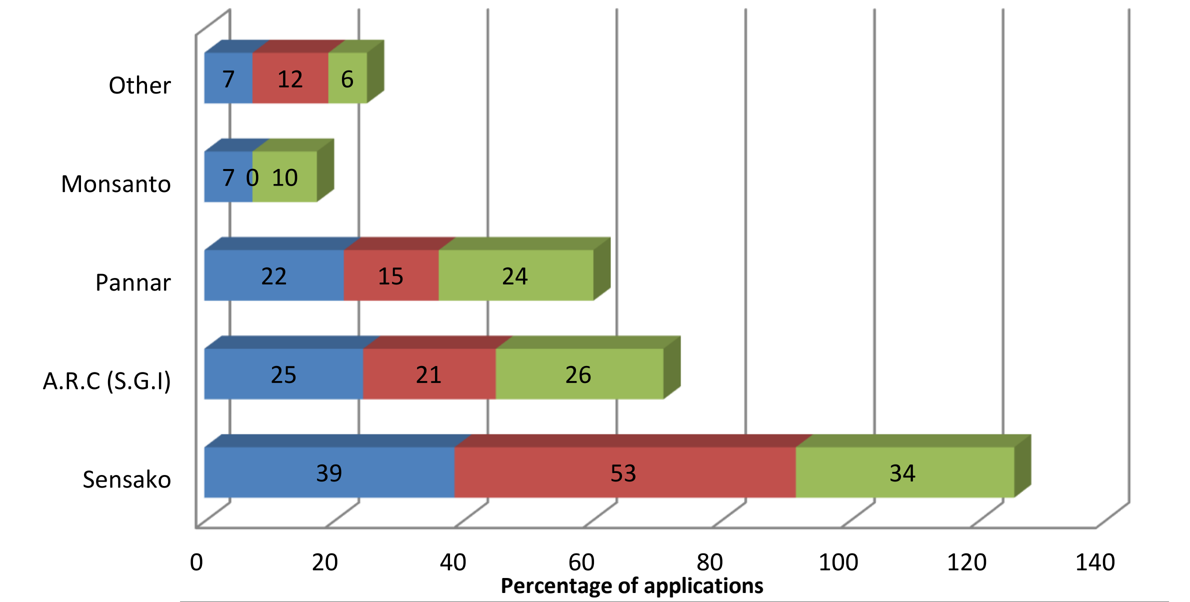
Year	Number of wheat varietal PBR applications			
	Surrendered	Deleted	Rejected	Granted
1990	1	-	2	3
1991	2	2	-	3
1993	-	1	-	1
1994	4	3	-	7
1995	-	-	-	1
1996	3	2	-	6
1997	3	2	-	6
1998	1	1	-	3
1999	1	2	-	8
2000	1	-	-	3
2001	1	-	-	3
2002	1	1	-	4
2003	2	1	-	8
2006	3	-	-	12
2008	2	-	1	5
2009	1	-	-	3
2010	1	-	-	9
2011	-	-	-	2
2012	5	-	-	20
2013	1	-	-	6
Total	**33**	**15**	**3**	**113**

Source: Author's own data compilation from Plant Variety Journals

3.5.3 Applicants of wheat varietal plant breeders' rights

This section analyses the composition of applicants seeking wheat varietal improvements Plant Breeders' Rights from 1979 to 2013. The focus is on identifying the changing public and private roles in wheat varietal improvements Plant Breeders' Rights in South Africa. Figure 3.5 presents the composition of applicants for wheat varietal improvements PBRs from 1979 to 2013. Based on analysis of shares of wheat varietal improvements PBRs since the publication of the South African Plant Variety Journal in 1979, the main applicants were Sensako (39%), ARC-SGI (25%) and Pannar (15%). Before 1997, the share of applications from Sensako constituted 53% of all the applications, while that of the ARC-SGI was 21% and Pannar had 15%. Other stakeholders such as CIMMYT, University of Free State, Carnia Seeds, Cargill USA and Gwk Beperk constituted 12% of the applications. Analysis of the period after the abolishment of the wheat board shows that Sensako's share decreased to 34% while that of the ARC-SGI (26%) and Pannar (24%) increased by 5% and 9% respectively. The share of applications and grants held by the ARC-SGI is comparable to other countries. In the Netherlands, Louwaars et al., (2009) found that the public sector (universities, government bodies and private non-profit organisations) submitted 23.8% of plant based patents while in the USA public bodies were granted 21.9%. Furthermore, Louwaars et al., (2009) found that in the Netherlands, private companies dominated the number of plant-based patents granted in the country.

In many developing countries, National Agricultural Research Systems such as the ARC-SGI and CGIARs dominated agricultural research, including varietal improvements. The development of new varieties was driven by the exchange of plant varieties and genetic resources between the NARS and the Consultative Group for International Agricultural Research (CGIAR) institutions unencumbered by IPRs (Srinivasan, 2003). In this case, ownership of IPRs was irrelevant to plant breeding and for accessing plant genetic resources from other countries (Srinivasan, 2003). Similarly, the ARC-SGI was not applying for PBRs previously despite being actively involved in wheat varietal improvements. However, since the abolishment of the Wheat Board in 1997, the ARC-SGI increased their share of Plant Breeders' Rights lodged by 5% to 26% with most of the applications being in recent years. It might be that reduced funding for the ARC-SGI might have contributed to the institution seeking for protection of its varieties as a way to generate additional revenue.



	Sensako	A.R.C (S.G.I)	Pannar	Monsanto	Other
1979-2013	39	25	22	7	7
1979-1997	53	21	15	0	12
1998-2013	34	26	24	10	6

Figure 3.5: The structure of applicants of wheat PBRs, 1979-2013

Source: Author's own data compilation from Plant Variety Journals

Figures 3.6 and 3.7 present the changing composition of applicants of wheat PBRs. The majority of the PBRs applications for wheat varietal improvements were filed by private companies (Figure 3.6). Among the private companies, the two main actors were Sensako and Pannar (Figure 3.7). Pardey et al., (2013) found that the private sector constituted the largest share, accounting for 82% of the total plant varietal rights in the United States. The study further found that the share of varietal rights owned by public entities in the US, for example the US and foreign universities, research foundations and government agencies, was very small considering the high volume of research they perform. In the South African wheat sector, the public sector, especially the ARC-SGI, continues to play a major role in the development of wheat varieties and PBRs from wheat varietal improvement. Before the establishment of the ARC, the public sector had no applications for PBRs for wheat variety improvements. Since the establishment of the ARC in 1991, the public sector applications for wheat variety

PBRs drastically increased in the following years 1993 (4); 2002 (4); 2005(2) and 2012 (11). For instance, the public sector had the largest number of wheat variety PBR applications (11) in 2012 compared to 3 from private companies in the same year.

It is important to note that, public and private sector institutions freely exchanged plant genetic resources and breeding lines before the advent of IPRs (Srinivasan, 2003). Public sector institutions used to develop basic breeding lines and made them available for the development of 'finished products' by the private sector. The advent of PVPs/IPRs considerably restricted exchange of plant genetic resources and breeding lines between the public and private research institutions (Price, 2000). With this background, it can be argued that the ARC-SGI has significantly contributed to some of the PBRs owned by private companies through shared genetic resources before the PVP/IPR were implemented.

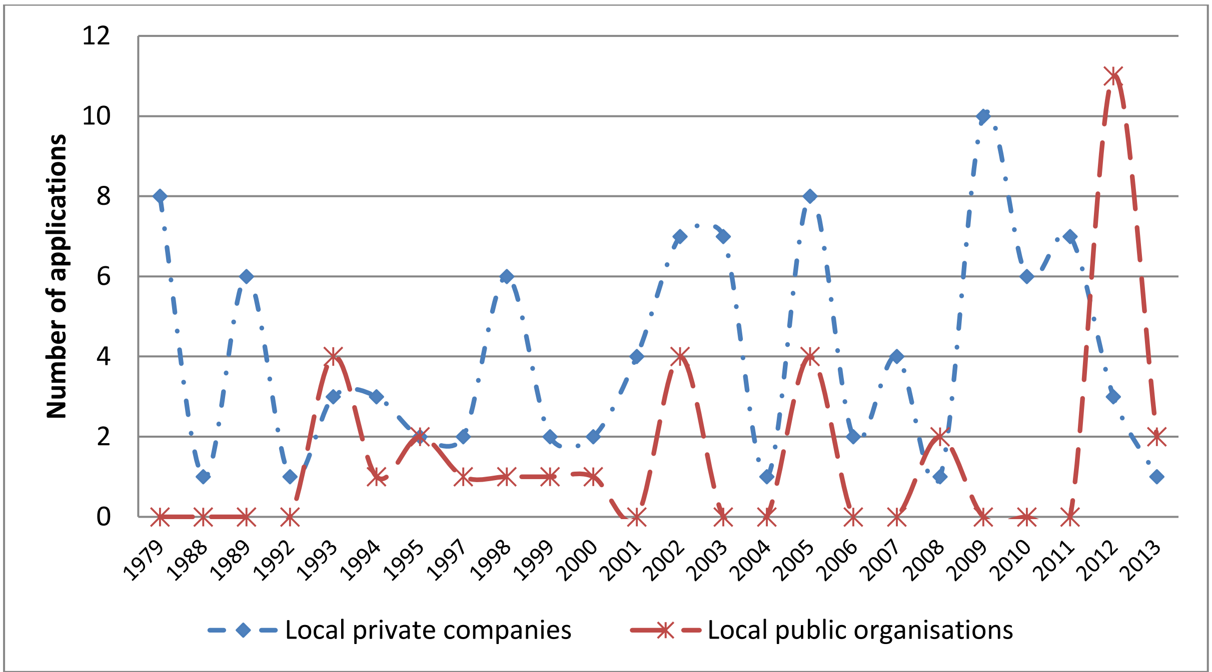


Figure 3.6: Applications by private vs public organisations, 1979-2013

Source: Author's own data compilation from Plant Variety Journals

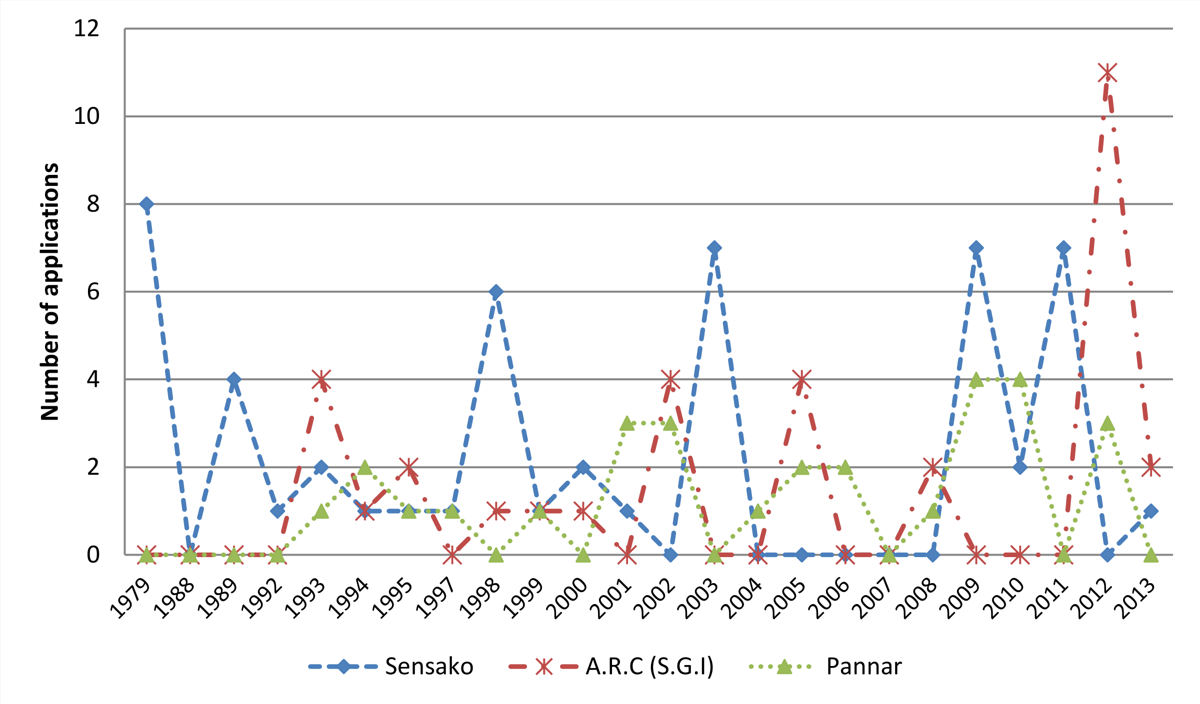


Figure 3.7: Applications made by the main role players, 1979-2013

Source: Author's own data compilation from Plant Variety Journals

3.5.4 Implications of the observed wheat plant variety protection trends

Plant Breeders Rights are the predominant intellectual assets of the ARC (Moephuli et al., 2012). Other forms of ARC intellectual assets include patents, copyrights (publications), trademarks, trade secrets and Know How. The South African Intellectual Property Rights from publicly financed R&D Act (Act No. 51, 2008) prescribes that publicly funded R&D must be protected, utilised and commercialised. This is to ensure that it benefits the people of South Africa, that recipients of public funding act in a manner conducive to public good, that it acknowledges and rewards innovation, enables economic growth through enterprise development and allows publishing of scientific results (Moephuli et al., 2012). The challenge for public institutions like the ARC-SGI is that traditionally, their research outputs have been in the public domain and the public sector had to ensure widest dissemination of innovations (Diez, 2002, Srinivasan, 2003). Efforts to make public research institutions such as the ARC-SGI generate revenue from holding IPRs on plant varieties requires some exclusive licensing as is the case with US Land Grant Universities (Srinivasan, 2003). According to Srinivasan (2003) PVP/IPRs ownership by the public sector discourages exchanges of plant genetic resources and development of follow-on varieties. Furthermore, if exclusive rights are granted to larger companies, small businesses relying on public varieties or varieties derived from public varieties would be forced out of business. This would affect the development of the domestic wheat seed sector through creating monopolies of big private companies. Concentration of ownership of plant variety rights in a few companies discourages follow-on innovations by other firms and researchers (Srinivasan, 2003).

The major role played by the ARC-SGI is supported by evidence from around the world indicating that plant breeding innovations in non-hybrid crops like wheat have largely been sustained by the public sector. For example, Srinivasan, (2003) found that in cases where the public sector has played a major role in plant breeding, the overall concentration is less. In addition, Eaton et al., (2006) argue that although plant variety protection is expected to stimulate investments in plant breeding for national agricultural research institutes (NARIs), PVP may address the following three objectives which are not always compatible: revenue collection, recognition of achievement and technology transfer. Their study found no evidence of potential revenue generation from plant breeding taking place in national agricultural research institutes in Colombia and Uganda. In addition, one of the challenges for NARIs is to keep control of the plant breeding skills and resources for commercially important crops. For example, evidence from India and Kenya showed that the development of the private sector resulted in the hiring of experienced NARI staff making it difficult for the NARI to retain plant breeding staff and resources Eaton et al., (2006).

This implies that although the ARC-SGI is expected to generate revenue to sustain their activities, the concentration of potential revenue generation activities in more commercial crops brings into question public research resource allocations. Public research institutions would be required to still engage in research and plant breeding for mandate crops such as staples, which might not be very lucrative compared to commercial crops. Such investments would have to be funded by public agricultural expenditures and other sources, making it difficult for NARIs such as the ARC to focus on revenue generation in their plant breeding activities. In addition, the ARC faces competition from private companies in retaining its breeding skills and resources.

3.6 Summary and recommendations

This chapter analysed the evolving landscape of wheat plant breeders' rights to address the dearth of empirical evidence of the patterns and trends of wheat varietal improvements in South Africa. The aim was to provide evidence on the evolution of varietal rights, the extent of varietal rights granted, changes of the rights on offer overtime, changing ownership of the rights (including comparison between public and private as well as domestic and foreign breeders) and the impact of plant variety protection on wheat varietal development. The study compiled a detailed and novel count and attribute database of wheat varietal innovations in South Africa from 1979 – 2013, using information from *Plant Variety Journal*, Department of Agriculture Forestry and Fisheries; South African National Library and ARC. The empirical analyses were based on descriptive statistics, trend analysis and graphical representation of trends and ownership of wheat varietal improvements PBRs.

The total number of 134 PBRs for wheat varietal innovations were lodged from 1979 to 2013, which is an average of 6 applications per year. This could have been driven by some breeders choosing to apply for their new varieties to be included on the national variety list and not applying for varietal protection. The other influence could have come from natural triggers such as outbreak of pests and diseases, for example wheat rust, septoria and Russian wheat aphid as well as different environmental and climatic conditions. The results indicate that plant breeders are increasingly seeking protection of their innovations. The number of PBR applications and grants for wheat variety innovations increased after the abolishment of the Wheat Board (6 applications compared to 4 per year before deregulation). The results also show that the administrative delays in granting PBR applications have been substantially reduced (by 77days), post-deregulation indicating increased efficiency in the processing of PBRs.

Since the publication of the South African Plant Variety Journal in 1979, the main applicants for wheat PVP were Sensako (39%), ARC-SGI (25%) and Pannar (15%). After deregulation, Sensako's share decreased to 34% while that of the ARC-SGI and Pannar increased by 5% and 9% respectively. The results show that the ARC-SGI faces stiff competition from these well-established private companies. Establishing opportunities for collaboration with the private sector would increase wheat variety innovation development. The ARC-SGI has contributed to some of the PBRs owned by private companies through shared genetic resources before the PVP/IPR were implemented. Future innovations and dissemination of wheat innovations can be stimulated by plant variety protection together with the broader variety sector legislations that encourage both public and private sector investments.

CHAPTER 4

THE EFFECTS OF PLANT BREEDERS' RIGHTS ON WHEAT PRODUCTIVITY AND VARIETY IMPROVEMENT IN SOUTH AFRICA

4.1 Introduction

The global demand for food increases with growing world population projected to be 9.8 billion in 2050 and 11.2 billion by 2100 (United Nations Department of Economic and Social Affairs Population Division, 2017). The challenges of increasing world population, global climate change, shortages of irrigation water, degradation of agricultural land increases the need to enhance agricultural productivity. Limited opportunities of opening new agricultural land means that increasing productivity from existing cropping systems and promoting sustainable production remains an important alternative to meet the rising demand for food and fibre (van Wart et al., 2013, Anderson et al., 2016, Licker et al., 2010). Research in varietal innovations particularly for the main food crops such as wheat remains important for increasing agricultural productivity and addressing food security concerns and meeting growing world food demand.

The developments and changes in Intellectual Property Rights (IPRs) systems for agricultural innovations (such as varietal improvements) are one of the institutional factors[2] expected to impact on the productivity of agricultural systems (Campi, 2017). The International Union for the Protection of New Varieties of Plants (UPOV) established in 1961 advocates for strengthening and harmonisation of plant variety protection (PVP) laws and standards (UPOV, 1961). The strengthening of *sui generis* plant IPRs is expected to provide incentives to stimulate investments in plant R&D as development of local seed sector (Tripp et al., 2007). In addition, stronger IPRs are expected to stimulate technology development and transfer and effective utilisation of

[2] Other factors that affect agricultural productivity include: capital, land, labour, environmental and climatic factors, technological capabilities (Campi, 2017)

genetic resources that would contribute to enhancing agricultural productivity and economic benefits (Campi, 2017).

Despite the above arguments for stronger plant IPRs, empirical research on their effects on agricultural innovations and productivity have produced mixed results. For example, Campi (2017) found significant and positive relationship between stronger IPRs and cereal productivity in high-and low-income countries while the relationship was negative and insignificant in middle-income countries. In a separate study Naseem et al., (2005) found that plant variety protection (PVP) contributed to development of more varieties and positively impacted on cotton yields in the United States. On the negative side, plant IPRs have been argued to affect innovations and availability of new plant varieties, increasing input market concentration and impact on productivity is either insignificant or negative (Dutfield, 2009).

In addition, some empirical studies have argued that IPRs or PVP systems might not be strong enough to stimulate significant investments in plant breeding research/ innovations (Eaton et al., 2006, Srinivasan and Thirtle, 2003, Tripp et al., 2007). For example, Tripp et al. (2007) based on case studies from China, Colombia, India, Kenya and Uganda, found that development of PVP systems in developing countries were inadequate for stimulating development of local commercial seed sector and recommended that efforts need to be integrated in broader seed system development strategies. Furthermore, the monopoly power provided through IPRs has been argued to negatively affect domestic innovation, technology transfer, local market development and agricultural productivity (Campi and Duenas, 2016).

However, there is no empirical analysis that has been done specifically for the South African wheat sector to explore the relationship between Plant Breeders' Rights and or strengthening of the IPR environment for plants with wheat productivity. In addition, there is no empirical work that has assessed how strengthening wheat variety IPRs have affected the wheat sector variety improvement landscape and seed industry. The empirical analyses from this chapter contributes to the knowledge and debate on the effects of Plant Breeders' Rights and or strengthening of IPRs on plant varieties on agricultural productivity, the release of improved varieties and changing roles of public and private sector R&D investments in agriculture. Therefore, the main objective of this chapter was to analyse the effects of strengthening wheat variety intellectual protection on wheat productivity and varietal improvement (release of new improved varieties). Stronger intellectual property rights are expected stimulate investments in wheat productivity and varietal improvements. The strength of IPR systems was measured using an IP protection index, plant variety protection legislation and the number of Plant Breeders' Rights granted for wheat varieties.

The rest of the chapter is organised as follows: the next Section discusses the review of literature on the effects of IPRs on agricultural development. Based on the review, hypotheses are proposed for the current study. The methodology and data of the study is presented in Section 4.3. Section 4.4 presents and discusses the empirical estimation results. The conclusions and recommendations are presented in Section 4.5.

4.2 A concise review of empirical studies on the relationship between IPRs and agricultural innovations and productivity

Plant Breeders' Rights (PBRs) are a form of Intellectual Property Rights (IPRs) that provides exclusive rights to the breeder to benefits from their innovations. This means the breeder has protection from unauthorised imitation of the protected variety for commercial purposes by competitors and farmers. Furthermore, investments in agricultural innovations such as varietal improvements are motivated by objectives of acquiring and growing market share by breeders (Louwaars et al., 2009). For example, the main factors that contributed to the growth in private agricultural R&D investments include: increased demand for modern agricultural inputs driven by increased demand for food and fiber; incentives stimulated by policy reforms that deregulated agricultural input sectors; and the strengthening of IPRs that helped protect innovations from being imitated without permission (Pray and Fuglie, 2015, Fuglie and Toole, 2014, Fuglie et al., 2012). Overall, the strengthening of the IPRs for plant varieties is expected to provide incentives for breeding companies to invest more resources in plant breeding. Strengthening of IPRs for plants is expected to result in increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth (Campi, 2017, Tripp et al., 2007).

Despite the incentives presented for promoting IPRs for plants the development of new plant innovations requires access to existing genetic material. The restrictions on access to existing genetic material presented by IPRs in plant varieties might affect breeding programmes although there might be legislative exceptions that provide access to such material for R&D purposes (Campi, 2017). The protection from the IPRs can lead to high concentration and creation of monopolistic actors in seed input markets that adversely impacts on local innovations, market development and productivity (Campi and Duenas, 2016, Dutfield, 2009). On the contrary, Wright and Pardey (2006b) argue that since the diffusion of IPRs across the world, developments in scientific innovations (rather than IPRs) have contributed to yield improvements.

The impact pathway of the effects of IPRs on productivity is indirectly observed and may be difficult to isolate. Most of the research on effects of IPRs focus on their impacts on agricultural innovations and there is limited empirical evidence on the relationship between IPRs and productivity (Campi, 2017). This means research on the effects of IPRs on wheat productivity provides important contribution to empirical knowledge in this field. Empirical research on the relationship between IPRs, varietal innovations, agricultural productivity, trade and economic growth have produced mixed results. Some of the empirical findings are briefly discussed below. Using a panel of countries and data for the years 1961 to 2011 Campi (2017) assessed the effects of strengthening intellectual property (IP) protection on agricultural productivity. The effect of strengthening IP rights (IPRs) on both wheat and maize was explored using an index of IP protection for plant varieties. Empirical results found that for middle income countries such as South Africa, the relationship between stronger IPRs and cereal productivity (wheat and maize) was insignificant. This was contrary to the same relationship in high- and low-income countries. The implications for these results is that variety IP protection might not have positively impacted on commercial wheat productivity in South Africa.

Spielman and Ma (2016) applied an Arellano-Bond linear dynamic panel data estimation approach using a data set of six major crops to assess the effect of IPRs on yield growth through stimulating incentives for investments by the private sector in varietal improvements. The findings from the study showed that despite the effects being crop-specific, different forms of IPRs (biological and legal) contributed to the reduction of the gap in yields between developing and developed countries. In a separate study, Payumo et al., (2012) analysed the effect of strengthening IPRs systems in TRIPS member countries on agricultural gross domestic product (GDP) for the period 1980 - 2005. The two variables were found to be positively related in both developed and developing countries.

Pray and Nagarajan (2014) found that in India, strengthened IPRs allowing innovators to patent their innovation positively impacted on private agricultural research. Flister and Galushko (2016) argue that the introduction of the PVP Law in Brazil stimulated private investments in wheat R&D and the establishment of a strong private wheat breeding sector. These results indicate that strengthening IPR systems would contribute to stimulating private sector investments in agricultural R&D.

Kolady and Lesser (2009) analysed the impacts of the implementation of PVP to crop productivity in Washington State in the United States. The findings from this study showed that PVPs had a positive relationship with private investments in open pollinated crops (such as wheat). In addition, implementation of PVPs resulted in increased number of high yielding varieties of these crops that were released from both private and public breeding programmes. The authors extended the implications from their analysis as important lessons for developing countries on how IPRs for plants and their TRIPS commitments can affect both release of high yielding varieties, and private sector investments.

Naseem et al., (2005) examined the effects of PVP and cotton yields in the United States. The empirical findings found that PVP contributed to development of more cotton varieties and had a positive impact on yields. The results contrasted the criticism that PVP was more than a marketing tool with insignificant impacts on agricultural productivity.

Knudson and Pray (1991) analysed the impacts of the Plant Variety Protection Act of 1970 (PVPA) on public sector research priorities of five crops (corn, wheat, sorghum, cotton and soybeans) in the United States. The empirical regression results showed social benefits from public research investments were important in directing research priorities. Furthermore, the results showed some support that new income opportunities provided by the PVPA influenced the direction of public research. Similarly, for the current research, the expectation was that granting of PBRs and stronger IPR environment would stimulate further investments in wheat varietal improvements and release of improved varieties that would contribute to improve productivity.

Tripp et al., (2007) examined the effects of PVP systems in five developing countries (China, Colombia, India, Kenya and Uganda). The findings from the study showed that PVP systems were inadequate for stimulating development of commercial seed development. The authors argued that to be effective, PVP systems should be framed within broader seed system development strategies. Léger (2005) investigated the role IPRs in Mexican maize breeding industry. The empirical results indicated that IPRs had no role in the industry and did not stimulate innovation as expected. The author argued for revision of the IPR theory to integrate country characteristics such as quality of the institutional environment and role of transaction all important for well-functioning IPR systems. Considering these factors is expected to result in IPR systems contributing even small role in developing countries.

Dosi et al., (2006) analysed the relations between appropriability, opportunities and rates of innovation. The evidence from the study suggested that IPRs were not very important mechanism for breeding firms to earn profits from their innovation. Based on the findings, the authors highlighted that at best IPRs have no or could have negative impacts on rates of innovation. The authors argued that each technology paradigm was more important in determining technology- and industry-specific patterns of innovation.

Alston and Venner (2002) analysed the effects of the PVP Act (PVPA) of 1970 in the United States on wheat genetic improvement. The PVPA was expected to strengthen IP protection for plant breeders stimulate investments in varietal R&D, improve varietal quality and enhance royalties. The empirical results found that the PVPA contributed to increased public investments (and not private sector investments) in wheat varietal improvement. The results on the impacts of the PVPA on experimental and commercial wheat yields was negative. The authors found that the PVPA didn’t have much impact on excludability in wheat varieties.

The above discussion indicates that the empirical research on the effects of IPRs for plants on varietal innovations and crop productivity are mixed. Some of the contributing factors to the mixed findings may include: country specific characteristics (such as institutional environment), the technologies being considered, imperfect data, etc. Campi (2017) argues that IPRs systems may be the result and not the cause of innovation and improvements in productivity. There is need for further empirical research to explore the relationship between IPRs systems in different country context and sectors. The current study contributes to the growing knowledge in this field through analysing the effects of Plant Breeders' Rights and IPRs systems on wheat productivity and varietal improvement in South Africa. The proposed hypotheses are restated below:

> ***H_3:*** Strengthening Plant Breeders' Rights in South Africa increased investments and release of improved wheat varieties by the private sector.
>
> ***H_4:*** Strengthening Plant Breeders' Rights in South Africa positively and significantly impacted on wheat productivity.

4.3 Research methodology

To measure the productivity of wheat, the study used yields calculated as total commercial wheat output divided by total harvested area in hectares. Campi (2017) discusses the advantages of using yield as a measure of productivity over other indicators such as output per worker or total factor productivity such as reliability of yield data, and its reflection to a large extent of the effect of technical change in agriculture. The dependent variables were the log of wheat yields and the number of wheat varieties released each year. The independent variables included data on Plant Breeders Rights for wheat compiled as part of this research (Nhemachena et al., 2016b), and the IPR index developed by Campi and Nuvolari (2015).

The IPR index quantifies the strength of IP protection for plant varieties in different countries (who are members of the UPOV convention) for the period 1961-2011. The IPR index has five equally weighted elements (ratification of UPOV Conventions; farmers' exception; breeder's exception; protection length; and patent scope) that measure the strength of the IP protection system for plant varieties in each country (Campi and Nuvolari, 2015). South Africa is a member of the UPOV convention and the respective data for the country was used for empirical analyses to explore the relationship between stronger IPRs and wheat productivity and wheat varietal research improvements in the country. Detailed discussion of the evolution of Plant

Breeders' Rights in wheat varietal improvement in South Africa is presented by Nhemachena et al., (2016b). The period from 1996 in which South Africa became amended the PBR Act (Act 15 of 1976) to confirm with the constitution and the UPOV 1991 was also included as a dummy independent variable. This represented an undertaking to implement stronger IP protection for innovations from the country.

Similar to other studies (Campi, 2017, Falvey et al., 2006, Alston and Venner, 2002, Payumo et al., 2012) that have explored the relationship between IPR systems and agricultural productivity, the empirical analyses of the effects of IPR systems and wheat varietal release and productivity in South Africa was based on correlation analysis and multiple regression analysis. Correlation analysis was used to explore the nature of the relationships between IPR systems and wheat productivity as well as release of new varieties both by the Agricultural Research Council-Small Grains Institute (ARC-SGI) wheat breeding programme and Sensako (the main domestic private sector actor). To explore the hypothesised relationships above, simple regression models were defined as in equations 4.1 and 4.2 below:

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \qquad (4.1)$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \mu_t \qquad (4.2)$$

where Y_t is the logarithm of wheat yields in year t, V_t is the number of wheat varieties released in each year, IPR_t is the index of IPR protection in year t and μ_t is the error term.

To further explore the relationships between IPR systems, Plant Breeders' Rights and wheat productivity and release of new wheat varieties the study applied multiple regression analyses defined by the following equations 4.3 and 4.4 below. In this case PBRs granted to both the ARC-SGI and Sensako were added as independent variables. The PBRs granted to Pannar the other key private sector actor were not included since the numbers were very small. The total number of wheat PBRs granted each year was also used as an independent variable in place of the individual variables of PBRs granted to the ARC-SGI and Sensako.

$$Y_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 PBRAct_t + \mu_t \tag{4.3}$$

$$V_t = \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN\,t} + \alpha_5 PBRAct_t + \mu_t \tag{4.4}$$

where PBR_{ARC_t} and PBR_{SEN_t} are the number of PBRs granted for wheat variables released by the ARC-SGI wheat breeding programme and Sensako respectively, $PBRAct_t$ is the years after which South Africa amended the PBR Act (Act 15 of 1976) to confirm with the constitution and the UPOV 1991. The relationship between both wheat yield and number of varieties released each year was tested using the following multiple regression equation with PBRs granted to both the ARC-SGI and Sensako added as independent variables. The total number of wheat PBRs granted each year was also used as an independent variable in place of the individual variables of PBRs granted to the ARC-SGI and Sensako. The study also explored other characteristics that affect agricultural productivity as explanatory variables similar to Campi (2017): schooling, agricultural labour, number of tractors in use and total area equipped for irrigation and total consumption of fertilisers. The multiple regression models estimated are defined in equations 4.5 and 4.6 below. However, due to high levels of collinearity between these variables for the South African data, these multiple regressions were excluded.

$$\begin{aligned} Y_t = {} & \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 \mathrm{PBRAct}_t + \alpha_6 school_t \\ & + \alpha_7 \log labour_t + \alpha_8 \log tract_t + \alpha_9 \log fertil_t + \alpha_{10} \log irrig_t + \mu_t \end{aligned} \tag{4.5}$$

$$\begin{aligned} V_t = {} & \alpha_1 + \alpha_2 IPR_t + \alpha_3 PBR_{ARC_t} + \alpha_4 PBR_{SEN_t} + \alpha_5 \mathrm{PBRAct}_t + \alpha_6 school_t \\ & + \alpha_7 \log labour_t + \alpha_8 \log tract_t + \alpha_9 \log fertil_t + \alpha_{10} \log irrig_t + \mu_t \end{aligned} \tag{4.6}$$

Table 4.1 below summarises the variables used in the regression analyses and the data sources. The empirical results and discussion are presented in the next section.

Table 4.1: Variables used in the regression analyses and data sources[3]

Variable name	Description	Data source
logyield	Wheat yield (tonnes/ha)	South African Grain Information Service http://www.sagis.org.za/
IPR	Index of IPR protection for plant varieties	Campi and Nuvolari (2015)
$PBRAct_t$	Dummy variable for the period the PBR Act was amended	Nhemachena et al., (2016b) and Chapter 3
PBR_{ARC}	Number of PBRs granted for wheat variables released by the ARC-SGI (main public sector actor)	Nhemachena et al., (2016b) and Chapter 3
PBR_{SEN}	Number of PBRs granted for wheat variables released by Sensako (main domestic private sector actor)	Nhemachena et al., (2016b) and Chapter 3
School	Educational attainment for total population aged 15 or over	Campi (2017)
loglabour	Agricultural labour per arable land	Campi (2017)
logtract	Agricultural machinery, tractors per arable land	Campi (2017)
logfertil	Fertilisers consumption per arable land	Campi (2017)
logirrig	Total area equipped for irrigation (1000 hectares)	Campi (2017)

4.4 Empirical results and discussions

4.4.1 Wheat varietal improvement and changing structure of seed market in South Africa

This section briefly discusses the changing roles in wheat varietal improvement in South Africa based on shares of varieties in the national commercial crop. The analyses of shares of wheat seed market were based on the shares of varieties in the

[3] Data used in the cross-country study: "CAMPI, M. 2017. The effect of intellectual property rights on agricultural productivity. Agricultural Economics, 48, 327-339" was provided by Dr Mercedes Campi.

national crop obtained from the South African Grains Laboratory (SAGL) and former Wheat Board reports. Details of these data are elaborated in chapter 5 of this thesis. Figure 4.1 presents the summary of breeders' shares of wheat varieties based on area estimates from cultivar composition in national output. The analysis shows varying trends in the proportion of wheat seeds obtained from breeding programmes from the main wheat breeding programmes in the country: ARC-SGI (main public wheat breeding programme), Sensako (main private wheat breeding programme) and Pannar (minor private wheat breeding programme).

The graph indicates that from the period 1992 when the ARC was established and prior when the Wheat Board was still operational the results indicate that public research support for wheat breeding played a significant role in producing wheat varieties that contributed to the national crop. For the period up to the deregulation of the wheat sector, the wheat national crop was dominated by publicly developed varieties. These trends rapidly changed after deregulation with the private sector, mainly Sensako dominating the wheat input market.

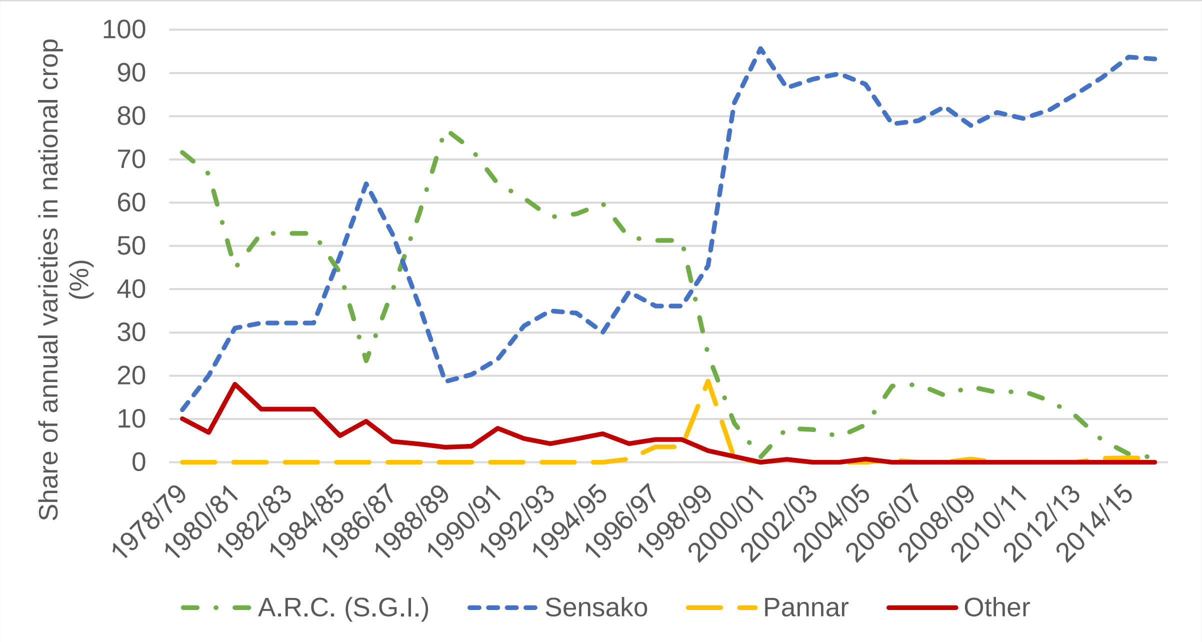


Figure 4.1: Summary of breeders shares of wheat varieties based on area estimates from cultivar composition in national output

Source: Author calculations based on area by variety estimates from wheat reports by the former Wheat Control Board and South African Grain Laboratory (See also Chapter 5)

The deregulation of the wheat sector with the abolishment of the Wheat Board in 1996, also resulted in the structural transformation of the wheat seed sector market. This led to the reduction of the share of the market share of public-produced wheat varieties in the national crop from above 50% in 1997 to less than 2% in 2015 while that of the private sector (particularly Sensako) rapidly increased from 37% to 96% in the same period. Experiences in India also showed structural transformation of agricultural input industries after policy reforms that liberalized input sectors (Pray and Nagarajan, 2014).

Furthermore, the results clearly show that the domestic private sector has dominated the wheat seed sector and this was rapid since the deregulation of the wheat sector in 1996. The findings conform to the review evidence from Pray and Fuglie (2015) that the role of the private sector in developing improved agricultural and food technologies has increased in the recent decades and private agricultural R&D investments has surpassed that from the public sector. Based on Pray and Fuglie's assessment, new commercial opportunities created by scientific advances and the liberalisation of agricultural input markets have been the major factors driving the growth of private agricultural R&D investments. The authors argued that based on empirical evidence from many studies, there are complementarities between public and private agricultural R&D despite the increased role of private R&D.

Similarly this study argues that the ARC-SGI and the domestic private sector can provide complementary benefits to each other. In this case, public wheat varietal improvement R&D investments can stimulate additional domestic private sector R&D investments and vice versa. However, when public and private R&D investments substitute each other the private sector tend to reduce their R&D investments compared to what they could have invested in the absence of public R&D (Pray and Fuglie, 2015). Additional research would be required to test the complementarity versus substitution effects in public and private wheat varietal improvement research which could not be done in the current study.

From the above analysis, it is can also be argued that the deregulation has contributed to concentration of wheat seed markets into a single private actor, Sensako, which is acting as a monopoly. Intellectual Property Rights through providing temporary monopoly in the use of an innovation, impose social costs as the monopolistic firms sell less at higher prices and might innovate less taking advantage of their market power (Boldrin and Levine, 2004). The creation of monopolistic firms in both genetic resources and seed markets have adverse implications on efforts to enhance agricultural productivity. For strategic and main food crops in a country, it might be of national interest for ensuring public resources are invested in plant breeding and varietal improvement. Though, this could not be done for the current research, future research can explore whether Sensako is acting like a monopolist, raising wheat seed prices and lowering seed supplies.

4.4.2 Correlation analyses of wheat productivity, number of varieties released and IPRs

The empirical analysis of the relationship between strong IPRs and Plant Breeders' Rights and wheat productivity and release of new high yielding wheat varieties are presented and discussed in this section. The correlation analysis of the relationship between the wheat productivity and the variables explaining IPRs/PBRs are presented in Table 4.2 below. The correlation analysis was also performed for the relationship between number of wheat varieties released and the variables explaining IPRs/PBRs (see Table 4.3).

The correlation results indicate that all coefficients of the relationships between the dependent variables (wheat productivity and number of wheat varieties released) are positive and statistically significant at 5% and 1% significance levels. The findings from this study contrast results by Campi (2017) who found no significant relationship between IPR systems and cereal productivity in middle income countries such as South Africa. The findings show that the wheat productivity and the number of wheat varieties released correlate with each of the variables representing strengthening of IPRs.

Table 4.2: Correlation analysis between wheat productivity and IPRs

DESCRIPTIVE STATISTICS & PEARSON CORRELATIONS								
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Wheat productivity	9.49	0.54	1.00					
2. IPR	1.81	1.11	0.93***	1.00				
3. PBRAct$_t$	0.33	0.48	0.80***	0.84***	1.00			
4. PRB granted	1.71	2.92	0.59***	0.62***	0.63***	1.00		
5. PBR$_{ARC}$	0.41	1.02	0.38***	0.36***	0.37***	0.16	1.00	
6. PBR$_{SEN}$	1.82	2.78	0.63***	0.60***	0.60***	0.35**	0.38***	1.00

Notes: M = Variable mean, SD = standard deviation, *** = p < .01, ** = p < .05, * = p < .10

Table 4.3: Correlation analysis between number of wheat varieties released and IPRs

DESCRIPTIVE STATISTICS & PEARSON CORRELATIONS								
	M	**SD**	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**
1. Number of wheat varieties	3.71	2.74	1.00					
2. IPR	1.81	1.11	0.50***	1.00				
3. PBRAct$_t$	0.33	0.48	0.37***	0.84***	1.00			
4. PRB granted	1.71	2.92	0.41***	0.62***	0.63***	1.00		
5. PBR$_{ARC}$	0.41	1.02	0.32**	0.36***	0.37***	0.16	1.00	
6. PBR$_{SEN}$	1.82	2.78	0.32**	0.60***	0.60***	0.35**	0.38***	1.00

Notes: M = Variable mean, SD = standard deviation, *** = p < .01, ** = p < .05, * = p < .10

Using rough commonly-held guidelines on the sizes of correlations (Lee, 2016), analysis of the correlation sizes between wheat productivity and the PBRs granted (total, and Sensako) show correlations ranging from 0.5 to 0.8 which indicate that there is large correlation/ good evidence of association between these variables. The results for the PBRs granted to the ARC-SGI and wheat productivity has a correlation of 0.38 which points to moderate evidence of association between the variables. Furthermore, the correlations between wheat productivity and IPR index and period after amendment of PBR Act to align with the constitution and UPOV 1991 has very big correlations/ strong evidence of association (above 0.80) between the variables. The results points to more influence of Sensako (domestic private sector) developed varieties in the harvested national crop. The findings point to stimulation of private sector investments by stronger IPR systems in the country. As indicated in the review above, evidence from other countries such as India and Brazil demonstrated that private sector investments were stimulated by strengthened IPR systems (Pray and Nagarajan, 2014, Flister and Galushko, 2016).

In addition, the correlations between the number of varieties released and PBRs granted (total, ARC-SGI and Sensako) were found to be statistically significant (at 5% and 1% levels). The correlation coefficients were in the range 0.30 to 0.49 which indicate moderate correlations/ evidence of association between the variables. From these results it can be argued that although there is some relationship between number of varieties released and PBRs granted the relationships are not very strong. This might point to the fact that PBRs alone does not have very strong influence on the decisions to invest more in wheat varietal improvements. For example, for private firms, the seed royalties are insufficient to conduct basic research and experiences from Brazil indicated that the private sector directed their investments to more profitable ventures like applied research and development of new cultivars (Flister and Galushko, 2016). This means stimulating investments in wheat varietal improvements in South Africa should go beyond strengthening IPR systems.

Although the results suggest the dominance of private sector activity in wheat breeding in the country, empirical evidence from other countries indicate that public research investments provide complementary stimulus to investments by the private sector in agricultural R&D (Pray and Nagarajan, 2014, Wang et al., 2013). For example, in India, public research institutions generated parental breeding lines that were used by private seed companies to produce hybrid varieties for crops such as cotton, sorghum, maize and rice (Pray and Nagarajan, 2014). Pedigree analysis of the domestic private sector varieties especially from Sensako (see chapter 5 of this thesis) also demonstrated that they have benefited from parental breeding lines produced by the ARC-SGI. This indicates that complementary investments in wheat varietal improvements should be strengthened as part of efforts to improve delivery of improved wheat varieties and enhance productivity in the country.

4.4.3 Estimating effects of IPRs/PBRs on wheat productivity and number of varieties released

To further explore the findings from correlation analyses presented above, regression analyses were performed. As indicated above, the dependent variables used in the analyses were wheat productivity and the number of wheat varieties released. The independent variables included the IPR index, number of Plant Breeders' Rights granted for wheat varietal releases, Plant Breeders' Rights for ARC and Sensako varieties and a dummy variable for the period the country amended the Plant Breeders' Rights Act to confirm with the constitution and UPOV 1991. Econometric tests were performed to test for potential multicollinearity in independent variables before performing the final regressions. If multicollinearity is exist among the regressors, it results in imprecise estimates of the parameters (Cameron and Trivedi, 2005).

The correlation analyses presented above didn't show very high correlations to suspect problems of multicollinearity. Furthermore, multicollinearity was tested based on the variance inflation factor (VIF) (Lee, 2016). The VIF values of less than 10 in the regression results imply that multicollinearity is not a problem in the model specification. The empirical results from the estimations showed that multicollinearity was not a major issue in each of the models. However, as indicated above, multicollinearity was a challenge with other variables used by Campi (2017) and these were dropped in the regressions performed for this study.

Another challenge of multiple regression analyses is the presence of heteroscedasticity in the error terms which results in inconsistent but inefficient estimates of parameters and inconsistent estimates of the covariance matrix (White, 1980). Incorrect inferences can be drawn if hypotheses are tested in the presence of heteroscedasticity. To address potential problems of heteroscedasticity, the regression models were estimated using a heteroscedasticity-robust standard error estimation procedure. The heteroscedasticity-robust standard error estimation computes robust variance estimators using equation level scores and a covariance matrix (Cameron and Trivedi, 2010).

The results of a simple regression model of each of the dependent variables and IPR index and number of PBR granted are presented in Tables 4.4 and 4.5 respectively.

The R-Square adjusted of the models with IPR Index as an independent variable show that the regressions explained 70% and 23% of the variability in wheat productivity and the number of wheat varieties released respectively. For the regressions with the PBR granted as independent variable the models explained 33% and 19% of the variability in the same dependent variables respectively. The coefficients of the IPR index and PBR granted show that both independent variable had a positive and statistically significant relationship with both wheat productivity and the number of wheat varieties released. These results confirm the findings of the correlation analyses discussed above and demonstrate that strengthening IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. This confirms to findings discussed in the literature review above from other parts of the world (Knudson and Pray, 1991, Kolady and Lesser, 2009, Naseem et al., 2005, Spielman and Ma, 2016) that strengthening IPR systems stimulate investments in plant breeding, release of new varieties and enhances crop yields.

Table 4.4: Simple regression model of wheat yield/ number of varieties released and IPR index

	OLS parameters					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.66***		0.000	8.55 to 8.77	0.00	8.68***		0.000	8.55 to 8.81
IPR Index	0.46***	0.93	0.000	0.40 to 0.51	1.00	0.45***	0.92	0.000	0.39 to 0.51
R Square	**0.86**					**0.70**			
Dependent variable: Number of wheat varieties released									
Intercept	**1.52****			0.02 to 2.84	0.00	1.28**		0.041	0.05 to 2.51
IPR Index	**1.27*****			0.62 to 1.91	1.00	1.22***	0.49	0.000	0.62 to 1.83
R Square	**0.25**					**0.23**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

Table 4.5: Simple regression model of wheat yield/ number of varieties released and PBR granted

	OLS parameters					Robust Parameters			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	9.30***		0.000	9.16 to 9.44	0.00	9.28***		0.000	9.12 to 9.44
PBR granted	0.11***	0.59	0.000	0.07 to 0.15	1.00	0.11***	0.58	0.000	0.06 to 0.15
R Square	**0.35**					**0.33**			
Dependent variable: Number of wheat varieties released									
Intercept	3.11***		0.000	2.27 to 3.94	0.00	2.67***		0.000	1.90 to 3.45
PBR granted	0.40***	0.41	0.004	0.13 to 0.66	1.00	0.47***	0.50	0.000	0.23 to 0.71
R Square	**0.16**					**0.19**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

The empirical results from the multiple regression analyses using all the variables of the IPRs are presented in Tables 4.6 and 4.7 below. Table 4.6 present the results with the PBR granted variable disaggregated between PBR granted for wheat varieties released by the ARC-SGI and Sensako. Table 4.7 shows the results with the aggregated PBR granted variable. An additional variable added is the dummy variable for the years South Africa amended the Plant Breeders' Rights Act to confirm with the constitution and UPOV 1991. The results show that for the first regression with disaggregated PBR granted variable, the robust estimate of the IPR index for the wheat productivity variable is positive and statistically significant. These results of the regression implies that international spillovers are much more important in local wheat breeding. These findings are confirmed by pedigree analysis of wheat varieties and attribution of benefits presented in chapter 5. The coefficient of the same variable is positive and insignificant with the dependent variable of number of wheat varieties released.

The results further suggest the strong relationship between wheat productivity and strengthening of IPR systems in the country. As reviewed in the literature section above, strengthening of the IPRs for plant varieties result in increased release of improved crop varieties and technologies that positively contribute to enhancing agricultural productivity and economic growth (Campi, 2017, Tripp et al., 2007). On the contrary as indicated earlier the relationship between release of new varieties and IPR systems is not that strong although it is positive. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios. The results also suggest that the relationship between PBR granted might also not have a very strong relationship with wheat productivity and the number of wheat varieties released. This indicates that there is need for more incentives beyond granting PBRs to be provided in the whole wheat sector to stimulate increased investments and release of new varieties.

Table 4.6: Multiple regression model of wheat yield/ number of varieties released and IPRs

	OLS parameters					**Robust Parameters**			
Dependent variable: Wheat productivity									
Variable	**B**	**β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.70***		0.000	8.56 to 8.83	0.00	8.72***		0.000	8.57 to 8.87
IPR Index	0.41***	0.83	0.000	0.31 to 0.50	3.51	0.39***	0.80	0.000	0.28 to 0.51
PBR_{ARC}	0.02	0.03	0.557	-0.04 to 0.08	1.22	0.02	0.03	0.610	-0.05 to 0.09
PBR_{SEN}	0.02	0.10	0.176	-0.01 to 0.05	1.72	0.02	0.09	0.250	-0.01 to 0.05
$PBRAct_t$	0.04	0.04	0.718	-0.19 to 0.27	3.55	0.07	0.06	0.613	-0.19 to 0.33
R Square	**0.87**					**0.73**			
Dependent variable: Number of wheat varieties released									
Intercept	1.35*		**0.093**	-0.24 to 2.93	0.00	1.55**		0.033	0.12 to 2.97
IPR Index	1.40**	0.56	**0.020**	0.22 to 2.58	3.18	0.86	0.35	0.124	-0.24 to 1.96
PBR_{ARC}	0.38	0.14	**0.360**	-0.45 to 1.20	1.45	0.43	0.16	0.254	-0.31 to 1.17
PBR_{SEN}	0.03	0.03	**0.881**	-0.36 to 0.42	1.72	0.08	0.08	0.671	-0.28 to 0.44
$PBRAct_t$	-0.94	-0.16	**0.500**	-3.71 to 1.84	3.16	0.10	0.02	0.942	-2.54 to 2.74
R Square	**0.27**					**0.27**			

Notes for parameters: B = unstandardized parameters, β = standardized parameters, $^{***} = p < .01$, $^{**} = p < .05$, $^{*} = p < .10$

Table 4.7: Multiple regression model of wheat yield/ number of varieties released, IPRs and aggregate PBR granted

	OLS parameters					Robust Parameters			
Dependent variable: Wheat productivity									
Variable	**B**	**Β**	**Pr > |t|**	**95 % CI**	**Variance Inflation**	**B**	**β**	**p**	**95 % CI**
Intercept	8.69***		0.000	8.55 to 8.83	0.00	8.72***		0.000	8.56 to 8.87
IPR Index	0.42***	0.86	0.000	0..32 to 0.52	3.51	.041***	0.83	0.000	0.29 to 0.52
PBR granted	0.0008	0.004	0.952	-0.03 to 0.03	1.76	0.003	0.01	0.886	-0.03 to 0.03
$PBRAct_t$	0.09	0.08	0.465	-0.15 to 0.32	3.57	0.10	0.09	0.450	-0.16 to 0.37
R Square	**0.86**					**0.71**			
Dependent variable: Number of wheat varieties released									
Intercept	1.42*		0.074	-0.14 to 3.00	0.00	1.58**		0.034	0.12 to 3.03
IPR Index	1.33**	0.53	0.026	0.17 to 2.50	3.19	0.90	0.36	0.116	-0.22 to 2.02
PBR granted	0.19	0.19	0.267	-0.15 to 0.52	1.73	0.24	0.25	0.155	-0.09 to 0.56
$PBRAct_t$	-1.05	-0.18	0.449	-3.82 to 1.72	3.24	-0.11	-0.02	0.934	-2.84 to 2.61
R Square	**0.28**					**0.26**			

*Notes for parameters: B = unstandardized parameters, β = standardized parameters, *** = p < .01, ** = p < .05, * = p < .10*

4.5 Summary and recommendations

The chapter analysed the effects of strengthening wheat variety intellectual (IP) protection on wheat productivity and release of new varieties. The strength of IPR systems was measured using an IP protection index, plant variety protection legislation and the number of Plant Breeders' Rights granted for wheat varieties. Analysis of changes in the roles of public and private wheat research based on shares of varieties in the national commercial crop showed that wheat sector reforms resulted in the structural transformation of the wheat seed sector market. This led to the reduction of the share of the market share of public-produced wheat varieties in the national crop from above 50% in 1997 to less than 2% in 2015 while that of the private sector (particularly Sensako) rapidly increased from 37% to 96% in the same period.

The empirical analyses were based on correlation and multiple regression analyses. The correlation analyses results showed that wheat productivity and the number of wheat varieties released correlate with each of the variables representing strengthening of IPRs. Furthermore, correlation analysis showed that for the wheat productivity relationship, the results indicate a higher correlation with PBR granted for Sensako (domestic private sector) breeding programmes compared to those from the ARC-SGI (main public sector actor). However, the correlation values were small for PBRs granted for both ARC-SGI and Sensako varieties indicating that the relationship might be weak.

The simple regression model results with IPR index and PBR granted as independent variables confirmed the positive and significant relationship between these variables and wheat productivity and the number of varieties released. The findings demonstrate that strengthening IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. Multiple regression analyses results suggested a strong relationship between wheat productivity and strengthening of IPR systems in the country. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios.

Overall, based on these findings it can be argued that in the South African wheat sector, strengthening PBRs (or IPR systems) contribute to increased investments and release of wheat varieties. However, there is need for more incentives beyond granting PBRs and strengthening of IPR systems to be provided in the whole wheat sector to stimulate increased investments and release of new varieties.

CHAPTER 5

ESTIMATING AND ATTRIBUTING BENEFITS FROM WHEAT VARIETAL INNOVATIONS IN SOUTH AFRICAN AGRICULTURE

5.1 Introduction

Biological innovations, particularly varietal improvements have greatly contributed to agricultural yield and output growth in the past (Alston et al., 2000, Pardey et al., 2016a, Pardey et al., 2016b, Fan et al., 2005, Lantican et al., 2016, Pingali, 2010, Rao et al., 2016). Varietal improvements are beneficial to farmers through improving yield potential, increasing resistance to biotic and abiotic stresses and improving other qualities of crops such as nutrition and processing (Atack et al., 2009, Lantican et al., 2005, Lantican et al., 2016). For example, the benefits of improved wheat varieties include gains in productivity, better quality of grain and end products, reduced food prices for consumer and reduced negative impact on the environment (Lantican et al., 2005, Lantican et al., 2016, Pal, 2011). Investments in biological innovations (varietal improvements) are important in increasing and sustaining agricultural productivity in the face of changes in agricultural production potential and other factors (Nhemachena et al., 2016a).

Given the competing needs for public resources and the current changing political climate where public funding for research and development has been decreasing (Pardey et al., 2016a, Pardey et al., 2016b, Pal, 2011, Maredia and Byerlee, 2000), further support for wheat varietal research depends on the benefits to the public from the investments. For example, despite the widely accepted contribution of the Agricultural Research Council (ARC) in improving performance of the agricultural sector in South Africa (Liebenberg, 2013), public funding (through the Parliamentary Grant) to the ARC has been declining in real terms over the recent years (Dlamini et al., 2015). This affects research activities of the ARC, including crop breeding programmes, which would have to compete for the declining resources for their continued operations (Dlamini and Liebenberg, 2015, Dlamini et al., 2015). The reality of declining public funding emphasises the need for the different research programmes to demonstrate their returns to public investments to prove their worth for continued funding. Estimation of empirical benefits from wheat varietal improvement research provides an important source of information that decision-makers could use to make informed decisions on prioritisation and allocation of public funding for wheat varietal research and other research needs.

Agricultural research and development by nature involves collaboration among different institutions and failure to properly attribute benefits from research investments from various players in both the public and private sectors leads to overestimation of economic benefits from research (Alston and Pardey, 2001, Pardey et al., 2006, Alston et al., 2009, Fuglie and Heisey, 2007, Lantican et al., 2016). South African wheat farmers use seeds generated from research efforts from different sources in the public and private sectors as well as breeding programmes from outside the country. Various studies measuring economic benefits from crop breeding research have applied different methods for estimating aggregate benefits generated from farmers' adoption of new varieties. As discussed in Chapter 1, the challenge is how these aggregate benefits can be attributed to a specific institution or breeding programme in a scenario where the benefits generated benefited from research investments from other research institutions (public and private) (Maredia et al., 2010, Alston and Pardey, 2001, Alston et al., 2009, Pardey et al., 2006, Fuglie and Heisey, 2007).

A number of studies (Brennan and Quade, 2004, Heisey et al., 2002, Lantican et al., 2016, Lantican et al., 2005, Maredia et al., 2010, Pardey et al., 2006) have made an effort to estimate economic benefits from crop varietal improvements and attribute the benefits to different institutions that were actively involved. The current study uses the econometric methodology applied by Maredia et al., (2010) and Pardey et al., (2006) to estimate benefits of the ARC Small Grains Institute (ARC-SGI) wheat varietal improvement research programme. Based on the econometric approach, the current study estimated vintage regression models to generate estimates of wheat yield gains from release of new varieties. Using the estimates of the wheat yield gain from wheat varietal research and data on wheat production and producer prices, the aggregate benefits from investments in wheat varietal research in South Africa were estimated for the period 1978 – 2015. The approach applied estimated benefits credited to ARC-SGI wheat varietal research investments and other sources, as well as across different time periods.

Following earlier research on the economic impact of wheat and other crop breeding research (Heisey et al., 2002, Lantican et al., 2016, Lantican et al., 2005, Maredia et al., 2010, Reyes et al., 2016), the process of estimating benefits from wheat varietal improvement in South African agriculture involved the following:

(a) the investments in the development of new wheat varieties;
(b) the adoption of the released varieties by farmers and generation of benefits through yield gains;
(c) the estimation of benefits credited to different sources of wheat varietal investments and to different time periods.

If the ARC-SGI wheat research costs had been available during this study, the last part would be to estimate returns per each R1 invested in wheat varietal research over time. The study collected a detailed dataset for the empirical estimation of economic benefits of ARC-SGI wheat varietal improvement research. The data and empirical estimations for each of the above steps are discussed in detail below.

5.2 Description of data and sources

The empirical analyses were based on secondary data from different sources and consultations with key informants at the ARC-SGI and Department of Agriculture, Fisheries and Forestry (DAFF). Data of wheat trends in area, production, and yield were obtained from the DAFF's Crop Estimation Committee (CEC) and wheat prices were obtained from the South African Grain Information Service (SAGIS). The price data represents the annual average producer price of wheat per tonne. Data of wheat varieties and other characteristics were collected from annual wheat reports of the former Wheat Control Board, agricultural statistics reports (gathered from Statistics South Africa and the National Library of South Africa) and the South African Grain Laboratory (SAGL). The information regarding the structure of the wheat varietal improvement sector was derived from a review of published articles, reports from the ARC-SGI and engagements with experts from both the DAFF, ARC-SGI, CEC, SAGL.

Estimation of varietal adoption was based on estimating the area planted to each ARC-SGI variety. Data on the proportion of each variety planted in each year in the national wheat crop was derived from wheat quality reports from the SAGL and wheat annual reports from the former Wheat Control Board (see Tables 5.3 and 5.4 below). These sets of data were used to estimate the area planted to each variety, together with data from trends in area, production, and yield from the CEC. Three different time periods that were used in the analysis are: 1991 (representing the period before establishment of the ARC-SGI. During this period, it was still the Small Grains Centre), 1996 (representing the period from establishment of the ARC and deregulation of the wheat sector in 1996) and 2015 (representing the deregulated wheat sector period).

Information of pedigrees of varieties released during the study period were obtained from different sources including the CIMMYT wheat map website, the Farming in South Africa Journal and other published literature. The information on pedigrees of selected wheat varieties was used to determine attribution of benefits from wheat varietal research from different sources.

The data on investments on wheat varietal improvement research by the ARC-SGI could not be obtained for the purposes of this research. In the absence of investment and cost data for the wheat varietal improvement research programme, the study could not estimate benefit-cost ratios as initially planned. Future research can estimate the benefit-cost ratio when the respective data are made available.

5.3 Investments in wheat varietal improvement research and the use of new varieties

The South African wheat seed industry consists of breeders, and a developed private sector that multiplies and sells improved seeds to farmers. The main breeders of improved wheat varieties are Sensako, ARC-SGI and Pannar. Sensako has the largest proportion of seeds commercially grown in South Africa. The private companies develop wheat varieties for different growing regions of South Africa and most probably, their seed is also sold to neighbouring countries such as Lesotho, Swaziland and Namibia. This also applies to ARC-SGI varieties which are commercially sold in the market. In this case, both ARC-SGI-bred varieties spillover to other countries. Similarly, wheat varietal improvement research by the ARC-SGI benefits from collaboration with various institutions both public and private.

The wheat varietal improvement research by the ARC-SGI and other institutions focusses on crossing and testing for higher yielding varieties across the different wheat production regions. In addition, wheat varietal improvement in the country aims at addressing the following wheat production challenges: disease and pest resistance, wheat quality (especially for bread wheats), drought resistance and suitability to different agro-climatological conditions in each wheat production region. To illustrate the role of the ARC in wheat varietal improvement, the study gathered data on all wheat varieties released since the establishment of the ARC-SGI from all sources (ARC and other research centres)[4]. Table 5.1 summarises wheat varietal releases from 1976 – 2013. The data indicates that the private sector in South Africa, dominated by Sensako, releases the bulk of new wheat varieties in South Africa. However, the ARC-SGI has been central to wheat varietal releases in the country since the establishment of the Small Grains Centre in 1976 and has provided varietal releases, most of which were licensed to the private sector for multiplication. In recent years, the contribution of the ARC-SGI has decreased with the decline of public funding since the deregulation of the wheat market in 1997.

Table 5.1: Summary of wheat varieties released by the main breeding institutions

Institution	Varieties		Percentage share of total from 1976 to 2013	Percentage share of total 1996 to 2013
	Total	Average per year		
Sensako	102	2.6	59	61.8
ARC-SGI	51	1.1	24.1	16.5
Pannar	41	0.74	16.9	21.8

Source: Author calculations based on wheat varietal improvement data gathered from various sources

Table 5.2 summarises the wheat varieties that were included in the multiple regression analyses. The selection was based on commercial success of the varieties derived

[4] Data on wheat varietal improvement research in the years prior to this study was also gathered and presented in detail in the earlier chapters of this study.

from the proportion of the variety in the national crop output for each year. The 82 varieties selected in Table 5.2 had a proportion of share in the national crop of at least 1%. The proportion represented by the varieties selected ranged from 92% to 99% of the national crop each year. About 48% of the selected varieties were grown under irrigation, while about 40% were grown under dryland summer areas; the remainder were produced under dryland winter conditions.

Table 5.2: Wheat varieties included in multiple regression analysis

Production type	**Variety****	**Breeder**	**Type of Breeder**	**Year of Release**
Irrigation	Adam Tas	Sensako	Private	1989
	CRN826	Sensako	Private	2002
	Dias	Other	Other	1988
	Duzi	ARC-SGI	Public	2004
	Elize	CIMMYT	International Research	1975
	Elrina	ARC-SGI	Public	1976
	Gamtoos	ARC-SGI	Public	1985
	Helene	CIMMYT	International Research	1975
	Inia	CIMMYT	International Research	1970
	Kariega	ARC-SGI	Public	1993
	Krokodil	ARC-SGI	Public	2004
	Marico	ARC-SGI	Public	1992
	Nantes	Sensako	Private	1989
	Olifants	ARC-SGI	Public	2001
	Palmiet	ARC-SGI	Public	1984
	PAN3471	Pannar	Private	2008
	SST 2	Sensako	Private	1979
	SST 23	Sensako	Private	1981
	SST 25	Sensako	Private	1984
	SST 3	Sensako	Private	1973
	SST 44	Sensako	Private	1979
	SST 55	Sensako	Private	1992
	SST 57	Sensako	Private	1994
	SST 65	Sensako	Private	1995
	SST 66	Sensako	Private	1979
	SST 806	Sensako	Private	2000
	SST 822	Sensako	Private	1992
	SST 825	Sensako	Private	1992
	SST 835	Sensako	Private	2003
	SST 843	Sensako	Private	2008
	SST 86	Sensako	Private	1987
	SST 875	Sensako	Private	1997
	SST 876	Sensako	Private	1997
	SST 877	Sensako	Private	2009

Production type	Variety**	Breeder	Type of Breeder	Year of Release
	SST 884	Sensako	Private	2011
	SST 895	Sensako	Private	2010
	Steenbras	ARC-SGI	Public	1999
	T 4	ARC-SGI	Public	1965
	Zaragosa	CIMMYT	International Research	1978
Dryland (summer)	**Belinda**	ARC-SGI	Public	1970
	Betta	ARC-SGI	Public	1970
	Betta DN	ARC-SGI	Public	1992
	Caledon	ARC-SGI	Public	1996
	Carina (205)	Carnia	Private	1988
	Caritha (301)	Carnia	Private	1986
	Carol (310)	Carnia	Private	1987
	Elands	ARC-SGI	Public	1998
	Flamink	ARC-SGI	Public	1979
	Gariep	ARC-SGI	Public	1994
	Hugenoot	Sensako	Private	1987
	Karee	ARC-SGI	Public	1981
	Komati	Monsanto/ ARC-SGI	Public and Private	2002
	Limpopo	ARC-SGI	Public	1994
	Matlabas	ARC-SGI	Public	2003
	Molen	ARC-SGI	Public	1986
	Oom Charl	ARC-SGI	Private	1988
	PAN3211	Pannar	Private	1992
	PAN3235	Pannar	Private	1993
	PAN3349	Pannar	Private	1994
	PAN3377	Pannar	Private	1997
	PAN3408	Pannar	Private	2001
	Scheepers 69	ARC-SGI	Public	1969
	SST 101	Sensako	Private	1978
	SST 102	Sensako	Private	1978
	SST 107	Sensako	Private	1979
	SST 124	Sensako	Private	1981
	SST 356	Sensako	Private	2005
	SST 399	Sensako	Private	1992
	SST 94	Sensako	Private	1999
	SST 966	Sensako	Private	1996
	Tugela	ARC-SGI	Public	1985
	Tugela DN	ARC-SGI	Public	1992
Dryland (winter)	Gouritz	Other	Other	1978
	SST 015	Sensako	Private	2001
	SST 027	Sensako	Private	2002
	SST 047	Sensako	Private	2005
	SST 056	Sensako	Private	2005
	SST 087	Sensako	Private	2009
	SST 127	Sensako	Private	2013
	SST 16	Sensako	Private	1977

Production type	Variety**	Breeder	Type of Breeder	Year of Release
	SST 33	Sensako	Private	1979
	SST 88	Sensako	Private	1998

[a]ARC-SGI varieties are identified in bold letters

Every production year, wheat varieties are grown across the country, based on farmer's preferences and other factors that include access to the seeds, suitability to specific agro-climatological regions and quality of grain yield. Varieties that have the most preferred characteristics have higher chances of being adopted by farmers. The amount of land area planted to each wheat variety determines the commercial success of the variety. However, no variety can be successful in all environments and at all times; as some have specific areas where they are partially successful (Maredia et al., 2010).

The wheat varieties that were adopted by farmers and have been fully or partially successful commercially were selected for empirical analysis in this study. The selection criteria involved analysis of the shares of wheat varieties in the national crop. The shares of each wheat variety for each year were gathered from estimates from SAGL and the former Wheat Control Board (from the wheat quality reports). In addition to having a proportion of at least 1% in the national crop, a variety was selected only if it was represented in at least two years between 1978 and 2015. Based on technical expert advice from the ARC-SGI, the average wheat varietal research lag was assumed to be 8 years. This meant that wheat varieties released post-1986 were considered to be the benefits from investments in varietal improvement from 1978 onwards, which is the period of analysis for this study. Therefore, for the empirical analysis, varieties commercially grown for at least 2 years from 1985 – 2015 were included in the analysis. The year 1985 was selected as the base year because this was the last year before release of new wheat varieties based on varietal improvement efforts invested in the post-1978 period. Based on these assumptions, the following varieties were dropped from the analysis as they were grown prior to 1985 (Elrina, Gouritz, Helene, SST 101, SST 2 and SST 3). The summary of the market shares of selected from 1985 to 2015 is presented in Tables 5.3 and 5.4 below.

Table 5.3: Market share of wheat varieties adopted in South Africa, 1985 – 2000

Variety	**Breeder**	**Year of Release**	**1985/86**	**1986/87**	**1987/88**	**1988/89**	**1989/90**	**1990/91**	**1991/92**	**1992/93**	**1993/94**	**1994/95**	**1995/96**	**1996/97**	**1997/98**	**1998/99**	**1999/00**
Irrigation wheat																	
Adam Tas	Sensako	1989							0,6	6,1	5,9	6,4	4,9	1,5	1,5		0,6
CRN826	Sensako	2002															
Dias	Other	1988						2,9	1,0	1,1							
Duzi	**ARC-SGI**	**2004**															
Elize	CIMMYT	1975	0,7	0,6	0,6												
Elrina	**ARC-SGI**	**1976**															
Gamtoos	**ARC-SGI**	**1985**			1,8	3,3	5,8	5,5	4,5	7,0	5,6	6,4					
Helene	CIMMYT	1975															
Inia	CIMMYT	1970	4,6	1,9	3,0	3,5	2,8	2,9	2,2	3,2	1,8	4,2	1,8	1,9	1,9		1,3
Kariega	**ARC-SGI**	**1993**											1,5			2,1	3,8
Krokodil	**ARC-SGI**	**2004**															
Marico	**ARC-SGI**	**1992**											1,5	1,2	1,2	1,0	0,7
Nantes	Sensako	1989								0,6	2,4	3,4	3,2	1,0	1,0		
Olifants	**ARC-SGI**	**2001**															
Palmiet	**ARC-SGI**	**1984**		0,8	8,2	17,7	26,0	23,7	22,0	45,0	32,6	43,0	33,7	29,0	29,0	1,3	1,2
PAN3471	Pannar	2008															
SST 2	Sensako	1979	1,2														
SST 23	Sensako	1981	4,8	1,9													
SST 25	Sensako	1984		1,5	2,4	1,1	0,7										
SST 3	Sensako	1973	2,2	1,3	1,1												
SST 44	Sensako	1979	5,6	2,8	1,3	1,1	0,7										
SST 55	Sensako	1992										2,2	8,6	5,2	5,2	0,6	2,9
SST 57	Sensako	1994														2,8	19,8
SST 65	Sensako	1995															17,9
SST 66	Sensako	1979	29,9	24,3	17,8	8,9	7,8	5,9	4,9	4,5	3,3	2,5	2,4	0,7	0,7		
SST 806	Sensako	2000															
SST 822	Sensako	1992											2,8	5,1	5,1	1,6	8,6
SST 825	Sensako	1992											4,2	6,5	6,5	31,1	26,2
SST 835	Sensako	2003															
SST 843	Sensako	2008															
SST 86	Sensako	1987					2,6	9,4	8,3	10,7	6,3	8,2	2,4	1,7	1,7		
SST 875	Sensako	1997															
SST 876	Sensako	1997															4,9
SST 877	Sensako	2009															
SST 884	Sensako	2011															
SST 895	Sensako	2010															
Steenbras	**ARC-SGI**	**1999**															
T 4	**ARC-SGI**	**1965**	5,0	3,2	4,5	4,0	2,9	2,7	2,3	1,1	1,0	0,9				2,3	
Zaragosa	CIMMYT	1978	4,1	2,3	0,7												

Variety	Breeder	Year of Release	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00
Dryland (summer) wheat																	
Belinda	**ARC-SGI**	**1970**	1,0	1,8	1,5	1,9	1,6	1,8	1,7		1,0	0,6	1,0	1,5	1,5		
Betta	**ARC-SGI**	**1970**	7,5	17,8	11,0	13,1	10,6	7,3	6,0	1,0	3,9	1,5	2,3	1,7	1,7	1,2	
Betta DN	**ARC-SGI**	**1992**														0,7	1,4
Caledon	**ARC-SGI**	**1996**														2,1	
Carina (205)	Carnia	1988						0,7	0,9		2,0	1,5	2,5	1,9	1,9	1,2	
Caritha (301)	Carnia	1986					0,9	1,4	1,4		1,6	0,9		0,8	0,8	1,5	
Carol (310)	Carnia	1987												0,7	0,7		
Elands	**ARC-SGI**	**1998**															
Flamink	**ARC-SGI**	**1979**		1,6	1,2	1,1	0,6			0,7							
Gariep	**ARC-SGI**	**1994**												0,8	0,8	13,4	0,8
Hugenoot	Sensako	1987							1,1		3,6	2,1	3,9	3,3	3,3	2,9	
Karee	**ARC-SGI**	**1981**	2,0	3,5	6,8	10,1	9,0	8,7	7,9	1,9	4,1	1,9	2,8	4,2	4,2		
Komati	**Monsanto /ARC-SGI**	**2002**															
Limpopo	**ARC-SGI**	**1994**															1,3
Matlabas	**ARC-SGI**	**2003**															
Molen	**ARC-SGI**	**1986**			3,9	9,8	5,9	5,0	5,6		3,1	2,3	2,1	4,3	4,3		
Oom Charl	**ARC-SGI**	**1988**						1,9	1,8				0,7				
PAN3211	Pannar	1992											0,7	3,5	3,5	14,8	1,0
PAN3235	Pannar	1993														3,1	
PAN3349	Pannar	1994														0,9	
PAN3377	Pannar	1997															
PAN3408	Pannar	2001															
Scheepers 69	**ARC-SGI**	**1969**	7,9	11,0	13,4	8,8	4,7	3,9	4,6		2,0	0,6	0,9	1,2	1,2		
SST 101	Sensako	1978															
SST 102	Sensako	1978	2,1	4,9	1,9	2,2	2,4	1,4	1,2		1,5		0,8	0,8	0,8		
SST 107	Sensako	1979	0,6	6,1	5,8	2,3	1,3	1,2	1,8		1,0			0,7	0,7		
SST 124	Sensako	1981					1,1	2,9	11,2	8,9	8,1	3,5	5,1	9,4	9,4	6,5	1,3
SST 356	Sensako	2005															
SST 399	Sensako	1992															
SST 94	Sensako	1999															
SST 966	Sensako	1996															1,0
Tugela	**ARC-SGI**	**1985**			5,1	7,3	5,2	3,8	4,6		4,1	2,6	4,2	4,7	4,7	0,9	
Tugela DN	**ARC-SGI**	**1992**											1,2	2,6	2,6		
Dryland (winter) wheat																	
Gouritz	Other	1978															
SST 015	Sensako	2001															
SST 027	Sensako	2002															
SST 047	Sensako	2005															

Variety	Breeder	Year of Release	1985/86	1986/87	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00
SST 056	Sensako	2005															
SST 087	Sensako	2009															
SST 127	Sensako	2013															
SST 16	Sensako	1977	11,0	6,5	4,6	2,4	3,9	3,1	2,4	4,1	2,3	1,8	1,1	0,5	0,5		
SST 33	Sensako	1979	7,1	3,4	1,5	0,7											
SST 88	Sensako	1998															

** ARC-SGI varieties are bolded

Table 5.4: Market share of wheat varieties adopted in South Africa, 2001 – 2015

Variety	Breeder	Year of Release	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/2015	2015/2016
Irrigation wheat																		
Adam Tas	Sensako	1989																
CRN826	Sensako	2002					3,2	3,5	4,4	1,1	9,9	8,9	4,2	3,0				
Dias	Other	1988																
Duzi	**ARC-SGI**	**2004**							7,0	9,3	6,1	9,2	8,4	10,2	7,9	4,2	1,9	
Elize	CIMMYT	1975																
Elrina	**ARC-SGI**	**1976**																
Gamtoos	**ARC-SGI**	**1985**																
Helene	CIMMYT	1975																
Inia	CIMMYT	1970		0,7			0,7											
Kariega	**ARC-SGI**	1993	1,2	2,2	1,2	1,0	1,4	2,2	1,3	1,3	1,1	1,6		0,8	0,8	0,9		
Krokodil	**ARC-SGI**	2004							4,4		1,9	0,6	1,2	1,5	1,0			
Marico	**ARC-SGI**	**1992**																
Nantes	**Sensako**	**1989**																
Olifants	**ARC-SGI**	**2001**				1,4	2,7	3,3	0,7		0,8							
Palmiet	**ARC-SGI**	1984																
PAN3471	Pannar	2008															0,6	0,8
SST 2	Sensako	1979																
SST 23	Sensako	1981																
SST 25	Sensako	1984																
SST 3	Sensako	1973																
SST 44	Sensako	1979																
SST 55	Sensako	1992																
SST 57	Sensako	1994	3,5	18,9	16,9	17,9	18,7	13,7	7,0	7,7	3,3							
SST 65	Sensako	1995	3,0	8,8	4,9	4,8	1,6	0,8										
SST 66	Sensako	1979																

Variety	Breeder	Year of Release	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/2015	2015/2016
SST 806	Sensako	2000			6,5	16,2	7,5	7,9	6,1	3,0	2,0		0,7	1,2	3,0	3,4	2,0	2,0
SST 822	Sensako	1992	16,4	7,4	7,9	3,8	4,0	2,4	3,2	1,2	1,7		2,2	1,9	3,7	1,4	0,6	
SST 825	Sensako	1992	48,2	9,3	6,1	4,4	2,8	3,4	0,7									
SST 835	Sensako	2003								2,1	10,0	17,8	13,1	12,8	7,2	5,5	3,3	3,1
SST 843	Sensako	2008										7,1	9,3	8,5	4,3	2,4	3,3	3,4
SST 86	Sensako	1987																
SST 875	Sensako	1997												0,9	7,3	4,7	3,6	2,0
SST 876	Sensako	1997	23,3	18,1	14,3	7,3	9,0	6,3	4,3	3,1	3,2	1,5	0,6	0,8				0,9
SST 877	Sensako	2009											0,9	1,1	1,6	1,3		1,0
SST 884	Sensako	2011													2,7	5,6	8,7	6,7
SST 895	Sensako	2010															1,4	2,0
Steenbras	**ARC-SGI**	**1999**		0,7	0,8													
T 4	**ARC-SGI**	**1965**																
Zaragosa	CIMMYT	1978																
Dryland (summer) wheat																		
Belinda	**ARC-SGI**	**1970**																
Betta	**ARC-SGI**	**1970**																
Betta DN	**ARC-SGI**	**1992**		1,6	1,7			0,9	0,7		0,5							
Caledon	**ARC-SGI**	**1996**																
Carina (205)	Carnia	1988																
Caritha (301)	Carnia	1986																
Carol (310)	Carnia	1987																
Elands	**ARC-SGI**	**1998**		2,1	3,9	3,5	4,6	6,6	2,4	1,4	3,0	4,7	6,2	1,8	0,9			0,5
Flamink	**ARC-SGI**	**1979**																
Gariep	**ARC-SGI**	**1994**		0,7				0,6			0,6							
Hugenoot	Sensako	1987																
Karee	**ARC-SGI**	**1981**																
Komati	**Monsanto /ARC-SGI**	**2002**						4,2	1,4	1,6	2,6							
Limpopo	**ARC-SGI**	**1994**		0,6														
Matlabas	**ARC-SGI**	**2003**								1,9	1,0		0,7					0,5
Molen	**ARC-SGI**	**1986**																
Oom Charl	**ARC-SGI**	**1988**																
PAN3211	Pannar	1992																
PAN3235	Pannar	1993																
PAN3349	Pannar	1994									0,7							
PAN3377	Pannar	1997		0,6				0,5										

Variety	Breeder	Year of Release	2000/01	2001/02	2002/03	2003/04	2004/05	2005/06	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/2015	2015/2016
PAN3408	Pannar	2001														0,9	0,5	
Scheepers 69	**ARC-SGI**	**1969**																
SST 101	Sensako	1978																
SST 102	Sensako	1978																
SST 107	Sensako	1979																
SST 124	Sensako	1981		0,9														
SST 356	Sensako	2005									1,5	2,9	4,7	3,5	1,3	0,6		1,0
SST 399	Sensako	1992			0,9	1,6	0,9	0,7										
SST 94	Sensako	1999		7,2	13,3	9,6	8,5	3,2	1,0									
SST 966	Sensako	1996			0,6	0,5												
Tugela	**ARC-SGI**	**1985**																
Tugela DN	**ARC-SGI**	**1992**																
Dryland (winter) wheat																		
Gouritz	Other	1978																
SST 015	Sensako	2001					6,1	8,4	11,7	15,8	12,7	7,2	8,7	5,8	8,5	9,5	9,4	8,5
SST 027	Sensako	2002							22,9	26,3	18,0	14,2	16,2	14,7	13,4	13,9	8,5	4,8
SST 047	Sensako	2005									0,5	11,6	5,3	4,5	2,2	1,7		
SST 056	Sensako	2005											0,7	13,3	15,7	21,7	21,3	23,1
SST 087	Sensako	2009														0,6	23,1	18,5
SST 127	Sensako	2013																9,2
SST 16	Sensako	1977																
SST 33	Sensako	1979																
SST 88	Sensako	1998	1,2	15,9	17,3	23,7	25,3	27,9	17,7	22,0	15,2	9,9	12,8	9,7	14,2	16,8	8,4	7,1

** ARC-SGI varieties are in bold.

Figure 5.1 presents a summary of shares for irrigation, summer dryland and winter dryland wheat production in South Africa. The results indicate that on the one hand, irrigation wheat production dominates shares of national wheat crop in South Africa while the share of dryland wheat has been declining over the years. On the other hand, shares of winter show an increasing trend in recent years. Figure 5.2 presents shares of the main wheat breeders based on area estimates from cultivar composition of production for the period 1978 to 2015 using the last cross rule. The results indicate that prior to the deregulation of the wheat industry in 1997, public contribution to wheat varietal improvement research played a major role in the wheat sector. The shares of breeders based on area estimates planted to wheat varieties indicate that publicly produced varieties dominated in terms of area estimates prior to 1997. Since the disbandment of the Wheat Control Board, the private sector, mainly represented by Sensako, has dominated the shares of area planted by variety. The share of ARC-SGI varieties has taken a dramatic decline since the deregulation of the wheat sub-sector in 1997. The trend slightly peaked in the last 2000s but has declined again in recent years approaching 2015. The market shares of each variety in the national crop were assumed to be a good proxy of the adoption rate of each variety. The age of a variety reflects wider adoption over long periods and the short average age indicates that either the variety became popular recently or it is meant for a niche market. Wheat varieties developed by the ARC-SGI and other breeders are sold both in South Africa and other parts of the region. It is important to highlight that some of the Sensako varieties originate from ARC-SGI wheat breeding investments.

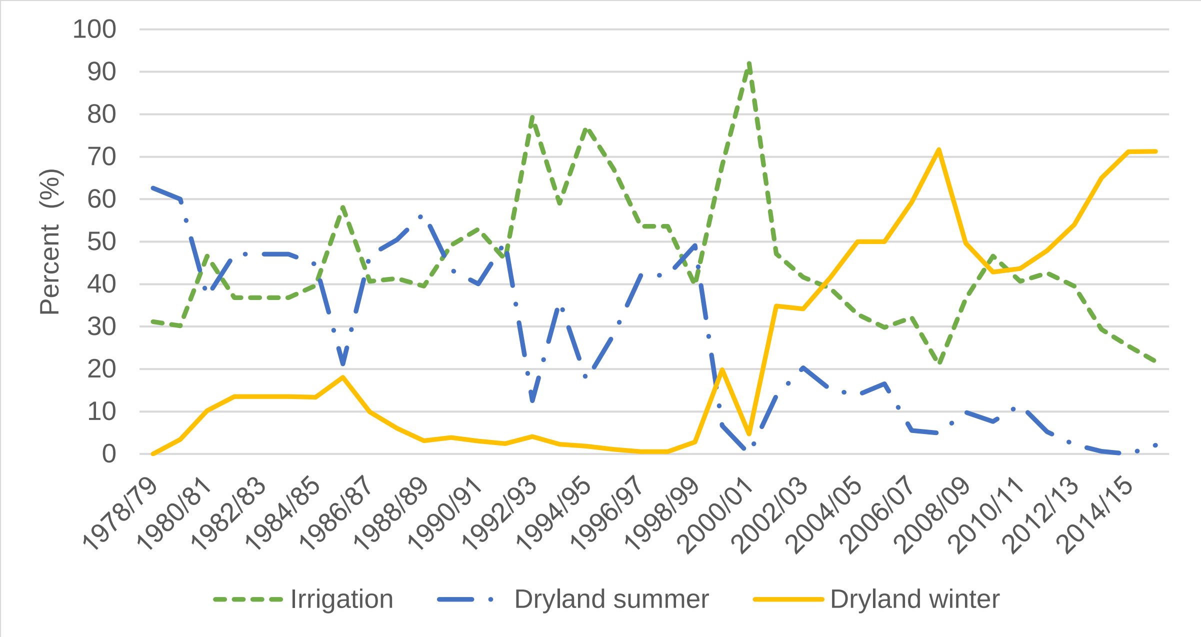


Figure 5.1: Production area of wheat based on estimates from cultivation composition in national output (share of national output)

Source: Author calculations based on area by variety estimates from wheat reports by the former Wheat Control Board and South African Grain Laboratory

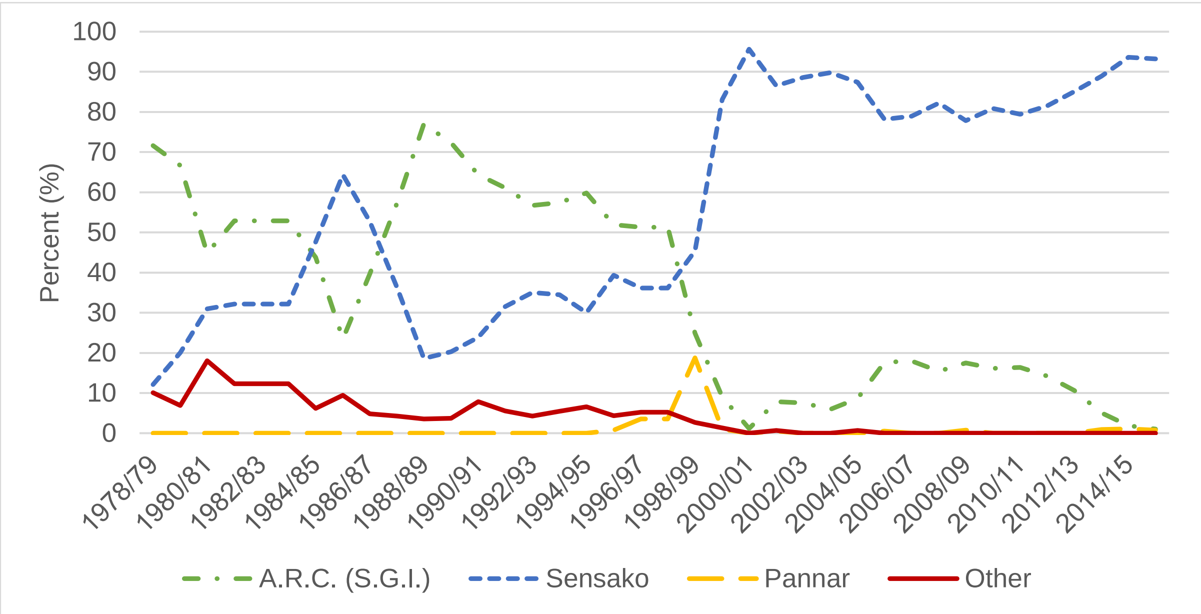


Figure 5.2: Breeders' shares of wheat varieties cultivated based on area estimates from cultivar composition in national output

Source: Author calculations based on area by variety estimates from wheat reports by the former Wheat Control Board and South African Grain Laboratory

5.4 Estimating economic benefits of wheat varietal improvement research

The data on varieties released and estimated adoption rates in the previous section provide the foundation for estimating the benefits of wheat breeding research in South Africa. Benefits from varietal improvement to farmers and society are derived from increases in crop yields, improved quality and cost reduction (Maredia et al., 2010). The Gross Annual Research Benefits (GARB) to ARC-SGI from wheat varietal improvement research are estimated using the following formula: $GARB = KPQ$, where K is the proportion of the crop output that is attributed to use/adoption of new varieties released from variety research efforts (or supply shift factor); P is the producer average price of wheat and Q represents the amount of wheat produced. The same approach developed by Griliches (1958) has been applied in many studies estimating benefits from crop varietal improvement research such as (Maredia et al., 2010, Pardey et al., 2006, Heisey et al., 2002, Lantican et al., 2016, Lantican et al., 2005, Reyes et al., 2016).

The estimation of total research benefits using this approach is based on the following assumptions: there is a linear and parallel shift in supply as a result of gains/ losses from research; the increase in supply does not affect world market price; the changes in wheat varieties in South Africa does not affect wheat production in other countries, that is, there are no spill over effects. The limitation of the GARB measure is that it assumes a parallel reduced-induced supply shift, in reality it is pivotal and the GARB estimate will overstate the benefits from research – this is however inevitable in the absence of information on national supply shift.

The supply shift factor, K , measures proportional gains in grain yield from farmers adopting new wheat varieties. Estimation of economic benefits of variety research requires the yield gain of the improved varieties to be calculated on all farms they are grown. Due to challenges in getting farm-specific estimates of yield gains, the practical approach is to estimate an index of crop varietal improvement research due to the development of new varieties and their adoption over time using the scenario with research and the counterfactual without research (Maredia et al., 2010, Reyes et al., 2016).

Following the approach applied by Pardey et al., (2006), Maredia et al., (2010) and Reyes et al., (2016), the K-factor is calculated using estimates of gains in grain yield based on observed/ actual rates of adoption for the new varieties in each production year – the case "with-varietal research". The K-factor for counterfactual scenario is calculated based on estimates of grain yield gains assuming base year conditions (varieties and weights for adoption rates) that are kept constant over the analysis period. The other scenario is the counterfactual which is based on yield gains. The "with" and "without" scenarios are used to estimate the proportional gain in grain yields that is attributable to wheat varietal research, K. The index of wheat varietal improvement is estimated as follows:

$$K_t = \frac{Y_t^a - Y_t^c}{Y_t^a} \qquad (5.1)$$

Where Y_t^a is the "observed area-weighted index of experimental yield" in South Africa in year t - indicating gains in yield from adoption of improved varieties over time; Y_t^c is the "counterfactual" index for experimental yields in year t (based on base year area weights) - indicating that adoption of new varieties does not change during the period of analysis. The estimation of these yield indices is presented in the next section. The data were prepared in Microsoft Excel and empirical estimations were done using SAS University Edition (2016 version).

5.5 Estimating potential yield gain from wheat varietal improvement research

Experimental yields from the ARC-SGI wheat improvement research programme for the period 1985 – 2015 (based on the assumption of 8 years research lag) were used to measure gains (rate of) in wheat yields for the varieties that succeeded commercially as presented in Tables 5.3 and 5.4 above. The experimental trials for wheat varietal improvement were based on research efforts in different parts of the country where wheat is produced, particularly in the Free State and Western Cape. The experimental trials of the ARC-SGI constitute wheat varieties that succeeded commercially and benefited from research efforts from other research programmes in South Africa and other countries.

As with other research that has applied the same methods to estimate benefits from variety research (Maredia et al., 2010, Pardey et al., 2006), the data from experimental trials had gaps since the varieties in the sample were not all included in variety trials each year for the entire period of analysis. Therefore, the process of estimating yield gains involved initially estimating the adjusted yield for individual varieties in the sample (Maredia et al., 2010, Pardey et al., 2006, Reyes et al., 2016). The least squares estimation of the adjusted yield gains for each variety i in a given time period (year) t from an experimental site located in area j is given by the following equation:

$$Y_{ijt} = a + \sum b_t D_t + \sum c_i D_i + \sum d_j D_j + \mu_t \qquad (5.2a)$$

where, D_t represents time dummies, D_i represents variety dummies (for selected varieties in Table 5.2); D_j represents experimental site location dummies; μ_t represents the error terms; and the estimated parameters are represented by: $a,$ $b,$ $c,$ and d .

Equation 5.2a presents an ideal scenario where the trails are consistently conducted in all locations across the entire time period and the same varieties are tested in all experimental sites. However, this is not possible in reality and modification of equation (4.2a) (Maredia et al., 2010) is presented below:

$$Y_{it} = a + \sum b_t D_t + \sum c_i D_i + \mu_t \qquad (5.2b)$$

where, Y_{it} represents the average yield of variety i for all experimental sites for each given year t.

The predicted yield $\hat{Y}_{it}$ based on results from equation 5.2b, represents the adjusted average yield for each variety i accounting for the estimate of the year effect. Since any variety included in the sample was not tested across the entire time period (including periods of high and low yields), the method compensates for this fact by adjusting the yield effect either upward or downward. To avoid the dummy trap, the regression analysis excluded the oldest variety in each model. The estimated coefficients in each model represent losses or gains in yield compared to the excluded variety. The varieties that were excluded are T4 (irrigation model), Scheepers 69 (dryland summer model) and SST 33 (dryland winter model). Table 5.5 summarises the descriptive statistics of estimated wheat yields based on estimation of equation (4.2b) using wheat experimental data for the period 1985 – 2015.

Table 5.5: Summary descriptive statistics of estimated wheat yields based on wheat experimental data, 1985 – 2015

Year of Release	Variety	N[8]	Mean	Std Dev	Std Error	Lower 95% CL for Mean	Upper 95% CL for Mean	Minimum	Maximum
Irrigation wheat									
1989	**AdamTas**	4	6.45	0.97	0.48	4.91	7.99	5.58	7.77
2002	**CRN826**	10	6.69	0.84	0.26	6.09	7.28	5.25	8.02
1988	**Dias**	4	6.59	0.97	0.48	5.05	8.13	5.72	7.91
2004	**Duzi**	12	6.71	0.85	0.25	6.17	7.26	4.97	7.74
1975	**Elize**	7	4.94	1.07	0.40	3.95	5.92	3.81	6.94
1985	**Gamtoos**	10	6.09	0.45	0.14	5.76	6.41	5.23	6.64
1970	**Inia**	19	5.14	0.85	0.20	4.73	5.55	3.99	7.12
1993	**Kariega**	21	6.36	0.77	0.17	6.00	6.71	4.79	7.64
2004	**Krokodil**	11	7.13	0.69	0.21	6.67	7.59	5.96	8.00
1992	**Marico**	16	6.32	0.91	0.23	5.83	6.80	4.80	8.28
1989	**Nantes**	4	6.42	0.97	0.48	4.88	7.96	5.55	7.74
2001	**Olifants**	12	6.28	0.81	0.23	5.76	6.80	4.94	7.71
2008	**PAN3471**	8	7.45	0.96	0.34	6.65	8.26	5.50	8.27
1984	**Palmiet**	15	6.24	0.86	0.22	5.76	6.72	4.93	8.06
1984	**SST25**	7	5.17	0.63	0.24	4.59	5.74	4.32	6.23
1979	**SST44**	7	5.69	0.95	0.36	4.81	6.57	4.74	7.53
1992	**SST55**	6	6.47	0.86	0.35	5.57	7.36	5.82	8.14
1994	**SST57**	4	6.23	0.75	0.37	5.04	7.42	5.60	7.29
1995	**SST65**	2	5.97	0.16	0.12	4.50	7.43	5.85	6.08
1979	**SST66**	11	5.84	0.84	0.25	5.28	6.41	4.68	7.81
2000	**SST806**	15	6.96	0.86	0.22	6.49	7.44	5.40	8.17
1992	**SST822**	20	6.35	0.79	0.18	5.98	6.72	4.77	7.62
1992	**SST825**	12	6.61	0.75	0.22	6.13	7.08	5.52	7.97
2003	**SST835**	12	7.16	0.85	0.25	6.62	7.71	5.42	8.19
2008	**SST843**	8	6.63	0.96	0.34	5.83	7.44	4.68	7.45
1987	**SST86**	9	6.16	0.76	0.25	5.58	6.75	5.38	7.91
1997	**SST875**	7	7.53	0.60	0.23	6.98	8.08	6.69	8.07
1997	**SST876**	17	6.89	0.85	0.21	6.46	7.33	5.31	8.16
2009	**SST877**	6	7.45	0.52	0.21	6.91	7.99	6.48	7.85
2011	**SST884**	5	7.99	0.22	0.10	7.72	8.27	7.68	8.20
2010	**SST895**	5	8.03	0.22	0.10	7.76	8.31	7.72	8.24
1999	**Steenbras**	11	6.00	0.73	0.22	5.51	6.49	4.93	7.30
1965	**T4**	14	6.21	0.89	0.24	5.70	6.72	4.87	8.00
1978	**Zaragosa**	9	6.94	0.93	0.31	6.22	7.66	5.83	8.96

Year of Release	Variety	N[8]	Mean	Std Dev	Std Error	Lower 95% CL for Mean	Upper 95% CL for Mean	Minimum	Maximum
Dryland summer wheat									
1970	**Belinda**	5	2.32	0.98	0.44	1.11	3.53	1.01	3.18
1970	**Betta**	12	2.08	0.74	0.21	1.60	2.55	0.96	3.13
1992	**BettaDN**	18	2.40	0.67	0.16	2.06	2.73	1.44	3.72
1996	**Caledon**	16	2.62	0.65	0.16	2.28	2.97	1.59	3.87
1988	**Carina205**	8	2.30	0.57	0.20	1.83	2.78	1.55	3.12
1986	**Caritha301**	11	2.33	0.66	0.20	1.88	2.77	1.44	3.31
1987	**Carol310**	11	2.51	0.66	0.20	2.06	2.95	1.62	3.49
1998	**Elands**	18	2.64	0.62	0.15	2.33	2.94	1.61	3.89
1979	**Flamink**	9	2.31	0.81	0.27	1.68	2.94	1.21	3.38
1994	**Gariep**	21	2.61	0.61	0.13	2.34	2.89	1.61	3.89
1987	**Hugenoot**	10	2.25	0.52	0.16	1.88	2.62	1.66	3.00
1981	**Karee**	12	2.05	0.74	0.21	1.58	2.53	0.94	3.11
2002	**Komati**	9	2.52	0.77	0.26	1.93	3.12	1.61	3.89
1994	**Limpopo**	16	2.46	0.66	0.17	2.11	2.82	1.47	3.75
2003	**Matlabas**	13	2.90	0.68	0.19	2.49	3.31	1.94	4.22
1986	**Molen**	13	2.46	0.65	0.18	2.07	2.85	1.54	3.41
1988	**OomCharl**	7	1.99	0.59	0.22	1.44	2.54	1.37	2.94
1992	**PAN3211**	8	2.33	0.62	0.22	1.81	2.85	1.39	3.07
1993	**PAN3235**	11	2.39	0.59	0.18	1.99	2.78	1.53	3.23
1994	**PAN3349**	13	2.58	0.70	0.19	2.16	3.00	1.55	3.83
1997	**PAN3377**	13	2.70	0.70	0.19	2.28	3.12	1.68	3.96
2001	**PAN3408**	6	3.46	0.43	0.18	3.01	3.92	3.03	4.09
1978	**SST102**	11	2.24	0.78	0.23	1.72	2.77	1.11	3.28
1979	**SST107**	5	2.37	0.97	0.44	1.16	3.58	1.06	3.23
1981	**SST124**	16	2.26	0.65	0.16	1.92	2.61	1.35	3.24
2005	**SST356**	9	2.79	0.50	0.17	2.41	3.17	2.21	3.58
1992	**SST399**	12	2.72	0.71	0.21	2.27	3.18	1.75	4.03
1996	**SST966**	12	3.10	0.73	0.21	2.63	3.56	2.03	4.31
1969	**Scheepers 69**	12	2.06	0.83	0.24	1.53	2.59	0.82	3.25
1985	**Tugela**	11	2.51	0.76	0.23	2.00	3.02	1.54	3.67
1992	**TugelaDN**	9	2.64	0.71	0.24	2.09	3.19	1.70	3.96
Dryland winter wheat									
2001	**SST015**	7	3.45	0.46	0.18	3.02	3.88	2.82	4.09
2002	**SST027**	7	3.47	0.46	0.18	3.04	3.90	2.84	4.11
2005	**SST047**	5	3.41	0.43	0.19	2.87	3.95	2.84	3.99
2005	**SST056**	6	3.53	0.48	0.20	3.02	4.03	2.95	4.22
2009	**SST087**	6	3.55	0.48	0.20	3.04	4.05	2.97	4.24
2013	**SST127**	2	3.44	0.59	0.42	-1.90	8.78	3.02	3.86
1979	**SST33**	5	2.31	1.49	0.66	0.46	4.15	1.06	4.67
1998	**SST88**	7	3.41	0.46	0.18	2.98	3.84	2.78	4.05

Source: Author calculations based on regression results from equation (5.2b). *N is the number of years the variety was on trials

Using equation (5.2b), a simple vintage regression model was estimated as presented below:

$$\ln(\hat{Y}_{it}) = a + \sum b_t D_t + gV_i + \mu_t \qquad (5.3)$$

where $\ln(\hat{Y}_{it})$ represents the natural logarithm of the predicted yield (from equation 5.2b), V_i represents the year of release for each variety i which is the "vintage variable". The log function specification of the predicted yield provides the estimate of "relative increase in yield" $\left[100d\ln(Y_{it})/dV_i) = 100g\right]$ which measures the yield gain per year expressed as a percentage (Maredia et al., 2010).

Table 5.6 presents the results from the vintage multiple regression models estimated using fitted values from equation (5.2b). The vintage model regresses the natural log of the predicted yield values (from equation 5.2b) as a function of time dummy variables D_t and the year of release of each variable V_i (the vintage variable). The hypothesis that the dummy variables are all equal to zero $(D_1 = D_2 = \cdots = D_n = 0)$ was tested by including the time dummies in the vintage regression models. The results of the F -ratio are statistically significant at 1% significance level, indicating that there are significant variations in average wheat yields from year to year.

The results of the vintage variable V_i in each model give the rate of yield gain per year released from varietal improvement research. The estimations from the vintage models indicate that the wheat yield gain per year from new wheat varieties was 0.8% for the dryland summer model and 0.5% for the irrigation and dryland winter models. The results are consistent with findings from other studies such as Maredia et al., (2010) who estimated yield gains from bean research in Michigan and Reyes et al., (2016) who estimated yield gain from bean research in five countries in Latin America.

Combining these results and estimations of yield presented in Table 5.5 above, the average estimated yield for dryland summer wheat was 2.48 tonnes/ha/year, implying that the wheat yield gain per year from new varieties is equivalent to 19.84kg per ha per year. The estimated wheat yields per ha for the irrigation and dryland winter models were 6.44 tonnes/ha/year (irrigation) and 3.33 tonnes/ha/year (dryland winter). This means that the estimated yield gain is equivalent to 32.20 kg/ha/year and 16.65 kg/ha/year for irrigation and dryland winter wheat respectively.

The fit diagnostic tests for the vintage model estimations are presented in Figures 5.3, 5.4 and 5.5 for the irrigation, dryland summer and dryland winter vintage regression models respectively. The results of the residual normality plots show that the data approximate a normal distribution for estimation of linear regression equations. Overall, the tests indicate statistically significant model fit for all estimations based on the Analysis of Variance (ANOVA) F statistic and the residual normality plots. The Variance Inflation Factors (VIF) were all less than 10, indicating that multicollinearity was not a problem in the vintage model estimations.

Table 5.6: Multiple regression analysis results of the vintage models using wheat experimental data, 1985 – 2015

Variable	Irrigation wheat model		Summer wheat model		Winter wheat model	
	Parameter Estimate	t Value	Parameter Estimate	t Value	Parameter Estimate	t Value
Intercept	-7,249***	-7,54	-15,281***	-12,46	-8,247***	-4,98
Released	**0,005*** **	**9,66**	**0,008*** **	**13,24**	**0,005*** **	**5,62**
d85	-0,363***	-11,12	-0,740***	-17,87		
d86	-0,302***	-9,24	0,316***	7,90		
d87	-0,185***	-5,85	0,399***	10,70		
d88	-0,186***	-5,49	0,331***	8,90		
d89	-0,252***	-7,94	-0,247***	-6,79	0,597***	19,52
d90	-0,133***	-4,41	-0,313***	-8,62		
d91	-0,044	-1,46	0,455***	8,06	0,112***	4,04
d92	0,133***	4,50	-0,177***	-4,95	-0,607***	-19,86
d93	-0,181***	-6,37	0,205***	5,78		
d94	-0,094***	-3,11	-0,467***	-13,21	-0,886***	-28,95
d95	-0,097***	-3,32	-0,221***	-6,45	-0,506***	-16,53
d96	-0,195***	-6,57	0,272***	8,02		
d97	-0,150***	-5,19	-0,113***	-3,33		
d98	0,067**	2,15	0,166***	4,90		
d99	0,072**	2,24	-0,129***	-3,77		
d00	-0,137***	-4,17	0,204***	5,85		
d01	-0,331***	-10,90	0,291***	8,25		
d02	-0,171***	-5,61	0,028	0,79		
d03	-0,251***	-8,50	-0,427***	-12,30		
d04	-0,261***	-9,44	-0,386***	-10,99		
d05	-0,113***	-3,86	-0,055	-1,56		
d06	-0,121***	-4,23	0,325***	9,29		
d07	-0,137***	-4,82	0,454***	12,94		
d08	-0,151***	-5,41	-0,173***	-4,95		
d09	-0,387***	-13,61	0,170***	4,80	0,234***	19,75
d10	-0,142***	-5,18	-0,126***	-3,56	0,030**	2,54
d11	0,032	1,23	0,115***	2,99	0,288***	19,34
d12	0,045*	1,71	0,288***	6,93	0,358***	30,23
d13	-0,018	-0,66	0,156***	3,53	0,133***	11,20
d14	0,040	1,37	-0,073*	-1,74	0,248***	21,81
n	**340**		**357**		**45**	
F - statistic (Pr > F)	**58.41 (0.0001)**		**240.70 (0.0001)**		**683.97 (0.0001)**	
Adjusted R^2	**0,84**		**0.95**		**0.99**	

*NB: ***, **, * Significance at 1%, 5% and 10% respectively*

Source: Author estimation using vintage model equation (4.3) and experimental data from 1985 to 2015

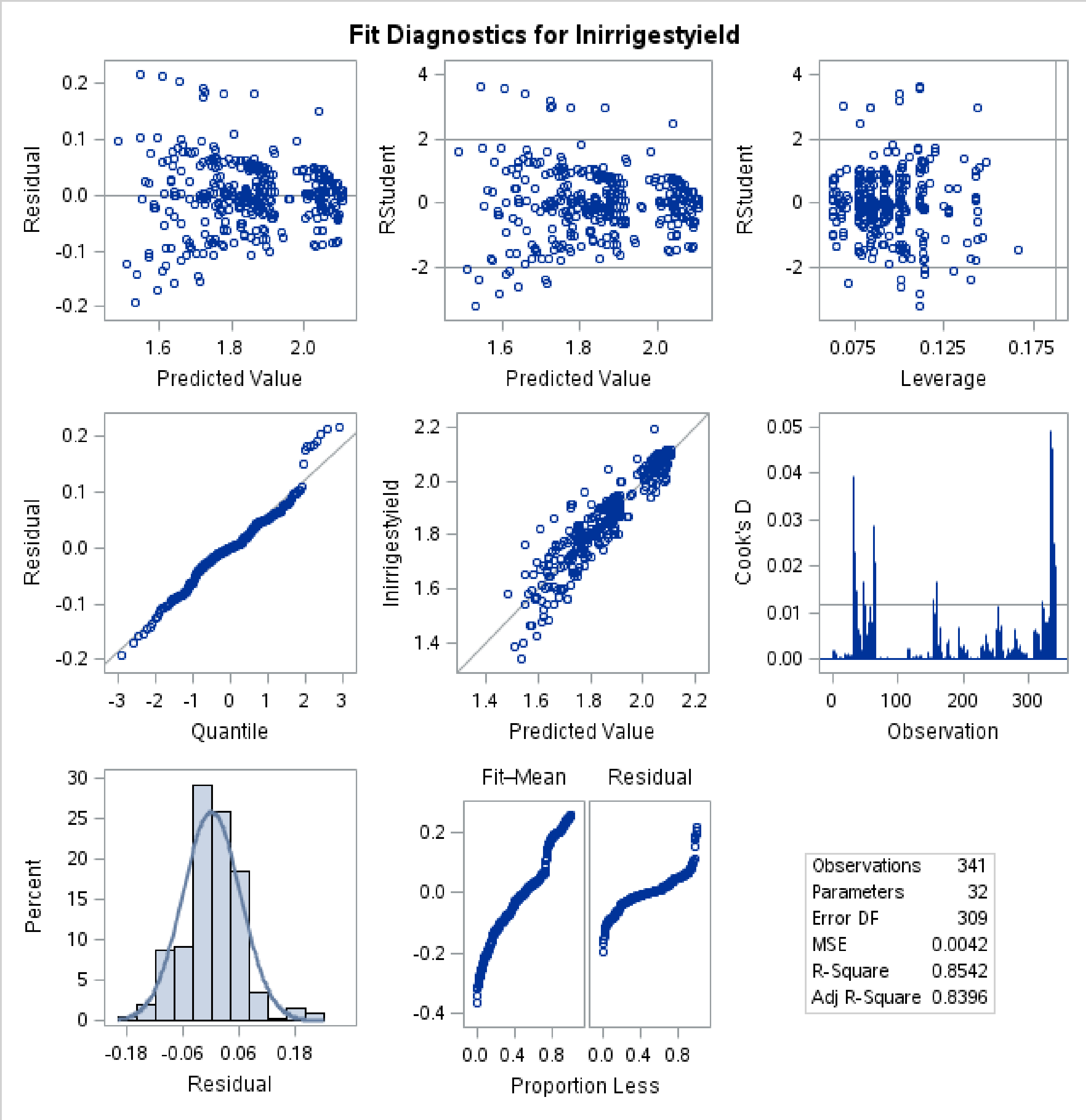


Figure 5.3: Fit diagnostic tests for the irrigation vintage regression model

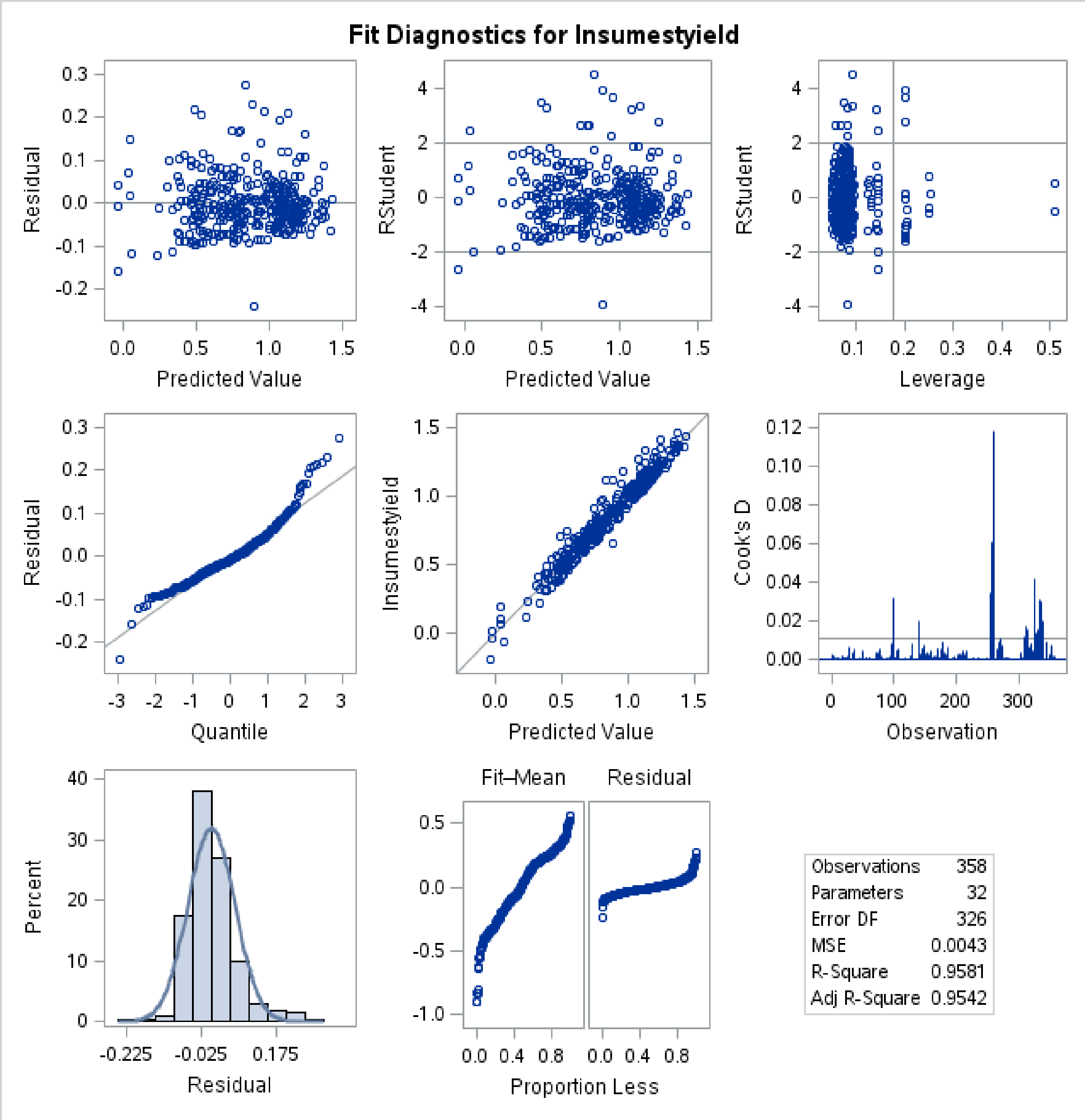


Figure 5.4: Fit diagnostic tests for the dryland summer vintage regression model

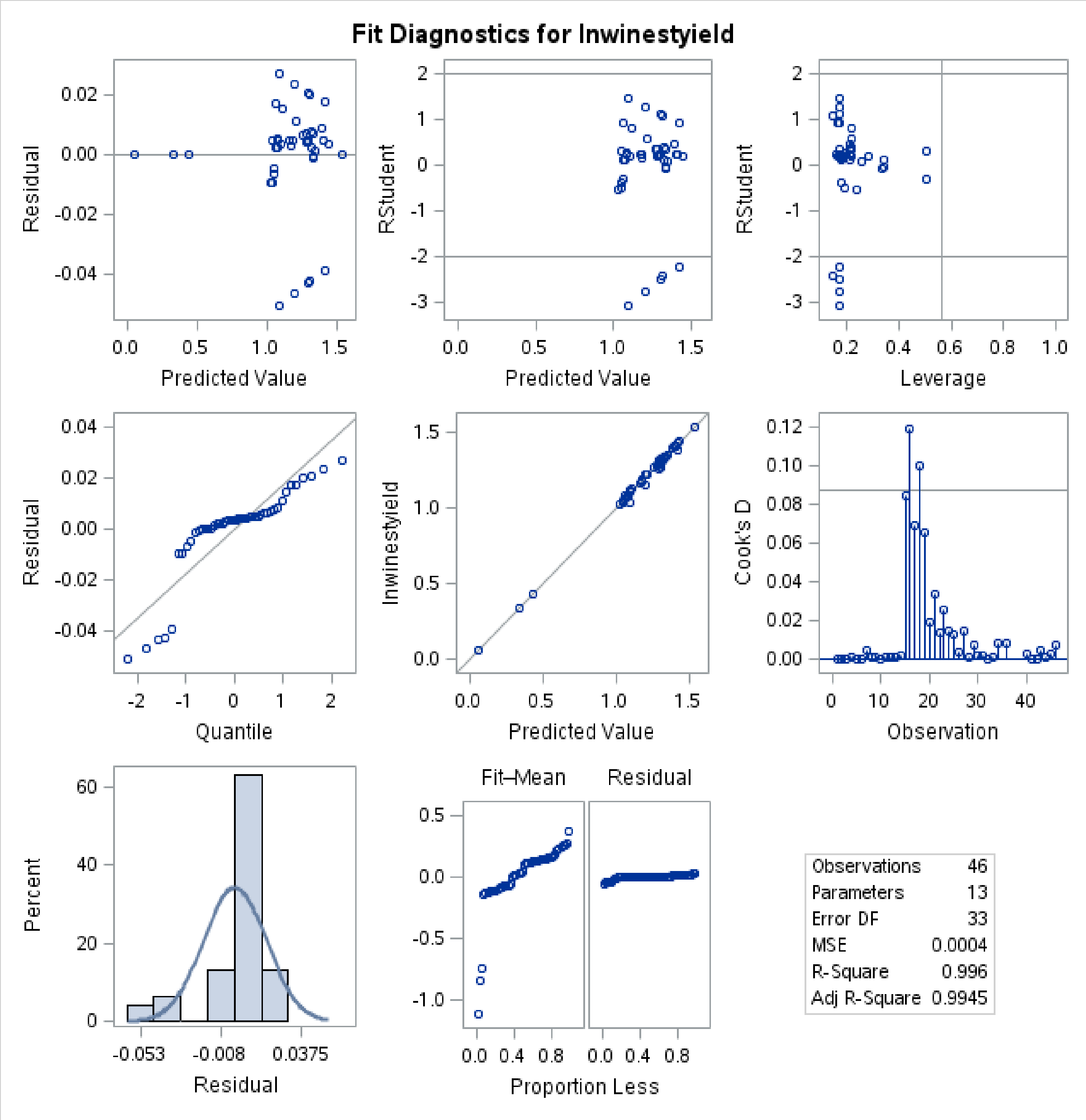


Figure 5.5: Fit diagnostic tests for the dryland winter vintage regression model

5.6 Estimating yield gains "with" and "without" research scenarios

Economic benefits from varietal improvement research are generated when farmers adopt new varieties. Factors that determine the type of new varieties that farmers adopt include their agricultural land characteristics, risk perspectives and differences in adoption lags. This means that the economic benefits generated from farmers growing new released varieties varies from year to year and can be less than the estimated gains in yield from Table 5.6 above. The average weighted mean for yield

$\hat{Y}_t^a$ for $t = 1985 - 2015$ was estimated using the following formula to account for the effects of the above factors:

$$\hat{y}_{wt}^a = \sum_i (\ddot{Y}_{it} \alpha_{it}) \qquad (5.4)$$

where $\ddot{Y}_{it}$ represents the actual yields for each variety i, for each experimental year t (Y_{it}), alternatively, $\ddot{Y}_{it}$ can be the estimated yields using equation (5.2b) $(\hat{Y}_{it})$ (Maredia et al., 2010). Area shares for each variety i for each experimental year t is measured by α_{it}.

As there is no information on the actual areas grown to new wheat varieties (or the rates of adoption of the new wheat varieties), the study used shares in national crop reported in Tables 5.3 and 5.4 above as proxies of adoption rate α_{it} of each variety in the farmers' fields in each corresponding year. The yield index $\hat{Y}_t^a$ is a measure of yields relating to actual farmer growing patterns (rate of adoption) of new wheat varieties.

The yield gains for the case "without" varietal improvement research or the "counterfactual scenario" was estimated by using same weights of adoption of new wheat varieties in the base year across the entire period of analysis. In other words, the "counterfactual scenario" was represented by holding constant for the entire period of analysis the area share of wheat varieties grown in the base year. In equation (5.4), α_{it} was replaced by α_{ib} for $b = 1985$ which was the preceding year before release and growing of new wheat varieties from investments post-1978. The estimated area weighted wheat yield gains $\hat{y}_t^b$ keeping the base year conditions constant in year t is derived using the following formula:

$$\hat{y}_{wt}^c = \sum_i (\ddot{Y}_{it} \alpha_{ib}) \qquad (5.5)$$

The estimated yield gains $\hat{y}_{wt}^a$ and $\hat{y}_{wt}^c$ using equations (5.4) and (5.5) across all wheat production regions, gives the gains in yield for the scenario "with varietal improvement research" ($\hat{y}_{wt}^a$ in Equation (5.1)) and the counterfactual scenario yield gains ($\hat{y}^{a}_{wt}$ in Equation (5.1)) “without varietal improvement research”. The proportional gain in experimental yields generated from wheat improvement research is given by the following formula:

$$k_{wt} = \frac{\hat{y}^{a}_{wt} - \hat{y}^{c}_{wt}}{\hat{y}^{a}_{wt}} \tag{5.6}$$

The actual yield index reflects farmers’ decisions in changing composition of varieties they grow from year to year to take advantage of improved varieties from improvement research programmes. Assuming area weights remain constant – that is, variety mix does not change from year to year, the estimate of the “counterfactual yield index” $\hat{y}^{c}_{wt}$ is different from the actual yields index $\hat{y}^{a}_{wt}$ as a result of changes in “variety-specific yield response” to the environment and varietal mix planted over time (Maredia et al., 2010). Figure 5.6 below presents changes in the “estimated proportional yield gains or losses” due to wheat varietal research.

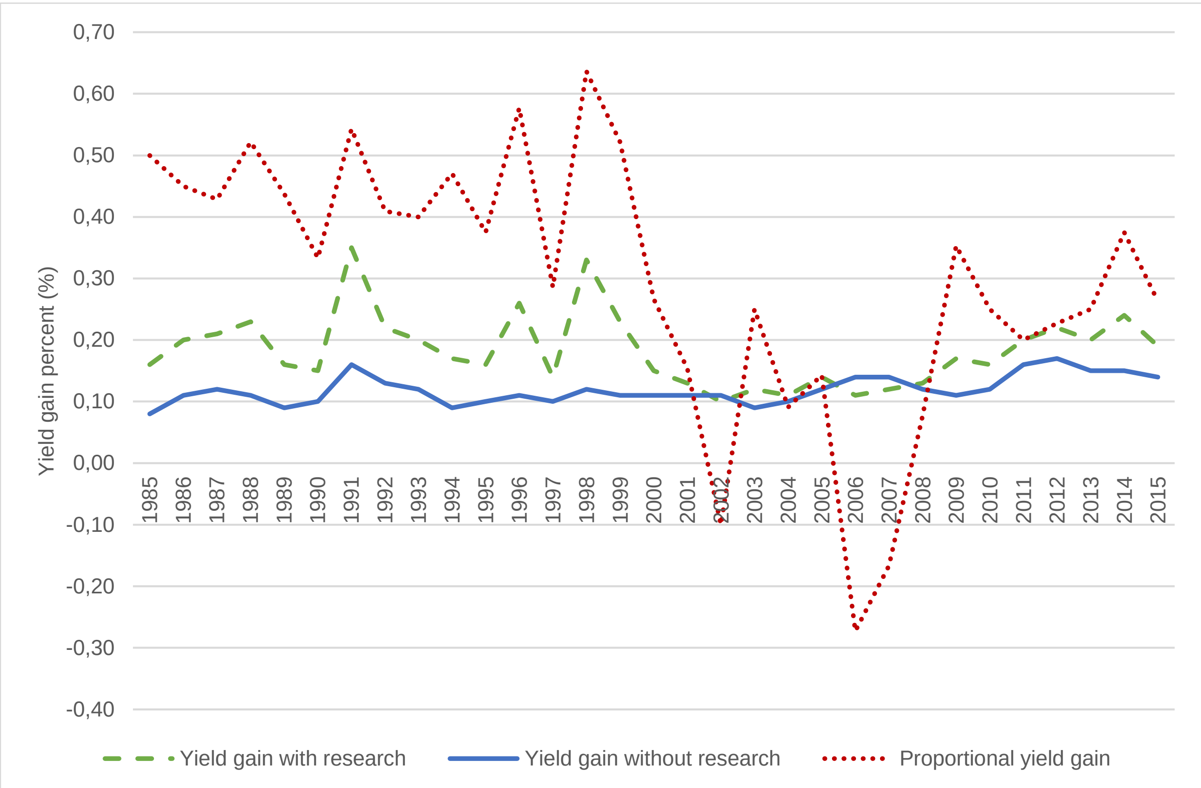


Figure 5.6: Wheat yield gain with and without research and proportional yield gain from wheat research, 1985 – 2015

The benefits in wheat production from varietal improvement for the period 1985 – 2015 assuming everything remains constant were estimated using the formula:

$$B_t = k_t P_t Q_t \tag{5.7}$$

The benefits from adopting improved varieties can be negative in years when the actual/observed yields were less than yields from the counterfactual scenario (Figure 5.3). Negative benefits from improved varieties might indicate that farmers preferred old varieties to new improved ones. This could be driven by factors such as consistent performance of the variety and other yield qualities. In addition, climate related events such as droughts contributed to the significant declines observed above especially for the years 2002 and 2006. For example, South Africa experienced an El Nino event in 2002 with most parts of the country recording below average normal rainfall (Reason and Phaladi, 2005). The Department of Agriculture, Forestry and Fisheries and South African Weather Services further confirms that the period 2002 to 2005 received below normal rainfall with devastating impacts of agricultural activities (South Africa Weather Services, 2017, Department of Agriculture Forestry and Fisheries, 2006). The drought conditions affected wheat production in the main producing areas of the Free State and Western Cape contributing to the observed trends shown above.

5.7 Attribution of benefits to ARC-SGI's wheat research improvement programme

This section focuses on estimating benefits attributed to wheat varietal improvement research programme of the ARC-SGI for the period 1978-2015. Table 5.7 below presents the pedigree information of the wheat varieties used in the empirical analysis. The critical question that should be addressed in estimating benefits of wheat varietal improvement research is: What proportion of benefits should be attributed to the efforts of the ARC-SGI and that of other research institutions? Analysis of pedigrees of each variety helps illustrate the need for attributing benefits among different sources and presents a practical and transparent way of addressing the attribution problem. Analysis of the pedigree of ARC-SGI varieties and those from other sources clearly indicates that wheat varietal releases by the ARC-SGI draw from prior research by many other research institutions such as universities, private research companies and international organisations. Other research programmes also draw from germplasm developed by the ARC-SGI. It is therefore important to estimate the share of wheat varietal improvement benefits that are attributed to the efforts of the ARC-SGI compared to that of other institutions. Plant breeding by its nature is cumulative and crediting all the benefits for wheat varietal releases to the ARC-SGI would be inappropriate.

Table 5.7: Pedigree information of wheat varieties selected for empirical analysis

Year of Release	Variety	Breeder	Pedigree
Irrigation varieties			
1989	Adam Tas	Sensako	SST16*3//T4*5/S67-336
2002	CRN826	Sensako	
1988	Dias	Other	SST16*3//5*T4/S67336/3/4*SST16/VER
2004	Duzi	ARC-SGI	Kariega/Palmiet
1975	Elize	CIMMYT	INIA"S"//SN64/KLRE/3/8156
1976	Elrina	ARC-SGI	CC/INIA"S"
1985	Gamtoos	ARC-SGI	KVZ/BUHO//KAL/BB
1975	Helene	CIMMYT	BB//CNO67/SN64
1970	Inia	CIMMYT	LR64/SN64
1993	Kariega	ARC-SGI	SST44//K4500/SAPSUCKER
2004	Krokodil	ARC-SGI	Marico*2//PI262660/5*Palmiet
1992	Marico	ARC-SGI	CMT/MO73//TRM
1989	Nantes	Sensako	SST16*3//T4*5/S67-336
2001	Olifants	ARC-SGI	Jupateco'S'/Bobwhite'S'//Veery#5/Buckbuck'S'/3/Tui'S'
1984	Palmiet	ARC-SGI	SST3*2//SCOUT*5/AGENT
2008	PAN3471	Pannar	
1979	SST 2	Sensako	CAL/TOB
1981	SST 23	Sensako	INIA66*6/SST44
1984	SST 25	Sensako	Inia66*6/SST44
1973	SST 3	Sensako	INIA66/CAL
1979	SST 44	Sensako	T4**5/567-336
1992	SST 55	Sensako	SST16*3//T4*5/S67-336/3/SST16*4/EAGLE
1995	SST 65	Sensako	NANTES/4/PALMIET/A2398/3/SST66//PA124/ALONDRA
1979	SST 66	Sensako	LD398/LD357//SST464/3/3*FLAM/4/3*SST16
2000	SST 806	Sensako	
1992	SST 822	Sensako	SST 86*3/3/SST16//T4*3/S67-336//NANA*3//T4/AURORA
1992	SST 825	Sensako	HER/SAP//VEE
2003	SST 835	Sensako	
2008	SST 843	Sensako	

Year of Release	Variety	Breeder	Pedigree
1987	SST 86	Sensako	PLMT/A2398//ADAM TAS/3/SST 825
1997	SST 875	Sensako	Information withheld
1997	SST 876	Sensako	PALMIET/A2398//ADAM TAS/3/SST825
2009	SST 877	Sensako	
2011	SST 884	Sensako	
2010	SST 895	Sensako	
1999	Steenbras	ARC-SGI	SST44/SST66/4/HOOPV/CI297001/3/T.AEST/BON//CNO/7C
1965	T 4	ARC-SGI	LR/N10B//3*ANE
1978	Zaragosa	CIMMYT	
Dryland summer varieties			
1970	Belinda	ARC-SGI	OTTAWA/2*CHEYENNE(W65/155)
1970	Betta	ARC-SGI	SYN=KLEIN IMPACTO
1992	Betta DN	ARC-SGI	BETTA*4/SA1684
1996	Caledon	ARC-SGI	MOLOPO*4/GANDUM I FASAI
1988	Carina (205)	Carnia	F1-HYBRID
1996	Caritha (301)	Carnia	F1-HYBRID
1987	Carol (310)	Carnia	F1-HYBRID
1998	Elands	ARC-SGI	Molopo*3/PI137739
1979	Flamink	ARC-SGI	PAWNEE//T.TIM/AG.EL/3/FLAM/MINT/4/3*FLAM
1994	Gariep	ARC-SGI	SA1684/MOLOPO*4
1987	Hugenoot	Sensako	BETTA//FLAMINK/AMIGO
1981	Karee	ARC-SGI	BET//TRUIMPH/AGENT
2002	Komati	Monsanto/ARC-SGI	Molopo//PI137729/5*Tugela-26
1994	Limpopo	ARC-SGI	SA1684/BETTA*4
2004	Matlabas	ARC-SGI	Saulesku28/Tugela-DN
1986	Molen	ARC-SGI	BETTA/3/YAKTANA//N10B/MAZOE
1988	Oom Charl	ARC-SGI	BETTA/M.N.
1992	PAN3211	Pannar	F1-HYBRID
1993	PAN3235	Pannar	F1-HYBRID
1994	PAN3349	Pannar	F1-HYBRID
1997	PAN3377	Pannar	
1969	Scheepers 69	ARC-SGI	
1978	SST 101	Sensako	BETTA/3/PAWNEE//CHCYENNI/MIN. 11-54-12
1978	SST 102	Sensako	BETTA*2/IAGENT
1979	SST 107	Sensako	TRIUMPH/AGENT//4*SCHECPCRS 69/3/SCHEEPERS 69/TIFTON/ 412 *SCHEEPERS 69
1981	SST 124	Sensako	
2005	SST 356	Sensako	
1992	SST 399	Sensako	
1999	SST 94	Sensako	
1996	SST 966	Sensako	F1 Hybrid: A966/R41
1985	Tugela	ARC-SGI	KAVKAZ/JARAL
1992	Tugela DN	ARC-SGI	TUGELA*4/SA1684

Year of Release	Variety	Breeder	Pedigree
Dryland winter varieties			
1978	Gouritz	Other	PAWNEE//T.TIM/AG.EL/3/FLAM/MINT/4/3*FLAM
2001	PAN3408	Pannar	
2001	SST 015	Sensako	
2002	SST 027	Sensako	Information withheld
2005	SST 047	Sensako	Information withheld
2005	SST 056	Sensako	Information withheld
2009	SST 087	Sensako	Information withheld
2013	SST 127	Sensako	
1977	SST 16	Sensako	INIA 66/CALIDAD
1979	SST 33	Sensako	RWD/CI12632//3*FLAM/3/3*SST 3
1994	SST 57	Sensako	SST16*3//T4*5/S67-336/3/A2398
1998	SST 88	Sensako	

Source: CIMMYT international wheat database and other published reports

Based on the analysis of pedigree information for the selected varieties, every variety i that was released by an institution post-1985 contains some proportion E_i of benefits that were generated from ARC-SGI research efforts from post-1978 investments (formerly as SGC). Using the same approach as Maredia et al., (2010) and Pardey et al., (2006), the benefits/ credit to ARC-SGI research efforts post-1978 are estimated by applying area share of each planted variety α_{it} and the benefits to ARC-SGI investments, B_{it}^{S} are expressed as:

$$B_t^S = B_t \sum_i \alpha_{it} \quad (5.8)$$

where B_t measures the aggregate benefits from wheat varietal research in South Africa after 1978 estimated using equation (5.7).

Therefore, for the selected varieties in Table 5.3 above, the estimated credit weights E_i for every variety measure the amount of benefits attributed to ARC-SGI varietal improvement efforts, given the contributions of other private, public and international wheat breeding programmes. Different attribution methods are used in literature to measure the benefits that are attributable to research efforts of different institutions. For the purposes of this study, following Maredia et al., (2010) and Pardey et al., (2006), two attribution rules methods — the last cross rule and geometric rule — were used to determine the weights E_i to apportion credit for wheat varietal research.

The last cross rule (rule 1): Based on this rule, the benefits from every variety i developed after 1978 (that was released after 1985) are credited to the institution that released the variety. No credit is given to any of the parents of the variety. Therefore a value of 1 is assigned in the base scenario analysis for ARC-SGI wheat research programme for varieties released after 1985 and 0 for all others. The same applies to credit to research investments of other programmes (private sector, public sector) and to pre-1978 research efforts by all institutions involved in wheat varietal improvement.

The Geometric rule (rule 2): The geometric rule applies geometrically declining weights to variety improvement efforts generated from prior research for each variety. In this case, the institution that developed each variety is credited with 50% of the benefits, 1/8 is given to the institution that developed each of the parents, and 1/32 to the institution that developed each of the grandparents. Therefore, at generation g, $\frac{1}{2}^{2g+1)}$ of benefits for variety i are attributed to the institution that developed each ancestor. Overall, the weight of benefits attributed to the last generation G where the attribution stops is $\frac{1}{2}^{2g}$. Credit to prior research efforts was applied up to the level of grandparents. In this case, the institution that developed the variety is allocated 50% of the credit for each variety; 25% are equally shared between the institutions that developed each of the parents and the remaining 25% are equally shared among the institutions that developed the four grandparents. Based on the geometric rule, attribution weights for benefits for varieties released by the ARC-SGI ranges between 0.5 and 1 and are determined by ARC-SGI's contribution in each of the variety, the parents and/ or grandparents. In the case of varieties developed by other institutions, the attribution weights range between 0 and 0.49, determined by the amount of ARC-SGI genetic material as parents and/ or grandparents. Table 5.8 summarises the attribution of benefits from releases of new varieties based on the analysis of pedigree information of each variety, while applying the two rules discussed above. These shares are discussed below together with the results of attribution of economic benefits from wheat varietal research among different institutional sources and time periods.

Table 5.8: Attribution of share of benefits to different institutional sources and time periods

Attribution of benefits based on periods varieties were released	ARC-SGI[1]	Sensako	Pannar	CIMMYT	Other[2]	Total
Last Cross Rule: Share of benefits (%)						
Pre 1986	13,41	14,63		3,66	1,22	32,93
1986-1991	2,44	4,88			3,66	10,98
1992-1997[3]	8,54	10,98	4,88		1,22	25,61
1998-2015[4]	8,54	19,51	2,44			30,49
1985 - 2015	**32,93**	**50,00**	**7,32**	**3,66**	**6,10**	**100,00**
Geometric Rule: Share of benefits (%)						
Pre 1986	7,62	8,23	0,00	7,77	9,30	32,93
1986-1991	2,52	3,20	0,00	0,76	4,50	10,98
1992-1997[3]	6,10	7,01	2,44	1,45	8,31	25,30
1998-2015[4]	5,26	10,90	1,22	3,13	10,29	30,79
1985 – 2015	**21,49**	**29,34**	**3,66**	**13,11**	**32,39**	**100,00**

[1]Benefits in the pre-1986 and 1986-1991 attributed to ARC were from varieties released by the Small Grains Centre

[2]This represents benefits to other sources such as international public research, and others not indicated in the share of national crop database collected by the author.

[3]Represents the period when the ARC was established and operated before deregulation of the wheat sector.

[4]Period after deregulation of the wheat sector.

5.8 Measuring and attributing benefits of wheat varietal improvement research

Equation (5.7) was used to estimate aggregate economic benefits generated from wheat variety research efforts in South Africa. The estimation used estimates of gains in wheat yields (Figure 5.6), annual wheat farmer prices and annual quantity of wheat produced in South Africa. The estimated aggregate economic benefits over the analysis period 1985-2015 amounted to R22.81 billion from all sources (Table 5.9)[5] indicating an average of R0.76 billion per year. About R7.52 billion (33%) of the aggregate economic benefits from wheat variety research programmes in South Africa were from varieties developed in the pre-1985 period. The results highlight the long

[5] The benefits estimated only cover benefits from yield gains from varietal improvement and exclude benefits from other sources such as improved management practices, increased inputs etc. The benefits also exclude benefits of improvements in other characteristics like improved variety qualities, reduced yield variability, maturity etc.

periods often realised to reap the benefits from crop variety research and improvement. Furthermore, R4.4 billion (30%) and R5.2 billion (37%) of the aggregate benefits were attributed to wheat varieties released before (1986-1997) and after the (1998-2015) deregulation of the wheat sector respectively.

Using the last cross rule, the analysis shows that R7.51 billion (33%) was attributed to the wheat variety research programmes of the ARC. This also includes wheat variety research programmes of the SGI. Furthermore, partitioning these benefits indicates that R3.62 billion (16% of aggregate benefits or 48% of the benefits attributed to ARC-SGI) was attributed to the research efforts of the SGI. The benefits attributed to the wheat research programmes of the ARC-SGI were R2.45 billion (17% of aggregate benefits or 52% of the benefits attributed to ARC).

Applying the geometric rule, the share of the benefits attributed to the wheat variety research programmes of the ARC-SGI, Sensako and Pannar, which are the main local wheat research breeding companies, decreased from R7.51 billion (33%), R11.4 billion (50%) and R1.67 billion (7%) to R4.90 billion (21%), R6.69 billion (29%) and R0.83 billion (4%) of the aggregate benefits respectively. On the contrary, the benefits attributed to the efforts from CIMMYT and other sources increased from R0.83billion (4%) and R1.39 billion (6%) to R2.99 billion (13%) and R7.39 billion (32%) of the aggregate benefits respectively. This evidence indicates that local wheat research programmes have been relying on breeding efforts from CIMMYT and other sources. The results confirms that not accounting for attribution of benefits by source and time period results is overestimation of benefits to any specific research programme.

A comparison of the attribution of benefits of the ARC-SGI and those of other local wheat breeding programmes reveals that the ARC-SGI remains an important source of successful wheat varieties in the country. The benefits attributed to the ARC-SGI were second to those of Sensako, the main private actor in wheat breeding research. An analysis of the benefits among different time periods shows that the benefits to the ARC-SGI decreased after deregulation while the benefits to Sensako increased. The results highlight the impact of the drop in public funding for wheat variety improvement research after deregulation. Given the importance of wheat as a main cereal crop (second after maize) in South Africa, public funding for variety improvement remains critical for the country.

Table 5.9: Estimated wheat varietal research benefits and attribution to different institutional sources and time periods

Attribution of benefits based on periods varieties were released	ARC-SGI[1]	Sensako	Pannar	CIMMYT	Other[2]	Total
Last Cross Rule: R Billion						
Pre 1986	3.06	3.34		0,83	0,28	7.51
1986-1991	0.56	1.11			0,83	2.50
1992-1997[3]	1.95	2.50	1.11		0,28	5.84
1998-2015[4]	1.95	4.45	0.56			6.95
1985 – 2015	**R 7.51 billion**	**R 11.40 billion**	**R 1.67 billion**	**R 0,83 billion**	**1.39 billion**	**22.81 billion**
Geometric Rule: R Billion						
Pre 1986[2]	1.74	1.88		1.77	2.12	7.51
1986-1991[3]	0.57	0.73		0.17	1.03	2.50
1992-1997[4]	1.39	1.60	0.56	0.33	1.89	5.77
1998-2015[5]	1.20	2.49	0.28	0.71	2.35	7.02
1985 – 2015	**R 4.90 billion**	**R 6.69 billion**	**R 0.83 billion**	**R 2.99 billion**	**R 7.39 billion**	**R 22.81 billion**

[1]Benefits in the pre-1986 and 1986-1991 attributed to ARC were from varieties released by the Small Grains Centre.

[2]This represents benefits to other sources such as international public research and others not indicated in the share of national crop database collected by the author.

[3]Represents the period when the ARC was established and operated before deregulation of the wheat sector.

[4]Period after deregulation of the wheat sector.

5.9 Summary and recommendations

The main objective of this chapter was to estimate the economic benefits that are attributed to ARC-SGI's wheat varietal improvement research programme and research efforts over different timeframes. The empirical analyses used data on market shares of wheat varieties planted by farmers (used as a measure of adoption rate of the varieties) and estimates of proportional yield gains, annual wheat farmer prices and annual quantity of wheat produced across different wheat production areas in South Africa (dryland summer areas, dryland winter areas, and irrigation areas). A vintage regression model was applied to estimate the proportional yield gain from wheat varietal improvement in South Africa. The results indicated that the rate of gain in yield as a result of release of new wheat varieties (variety research) was 0.8% per year (equivalent to 19.84 kg/ha/year) for dryland summer varieties and 0.5% for both irrigation (equivalent to 32.20 kg/ha/year) and dryland winter varieties (equivalent to 16.65 kg/ha/year). The estimated aggregate economic benefits over the analysis period (1985-2015) amounted to R22.81billion from all sources, which is an average of R0.5 billion per year. About R7.51billion (33%) of the aggregate economic benefits from wheat variety research programmes in South Africa were from varieties developed in the pre-1985 period.

Given the fact that wheat varietal improvement research draws from efforts from other institutions (public and private) and from previous varietal research efforts, not accounting for the institutional sources and period of investments in variety research results in overestimation of benefits attributed to a specific varietal research programme or time period. This study addressed this through applying attribution methods to partition benefits to the ARC-SGI wheat varietal improvement investments as well as to non-ARC-SGI research programmes and different time periods: 1985-1997 and post – 1997. The results show that the total benefits attributed to ARC-SGI, Sensako and Pannar decreased while those of CIMMYT and other sources increased when the geometric attribution rule was applied. This evidence indicates that local wheat research programmes have been relying on breeding efforts from CIMMYT and other sources. The results further show that not accounting for attribution of benefits by source and period of time results in overestimation of benefits to any specific research programme.

The results of sources of wheat varieties by institution in South Africa indicate that the share of ARC-SGI wheat varietal improvement dramatically decreased after deregulation post – 1997. The results highlight the impact of the wheat sector reforms and decline in public funding for wheat variety improvement research. The findings also reveal that the share of the private sector significantly increased post deregulation of the wheat sub-sector. From the findings the share of ARC-SGI varieties in the national commercial wheat crop substantially decreased after market reforms. Given the importance of wheat as a main cereal crop (second after maize) in South Africa, public funding for variety improvement remains critical for the country. However, further research would be required to assess complementarity and substitution effects of these changing roles and how best public and private wheat varietal improvements in the country can be further stimulated to enhance productivity.

CHAPTER 6

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter summarises the main findings and conclusions of the study. The contributions as well as the recommendations and areas for further research are also presented.

6.2 Conclusions and contributions of the study

6.2.1 Recapitulation of objectives of the study

The main objective of this study was to assess the economic performance of biological innovation in South African agriculture focusing on wheat varietal change from 1950 to 2012. Specifically, the study focused on addressing the following three objectives: (a) assess the sources and use of wheat varietal innovations in South African agriculture from 1950 to 2012; (b) assess the changing public and private roles in wheat varietal rights in South African agriculture; analyse the effects of strengthening wheat variety intellectual protection on wheat productivity and varietal improvement (release of new improved varieties); and (c) estimate the benefits of varietal innovations in South African agriculture. Conclusions and contributions related to each of the specific objectives are presented in detail below.

6.2.2 Historical evolution of wheat varietal improvement research and production

This chapter examined the historical evolution of wheat varietal improvements in South Africa, including the identification of popular varieties, their history, sources and uses from 1891 to 2013. The analyses extended the period of analysis from early breeding periods in the early 1900s until 2013. In addition, an analysis of how policy changes in the wheat sector have affected wheat varietal improvements in the country over time was conducted. The empirical analysis was based on the critical review of information from policies, varieties bred and their breeders, years when varieties were bred, as well as pedigree information, as gathered from the journal "*Farming in South Africa*" (sourced from the National Library of South Africa), the CIMMYT database, and several other sources of literature. A database of the sources and uses of wheat varietal innovations in South Africa was developed using information from the above resources. The data was analysed using trend and graphical analysis.

Wheat was first produced in South Africa in the 1600s, and the first wheat varietal improvements were reported two centuries later in 1891. The analysis of wheat releases for the period 1891 to 2013 indicates that about 501 varieties were released from wheat varietal innovations in South Africa. From the 1800s, wheat varietal improvements focused on addressing the following variety characteristics: adaptability to production area; yield potential and stability; and agronomic characteristics such as tolerance to diseases, pests and aluminium toxicity. The main sources of wheat varietal improvements in South Africa are Sensako, ARC-SGI and Pannar. In terms of growth habits, most wheat varietal improvements have focused on spring and winter wheat varieties grown mostly under dryland conditions. Analysis by geographic area indicates that most of the wheat varieties released between 1891 and 2013 were for the Western Cape and Free State regions, which are the major wheat-producing areas in the country.

Wheat varietal improvements in the early years of wheat breeding were decentralised and specific to the production area, with little or no movement from area to area. The structural changes that have occurred in the agricultural sector, particularly the establishment of the ARC-SGI and the deregulation of the wheat sector, have contributed to the effort to harness the impact of the existing fragmented research efforts, especially small-grain breeding programmes in the Cape Province and the former Transvaal and Orange Free State provinces. An analysis of the sources of wheat varietal improvements during the different periods indicates that initially, wheat breeding was driven by individual breeders and agricultural colleges. Since its establishment, Sensako has been the main source, followed by the ARC-SGI and Pannar.

6.2.3 Evolving landscape of plant breeders' rights for wheat varietal improvements

This chapter analysed the evolving landscape of wheat plant breeders' rights to address the dearth of empirical evidence of the patterns and trends of wheat varietal improvements in South Africa. The aim was to provide evidence on the evolution of varietal rights, the extent of varietal rights granted, changes of the rights on offer overtime, changing ownership of the rights (including comparison between public and private as well as domestic and foreign breeders) and the impact of plant variety protection on wheat varietal development. The study compiled a detailed and novel count and attribute database of wheat varietal innovations in South Africa from 1979 – 2013 using information from the Plant Variety Journal, Department of Agriculture Forestry and Fisheries, South African National Library and ARC. The empirical analyses were based on descriptive statistics, trend analysis and graphical representation of trends and ownership of wheat varietal improvements PBRs.

A total number of 134 PBRs for wheat varietal innovations were lodged from 1979 to 2013, which is an average of 6 applications per year. This could have been driven by some breeders choosing to apply for their new varieties to be included on the national variety list and not applying for varietal protection as well as natural triggers such as outbreak of pests and diseases such as wheat rust, septoria, Russian wheat aphid, and different environmental and climatic conditions. The results indicate that plant breeders are increasingly seeking protection of their innovations. The number of PBR applications and grants for wheat variety innovations increased after the abolishment of the Wheat Board (6 applications compared to 4 per year before deregulation). The results also show that the administrative delays in granting PBR applications have been substantially reduced (reduced by 77days), post-deregulation, indicating increased efficiency in the processing of PBRs.

Since the publication of the South African Plant Variety Journal in 1979, the main applicants for wheat PVP were Sensako (39%), ARC-SGI (25%) and Pannar (15%). After deregulation, Sensako's share decreased to 34% while that of the ARC-SGI and Pannar increased by 5% and 9% respectively. The results show that the ARC-SGI faces stiff competition from these well-established private companies. Establishing opportunities for collaboration with the private sector would enhance wheat variety innovation development. The ARC-SGI has contributed to some of the PBRs owned by private companies through shared genetic resources before the PVP/IPR were implemented. Future innovations and dissemination of wheat innovations can be stimulated by plant variety protection, together with the broader variety sector legislations that encourage both public and private sector investments.

6.2.4 Effects of Plant Breeders' Rights on wheat productivity and variety improvement

The effects of strengthening wheat variety intellectual (IP) protection on wheat productivity and release of new varieties were analysed in this chapter. The study measured strength of IPR systems using an IP protection index, plant variety protection legislation and the number of Plant Breeders' Rights granted for wheat varieties. Analysis of shares of varieties in the national crop illustrated the structural transformations in the wheat seed sector emanating from changing roles between private and public sector actors in wheat research after the sector reforms. Results indicate that the share of wheat varieties developed by the ARC-SGI in the national crop substantially decreased from above 50% in 1997 to less than 2% in 2015 while that of the private sector (particularly Sensako) rapidly increased from 37% to 96% in the same period. Sensako currently have monopoly power of the wheat seed sector based on evidence from this assessment.

The correlation analysis results showed that wheat productivity and the number of wheat varieties released correlate with each of the variables representing strengthening of IPRs. Furthermore, correlation analysis showed that for the wheat productivity relationship, the results indicate a higher correlation with PBR granted for Sensako (domestic private sector) breeding programmes compared to those from the ARC-SGI (main public sector actor). However, the correlation values were small for PBRs granted for both ARC-SGI and Sensako varieties indicating that the relationship might be weak.

The simple regression model results with IPR index and PBR granted as independent variables confirmed the positive and significant relationship between these variables and wheat productivity and the number of varieties released. The findings demonstrate that strengthening IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. Multiple regression analyses results suggested a strong relationship between wheat productivity and strengthening of IPR systems in the country. Furthermore, although the robust coefficients of the other IPR variables are positive, they are statistically insignificant for all scenarios.

6.2.5 Empirical estimations and attribution of research benefits from wheat varietal improvements

This chapter analysed and presented estimations of benefits from wheat varietal improvements, including attribution of benefits to different institutions. The empirical analyses used data on market shares of wheat varieties planted by farmers, as a measure of adoption rate of the varieties, and estimates of proportional yield gains, annual wheat farmer prices in South Africa and annual quantity of wheat produced across different wheat production areas in South Africa (dryland summer areas, dryland winter areas, and irrigation areas). A vintage regression model was applied to estimate the proportional yield gain from wheat varietal improvement in South Africa. The results indicated that the rate of yield gain due to release of new wheat varieties (varietal improvement) was 0.8% per year (equivalent to 19.84 kg/ha/year) for dryland summer varieties and 0.5% for both irrigation (equivalent to 32.20 kg/ha/year) and dryland winter varieties (equivalent to 16.65 kg/ha/year).

Wheat variety research programmes by an institution depend of previous research efforts of other institutions both public and private, and its own previous research programmes. The empirical results showed that applying last cross and geometric rules resulted in the benefits attributed to local wheat variety research programmes decreasing while those attributed to CIMMYT and other sources increased. The results from pedigree analysis and attribution of benefits showed that local wheat research programmes have been relying on breeding efforts from CIMMYT and other sources. The results confirmed that not accounting for attribution of benefits by source and time period results in overestimation of benefits to any specific research programme. These findings illustrated the need for attribution of benefits from wheat varietal improvements to avoid overestimation of benefits allocated to any institution.

Since the deregulation of the wheat control board, there has been a gradual decrease in both area under wheat production and production. The increasing trend in the value of additional annual production from wheat varietal improvement research was mainly due to increases in wheat prices. Attribution of benefits from wheat improvement research by institution showed that the private sector, in particular Sensako, mainly dominated, while the share of the ARC-SGI had declined over the years and substantially after the deregulation of the wheat sub-sector. The results highlight the impact of the drop in public funding for wheat variety improvement research after deregulation. Given the importance of wheat as a main cereal crop (second after maize) in South Africa, public funding for variety improvement remains critical for the country.

A summary of the conclusions on each of the hypotheses is presented in Table 6.1 below.

Table 6.1: Summary of the main conclusion for each hypothesis

Hypothesis	**Conclusion**
H_1: Public investment has been the main source of wheat varietal innovations in South African agriculture from 1950 to 2012.	Reject
H_2: After the abolishment of the wheat marketing board, private sector share of wheat varieties is more than that of the public sector.	Fail to reject
H_3: Strengthening Plant Breeders' Rights in South Africa increased investments and release of improved wheat varieties.	Fail to reject
H_4: Strengthening Plant Breeders' Rights in South Africa positively and significantly impacted on wheat productivity.	Fail to reject
H_5: Wheat varietal improvement investments by the ARC-SGI generated positive economic benefits for the period 1985 – 2015.	Fail to reject
H_6: The benefits from public research investments significantly decreased since the deregulation of the wheat sub-sector in 1997.	Fail to reject

The analysis of the main sources of wheat varietal innovations showed that Sensako, ARC-SGI and Pannar have been the main actors. The analysis showed that the private sector share of wheat varieties was more because Sensako had the highest number of varieties released even after abolishment of the Wheat Control Board. ARC was the second highest with Pannar being the third. With Sensako, Pannar and other small players combined the private sector remains the one with the highest share of wheat varieties. Based on the findings, the hypothesis that public investment has been the main source of wheat varietal innovations in South African agriculture from 1950 to 2012 is rejected.

The percentages of public wheat varietal innovations substantially decreased after deregulation of the wheat subsector in 1997. It is important to note that private sector innovations have also heavily relied on publicly funded wheat genetic materials and varieties released by the ARC-SGI. However, based on the findings, we fail to reject the hypothesis that after the abolishment of the wheat marketing board, private sector share of wheat varieties is more than that of the public sector.

Using the last cross rule, the analysis shows that R4.73 billion (33%) was attributed to the wheat variety research programmes of the ARC. This also includes wheat variety research programmes of the SGI. Partitioning these benefits indicates that R2.28 billion (16% of aggregate benefits or 48% of the benefits attributed to ARC-SGI) was attributed to the research efforts of the SGI. The benefits attributed to the wheat research programmes of the ARC-SGI were R2.45 billion (17% of aggregate benefits or 52% of the benefits attributed to ARC). Applying the geometric rule, the share of the benefits attributed to the wheat variety research programmes of the ARC-SGI decreased from R7.51 billion (33%) to R4.90 billion (21%) of the aggregate benefits. Based on the findings, we fail to reject the hypothesis that wheat varietal improvement investments by the ARC-SGI generated positive economic benefits for the period 1985 – 2015.

The benefits attributed to the ARC-SGI were second to Sensako (the main private actor in wheat breeding research). Results of an analysis of the benefits among different time periods indicates that the benefits to the ARC-SGI decreased after deregulation while those to Sensako increased. The results highlight the impact of the drop in public funding for wheat variety improvement research after deregulation.

Based on the findings, we fail to reject the hypothesis that the benefits from public research investments significantly decreased since the deregulation of the wheat sub-sector in 1997.

6.3 Recommendations

Wheat varietal innovations are important in agriculture, as they help to improve crop productivity, adaptability and resistance to pests and diseases, and also help to protect the environment. Analysis of wheat varietal improvements demonstrated that the public sector significantly contributed to wheat varietal improvements in South Africa till the deregulation of the wheat sub-sector in 1997. Declining research funding for public research and deregulation of the wheat sub-sector might have contributed to the declining area under wheat and its production, leaving the country a net importer of wheat.

An analysis of the sources of wheat varietal improvements during the different periods showed the dominance of the private sector. The ARC-SGI should strengthen mutually beneficial partnerships and collaborations with the private sector to facilitate commercialisation of the varieties that they develop. This would help ensure that innovations from public wheat varietal improvement research increase their chances of being adopted by farmers thereby generating tangible benefits to the country.

Strengthening IPR systems in South Africa contribute to improving wheat productivity and increasing the number of wheat varieties released. However, incentives beyond granting PBRs and strengthening of IPR systems are required to further stimulate increased investments and release of new varieties for enhancing wheat productivity.

An analysis of ARC-SGI partnerships and pedigree analysis of selected dominant varieties demonstrated that wheat varietal improvement research relies on efforts of other institutions and previous research. The results illustrated the need for attribution of benefits from wheat varietal improvements to avoid overestimation of benefits allocated to any institution. Different attributions methods and scenarios should be tried for further research and comparison of findings with the analysis of this study.

6.4 Areas for further research

The research on estimating research benefits from wheat varietal improvements could be extended in future through gathering data on estimates of area planted to improved varieties. This is critical for measuring benefits from adoption of improved wheat varieties. The estimates provided in this study are an important baseline for comparing estimates of research benefits from wheat varietal improvements.

Extend the research on effects of strengthening IPR systems to test the complementarity versus substitution effects in public and private wheat varietal improvement research which could not be done in the current study. Furthermore, more research is required on private sector research in the wheat sector and the effects of Sensako monopoly in the wheat sector.

Further research would be also be required to assess complementarity and substitution effects of the changing roles and how best public and private wheat varietal improvements in the country can be further stimulated to enhance productivity.

There is a need for continuous gathering of data on different aspects of wheat breeding research and ensuring that such information is well-kept for the data to inform research planning and decision-making for wheat varietal improvements. For example, data on research costs could not be gathered for this study despite efforts to get these data from the ARC-SGI. Future research should contribute to gather these data and further the empirical analysis to estimate net benefits from wheat varietal improvement research.

Future research should also consider applying other estimation methods of benefits from research beyond the economic surplus model and compare the findings with those from the current study. The databases gathered for this study should be continuously updated to allow on-going research analysis of benefits and costs of wheat varietal improvements research.

REFERENCES

ALSTON, J. M., CHAN-KANG, C., MARRA, M. C., PARDEY, P. G. & WYATT, T. J. 2000. *A meta-analysis of rates of return to agricultural R&D: Ex pede Herculem?*, Intl Food Policy Res Inst.

ALSTON, J. M. & PARDEY, P. G. 2001. Attribution and other problems in assessing the returns to agricultural R&D. *Agricultural Economics,* 25**,** 141-152.

ALSTON, J. M., PARDEY, P. G., JAMES, J. S. & ANDERSEN, M. A. 2009. The economics of agricultural R&D. *Annual Review of Resource Economics,* 1**,** 537-566.

ALSTON, J. M. & VENNER, R. J. 2002. The effects of the US Plant Variety Protection Act on wheat genetic improvement. *Research Policy,* 31**,** 527-542.

ANDERSON, W., JOHANSEN, C. & SIDDIQUE, K. H. 2016. Addressing the yield gap in rainfed crops: a review. *Agronomy for sustainable development,* 36**,** 1-13.

ATACK, J., COCLANIS, P. & GRANTHAM, G. 2009. Creating Abundance: Biological Innovation and American Agricultural Development—An appreciation and research agenda. *Explorations in Economic History,* 46**,** 160-167.

BOHN, A. & BYERLEE, D. 1993. The wheat breeding industry in developing countries: An analysis of investments and impacts. CIMMYT: International Maize and Wheat Improvement Center.

BOLDRIN, M. & LEVINE, D. K. 2004. 2003 Lawrence R. Klein Lecture The Case Against Intellectual Monopoly. *International Economic Review,* 45**,** 327-350.

BRENNAN, J. P. & QUADE, K. J. 2004. Analysis of the impact of CIMMYT research on the Australian wheat industry. *Economic Research Report No. 25.* Wagga Wagga: NSW Department of Primary Industries.

BYERLEE, D. & MOYA, P. 1993. *Impacts of international wheat breeding research in the developing world, 1966-1990*, CIMMYT.

CAMERON, A. C. & TRIVEDI, P. K. 2005. *Microeconometrics: methods and applications*, Cambridge University Press.

CAMERON, A. C. & TRIVEDI, P. K. 2010. *Microeconometrics using stata*, Stata press College Station, TX.

CAMPI, M. 2017. The effect of intellectual property rights on agricultural productivity. *Agricultural Economics,* 48**,** 327-339.

CAMPI, M. & DUENAS, M. 2016. Intellectual property rights and international trade of agricultural products. *World Development,* 80**,** 1-18.

CAMPI, M. & NUVOLARI, A. 2015. Intellectual property protection in plant varieties: A worldwide index (1961–2011). *Research Policy,* 44**,** 951-964.

CHIGEZA, G., MASHINGAIDZE, K. & SHANAHAN, P. 2012. Seed yield and associated trait improvements in sunflower cultivars over four decades of breeding in South Africa. *Field Crops Research,* 130**,** 46-56.

DE VILLIERS, P. & LE ROUX, J. 2003. Small Grain Institute: 27 years of excellence Bethlehem, South Africa: Agricultural Research Council, Small Grains Institute.

DEPARTMENT OF AGRICULTURE FORESTRY AND FISHERIES 2006. Wheat fact sheet. Pretoria: Department of Agriculture Forestry and Fisheries.

DEPARTMENT OF AGRICULTURE FORESTRY AND FISHERIES 2010. Wheat production guideline. Pretoria: Directorate Plant Production. Department of Agriculture, Forestry and Fisheries.

DEPARTMENT OF AGRICULTURE FORESTRY AND FISHERIES 2011. Plant Breeders' Rights Policy. Pretoria: Department of Agriculture Forestry and Fisheries.

DIEZ, M. 2002. The impact of plant varieties rights on research: the case of Spain. *Food Policy,* 27**,** 171-183.

DLAMINI, T. & LIEBENBERG, F. 2015. The Aggregate economic benefits of the National Cultivar Trials for Maize in South Africa with specific reference to the Highveld region. *Agrekon,* 54**,** 43-61.

DLAMINI, T. S., MAGINGXA, L. & LIEBENBERG, F. 2015. Estimating the economic value of the national cultivar trials in South Africa: A case for sorghum, sunflower, soybeans and dry beans. *Italian Association of Agricultural and Applied Economics (AIEAA)*.

DOSI, G., MARENGO, L. & PASQUALI, C. 2006. How much should society fuel the greed of innovators?: On the relations between appropriability, opportunities and rates of innovation. *Research Policy,* 35**,** 1110-1121.

DU PLESSIS, A. 1933. The history of small-grains culture in South Africa. *Annals of the University of Stellenbosch,* 8**,** 1652-1752.

DUTFIELD, G. 2009. *Intellectual property rights and the life science industries: past, present and future,* Singapore, World Scientific Publishing.

EATON, D., TRIPP, R. & LOUWAARS, N. The effects of strengthened IPR regimes on the plant breeding sector in developing countries. International Association of Agricultural Economists Conference, August 12-18, 2006 2006 Gold Coast, Australia. International Association of Agricultural Economists, 12-18.

EVENSON, R. E. & GOLLIN, D. 2003. *Crop variety improvement and its effect on productivity,* Wallingford, UK, Cabi Publishing.

FALVEY, R., FOSTER, N. & GREENAWAY, D. 2006. Intellectual property rights and economic growth. *Review of Development Economics,* 10**,** 700-719.

FAN, S., CHAN-KANG, C., QIAN, K. & KRISHNAIAH, K. 2005. National and international agricultural research and rural poverty: the case of rice research in India and China. *Agricultural Economics,* 33**,** 369-379.

FLISTER, L. & GALUSHKO, V. 2016. The impact of wheat market liberalization on the seed industry's innovative capacity: an assessment of Brazil's experience. *Agricultural and Food Economics,* 4**,** 1-20.

FUGLIE, K., HEISEY, P., KING, J., PRAY, C. E. & SCHIMMELPFENNIG, D. 2012. The contribution of private industry to agricultural innovation. *Science,* 338**,** 1031-1032.

FUGLIE, K. O. & HEISEY, P. W. 2007. *Economic returns to public agricultural research*, US Department of Agriculture, Economic Research Service.

FUGLIE, K. O. & TOOLE, A. A. 2014. The evolving institutional structure of public and private agricultural research. *American Journal of Agricultural Economics,* 96**,** 862-883.

GRACE, O. M. & VAN STADEN, J. 2003. A horticultural history of Lachenalia (Hyacinthaceae): review article. *South African journal of science,* 99**,** 526-531.

GRILICHES, Z. 1958. Research costs and social returns: Hybrid corn and related innovations. *Journal of political economy,* 66**,** 419-431.

HEISEY, P. W., LANTICAN, M. A. & DUBIN, H. J. 2002. *Impacts of international wheat breeding research in developing countries, 1966-97,* Mexico, D.F, CIMMYT.

KNUDSON, M. K. & PRAY, C. E. 1991. Plant variety protection, private funding, and public sector research priorities. *American Journal of Agricultural Economics,* 73**,** 882-886.

KOCK, M. & GOULD, C. 2013. Adapting IP to an evolving agricultural innovation landscape. *Sniper No. 2013/01028: WIPO Magazine,* 2.

KOLADY, D. E. & LESSER, W. 2009. Does plant variety protection contribute to crop productivity? Lessons for developing countries from US wheat breeding. *The Journal of World Intellectual Property,* 12**,** 137-152.

LANTICAN, M., BRAUN, H.-J., PAYNE, T. S., SINGH, R., SONDER, K., BAUM, M., VA GINKEL, M. & ERENSTEIN, O. 2016. *Impacts of International Wheat Improvement Research: 1994-2014,* Mexico, D.F, CIMMYT.

LANTICAN, M. A., DUBIN, H. J. & MORRIS, M. L. 2005. *Impacts of international wheat breeding research in the developing world, 1988-2002,* Mexico, D.F, CIMMYT.

LEE, G. J. 2016. *Business statistics from scratch to intermediate with SAS,* Randjiesfontein, Silk Route Press.

LÉGER, A. 2005. Intellectual property rights in Mexico: Do they play a role? *World Development,* 33**,** 1865-1879.

LICKER, R., JOHNSTON, M., FOLEY, J. A., BARFORD, C., KUCHARIK, C. J., MONFREDA, C. & RAMANKUTTY, N. 2010. Mind the gap: how do climate and agricultural management explain the 'yield gap'of croplands around the world? *Global ecology and biogeography,* 19**,** 769-782.

LIEBENBERG, F. 2013. *South African agricultural production, productivity and research performance in the 20th century.* PhD Thesis, University of Pretoria.

LIEBENBERG, F. & PARDEY, P. G. 2011. South African agricultural R&D: Policies and public institutions, 1880–2007. *Agrekon,* 50**,** 1-15.

LILL, D. V. & PURCHASE, J. 1995. Directions in breeding for winter wheat yield and quality in South Africa from 1930 to 1990. *Euphytica,* 82**,** 79-87.

LOUWAARS, N., DONS, H., VAN OVERWALLE, G., RAVEN, H., ARUNDEL, A., EATON, D. J. & NELIS, A. 2009. Breeding business. The future of plant breeding in the light of developments in patent rights and plant breeder's rights. *CGN Report 2009-14.* Wageningen: Centre for Genetic Resources, the Netherlands (CGN), Wageningen University and Research Centre.

MAREDIA, M. K., BERNSTEN, R. & RAGASA, C. 2010. Returns to public sector plant breeding in the presence of spill-ins and private goods: the case of bean research in Michigan. *Agricultural Economics,* 41**,** 425-442.

MAREDIA, M. K. & BYERLEE, D. 2000. Efficiency of research investments in the presence of international spillovers: wheat research in developing countries. *Agricultural Economics,* 22**,** 1-16.

MOEPHULI, S., MOSELAKGOMO, M. & PHEHANE, V. 2012. The Agricultural Research Council's role in plant variety protection and technology transfer - promoting publicly funded research *UPOV Workshop.* Zanzibar, Tanzania.

MORRIS, M. L. & HEISEY, P. W. 2003. Estimating the benefits of plant breeding research: methodological issues and practical challenges. *Agricultural Economics,* 29**,** 241-252.

NASEEM, A., OEHMKE, J. F. & SCHIMMELPFENNIG, D. E. 2005. Does plant variety intellectual property protection improve farm productivity? Evidence from cotton varieties. *AgBioForum,* 8**,** 100-107.

NEETHLING, J. 1932. Wheat Varieties in South Africa-Their History and Development Until 1912. South Africa Department of Agriculture.

NHEMACHENA, C., MATCHAYA, G., NHLENGETHWA, S. & NHEMACHENA, C. R. 2016a. Economic Aspects of Genetic Resources in Addressing Agricultural Productivity in the Context of Climate Change. *In:* LAL, R., KRAYBILL, D., HANSEN, D. O., SINGH, B. R., MOSOGOYA, T. & EIK, L. O. (eds.) *Climate Change and Multi-Dimensional Sustainability in African Agriculture.* Cham: Springer International Publishing.

NHEMACHENA, C. R., LIEBENBERG, F. G. & KIRSTEN, J. 2016b. The evolving landscape of plant breeders' rights regarding wheat varieties in South Africa. *South African Journal of Science,* 112**,** 1-8.

PAL, S. 2011. Impacts of CGIAR crop improvement and natural resource management research: a review of evidence. *Agricultural Economics Research Review,* 24**,** 185-200.

PANNAR 2009. Wheat production guide. Production Guide Series. Greytown, South Africa: Pannar Seed (Pty) Ltd.

PARDEY, P., KOO, B., DREW, J., HORWICH, J. & NOTTENBURG, C. 2013. The evolving landscape of plant varietal rights in the United States, 1930-2008. *Nature biotechnology,* 31**,** 25-29.

PARDEY, P. G., ALSTON, J., CHAN-KANG, C., MAGALHAES, E. & VOSTI, S. 2004. *Assessing and attributing the benefits from varietal improvement research in Brazil,* Washington DC, International Food Policy Research Institute.

PARDEY, P. G., ALSTON, J. M., CHAN-KANG, C., MAGALHÃES, E. C. & VOSTI, S. A. 2006. International and institutional R&D spillovers: Attribution of benefits among sources for Brazil's new crop varieties. *American Journal of Agricultural Economics,* 88**,** 104-123.

PARDEY, P. G., ANDRADE, R. S., HURLEY, T. M., RAO, X. & LIEBENBERG, F. G. 2016a. Returns to food and agricultural R&D investments in Sub-Saharan Africa, 1975–2014. *Food Policy,* 65**,** 1-8.

PARDEY, P. G., CHAN-KANG, C., DEHMER, S. P. & BEDDOW, J. M. 2016b. Agricultural R&D is on the Move. *Nature,* 537**,** 301-303.

PARDEY, P. G., KOO, B., DREW, J. & NOTTENBURG, C. 2012. The Evolving landscape of IP rights for plant varieties in the United States, 1930-2008. University of Minnesota, Department of Applied Economics.

PAYUMO, J., GRIMES, H. & WANDSCHNEIDER, P. 2012. Status of national intellectual property rights (IPRs) systems and its impact to agricultural development: a time series cross section data analysis of TRIPS member-countries. *International Journal of Intellectual Property Management,* 5**,** 82-99.

PINGALI, P. 2010. Global agriculture R&D and the changing aid architecture. *Agricultural Economics,* 41**,** 145-153.

PRAY, C. E. & FUGLIE, K. O. 2015. Agricultural research by the private sector. *Annual Review of Resource Economics,* 7**,** 399-424.

PRAY, C. E. & NAGARAJAN, L. 2014. The transformation of the Indian agricultural input industry: has it increased agricultural R&D? *Agricultural economics,* 45**,** 145-156.

PRICE, S. C. 2000. The public-private interface in plant breeding: Can there be a common culture? *Diversity,* 15**,** 6-7.

RAO, X., HURLEY, T. M. & PARDEY, P. G. Are Agricultural R&D Returns Declining and Development Dependent? 2016 Annual Meeting, July 31-August 2, 2016, Boston, Massachusetts, 2016. Agricultural and Applied Economics Association.

REASON, C. & PHALADI, R. 2005. Evolution of the 2002-2004 drought over northern South Africa and potential forcing mechanisms. *South African Journal of Science,* 101**,** 544-552.

REYES, B. A., MAREDIA, M. K., BERNSTEN, R. H. & ROSAS, J. C. 2016. Opportunities Seized, Opportunities Missed: Differences in the Economic Impact of Bean Research in Five Latin American Countries. *MSU International Development Working Paper No. 151.* Department of Agricultural, Food, and Resource Economics, Michigan State University.

SMIT, H., TOLMAY, V., BARNARD, A., JORDAAN, J., KOEKEMOER, F., OTTO, W., PRETORIUS, Z., PURCHASE, J. & TOLMAY, J. 2010. An overview of the context and scope of wheat (Triticum aestivum) research in South Africa from 1983 to 2008. *South African Journal of Plant and Soil,* 27**,** 81-96.

SOUTH AFRICA WEATHER SERVICES. 2017. *What kind of droughts does South Africa experience?* [Online]. Pretoria. Available: http://www.weathersa.co.za/learning/climate-questions/36-what-kind-of-droughts-does-south-africa-experience [Accessed Accessed 3 August 2017].

SOUTHERN AFRICAN GRAIN LABORATORY 2012. Wheat Crop Quality Report 2011/2012 Season. Pretoria: Southern African Grain Laboratory.

SPIELMAN, D. J. & MA, X. 2016. Private sector incentives and the diffusion of agricultural technology: Evidence from developing countries. *The Journal of Development Studies,* 52**,** 696-717.

SRINIVASAN, C. & THIRTLE, C. 2003. Potential economic impacts of terminator technologies: policy implications for developing countries. *Environment and Development Economics,* 8**,** 187-205.

SRINIVASAN, C. S. 2003. Concentration in ownership of plant variety rights: some implications for developing countries. *Food Policy,* 28**,** 519-546.

STANDER, C. 2012. *The Economics of Cultivar Improvement Research in the South African Wheat Industry* MSc University of Pretoria.

SUNDING, D. & ZILBERMAN, D. 2001. The agricultural innovation process: research and technology adoption in a changing agricultural sector. *Handbook of agricultural economics,* 1**,** 207-261.

THIELE-WITTIG, M. & CLAUS, P. 2003. Plant variety protection—A fascinating subject. *World Patent Information,* 25**,** 243-250.

THIS, P., LACOMBE, T. & THOMAS, M. R. 2006. Historical origins and genetic diversity of wine grapes. *TRENDS in Genetics,* 22**,** 511-519.

TRIPP, R., LOUWAARS, N. & EATON, D. 2007. Plant variety protection in developing countries. A report from the field. *Food Policy,* 32**,** 354-371.

UNITED NATIONS DEPARTMENT OF ECONOMIC AND SOCIAL AFFAIRS POPULATION DIVISION 2017. World Population Prospects: The 2017 Revision. New York: United Nations.

VAN NIEKERK, H. 2001. Southern Africa wheat pool. *In:* BONJEAN, A. & ANGUS, W. (eds.) *The world wheat book: the history of wheat breeding.* Paris: Lavoisier Publishing.

VAN WART, J., KERSEBAUM, K. C., PENG, S., MILNER, M. & CASSMAN, K. G. 2013. Estimating crop yield potential at regional to national scales. *Field Crops Research,* 143**,** 34-43.

WANG, S. L., HEISEY, P. W., HUFFMAN, W. E. & FUGLIE, K. O. 2013. Public R&D, private R&D, and US agricultural productivity growth: Dynamic and long-run relationships. *American Journal of Agricultural Economics,* 95**,** 1287-1293.

WHITE, H. 1980. A heteroskedasticity-consistent covariance matrix estimator and a direct test for heteroskedasticity. *Econometrica: Journal of the Econometric Society***,** 817-838.

WORLD BANK 2008. World Development Report 2008. Washington DC: World Bank.

WRIGHT, B. D. & PARDEY, P. G. 2006a. Changing intellectual property regimes: implications for developing country agriculture. *International Journal of Technology and Globalisation,* 2**,** 93-114.

WRIGHT, B. D. & PARDEY, P. G. 2006b. The evolving rights to intellectual property protection in the agricultural biosciences. *International Journal of Technology and Globalisation,* 2**,** 12-29.

APPENDIX 1: SUMMARY OF WHEAT VARIETIES RELEASED IN SOUTH AFRICA

Table A1: List of wheat varieties released in South Africa between 1810 and 1975

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
TAUTE		TURGIDUM SPECIES OF WHEAT OBTAINED BY THE FATHER OF F. TAUTE, LANGKLOOF GEORGE, FROM MR TURNER OF DURBANVILLE, AFTER 1880	1880		NOBBS				
RIETTI	IMPORTED FROM ITALY	ITALIAN ORIGIN	1892						RESISTANT TO RUST
MACLEAR	NO INFORMATION		1893						
HARM	NO INFORMATION		1897		NOBBS				
UNION	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	CROSS-BREED BETWEEN GLUYAS AND DARLING	1903						
DARLVAN	NO INFORMATION		1910						
NOBBS	NO INFORMATION		1910						
FLORENCE	NO INFORMATION		1914		WILLIAM FARRER, AUSTRALIAN BREEDER	WESTERN CAPE			SUSCEPTIBLE TO RUST
PRIMROSE	NO INFORMATION		1914	1938	WILLIAM FARRER, AUSTRALIAN BREEDER	WESTERN CAPE			
UNION 52	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SPECIAL SELECTION FROM UNION A, UNION B AND UNION C	1914	1930	PROF. J.H. NEETHLING			WINTER	
KLENITROU	NO INFORMATION		1916	1939		WESTERN CAPE		WINTER	SUSCEPTIBLE TO RUST
UNION 17	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SPECIAL SELECTION FROM UNION A, UNION B AND UNION C	1917	1927	PROF. J.H. NEETHLING	WESTERN CAPE			RESISTANT TO RUST
KASARWALI	IMPORTED FROM INDIA	IMPORTED FROM INDIA	1918			FREE STATE			
BOBRIET	NO INFORMATION		1925						SUSCEPTIBLE TO RUST
BURBANK	NO INFORMATION	SELECTION FROM FLORENCE	1925						MODERATELY RESISTANT TO LEAF AND STEM RUST
SCHEEPERS	IMPORTED FROM INDIA	UNKNOWN EX INDIA	1925		ORIGINALLY FROM INDIA	FREE STATE		SPRING	
GOLDEN BALL	IMPORTED BY ALBANY	IMPORTED BY ALBANY	1927			FREE STATE			
LALKASARWALI	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	INDIAN WHEAT FROM PUSA STATION	1927			FREE STATE		IRRIGATION	
GLUYAS EARLY	NO INFORMATION		1928			WESTERN CAPE			RESISTANT TO RUST

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
GLURETTY	NO INFORMATION	CROSS BETWEEN GLUYAS EARLY AND RIETTI	1930		PROF. J.H. NEETHLING	WESTERN CAPE		WINTER	
HOOPVOL	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	KLEINTROU//GLUYAS EARLY/ SPRING EARLY	1930		PROF. J.H NEETHLING	WESTERN CAPE			
IMPALA	NO INFORMATION		1930		PROF. J.H. NEETHLING	WESTERN CAPE			
KAFFIR VISTORIA	NO INFORMATION		1930						
KLEINKORING	NO INFORMATION		1930			NORTH WEST		WINTER	
ON BAARDT	NO INFORMATION		1930						
RED EGYPTIAN	IMPORTED FROM FRANCE	IMPORTED FROM FRANCE	1930	1939		EASTERN CAPE		SPRING	
ROOI INDIES	NO INFORMATION		1930	1939		NORTH WEST			
VAN DYK	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS		1930	1934					
FLORENCE X GLUYAS 17	NO INFORMATION		1931						SUSCEPTIBLE TO RUST
GLURIET	NO INFORMATION		1931						SUSCEPTIBLE TO RUST
BLOUAAR	NO INFORMATION		1932			MPUMALANGA			
BONTAAR	NO INFORMATION	RITTER'S SELECTIONS	1932			FREE STATE		WINTER	SUSCEPTIBLE TO RUST
JORDAAN	NO INFORMATION		1932						
PORT DARWIN	NO INFORMATION		1932			LIMPOPO			
VORENTOE	NO INFORMATION		1932			WESTERN CAPE			
WET ERF	NO INFORMATION		1932						
ELEKSIE	NO INFORMATION		1933		PROF. J.H. NEETHLING				
FARRARTROU	NO INFORMATION		1933		PROF. J.H. NEETHLING	WESTERN CAPE		SUMMER	SUSCEPTIBLE TO RUST
KAAL HAUS	NO INFORMATION		1933						
KENYA STANDARD	NO INFORMATION		1933						
KOALISIE	NO INFORMATION		1933		PROF. J.H. NEETHLING	WESTERN CAPE		WINTER	HIGHLY RESISTANT TO STEM RUST
ROOI LLAMA	NO INFORMATION		1933			FREE STATE			
SONOP	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	KLEINTROU/PELGRIM	1933		PROF. J.H. NEETHLING	WESTERN CAPE			
STERLING	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	COMEBACK/RIETI/EKSTEEN/KLEINTROU/MEDEAH	1933		PROF. J.H. NEETHLING	WESTERN CAPE		WINTER	PRONE TO RUST
EKSTEEN	NO INFORMATION		1935	1939					

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
PELGRIM	NO INFORMATION		1936		PROF. J.H. NEETHLING	EASTERN CAPE			
QUEEN FAN	NO INFORMATION		1936		GROOTFONTEIN SCHOOL OF AGRICULTURE	WESTERN CAPE		IRRIGATION	
BELTISTA	NO INFORMATION		1938		PROF. J.H. NEETHLING	WESTERN CAPE			
BOMBAY	NO INFORMATION		1938						
CILLIERS	NO INFORMATION		1938			FREE STATE			
DEPRESSIE	NO INFORMATION		1938		STELLENBOSCH-ELSENBURG AGRICULTURAL COLLEGE				HIGHLY RESISTANT TO RUST
F.A.Q. AUSTRALIAN	IMPORTED FROM AUSTRALIA	IMPORTED FROM AUSTRALIA	1938						
GARNET	IMPORTED FROM CANADA	CANADIAN WHEAT	1938			WESTERN CAPE			SUSCEPTIBLE TO RUST
GREAT SCOTT	NO INFORMATION		1938						
KRUGER	NO INFORMATION		1938			WESTERN CAPE		SPRING	
LAATBAARD	NO INFORMATION		1938			NORTHERN CAPE			
MANITOBA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	CANADIAN WHEAT COMPRISING THE RENOWNED MARQUIS VARIETY	1938			FREE STATE			
MEDEAH	NO INFORMATION		1938					WINTER	RESISTANT TO RUST
MONTSONYANE	NO INFORMATION		1938			FREE STATE			
PILGRIM	NO INFORMATION		1938		STELLENBOSCH-ELSENBURG COLLEGE OF AGRICULTURE	WESTERN CAPE			MODERATELY SUSCEPTIBLE TO RUST
ROOIKLEINKORING	NO INFORMATION		1938			LIMPOPO		IRRIGATION	
ROSSOUWS-BAARD	NO INFORMATION		1938			WESTERN CAPE			
SLAPAAR	NO INFORMATION		1938			WESTERN CAPE			
THEW	NO INFORMATION		1938						
UNION 81	NO INFORMATION		1938		PROF. J.H. NEETHLING			SPRING	
VONDELING	NO INFORMATION		1938		LOCAL MOORREESBURG FARMER				SUSCEPTIBLE TO RUST
WIT AUSTRALIE	NO INFORMATION		1938			FREE STATE			
WOLKORING	NO INFORMATION		1938			WESTERN CAPE			SUSCEPTIBLE TO RUST
VERBETERDE KENIA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SYN=KENIA GOVERNOR	1940			WESTERN CAPE		SPRING	
KLIPKOUS	NO INFORMATION		1941			WESTERN CAPE			

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
RENOWN	IMPORTED FROM CANADA	IMPORTED FROM CANADA, SHARING THE SAME NAME AS THE PARENT IN THE PARENT COUNTRY	1941			WESTERN CAPE		WINTER	MODERATELY SUSCEPTIBLE TO RUST
IMPROVED KENYA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS		1944			WESTERN CAPE		IRRIGATION	
KENYA GOVERNOR	NO INFORMATION		1944			WESTERN CAPE		WINTER	
OUBAARD	NO INFORMATION		1944			WESTERN CAPE		IRRIGATION	
ROOI STORMBERG	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MIXTURE OF ROOI EGYPTIAN, SCHEEPERS AND DUIMPIES	1944			EASTERN CAPE			
WOLKOPPIES	NO INFORMATION		1944			NORTHERN CAPE		IRRIGATION	
RED VICTORY	NO INFORMATION	UNKNOWN – POSSIBLY BROWN EAR	1946			FREE STATE		SPRING	
BOSSIESVELD	NO INFORMATION		1947						
REAGENT	IMPORTED FROM CANADA	IMPORTED FROM CANADA	1947		IMPORTED	WESTERN CAPE			
REWARD	NO INFORMATION		1947						
THATCHER	NO INFORMATION		1947						
KENYA SOKKIES	IMPORTED FROM KENYA		1949		DR SWART	WESTERN CAPE		SPRING	
DAERAAD	NO INFORMATION	UNIE52A/KRUGER	1950		PROF. J.H. NEETHLING	LIMPOPO		IRRIGATION	
DROMMEDARIS	NO INFORMATION	HOPE/GLURETTY	1950		PROF. J.H. NEETHLING	WESTERN CAPE		WINTER	
DUIKER	NO INFORMATION		1950		PROF. J.H. NEETHLING	WESTERN CAPE		WINTER	
MAGALIESBERG	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	AUSTRALIA 26 A 14/IH44-24/39W73	1950		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST			
MALUTI	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	H44-24/3 9W73//SCHEEPERS	1950		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST			
GOUDVELD	NO INFORMATION	SCHEEPERS/39W73//C 17-1-1-1/SCHEEPERS	1951		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST		MID-SEASON	
PENKOP	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	CI7-I-I-1/SCHEEPERS//KENYA B256/3/39W61	1951		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST			
ROOI SPITSKOP	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	H44-24/39W73//C 17-1-1-L/SCHEPPERS	1951		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST			
SPITSKOP	NO INFORMATION		1951			FREE STATE		SPRING	
WIT SPITSKOP	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	H44-24/39W73//C 17-1-1-L/SCHEPPERS LEE/FRONTANA	1951		POTCHEFSTROOM COLLEGE OF AGRICULTURE	NORTH WEST			

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
VROEE BAARD	NO INFORMATION		1957			EASTERN CAPE			
BETANA	NO INFORMATION	SELECTION FROM IMPORTED LEE-FRONTANA STRAIN	1959		A.R.C. (S.G.I.)	FREE STATE,		INTERMEDIATE	FAIRLY RESISTANT TO LEAF RUST AND SUSCEPTIBLE TO STEM RUST
BETMARK	NO INFORMATION	H44/MARQUIS	1960		BETHLEHEM (O.F.S.)	MPUMALANGA		IRRIGATION	
DELTA	NO INFORMATION	SUPREMO*2//KENYA	1960		BETHLEHEM (O.F.S.)	MPUMALANGA		IRRIGATION	
FLAMEKS	NO INFORMATION	CROSS BETWEEN FLORENCE, AURORE, KENIA, MENTANA AND SUPREMO	1962		STELLENBOSCH-ELSENBURG AGRICULTURAL COLLEGE	WESTERN CAPE		SPRING	SUSCEPTIBLE TO RUST
BONA	NO INFORMATION	LEE/FRONTANA KLEIN LUCERO/KLEIN 157//KLEIN 157/3/ KLEIN ORGULLO	1964		A.R.C. (S.G.I.)	FREE STATE		SUMMER	MODERATELY RESISTANT TO LEAF AND STEM RUST
CELEBRATION	IMPORTED FROM AUSTRALIA		1965		IMPORTED	WESTERN CAPE		WINTER	
CHARTER	IMPORTED FROM AUSTRALIA		1965		IMPORTED	LIMPOPO		IRRIGATION	
GAPO	NO INFORMATION		1965		IMPORTED FROM AUSTRALIA	WESTERN CAPE		SPRING	
JANITOR	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FRONTANA//KENYA 58/NEWTHATCH/3/THATCHER	1965			WESTERN CAPE		DRYLAND	
LEE MIDA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	LEE/MIDA	1965						
LOSPER	NO INFORMATION		1965		BETHLEHEM (O.F.S.)	LIMPOPO		IRRIGATION	SUSCEPTIBLE TO RUST
MALSON	NO INFORMATION		1965	1969 (4)					
PUNJAB	NO INFORMATION		1965			LIMPOPO		SPRING	
SABRE	IMPORTED FROM AUSTRALIA	IMPORTED FROM AUSTRALIA	1965		IMPORTED			WINTER	
SKEMER	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	CROSS BETWEEN FLORENCE, AURORA, KENIA, MENTANA AND SUPREMO	1965		STELLENBOSCH-ELSENBURG AGRICULTURAL COLLEGE	WESTERN CAPE		WINTER	SUSCEPTIBLE TO RUST
T4	CIMMYT ADVANCED LINE	LERMA ROJO//NORIN 10/BREVOR/3/ANDES 3-E (LR/N10B//3*ANE)	1965		A.R.C. (S.G.I.)	FREE STATE		SPRING	SUSCEPTIBLE TO RUST
TOBARI	NO INFORMATION	TZPP/SON64A	1966		CIMMYT	WESTERN CAPE		IRRIGATION	
AITSA	CROSS MADE IN COUNTRY, ONE CIMMYT PARENT	FLAM/N10B//YAKTNA 54	1967					SPRING	
BELLA	CROSS MADE IN COUNTRY, NO CIMMYT PARENT	1 CHANCELLOR/KENTUCKY	1967		A.R.C. (S.G.I.)	KWAZULU- NATAL		FACULTATIVE	RESISTANT TO LEAF AND STEM RUST, INHERITED FROM AGROPYRON
K 20	CROSS MADE IN OTHER COUNTRY, NO CIMMYT PARENTS	LEE MIDA//THATCHER/3/KENYA FARMER/?/LEE	1967			WESTERN CAPE		SPRING	HIGHLY RESISTANT TO RUST

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
KASTEEL	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	YAK.54 N10.B21.1//(FLAMEKS) MENTANA-KENYA-SUPREMO/FLORENCE AURORA	1967		STELLENBOSCH-ELSENBURG AGRICULTURAL COLLEGE	WESTERN CAPE		WINTER	MODERATELY SUSCEPTIBLE TO RUST
SABIE	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	FN/K-58//NEWTH/3/N10B	1967		A.R.C. (S.G.I.)			SPRING	
TOSCA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FN-K-58/NEWTH/N10B/3/NEWTH/MARQUIS/3/FN/3/KANT-54/4/FLAM/3/QNA/MAGALIESBERG 2/ROMINANS CHIESA	1968		STELLENBOSCH-ELSENBURG AGRICULTURAL COLLEGE	WESTERN CAPE		SPRING	
BARTA	CROSS MADE IN COUNTRY, NO CIMMYT PARENT	MADE FROM THE PROGENY OF A CROSS BETWEEN 43-MAYO 48 AND LEE FONTANA (BENTANA)	1969		A.R.C. (S.G.I.)	LIMPOPO		FACULTATIVE	MODERATELY RESISTANT TO LEAF RUST AND RESISTANT TO STEM RUST
KLEIN 157/3/KIEIN ORGULLO	NO INFORMATION		1969						
SCHEEPERS 69	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SELECTION FROM SCHEEPERS	1969		A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	
BELINDA	CROSS MADE IN OTHER COUNTRY, NO CIMMYT PARENT	STEMS FROM WHICH A CROSS IS MADE BETWEEN TWO WINTER CULTIVARS, OTTAWA AND CHEYENNE (OTTAWA/2*CHEYENNE(W65/155)	1970		A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	MODERATELY SUSCEPTIBLE TO LEAF AND STEM RUST
BETTA	CROSS MADE IN OTHER COUNTRY, NO CIMMYT PARENTS	(KLEIN IMPACTO) LEE/FRONTANA KLEIN LUCERO/KLEIN 157//	1970		A.R.C. (S.G.I.)	LIMPOPO		WINTER	RESISTANT TO LEAF AND STEM RUST
INIA	CIMMYT ADVANCED LINE	LERMA ROJO 64/ SONORA 64	1970		A.R.C. (S.G.I.)				FAIRLY RESISTANT TO RUST
BAJIO 66	NO INFORMATION		1971			FREE STATE		IRRIGATION	
ELAN	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FRONTANA-KENYA58-NEW THATCHER/NORIN I 0-BREVOR//908-FRONTANA/3/KENTANA 54-BAGE/4/MCNTANA/TXA 32// STERLING/3/QUADCMA/5/MIDA-MC MURACHY-ESCHANGE	1971		SENSAKO			FACULTATIVE	
FRISKO	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	NORIN 10-B17 X GABO-LANGDON DURUM 357	1971		SENSAKO	NORTH WEST		FACULTATIVE	
HEEMRAAD	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	KENYA FARMER/ KOALISIE	1971			FREE STATE		IRRIGATION	
INIA 66	NO INFORMATION	LR64/SON64A	1971		CIMMYT	FREE STATE		IRRIGATION	
KWARTA	NO INFORMATION		1971			FREE STATE		IRRIGATION	
LUNDI	NO INFORMATION		1971			FREE STATE		IRRIGATION	
SEBAKWE	NO INFORMATION		1971			FREE STATE		IRRIGATION	
T7	NO INFORMATION		1971			WESTERN CAPE		IRRIGATION	
TOKWE	IMPORTED FROM ZIMBABWE	ORIGIN IN ZIMBABWE	1971			FREE STATE		IRRIGATION	

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
ZAMBESI 2	NO INFORMATION		1971			FREE STATE		IRRIGATION	
GAMENYA	NO INFORMATION		1972			WESTERN CAPE			
GAMUT	NO INFORMATION		1972			WESTERN CAPE		DRYLAND	
KENYA FARMER	NO INFORMATION		1972			WESTERN CAPE		SPRING	
MENGAVI	NO INFORMATION		1972			WESTERN CAPE		SPRING	
RAVEN	NO INFORMATION		1972			WESTERN CAPE		SPRING	
SOBUKWE	NO INFORMATION		1972			WESTERN CAPE		SPRING	
ZAMBESI	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	8156//LEE/ND 74	1972			WESTERN CAPE		SPRING	
MUTI	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SN64/TZPP//YAKTANA54/BONKUTI/3/INIA66	1973		SENSAKO			SPRING	
NANA	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	UMTALI/TOBARI/3/CNO67//BB/CIANO"S"	1973		SENSAKO			SPRING	
BENITA	CROSS MADE IN OTHER COUNTRY, ONE CIMMYT PARENT	THATCHER*4//M2824/3/LL-54-8 (USDA)	1974					FACULTATIVE	
MEMNON	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	BAJIO/FLAM//YAKTANA 54/3/N10B	1974					SPRING	
SONDEREND	CIMMYT SEGREGATING LINE OR POPULATION	LERMA ROJO/SONORA 64/NAPO	1974			WESTERN CAPE		SPRING	
AERIE	CIMMYT SEGREGATING LINE OR POPULATION	CNO67//SN64//KLRE/3/8156	1975		CIMMYT			SPRING	
ELIZE	CIMMYT SEGREGATING LINE OR POPULATION	INIA 66/P 4160 (INIA"S"//SN64/KLRE/3/8156)	1975			LIMPOPO		SPRING	
HELENE	CIMMYT SEGREGATING LINE OR POPULATION	BLUEBIRD//CIANO/SON 64	1975			LIMPOPO		SPRING	

Table A2: List of wheat varieties released in South Africa between 1976 and 1995

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
ELRINA	CIMMYT SEGREGATING LINE OR POPULATION	SON64/Y50//GABOTA/3/INIA	1976		A.R.C. (S.G.I.)	LIMPOPO		SPRING	
LIESBEECK	CIMMYT SEGREGATING LINE OR POPULATION	CIANO'S'/INIA'S' (CNO67/INIA66)	1976					SPRING	
BAIJO	NO INFORMATION		1977						FAIRLY RESISTANT TO STEM RUST AND SUSCEPTIBLE TO LEAF RUST
DIPKA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	PAWNEE//T.TIM/AG.EL/3/FLAM/MINT/4/3*FLAM	1978					SPRING	
GOURITZ	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FLAMEKS//*4 MINTURKI/ TRITICUM TIMOPHEEVI (PAWNEE//T.TIM/AG.EL/3/FLAM/MINT/4/3*FLAM)	1978			MPUMALANGA		SPRING	
SST 101	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA/3/PAWNEE//CHCYENNI/MIN. 11-54-12	1978		SENSAKO			FACULTATIVE	
SST 102	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA*2/IAGENT	1978		SENSAKO	TRANSVAAL		FACULTATIVE	
ZARAGOZA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MENGAVI/8156	1978		CIMMYT				
FLAMINK	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MINTURKEY/T . TIMPOHEEVI// A.ELONGATUM/3/PAWNEE 327/4/4 FLAMEKS	1979		A.R.C. (S.G.I.)	MPUMALANGA		FACULTATIVE	
FRIASKO	NO INFORMATION		1979		SENSAKO				
SEKEL	NO INFORMATION		1979		SENSAKO				
SST 002	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	GALIDAD/TOBARI 66	1979		SENSAKO			SPRING	
SST 003	CIMMYT SEGREGATING LINE OR POPULATION	INIA 66/CALIDAD	1979		SENSAKO	LIMPOPO		SPRING	
SST 004	NO INFORMATION		1979		SENSAKO				
SST 006	NO INFORMATION	LR64/23584//SON 64	1979		SENSAKO				
SST 044	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	T4**5/567-336	1979		SENSAKO	WESTERN CAPE		WINTER	
SST 066	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	(INIA/CALIAD"S") LD398/LD357//SST464/3/3*FLAM/4/3*SST16	1979		SENSAKO	WESTERN CAPE		SPRING	
SST 33	CIMMYT SEGREGATING LINE OR POPULATION	REWARD/CI 12632//3* FLAMEKS/3/3 * SST 3	1979		SENSAKO	WESTERN CAPE		SPRING	
PALALA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	ND 487/WALDRON, ND 71-14-1189	1980		A.R.C. (S.G.I.)			SPRING	RESISTANT TO RUST
WILGE	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BELLA/ REWARD/ CI 12632	1980		A.R.C. (S.G.I.)	MPUMALANGA			RESISTANT TO RUST

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
SST 023	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	INIA66*6/SST44	1981		SENSAKO	LIMPOPO		SPRING	
CIANO	NO INFORMATION	P162/CHRIS//SON64	1982		CIMMYT				
GAMKA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FLAMEKS*5/SR24	1982					SPRING	
SNK 108	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	HYBRID	1982			FREE STATE	HYBRID	SPRING	
W 63	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	AZTECA F67/ PITIC 62	1982					SPRING	
W 64	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	AZTECA F67/ PITIC 62	1982					SPRING	
DOUGGA 74	NO INFORMATION	KLEIN PETITO/R RAFAELO MAZ//2/8156 (R	1983						
GLENLEA	NO INFORMATION	PERNBINA/BAGE//CB100	1983						
JUPATECO 73	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	II 12300//LERMA ROJO 64/8156/3/NORT 67	1983						
KAREE	DISTRIBUTION BY SENSAKO	BETTA/TRIUMPH/CI 13523	1983	2000 (17)	A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	
LINE 1	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	JUP 73/3/CNO'S'/GALLO//BLUEBIRD/INIA	1983						
LINE 2	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MENGAVI/8156 (R //BUHO	1983						
LINE 3	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	PITIC 62/3/ 1153/526/ SON 64 F8-4	1983						
LINE 4	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	INIA/ BAJIO//TIMGALEN	1983						
LINE 5	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	HOOPVOL/CI 297001	1983						
LINE 6	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	ARTHUR TYPE *3 (F.G. TRANSFER BULGARIA 88)	1983						
LINE 7	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	K20/MENGAVI	1983						
LINE 8	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	CIANO'S'/PJ 62//GALLO/JUP'S'	1983						
LINE 9	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	KAL/Bb//MENGAVI 8156 (R	1983						
MOROCCO	NO INFORMATION		1983						
MUSALA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	LEE/KAVKAZ/3/CC//RON/CHA	1983						

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
NACOZARI	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	TZPP/PALOMA//SIETTE CERROS	1983						
PAVON'S'	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	VICAM 71// CIANO 67 SIB/(SIETTE CERROS 66/3/ KAL/ BLUEBIRD	1983						
RO 1	NO INFORMATION	23584A/ CIANO	1983					SPRING	
SIETTES CERROS	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	PENJAMO 62 SIB/GABO 55	1983						
PALMIET	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST3*2//SCOUT*51AGENT	1984	2001 (17)	A.R.C. (S.G.I.)	WESTERN CAPE		WINTER	MODERATELY SUSCEPTIBLE
SST 025	NO INFORMATION	INIA66*/SST44	1984	1995 (11)	SENSAKO			SPRING	
SST 107	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	TRIUMPH/AGENT//4*SCHECPCRS 69/3/SCHEEPERS 69/TIFTON/ 412 *SCHEEPERS 69	1984	2000 (16)	SENSAKO			FACULTATIVE	
GAMTOOS	CIMMYT ADVANCED LINE	KAVKAZ/BUHO'S//KALYANSONA/BLUEBIRD	1985	2001 (16)	A.R.C. (S.G.I.)	WESTERN CAPE		SPRING	
MONI	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	LEEDS/CBO-58	1985		A.R.C. (S.G.I.)	NORTHERN CAPE		SPRING	
RAMA	CIMMYT ADVANCED LINE		1985			NORTHERN CAPE		SPRING	
MOLEN	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA/3/YAKTANA//N10B/MAZOE	1986	2002 (16)	A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	
TUGELA	CIMMYT SEGREGATING LINE OR POPULATION	KAVKAZ/JARAL	1986	2001 (15)	A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	
CARITHA	NO INFORMATION	FI HYBRID: NOT AVAILABLE	1987	2001 (14)	CARNIA		HYBRID	WINTER	
CAROL	NO INFORMATION	FI HYBRID: NOT AVAILABLE	1987	2001 (14)	CARNIA		HYBRID	WINTER	
CAROL 310	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1987				HYBRID	FACULTATIVE	
HARTS	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SCHEEPERS69/3/AGR. SUBSTR PW 327/S11-11-A1//3*SHASHI	1987	1995 (8)	A.R.C. (S.G.I.)			WINTER	
HUGENOO T	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA//FLAMINK/AMIGO	1987	2003 (16)	SENSAKO			FACULTATIVE	
LETABA	CROSS MADE IN OTHER COUNTRY, NO CIMMYT PARENTS	WARRIOR5*/AGENT//KAVKAZ (NE77637) (WRR*5/AG//KVZ)	1987	1999 (12)	A.R.C. (S.G.I.)			FACULTATIVE	
RIEMLAND	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FLAMINK/AMIGO	1987	1996 (9)	SENSAKO	FREE STATE		FACULTATIVE	
SST 065	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	NANTES/4/PALMIET/A2398/3/SST66*//PA124/ ALNDORA	1987	2005 (18)	SENSAKO	WESTERN CAPE		SPRING	
SST 086	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	YECORA/5/SN64/3/F573//2*ROBIN/GAZA/4/O PAL/F430	1987		SENSAKO			SPRING	
SST 124	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BEZOSTAYA//BETTA/LINE W	1987	2006 (19)	SENSAKO			FACULTATIVE	

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
CARINA	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	FI HYBRID: NOT AVAILABLE	1988	2001 (13)	CARNIA	FREE STATE	HYBRID	WINTER	
DIAZ	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST 16*3//5*T4/S67-336/3/4* SST 16/VERNSTEIN	1988						
GOOD HOPE	CIMMYT ADVANCED LINE	S179/PH158//GTA/S195/3/JNK/4/YAV_7	1988			NORTHERN CAPE			RESISTANT TO RUST
MOLOPO	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA//MONON/ARTHUR.OH130	1988	1998 (10)	A.R.C. (S.G.I.)	CENTRAL FREE STATE		FACULTATIVE	
OOM CHARL	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA*/MN1972	1988	2001 (13)	SENSAKO			FACULTATIVE	
R 654 *	NO INFORMATION		1988		CARGILL USA				
ADAM TAS	CROSS MADE IN COUNTRY, ONE CIMMYT PARENT	SST 16*3//T4*5/S67-336	1989	2000 (11)	SENSAKO	FREE STATE		SPRING	
B 617	NO INFORMATION		1989		CARNIA USA				
B 906	NO INFORMATION		1989		CARNIA USA				
CHOKKA	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST16*4/AURORA	1989	2000 (11)	SENSAKO			SPRING	
MULTILYN Z	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	T4 MULTILINE SR24, SR31, SR9E, SRTT1, SR26, SR27, SRTT2	1989			WESTERN CAPE			
NANTES	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST 16*3//5*T4/S67-336	1989	2000 (11)	SENSAKO			SPRING	
FARGO	NO INFORMATION		1990			NORTHERN CAPE			
ORANIA	CIMMYT ADVANCED LINE	GDOVZ578//LEEDS(DWARF-MUTANT)/GAVIOTA/3/FULIGULA	1990		A.R.C. (S.G.I.)			SPRING	
MARICO	CIMMYT SEGREGATING LINE OR POPULATION	(BROADBILL), CLEMENT/MOCHIS73//TORIM	1992		A.R.C. (S.G.I.)			SPRING	
PAN 3211	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1992	2003 (11)	PANNAR		HYBRID	FACULTATIVE	
SST 016	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	INIA 66/CALIDAD	1992		SENSAKO			SPRING	
SST 055	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST16*3//T4*5/S67-336/3/SST16*4/EAGLE	1992		SENSAKO			SPRING	
SST 822	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SST 86**3/3/SST 16//3*T4/S67-336//3*NANA//T4/AURORA	1992		SENSAKO			SPRING	
SST 825	CIMMYT SEGREGATING LINE OR POPULATION	KAVKAZ/BUHO'S,//KALYANSONA/BLUEBIRD/3/HERMOSILO77/SAPSUCKER (HER/SAP//VEE)	1992		SENSAKO	LIMPOPO		INTERMEDIATE	
TUGELA-DN	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	DEVELOPED FROM THE KNOWN CULTIVAR TUGELLA (TUGELA*4/PI137739) (TUGELA*4/SA1684)	1992	1999 (7)	A.R.C. (S.G.I.)			WINTER	
ALPHA	NO INFORMATION		1993		SENSAKO				
BETTA DN	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BACKCROSS DERIVATIVE OF BREAD WHEAT BETTA (BETTA*4/P1137739) (BETTA*4/SA1684)	1993		A.R.C. (S.G.I.)			WINTER	

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
KARIEGA	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST44//K4500.2/SAPSUCKER'S'	1993		A.R.C. (S.G.I.)	WESTERN CAPE		FACULTATIVE	
MINET	NO INFORMATION	USGEN19	1993					SPRING	
PAN 3235	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1993	2008 (15)	PANNAR		HYBRID	FACULTATIVE	
REX	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	TARASCA 87-1/YOGUI-1	1993						
SST 038	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	PALMIET/4/SST16*4/3/SST3*3//FM3/H441	1993	1999 (6)	SENSAKO			SPRING	
SST 333	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SST 124*4/PI262660	1993	2006 (13)	SENSAKO			FACULTATIVE	
SST 976	NO INFORMATION		1993		SENSAKO				
GARIEP	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MOLOPO*4/PI137739 (SA1684/MOLOPO*4)	1994		A.R.C. (S.G.I.)			INTERMEDIATE	
KIEWIET	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT		1994						
LIMPOPO	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	BETTA-TYPE CULTIVAR(BETTA*5/PI137739 (SA1684/BETTA*4)	1994		A.R.C. (S.G.I.)	FREE STATE		FACULTATIVE	
ORANGE	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MOLOPO(2) *4/PI137739	1994		A.R.C. (S.G.I.)				
PAN 3232	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1994	2003 (9)	PANNAR		HYBRID	FACULTATIVE	
PAN 3349	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1994		PANNAR		HYBRID	FACULTATIVE	
SBK 936	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1994					FACULTATIVE	
SST 038	NO INFORMATION		1994		SENSAKO				
SST 936	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1 HYBRID: A936/R41	1994	2004 (10)	SENSAKO		HYBRID	FACULTATIVE	
GARIP	NO INFORMATION	BETTA/MONONL ATR OH 130/3/3*GAUDAM 1/FISIA	1995						
LESATI	NO INFORMATION		1995		A.R.C. (S.G.I.)				
SST 057	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	SST16*3//T4*5/S67-336/3/A2398	1995		SENSAKO	WESTERN CAPE		SPRING	
CALEDON	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MOLOPO*4/PI137739 (MOLOPO*4/GANDUM I FASAI)	1996		A.R.C. (S.G.I.)	WESTERN CAPE		INTERMEDIATE	
CARITHA 301	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1996				HYBRID	FACULTATIVE	

VARIETY+ A1:B47 NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
PAN 3364	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1-HYBRID	1996		PANNAR		HYBRID	FACULTATIVE	
SST 363	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SST124*3/PI294994 (SST124*3/RWA-R)	1996	2004 (8)	SENSAKO			FACULTATIVE	
SST 367	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	PI137739/SST102//HUGENOOT/P1262660 (GANDUM I FASAI/SST102//HUGENOOT/TURKSIKUM)	1996	2006 (10)	SENSAKO			FACULTATIVE	
SST 964	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1 HYBRID	1996		SENSAKO		HYBRID	FACULTATIVE	
SST 966	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1 HYBRID: A966/R41	1996	2006 (10)	SENSAKO		HYBRID	FACULTATIVE	

Table A3: List of wheat varieties released in South Africa between 1996 and 2014

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
PAN 3377	NO INFORMATION	INFORMATION WITHHELD	1997		PANNAR			FACULTATIVE	
SNACK	NO INFORMATION		1997		UNIVERSITEIT VRYSTAAT				
SST 075	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	NANTES/4/A2398/3/SST16*3//T4*5/S67-336	1997	2004 (7)	MONSANTO			SPRING	
SST 875	NO INFORMATION	INFORMATION WITHHELD	1997		SENSAKO			SPRING	
SST 876	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	PALMIET/A2398//ADAM TAS/3/SST825	1997		SENSAKO	NORTH WEST		FACULTATIVE	
SST 972	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	F1 HYBRID: A972/R41	1997	2002 (5)	SENSAKO		HYBRID	FACULTATIVE	
ELANDS	NO INFORMATION		1998		A.R.C. (S.G.I.)				
KH198/41	NO INFORMATION		1998		SENSAKO				
KH298/44	NO INFORMATION		1998		SENSAKO				
SST 88	NO INFORMATION	INFORMATION WITHHELD	1998		SENSAKO	WESTERN CAPE		SPRING	
SST 885	NO INFORMATION	INFORMATION WITHHELD	1998		SENSAKO			SPRING	
SST 886	NO INFORMATION	INFORMATION WITHHELD	1998		SENSAKO			SPRING	
SST 983	NO INFORMATION	F1 HYBRID: A972/R44	1998	2006 (8)	SENSAKO		HYBRID	FACULTATIVE	
PAN 3191	NO INFORMATION	INFORMATION WITHHELD	1999	2008 (9)	PANNAR			FACULTATIVE	
SST 399	NO INFORMATION	INFORMATION WITHHELD	1999	2009 (10)	MONSANTO			FACULTATIVE	
SST 94	NO INFORMATION	INFORMATION WITHHELD	1999	2005 (6)	MONSANTO	WESTERN CAPE		SPRING	
SST 969	NO INFORMATION		1999		SENSAKO				
STEENBRAS	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SST44/SST66/4/HOOPVOL/C1297001/3/T.AEST/BONANZA//CIANO/7C	1999		A.R.C. (S.G.I.)			SPRING	
BAVIAANS	CROSS MADE IN COUNTRY, ONE CIMMYT PARENT	QUEEN FAN(A50)/4/JUP/EMU"S"//GJO"S"/3KVZ/K4500L-6-A-4	2000		A.R.C. (S.G.I.)			SPRING	
PAN 3490	NO INFORMATION	INFORMATION WITHHELD	2000		PANNAR			SPRING	
PAN 3492	NO INFORMATION	INFORMATION WITHHELD	2000		PANNAR			SPRING	
SST 806	NO INFORMATION	INFORMATION WITHHELD	2000		MONSANTO	NORTH WEST		IRRIGATION	
BIEDOU	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	KARIEGA*24/SST3//SCOUT*5/AG/3/KASTEEL/PY487	2001	2008 (7)	A.R.C. (S.G.I.)			SPRING	
OLIFANTS	CROSS MADE IN THE COUNTRY, ONE CIMMYT PARENT	JUPATECO'S'/BOBWHITE'S'//VEERY#5/BUCKBUCK'S'/3/TUI'S'	2001		A.R.C. (S.G.I.)	NORTH WEST		SPRING	
PAN 3118	NO INFORMATION	INFORMATION WITHHELD	2001		PANNAR			WINTER	

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
PAN 3404	NO INFORMATION	INFORMATION WITHHELD	2001		PANNAR			SPRING	
PAN 3408	NO INFORMATION	INFORMATION WITHHELD	2001		PANNAR			SPRING	
SST 015	NO INFORMATION	INFORMATION WITHHELD	2001		MONSANTO			SPRING	
CARINA 205	NO INFORMATION		2002						
GWK 101	NO INFORMATION		2002		GWK BEPERK				
GWK 102	NO INFORMATION		2002		GWK BEPERK				
GWK 103	NO INFORMATION		2002		GWK BEPERK				
GWK 201	NO INFORMATION		2002		GWK BEPERK				
KOMATI	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MOLOPO//PI137739/5*TUGELA-26	2002		MONSANTO/ A.R.C. (S.G.I.)			SPRING	
PAN 3120	NO INFORMATION	INFORMATION WITHHELD	2002		PANNAR			WINTER	
PAN 3122	NO INFORMATION	INFORMATION WITHHELD	2002		PANNAR			WINTER	
SST 027	NO INFORMATION	INFORMATION WITHHELD	2002		MONSANTO	WESTERN CAPE		SPRING	
SST 322	NO INFORMATION	INFORMATION WITHHELD	2002	2008 (6)	MONSANTO			FACULTATIVE	
SST 826	NO INFORMATION		2002		SENSAKO	WESTERN CAPE		SPRING	
SST 973	NO INFORMATION		2002		SENSAKO				
TARKA	NO INFORMATION	MOLOPO//PI137739/5*TUGELA-26	2002		A.R.C. (S.G.I.)			FACULTATIVE	
MACB	NO INFORMATION		2003		SENSAKO				
SST 035	NO INFORMATION	INFORMATION WITHHELD	2003		MONSANTO			SPRING	
SST 036	NO INFORMATION		2003		SENSAKO				
SST 334	NO INFORMATION	INFORMATION WITHHELD	2003	2009 (6)	MONSANTO			FACULTATIVE	
SST 835	NO INFORMATION	INFORMATION WITHHELD	2003		MONSANTO			SPRING	
SST 935	NO INFORMATION	F1 HYBRID: A966/R2	2003		MONSANTO		HYBRID	WINTER	
DUZI	NO INFORMATION	KARIEGA/PALMIET	2004		A.R.C. (S.G.I.)	LIMPOPO		SPRING	
KROKODIL	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	MARICO*2//PI262660/5*PALMIET	2004		A.R.C. (S.G.I.)			SPRING	
MATLABAS	CROSS MADE IN THE COUNTRY, NO CIMMYT PARENTS	SAULESKU28/TUGELA-DN	2004		A.R.C. (S.G.I.)			WINTER	
NOSSOB	NO INFORMATION	PI137739*4TUGELA(36)/3/AUS22498//MANN ING/SADOVOL	2004		A.R.C. (S.G.I.)			WINTER	
PAN 3434	NO INFORMATION	INFORMATION WITHHELD	2004		PANNAR			SPRING	
SST 347	NO INFORMATION	INFORMATION WITHHELD	2004		MONSANTO			WINTER	
SST 935 (B)	NO INFORMATION		2004		SENSAKO				
SST 946	NO INFORMATION	F1 HYBRID: A966/R6	2004		MONSANTO		HYBRID	WINTER	

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
PAN 3144	NO INFORMATION	INFORMATION WITHHELD	2005		PANNAR			WINTER	
SST 026	NO INFORMATION		2005						
SST 047	NO INFORMATION		2005		MONSANTO				
SST 056	NO INFORMATION		2005		MONSANTO				
SST 057	NO INFORMATION		2005						
SST 356	NO INFORMATION	INFORMATION WITHHELD	2005		MONSANTO			FACULTATIVE	
SST 954	NO INFORMATION		2005		SENSAKO				
AFG 554-8	NO INFORMATION		2006		KLEIN KAROO SEED MARKETING				
PAN 3355	NO INFORMATION	INFORMATION WITHHELD	2006		MONSANTO			FACULTATIVE	
SST 064	NO INFORMATION		2006						
SST 067	NO INFORMATION		2006						
SST 308	NO INFORMATION		2006		SENSAKO				
SST 319	NO INFORMATION		2006		SENSAKO				
SST 386	NO INFORMATION		2006		SENSAKO				
SST 963	NO INFORMATION	F1 HYBRID	2006		MONSANTO		HYBRID	FACULTATIVE	
SST 986	NO INFORMATION		2006		SENSAKO				
PAN 3161	NO INFORMATION	INFORMATION WITHHELD	2007		PANNAR			WINTER	
PAN 3368	NO INFORMATION	INFORMATION WITHHELD	2007		PANNAR			FACULTATIVE	
SST 077	NO INFORMATION		2007		MONSANTO				
SST 366	NO INFORMATION		2007		SENSAKO				
BUFFELS	NO INFORMATION		2008		A.R.C. (S.G.I.)				
PAN 3172	NO INFORMATION	INFORMATION WITHHELD	2008		PANNAR			WINTER	
PAN 3179	NO INFORMATION	INFORMATION WITHHELD	2008		PANNAR			FACULTATIVE	
PAN 3471	NO INFORMATION	INFORMATION WITHHELD	2008		PANNAR			SPRING	
PAN 3478	NO INFORMATION	INFORMATION WITHHELD	2008		PANNAR			SPRING	
SST 843	NO INFORMATION	INFORMATION WITHHELD	2008		MONSANTO			SPRING	
PAN 3379	NO INFORMATION		2009		PANNAR				
SST 087	NO INFORMATION		2009		SENSAKO				
SST 374	NO INFORMATION		2009		SENSAKO				
SST 387	NO INFORMATION		2009		SENSAKO				
SST 867	NO INFORMATION		2009		SENSAKO				

VARIETY NAME	VARIETY ORIGIN	PEDIGREE	YEAR OF RELEASE	LAST YEAR OF COMMERCIAL PRODUCTION	BREEDER 1	AREAS SUITABLE FOR PLANTING THE VARIETY	CULTIVAR TYPE	GROWTH HABIT	RUST RESISTANCE SCORE
SST 877	NO INFORMATION		2009		SENSAKO				
SST 878	NO INFORMATION		2009		SENSAKO				
PAN 3400	NO INFORMATION		2010		PANNAR				
PAN 3497	NO INFORMATION		2010		PANNAR				
SST 096	NO INFORMATION		2010		SENSAKO				
SST 398	NO INFORMATION		2010		SENSAKO				
PAN 3195	NO INFORMATION		2011		PANNAR				
SST 805	NO INFORMATION		2011		SENSAKO				
SST 807	NO INFORMATION		2011		SENSAKO				
SST 866	NO INFORMATION		2011		SENSAKO				
SST 884	NO INFORMATION		2011		SENSAKO				
SST 895	NO INFORMATION		2011		SENSAKO				
SST 896	NO INFORMATION		2011		SENSAKO				
HARTBEES	NO INFORMATION		2012		A.R.C. (S.G.I.)				
KOONAP	NO INFORMATION		2012		A.R.C. (S.G.I.)				
KWARTEL	NO INFORMATION		2012		A.R.C. (S.G.I.)				
PAN 3198	NO INFORMATION		2012		PANNAR				
PAN 3515	NO INFORMATION		2012		PANNAR				
PAN 3623	NO INFORMATION		2012						
RATEL	NO INFORMATION		2012		A.R.C. (S.G.I.)				
SELATI	NO INFORMATION		2012		A.R.C. (S.G.I.)				
SENQU	NO INFORMATION		2012		A.R.C. (S.G.I.)				
SST 316	NO INFORMATION		2012		SENSAKO				
SST 317	NO INFORMATION		2012		SENSAKO				
SST 815	NO INFORMATION		2012		SENSAKO				
SST 816	NO INFORMATION		2012		SENSAKO				
SST 977	NO INFORMATION		2012		SENSAKO				
GVATI	NO INFORMATION		2013		ARO VOLCANI CENTRE				
SST 0127	NO INFORMATION		2013		SENSAKO				
SST 971	NO INFORMATION		2013		SENSAKO				
SST 974	NO INFORMATION		2013		SENSAKO				

APPENDIX 2: SUMMARY OF WHEAT AREA PLANTED, PRODUCTION, PRODUCER PRICES, PRODUCER PRICE INDEX AND GROSS VALUE

Table A2: Wheat: area planted, production, producer prices, producer price index and gross value

Production year	Area planted[1]	Total produc-tion[2]	Gross value of production[2]	Producer prices[3]				Price index[6]	Marketing year: Oct. to Sep.
				BS1[4]		BL1[5]			
				Basic	Net	Basic	Net		
	1 000 ha	1 000 t	R1 000	R/ton				2010 = 100	
1980	1 627	1 490	313 765	215.20	215.00	208.74	208.54	11.1	1980/81
1981	1 812	2 356	556 089	241.40	240.40	234.16	233.16	12.4	1981/82
1982	2 013	2 448	705 031	295.00	294.00	286.75	285.75	15.2	1982/83
1983	1 819	1 786	480 935	275.00	274.00	266.75	265.75	14.2	1983/84
1984	1 942	2 346	690 202	299.00	298.00	290.03	289.03	15.4	1984/85
1985	1 983	1 691	534 916	325.00	322.00	315.25	312.25	16.6	1985/86
1986	1 946	2 333	864 521	376.80	375.30	366.00	364.50	19.4	1986/87
1987	1 749	3 154	1 257 265	405.00	403.50	393.07	391.57	20.9	1987/88
1988	2 009	3 557	1 220 682	353.75	351.75	343.25	341.25	18.2	1988/89
1989	1 843	2 033	929 947	458.25	452.50	446.68	440.93	23.0	1989/90
1990	1 563	1 709	879 422	521.43	515.14	505.79	499.50	26.2	1990/91
1991	1 436	2 142	1 321 345	653.32	620.76	643.95	611.39	31.6	1991/92
1992	750	1 324	923 083	748.24	713.09	737.09	701.94	36.3	1992/93
1993	1 075	1 984	1 492 808	801.48	750.69	789.44	738.65	38.3	1993/94
1994	1 048	1 840	1 389 553	770.50	754.90	747.38	728.14	38.4	1994/95
					[7]			[7]	
1995	1 363	1 977	1 568 773	846.78	802.58[8]	821.38	777.18	[8] 40.1	1995/96
1996	1 294	2 712	2 454 054	966.02	909.44	937.04	880.46	46.3	1996/97
1997	1 382	2 429	1 986 183	817.75	#	876.00	#	41.7	1997/98
1998	745	1 892	1 529 163	808.19	#	#	#	41.1	1998/99
1999	718	1 733	1 664 750	960.60	#	#	#	46.4	1999/00
2000	934	2 428	2 829 568	1 165.35	#	#	#	55.9	2000/01
2001	974	2 504	3 559 642	1 421.61	#	#	#	69.1	2001/02
2002	941	2 438	3 832 257	1 572.05	#	#	#	78.2	2002/03
2003	748	1 547	2 209 104	1 428.14	#	#	#	74.6	2003/04
2004	830	1 687	1 841 644	1 091.43	#	#	#	59.9	2004/05
2005	805	1 913	1 978 498	1 033.99	#	#	#	55.0	2005/06
2006	765	2 114	3 222 667	1 524.19	#	#	#	83.6	2006/07
2007	632	1 913	4 794 331	2 505.58	#	#	#	149.9	2007/08
2008	748	2 149	4 957 581	2 307.46	#	#	#	124.8	2008/09

2009	642	1 967	3 162 491	1 608.02	#	#	#	93.1	2009/10
2010	558	1 436	3 324 353	2 314.44	#	#	#	124.5	2010/11
2011	605	2 014	4 773 681	2 370.36	#	#	#	125.6	2011/12
2012	511	1 878	5 474 341	2 914.51	#	#	#	150.6	2012/13
2013	506	1 878	5 410 103	2 880.31	#	#	#	163.7	2013/14
2014	477	1 758	5 366 216	3 052.85	#	#	#	164.7	2014/15
2015[9]	482	1 457	5 678 518	3 880.13	#	#	#	200,1	2015/16

[1] Commercial

[2] Former TBVC states and self-governing territories are included

[3] Delivered in bulk. Until 1986 delivered in bags, prices of bags excluded

[4] From 1997/98, weighted average price

Prior to 1991/92, A1

[5] From 1997/98, estimated average price

Prior to 1991/92, B1

[6] Index figures are for split years

[7] Prices for “remaining” area. Prices for southern area are R784,58 for BS1 and R759,18 for BL1

[8] Prices for “remaining” area. Prices for southern area are R894,26 for BS1 and R865,28 for BL1

[9] Preliminary

Source: Abstract of Agriculture Statistics, 2017