Improving market access for smallholder farmers: Socio-economic determinants of pre-and post-harvest practices - and their potential role for microbial contamination of fresh produce

By

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ABSTRACT

Fresh produce is known to carry a natural microbial community however, during agricultural production and processing, any ready-to-eat fresh produce can become contaminated with pathogenic microbial organisms if inappropriate hygiene practices are used. As such fresh produce items go through minimal, if any inactivation or preservation treatments during further processing, hygiene quality and safety of the produce may be compromised thereby limiting market access and endangering consumer health. This study was conducted to determine if the Marianhill Agri-hub smallholder farmer socio-economic characteristics influence pre- and post-harvest practices and hygiene practices adopted. Furthermore, the contributions of these practices to microbial contamination of ready-to-eat fresh produce and its implications for market access, health and household food security were evaluated. Questionnaire results indicated a literate farmer community (88%), reliant on diversified income sources and farming as a livelihood strategy. Moderate interest in gaining market access to supplement household income was a key characteristic (61%). Most farmers utilized natural water sources (Mnini pond, Mnini river, stream and rain-fed) for irrigation, however, only a few (18%) pre-treated water prior to irrigation. Statistical analysis (Pearson Chi-square tests) indicated that farmer education levels and exposure to prior training have a statistically significant ($p<0.05$) impact on selected pre-and post-harvest practices implemented, highlighting the importance of farmer education and training. Microbiological analysis of fresh produce samples such as lettuce, parsley, carrots and spinach collected over at least a three month period from the main Agri-hub, showed the presence of total (ranging from 130-79000 MPN/g) and faecal coliforms (ranging from 22-1400 MPN/g) as well as *E. coli* (ranging from 2.2-49 MPN/g). These values were not satisfactory with respect to total coliform levels and presence of *E.coli* in view of South African legislation. In irrigation water samples, faecal coliforms were present up to 7000 MPN/100ml thereby frequently not meeting the WHO irrigation water quality requirements. Additionally, a number of irrigation water samples did not meet the South African standards for irrigation water applied to minimally-processed fresh produce of ≤ 1 *E. coli*/100ml, with values between 9.3-1400 MPN/100ml. *Salmonella* spp. was not detected in fresh produce and irrigation water samples. Antibiotic susceptibility patterns of 155 randomly selected *E. coli* isolates from both fresh produce and irrigation water were determined using the EUCAST disk diffusion method. The highest percentage of antibiotic resistance in *E.coli* isolates was detected against the antibiotic streptomycin at >94%. However, while 6% of the tested *E. coli* isolates were susceptible to all tested antibiotics, 2% of the *E. coli* isolates were multidrug-resistant. Multidrug-resistant strains of *E. coli* are concerning, as resistance genes are easily transferable to other potentially pathogenic bacteria present on produce, which might render the treatment of such pathogens difficult. Scanning Electron Microscopy showed the ability of *E.coli* isolates to form biofilms on PVC coupons mimicking contact surfaces. Antibiotic resistant and biofilm forming *E.coli* isolated from fresh produce and associated production and processing surfaces highlight the need of implementation of appropriate pre-and post-harvest hygiene practices. Stringent microbiological quality standards governing entry into high-value markets need to be adhered to by smallholder farmers. Therefore, understanding of smallholder farmer socio-economics is imperative to improving pre-and post-harvest hygiene practices, as the use of proper hygienic pre-and post-harvest practices is essential to prevent microbial contamination and improve quality of ready-to-eat fresh produce which will, in turn, facilitate improved market access.

Declaration

I T Beharielal declare that:

- The research reported in this mini-dissertation, except where otherwise indicated, is my original research.
- This mini-dissertation has not been submitted for any degree or examination at any other university.
- This mini-dissertation does not contain other persons' data, pictures, graphs or other information, unless specifically acknowledged as being sourced from those persons.
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Signed:

________________________________ 07/02/2017

T Beharielal **Date**

As Research Supervisor, I agree to the submission of this mini-dissertation for examination.

Signed:

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Dr JM Thamaga-Chitja **Date**

As Research co-supervisor, I agree to the submission of this mini-dissertation for examination.

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Prof S Schmidt **Date**

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Abbreviations and Acronyms

ART	Anti-Retroviral Treatment
BGA	Brilliant Green Agar
BGLB broth	Brilliant Green Lactose Bile broth
CCME	Canadian Council of Ministers of the Environment
CDC	Centers for Disease Control and Prevention
CFIA	Canadian Food Inspection Agency
CFS	Center for Food Safety
DAFF	Department of Agriculture, Forestry and Fisheries- South Africa
DGHM	Deutsche Gesellschaft für Hygiene und Mikrobiologie
DOH	Department of Health- South Africa
DWAF	Department of Water and Forestry- South Africa
EC broth	*Escherichia coli* broth
E. coli	*Escherichia coli*
EFSA	European Food Safety Authority
EHEC	Enterohemorrhagic *E.coli*
FAO	Food and Agriculture Organization of the United Nations
FBD	Food Borne Disease
FCD act	Foodstuffs, cosmetics and disinfectants Act, 1972 (Act 52 of 1972) RSA
FDA	Food and Drug Administration
GAP	Good Agricultural Practices
GHP	Good Hygienic Practices
GIMViC	Gas, Indole, Methyl-Red, Voges-Proskauer and Citrate Tests
GMP	Good Manufacturing Practices

GMO	Genetically Modified Organism
HACCP	Hazard analysis and critical control points
HIV	Human Immunodeficiency-Virus
HLPE	High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security
IFAD	International Fund for Agricultural Development
IFOAM	International Federation of Organic Agriculture Movements
IFPRI	International Food Policy Research Institute
IFT	Institute of Food Technologists
ISO	International Organizations for Standardization
L-EMB agar	Levine-Eosin Methylene Blue agar
LST broth	Lauryl Sulphate Tryptose broth
MATF	Maendeleo Agricultural Technology Fund
MPN	Most Probable Number
MPV	Minimally Processed Vegetables
NCCR	National Centre of Competence in Research
NCOA	Non Certified Organic Agriculture
RVS broth	Rappaport Vassiliadis Soy broth
SADC	Southern African Development Community
SEM	Scanning Electron Microscopy
STEC	Shiga-toxin producing *E.coli*
TB	Tuberculosis
UNEP	United Nations Environment Programme
USA	United States of America
USDA	United States Department of Agriculture

USAID	United States Agency for International Development
USEPA	United States Environmental Protection Agency
USFDA	United States Food and Drug Administration
WHO	World Health Organization
WRC	Water Research Commission- South Africa
XLD	Xylose Lysine Desoxycholate
YOPI	Young, Old, Pregnant and Immuno-compromised

Table of Contents

This thesis represents a compilation of manuscripts (Chapters 3 and 4) where each chapter is an individual entity and some repetition between chapters has therefore been unavoidable.

CHAPTER 1

Introduction

1.1) Contextual Background

Concerns of food security pertaining to an estimated population of 9 billion people by 2050 have again focused on agriculture, particularly smallholder agriculture, to reduce food insecurity utilizing sustainable methods (Machethe, 2004; Dercon, 2009; Birner and Resnick, 2010). The South African smallholder farming sector has been highlighted and identified as a crucial driver in alleviating household food insecurity through the production of good quality hygienically safe foods (von Fintel and Pienaar, 2015). Smallholder farmers have the potential to further improve food security through income generation from the sale of generated farm products, which at the same time indirectly promotes economic development (Thamaga-Chitja and Hendriks, 2008; Mdluli *et al*., 2013).

Organically produced fresh produce has been described as a lucrative commodity in both national and international markets, as consumers increasingly seek to live healthier lifestyles (Berger *et al*., 2010; Gorni *et al*., 2015). The greater demand for organic fresh produce has led to potential market opportunities for producers. South African smallholder farmers, for whom fresh produce is a common production commodity (Modi, 2003), have therefore been presented with a potential market opportunity (Mdluli *et al*., 2014).

Research into capacitating smallholder farmers in production and processing, has stressed the usefulness of capacity building and farmer training (Ko, 2010; Martins *et al.*, 2012). South African smallholder farmers are a diverse group of people, varying in age, gender and educational history. These socio-economic characteristics are important factors influencing decision making of smallholder farmers (Stewart *et al*., 2015). It is therefore important to understand these characteristics and how they influence smallholder farming pre-and post-harvest and general hygiene practices (Mdluli *et al*. 2014; Stewart *et al*., 2015). Contextual understanding of the smallholder farmers, for the development of capacity building and training programmes, is thus essential.

Food safety concerns are shared by both developed and developing countries (Unnevehr, 2003). However, climate, diets, income sources and population health are some of the factors which dictate the relative importance of food safety risks (Unnevehr, 2003). In South Africa, with a large proportion of the population classified as YOPI (Young, Old, Pregnant and Immuno-compromised) individuals (Gemmell and Schmidt, 2010; Oni *et al*., 2015), coupled with recommended intake of fresh produce in maintaining healthy diets, the quality and safety of fresh produce is imperative. Stringent hygiene and quality standards are set forth by high-value markets, challenging smallholder farmer market access (Mdluli *et al*., 2013).

Unfortunately, fresh produce despite being an ideal production commodity for smallholder farmers, can be subject to microbial contamination (Berger *et al*., 2010; Holvoet *et al*., 2015). Recent foodborne disease outbreaks as a result of contaminated fresh produce have highlighted the risks and consequences of microbial contaminated fresh produce (Buchholz *et al*., 2011, CDC, 2016 (a); CDC, 2016 (b)).

Pre-and post-harvest practices employed by smallholder farmers are often traditional methods (DAFF, 2012; Louw, 2013). These methods, with their minimal use of fertilizer and pesticides lead to the production of “organically produced” but not “organically certified” fresh produce (Mdluli *et al*., 2014). While these methods assist in the production of a “high-in-demand” commodity, they may also contribute to microbial contamination (Berger *et al*., 2010). Microbial contamination of fresh produce affects perishability, quality and safety of fresh produce (Rico *et al*., 2007). The quality of the final end product is therefore dependent on the use of good pre-and post-harvest practices, which ensure production of good quality fresh produce, thereby potentially improving market access.

This study investigated the influence of smallholder farmer socio-economic characteristics and how they affect the pre-and post-harvest practices employed. Pre- and post-harvest practices were evaluated in view of their potential to contribute to microbial contamination of fresh produce using microbiological methods.

1.2) Importance of the Study

As consequences of higher population growth and escalation of food insecurity, the calls for agriculture as a sustainable remedy are increasing. Smallholder farmers, historically not involved in supplying high-value regulated markets, are being viewed as potential market suppliers, as a means to support and improve their livelihoods. The stringent standards governing high-value market access are thus essential to being understood and adhered to by the smallholder farmers. Of paramount importance is informing smallholder farmers on improved pre-and post-harvest methods, in order to produce good quality hygienically safe fresh produce, thereby promoting potential market access. Firstly, the study aimed to determine socio-economic characteristics of the Marianhill Agri-hub smallholder farmers, assessing their relative influences on pre-and post-harvest hygiene practices in order to identify the appropriate design of training and capacity building programmes. Pre-and post-harvest practices, as determinants of fresh produce quality and safety, were evaluated on their ability to contribute to microbial contamination of fresh produce. Furthermore, the hygiene quality of selected fresh produce was assessed using microbiological analysis targeting selected hygiene indicators and a food pathogen. In doing so this study aimed to contribute to the body of knowledge that would inform and raise awareness of smallholder farmers on the necessity of improved pre- and post-harvest handling practices, to reduce microbial contamination, thereby potentially facilitating improved market access and production of good quality fresh produce for consumption.

1.3) Specific Research Objectives

- Determine the socio-economic characteristics and farming pre-and post-harvest hygiene practices employed by smallholder farmers.
- Assess the influences of smallholder farmer socio-economic characteristics on the pre-and post-harvest hygiene practices utilized.
- Determine the presence of selected hygiene indicators and the presence of a microbial pathogen in irrigation water and on selected fresh produce (carrots, spinach, lettuce, and parsley) and associated pre- and post-harvest contact surfaces.
- Assess the effects of microbial contamination on market access, health and household food security.

1.4) Study Limitations

The study only included 80 farmers from the Marianhill Agri-hub community, as a result this sample was not representative of all South African smallholder farmers. Therefore, findings cannot be generalized. Additionally, only the presence of selected hygiene indicators and a single microbial pathogen was determined.

1.5) Study Assumptions

It was assumed that smallholder farmer participants would have provided information which was honest, reliable and accurate, and that essential information that may have affected research findings would have not been withheld.

1.6) Structure of the Mini-dissertation

The mini-dissertation is divided into five chapters. Chapter one provides an introduction to the study, outlines the importance of the study and describes study limits and assumptions. Chapter two reviews the literature on the potential of agriculture, with particular focus on South African smallholder agriculture, to contribute to improved health and household food security through market access. Furthermore, it describes the susceptibility of fresh produce to microbial contamination, reviews further risks such as the presence of biofilm forming and antibiotic resistant bacteria as well as potential sources of microbial contamination. Chapter three presents - in the form of a draft journal manuscript - the socio-economic characteristics and pre- and post-harvest practices of the smallholder farmers. This chapter intends to identify relationships between socio-economic population characteristics and farming practices, thereby suggesting possible focal points for training initiatives. A second draft journal manuscript is presented in chapter four, illustrating the potential of pre- and post-harvest practices to contribute to microbial contamination along the fresh produce production and processing line. This chapter aims to determine the necessity of good pre-and post-harvest hygiene practices for the production of good quality fresh produce, meeting high-value market standards, thereby potentially improving health and household food security. Lastly, the fifth and concluding chapter provides an overall summary of the study, study conclusions, potential policy implications and avenues for further research.

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CHAPTER 2

Literature Review

2.1) Introduction

Reduction of global food insecurity and hunger are deemed to be some of the greatest challenges of the 21st century. Population growth is estimated to reach 9 billion people inhabiting the world by 2050, resulting in great concerns about sustenance for the whole population (Machethe, 2004; Dercon, 2009; Birner and Resnick, 2010). For most developing countries, hunger is a daily challenge, accounting for 780 million of the 795 million people worldwide who suffer from hunger (FAO, 2015). These problems have given rise to food security as a concept. Food security, most recently has been defined as "the situation, which exists when all people at all times have physical, social and economic access to sufficient safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2008). Food security is thus based on four pillars which encompass the availability, access, utilization and stability of food (FAO, 2008).

Poverty is a condition wherein the basic needs of people are not being met in order for them to survive at a minimum standard of life. The basic needs of people include food and nutrition, shelter and health care. Individuals experiencing poverty cannot obtain adequate resources to support a minimum standard of living. Globally poverty has been shown to display a decreasing trend, and statistics predict that the 2005 figure of 1.37 billion people living in a state of poverty will have decreased to almost half by 2015 (The World Bank, 2015). Simultaneously however, as global poverty seems to decrease, the conditions in countries which were suffering with the highest levels of poverty seem to be showing little improvement (IFAD, 2011).

South Africa is one such country, wherein the state of poverty is a persistent condition and currently encompasses 21.7% of the population (Nicolson, 2015). A condition that is often synonymous with poverty is that of hunger and food insecurity. Approximately 19% of all South African households have inadequate access, in varying degrees of severity, to food (Statistics SA, 2014). Social grants, rendered by the government, are estimated to support approximately 30% of the total population (von Fintel and Pienaar, 2015). It is with these social grants that these people are able to attain some basic needs. However with the rising rates of unemployment, the current economic situation and escalating food prices the provision of basic needs for a family is becoming increasingly difficult. In order to alleviate their current problem these food insecure families, usually practice subsistence farming in the form of home gardens (Aliber and Hart, 2009; Pienaar and Traub, 2015).

Subsistence farming in rural areas of South Africa has led to the development of smallholder farmers (Mdluli *et al.*, 2013). These farmers produce not only fresh produce for themselves, but also a little extra in the hopes of selling these “organically produced” minimally processed fresh produce with the aim of generating income (Mdluli *et al.*, 2013). The increased interest of consumers in fresh, healthy, and unprocessed foods has led to an increase in demand of minimally processed fresh produce food products (Rico *et al*., 2007; Berger *et al*., 2010; Mdluli *et al.,* 2014; Gorni *et al*., 2015). Sustainable agricultural methods are viewed as a key driver able to contribute to meeting the ever escalating food demands (IFAD, 2011). Smallholder farming is regarded as one of these methods and is thought to have potential to significantly contribute to food security, in terms of both availability and nourishment (Wegner and Zwart, 2011; IFAD, 2011). Thus the production of fresh produce from smallholder farmers has a potential market niche. However, due to multiple challenges faced by smallholder farmers, their ability to gain market access and thus contribute to food security is thwarted (Mdluli *et al*., 2013).

The concept of smallholder farming, more specifically in the South African context, is a potential contributor to food security in terms of food production and income generation through market access. Furthermore the susceptibility of fresh produce to microbial contamination, potential contamination sources and the adverse effects of minimally processed fresh produce, contaminated with microorganisms displaying biofilm formation capabilities and antibiotic resistances has to be considered. The pre- and post-harvest practices employed by South African smallholder farmers and their potential to contribute to microbial contamination of minimally processed fresh produce is addressed. The importance of food hygiene quality and safety and the applicable guidelines and regulations governing minimally processed fresh produce are highlighted with relevance to consumption, gaining and improving market access.

2.2) Agriculture

Agriculture, with a history dating back thousands of years, was a key development of human civilization (Price and Bar-Yosef, 2011). The term agriculture broadly refers to the cultivation of organisms (animals, plants and fungi etc.) for their utilization as food, medicine and other products used to sustain and enhance human life through farming and forestry (Price and Bar-Yosef, 2011). Agriculture encompasses a wide variety of specialities. Important agricultural products can be typically grouped into categories inclusive of foods, fuels, pharmaceuticals, and a variety of ornamental or exotic products (Lupien, 2007). However one of the main goals of agriculture has been and is currently, to be a supplier of food (Lupien, 2007). Food products all have their roots in agriculture, although nowadays seem to be manufactured in an industry. Agriculture, with its past rooted in enhancing human life, has been deemed a method to address the ever-escalating problem of food insecurity (DAFF, 2011).

Conventional Agriculture

Historically, conventional agriculture was the main means of agricultural farming to provide food. Conventional agriculture, also referred to as industrial agriculture, describes methods of farming, which share a multitude of main characteristics although vary from farm to farm and from country to country. The main characteristics include the use of large capital investments, more or less use of pesticides, fertilizers as well as external energy inputs, the production of uniform high-yield hybrid crops, and single crops grown continuously over many seasons (USDA, 2015). The most defining characteristic of conventional agriculture, however, is the production of food/crops in large quantities at cheaper prices usually at the detriment of the environment. Despite the thoughts that conventional agriculture is detrimental to the environment and largely an unsustainable methodology (Bonti-Ankomah and Yiridoe, 2006), there have been many recent efforts to improve conventional methodologies which ameliorate and ensure soil, water and atmosphere protection. This led to the formation of organic agriculture.

Organic Agriculture

Organic agriculture, which is on the rise, has been noted as a sustainable alternative to conventional farming. Organic agriculture is currently the fastest growing food sector in the world, wherein growth rates of organic food sales range from 20-25% per year (Dardak *et al*., 2009; IFOAM, 2016). The most common definition of organic agriculture refers to a process of food production, which utilizes methods respectful of the environment, from all production stages, through to handling and processing (Goldman and Hylton, 1972; FAO, 1999). Organic agriculture aims to operate without pesticides, herbicides or inorganic fertilizers (Luttikholt, 2007). Certified organic agriculture prohibits the use of synthetic agricultural inputs (e.g. preservatives), genetically modified organisms (GMO's), sewage sludge and irradiation (Kristiansen *et al*., 2006). At an international level there exist two main sources of general principles and requirements, which denote organic agriculture; namely: Codex Alimentarius Guidelines for the production, processing, labelling and marketing of organically produced foods (FAO/WHO, 2007) and the International Federation of Organic Agriculture Movements (IFOAM), which was founded in 1972 (Kristiansen *et al*., 2006). Similarly, there exists Non-Certified Organic Agriculture (NCOA), which refers to agriculture meeting organic agricultural production standards but which is not subject to organic inspection, certification and labelling (Caceres, 2005). Inclusive in NCOA are traditional farming systems, generally not using chemicals and applying ecological approaches to enhance agricultural production (e.g. inter-cropping). These traditional systems are sometimes born as a result of the farmer not being able to afford purchased inputs and give rise to food products labelled “organically produced, but not certified”, “environmentally friendly”, “green”, or “free-range”, which are not considered as organic as they do not adhere to the strict international standards of organic agriculture.

2.3) Smallholder farming

Sustainable agricultural methods have been acknowledged as a potential contributor to meet the ever escalating food demands (Wegner and Zwart, 2011). Smallholder farming across the world is deemed to be one of these sustainable agricultural methods which have a noteworthy potential to contribute to food security (Dercon, 2009; Birner and Resnick, 2010; Mdluli *et al*., 2013; Stewart *et al*., 2015). Smallholder farming, according to global standards, can be defined as farming that takes place on relatively small pieces of land by farming families, which mainly use their own labour (IFAD, 2011). However, regionally there exist multiple definitions of smallholder farming, due to the particular circumstances and conditions experienced around the world (Louw *et al*., 2008; Altman *et al*., 2009; Berdegue and Fuentealba, 2011).

Defining Smallholder Farming in South Africa

South African agriculture currently and historically has been split into two different sectors, namely the commercial sector and the subsistence sector (Ortmann and Machethe, 2003; Vink and Kirsten, 2003). This dual nature of agriculture is characterized by the two sectors existing on opposite ends of a continuum wherein commercial farming contributes the majority of agricultural outputs (90-95%) but has fewer active members while subsistence farming has a larger number of active members but only contributes a dismal 5-10% of agricultural outputs (Aliber and Hart, 2009). Multiple definitions exist for what exactly can be classified as smallholder farming and a smallholder farmer (Louw *et al.,* 2007; Louw *et al.,* 2008; Altman *et al.,* 2009). However, in the South African context, smallholder farming can be described as farming done on a small scale to provide food mainly for the family of the farmer (Groenewald and Nieuwoudt, 2003; Lahiff and Cousins, 2005) and a minimal surplus, which has the potential to be marketed. In terms of land access, smallholder farmers can be described to utilize only very small pieces of land such as home gardens or food plots ranging up to 2 hectares (Altman *et al.,* 2009; IFAD, 2011).

Contributions of the Smallholder Farming Sector to Food Security

It has been estimated that 30-40% of South African households are exposed to food insecurity; this inadequacy stems mainly from the lack of physical availability of food in rural areas or in terms of not having assured access to adequate diets (The World Bank, 2014). Approximately one-third of South Africans are involved in smallholder farming, even though it only contributes to less than 5% of their total income (Mdluli *et al*., 2013). Regardless of the low contribution of smallholder farming to South African agricultural production output, it can be said that they contribute directly to household food security (Pienaar and Traub, 2015). The contributions to household food security can be in terms of making food available through direct supply as well as through income generation from the sale of produce, which can be diverted to purchasing food from retail stores and meeting other requirements of the household such as utility bills (Hawkes *et al*., 2012). Engaging in smallholder farming has the potential to lead to a greater availability of food, and consequently increase economic growth and stability (IFAD, 2011).

2.4) Fresh produce

Fresh produce is a food product which can be (or usually are) consumed without further processing. This fresh produce is popular worldwide due to its contribution to a healthy diet, providing an important source of nutrients, vitamins and fibre for humans (Aruscavage *et al*., 2006; Baranowski, 2011; Jung *et al*., 2014, Pezzuto *et al*., 2016). Global production of fruit and vegetables, including fresh produce has increased substantially over the past two decades (WHO/FAO, 2008; Jung *et al*., 2014). Multiple reasons exist as to why this increase in production has occurred, the most common being the trend of consumers adopting a healthier lifestyle (Gorni *et al*., 2015). In response to the “healthy eating, healthy lifestyle” trend, the demands for fresh produce continue to increase (Warriner *et al.*, 2009). In conjunction with this increase, the rates of importation and exportation of fresh produce have also increased, due to demands for fresh produce all year round (Olaimat and Holley, 2012).

Common to most smallholder farmers in South Africa, the production of fresh produce is a norm (Modi, 2003; Mdluli *et al*., 2013). A study conducted by Modi (2003) revealed that the primary objective for the farming of fresh produce is to improve the food and nutritional security of their families. Additional factors contributing to the production of fresh produce by smallholder farmers include nutritional and health implications, affordability and ease of production (Mdluli *et al*., 2013; Roesel and Grace, 2015). Ease of production refers to the ability of farmers to grow these products on relatively small pieces of land, quick turnover times and the non-necessity of expensive farming equipment. The increase in demand for fresh produce indicates a potential income avenue for smallholder farmers, if their produce were to be marketed (Mdluli *et al*., 2013).

Microbial Contamination of Fresh Produce

Fresh produce show typically high water activities, high nutrient contents and pH ranges between 4.9-6.5 (Lund, 1992). As a result of bruising or damage to plant outer surfaces, microorganisms have the potential to gain access to the inside, which provides a favourable environment for the colonization and growth of microorganisms (Lund, 1992; Ragaert *et al*., 2007). Often Minimally Processed Vegetables (MPV’s) house total counts of microbial populations between 3.0 to 6.0 log CFU/g (Ragaert *et al*., 2007). Common epiphytic bacterial species inhabiting MPV’s include

Pseudomonas fluorescens, *Erwinia* spp. and *Rahnella* spp. (Lund, 1992; Nguyen-the and Carlin, 1994; Bennik *et al*., 1998). Unfortunately, however, the microbial populations able to colonize MPV's are not limited to harmless naturally occurring microflora, but also extend to foodborne disease causing pathogens. Furthermore, microbial contamination is of special significance in ready-to-eat MPV's, as minimal microbiological control steps are conducted in terminal processing, in comparison to other traditional vehicles of foodborne illness (e.g. poultry and other meat products).

One type of microorganisms, which are often associated with illness and disease, are bacteria. Despite the negative connotations implied, most bacteria are not harmful. Pathogenic bacteria conversely, are among the organisms which contribute to global diseases such as pneumonia and foodborne diseases.

Foodborne Diseases (FBD's)

Foodborne diseases (FBD's) are an important cause of illness and mortality globally, resulting from ingestion of contaminated foods or food products (WHO, 2008). Foodborne diseases are numerous and can range from mild aggravations to life threatening conditions (Linscott, 2011). Illnesses classified as foodborne diseases can be caused by parasites, chemicals, biotoxins and microbial pathogens. The contamination by these harmful agents can occur anywhere within food production, processing and preparation (Nicola *et al*., 2009; Jung *et al*., 2014). Increased incidences of foodborne diseases continue to be reported, with cases of outbreaks often of international concern (Critzer and Doyle, 2010; Teplitski *et al*., 2011; Hoelzer *et al*., 2012). However, the full extent and burden of FBD's still remains unknown (WHO, 2008).

Escherichia coli (E.coli), a common commensal human and animal gut bacterium (FAO, 2011), is often used as a hygiene indicator organism. Its presence in human consumption commodities such as water, food, and spices is often used as an indicator of faecal contamination (Krumperman, 1983). Unfortunately, in recent years several strains of pathogenic *E.coli* have been implicated in a number of foodborne disease outbreaks (CDC, 2006(a); Buchholz *et al*., 2011; CDC, 2014). Another well-known food pathogen is *Salmonella* spp., which was dubbed the most common foodborne disease causing bacterial pathogen for the years 2006-2011 (CDC, 2011) as well as the most common causative agent in foodborne outbreaks in the European

Union (EU) (EFSA, 2015). Thus its presence in any human consumption commodity is highlighted as a hazard (Zadernowska and Chajecka-Wierzchowska, 2012), and is still an important qualitative measure of food hygienic quality and safety. Like pathogenic strains of *E.coli*, *Salmonella* spp*.* was usually linked to foodborne illnesses of animal origin, however both have recently emerged as common causative agents in produce related disease outbreaks (Slayton *et al*., 2011; Kisluk and Yaron, 2012; Olaimat and Holley, 2012; Jung *et al*., 2014 ;CDC, 2016 (a); CDC, 2016 (b)).

The occurrences of foodborne illness linked to fresh produce has shown a great increase in recent times (Brackett., 1999; Warriner *et al*., 2009; Painter *et al*., 2013, Jung *et al*., 2014) and contaminated produce is now accountable for an estimated 12% of all foodborne illnesses (Painter *et al*., 2013). *Salmonella* spp. and pathogenic strains of *E.coli* (e.g. (enterohemorrhagic *E.coli* (EHEC) / Shiga-toxin producing *E.coli* (STEC)) are recognized as two of the most relevant pathogens contaminating minimally processed fresh produce (Gorni *et al*., 2015). Sprouts, originating from Egyptian fenugreek seeds contaminated with *E.coli* O104:H4 were the cause for several deaths (≈ 50) in Germany in 2011 (Buchholz *et al*., 2011; EFSA, 2011). Similarly, a multistate outbreak in the United States of America (USA) resulting in 14 hospitalizations was as a result of cucumbers contaminated with *Salmonella* Oslo. (Bottichio *et al*., 2016), illustrating the threat to public health posed by FBD's originating from microbial contaminated fresh produce.

The repercussions of FBD's are not restricted to affluent communities where the consequences are merely related to public health. Developing countries face the real brunt of FBD's (WHO, 2007; WHO, 2013). The often tropical climates, poverty, poorly enforced health and safety regulations and inferior literacy and limited understanding of hygienic food safety and quality, allow for the increased exposure and proliferation of FBD's (WHO, 2013). This proliferation not only affects the health of the population, but further risks their abilities to generate incomes, as many individuals rely on manual labour as employment (WHO, 2007).

Foodborne and waterborne diarrhoeal diseases constitute an estimated 2 million deaths worldwide, annually, including many children (WHO, 2014). In summation FBD's cause numerous deaths globally, and contribute to perpetuation of the never ending cycle of poverty and food insecurity experienced by the populations of mostly developing countries (Econex, 2009).

Disease prevalence in South Africa

In South Africa there is a high burden of disease, with diseases of bacterial origin accounting for a large proportion (Crowther-Gibson *et al*., 2011). Tuberculosis (8-9%), influenza and pneumonia (4-5.5%) and Human Immunodeficiency Virus (HIV) (3.9-5%) were ranked in the top five causes of death for the entire population during the years 2012-2014 (Statistics SA, 2015). Intestinal infectious diseases were the highest causes of death in children (aged 1-14 years) and in the top five causes of death for adults (aged > 65 years) (Statistics SA, 2015). These morbidity statistics provide relative insight on a specific group of people, known as YOPI, who are Young, Old, Pregnant and Immuno-compromised. It is persons within this group who are particularly vulnerable (Gemmell and Schmidt, 2010). The risks derived from contaminated fresh produce are increased for YOPI individuals, due to their increased susceptibilities and thus possibility for higher severity of diseases (Pezzuto *et al*., 2016). Furthermore, this group becomes increasingly susceptible to outbreaks related to fresh produce, as their recommended nutrition includes higher intakes of fresh produce (Roesel and Grace, 2015). The relative disease prevalence highlights the importance of thwarting the potential spread of disease through fresh produce and minimally processed food items.

Sources of Microbial Contamination

Bacterial contamination can occur anywhere along the farm to fork continuum. Thus the different stages of farming have the potential to influence the hygienic quality and safety of the final product (Nicola *et al*., 2009). Consequences of microbial contamination range from reduction in production levels, market access concerns to health-related effects and diseases. Therefore control and reduction of microbial contamination are important and dependent on identifying potential areas which contribute to microbial contamination (Mdluli *et al*., 2013).

Soil

Potential microbial contamination sources within pre-harvest practices include the soil used for growing. Soil not only affects the nutritional quality, but also the safety of fresh produce, as soil is a natural environment for a multitude of bacterial species. Due to direct contact between soil and plant, bacteria can contaminate the produce (Nicola *et* *al*., 2009). Transmission of human pathogens from soil to growing vegetables has been recorded (Natvig *et al*., 2002; Islam *et al*., 2004). Soil on the surface of fresh produce can harbour pathogenic microorganisms, which remain present and viable through subsequent handling and processing to the point of consumption unless effective sanitizing procedures are administered. The presence of bacterial pathogens in the soil might be a result from previous use as a grazing ground for livestock, as these may contaminate the soil with enteric pathogens (Nicola *et al*., 2009; Jung *et al*., 2014). Additionally, the presence of other pathogenic bacteria, viruses, and parasites in soil can likely result from the application of animal manure as a substitute for compost or fertilizer (Jung *et al*., 2014).

Manure and faecal matter

A well highlighted pre-harvest practice is the application of manure (faecal matter of animals) as a soil amendment either through composting or as a fertilizer, which in itself is not harmful. However, as has been reported in previous studies, particularly smallholder farmers often directly apply manure as a fertilizer without prior treatment (van Averbeke and Yogananth, 2003; Mdluli *et al*., 2013). Ingham *et al*. (2004) reported that even pre-treated manure composted until maturity supported growth of *E.coli* isolates, which served to contaminate fresh produce. Studies by Amoah *et al*. (2009) and Obi *et al*., (2014) also highlight manure application as a source of contamination in the production of fresh produce. Faecal matter of any origin is a reservoir of microorganisms, which often include pathogenic bacterial species (Buck *et al*., 2003; Berger *et al*., 2010). Additionally, faeces of wildlife might also be a cause of concern as methods to prevent wildlife intrusion are often costly and have limited effects (Jay *et al*., 2007; Jung *et al*., 2014).

Water

Water has been identified in the literature as one of the main sources of microbial contamination of fresh produce (Nicola *et al*., 2009; Amoah *et al*., 2009; Park *et al*., 2012; Jung *et al*., 2014). This potential contamination source is viewed as the most important, as it influences the microbial quality of raw material throughout the processing line (Nicola *et al*., 2009). Playing a role firstly in pre-harvest practices, where it is used as irrigation water, it can secondly affect post-harvest practices, where it is used for rinsing or washing produce (Nicola *et al*., 2009; Mdluli *et al*., 2013). Fresh produce can become contaminated through water-to-soil contact, as well as water-to-product contact (Solomon *et al*., 2003). Unfortunately, growers, particularly smallholder farmers, experience difficulties in controlling water quality, as the water used often originates from sources that are or can become polluted (Steele and Odumeru, 2004). The recognition of irrigation water as a contamination source has led to the development of national and international recommendations and guidelines, suggesting limiting values of selected hygiene indicator organisms like coliforms and *E.coli* (see Table 2.1), to ensure irrigation water quality.

Water quality, especially in the production of minimally processed fresh produce, can be a determinant of the final quality of the product (DWAF, 1996). Studies conducted by Gemmell and Schmidt (2010; 2012) found that irrigation water can transfer microorganisms to fresh produce. Other cases implicating water as the source of microbial contamination include outbreaks in 2005 and 2006 of *E.coli* O157 linked to lettuce (Sweden) and bagged spinach (USA) (Soderstrom *et al*., 2005; CDC, 2006 (b); Jay *et al*., 2007).

Contact surfaces

Cross-contamination of fresh produce can occur during harvest, storage, transportation and processing through the many different contact surfaces (Jung *et al*., 2014). This poses a unique and significant problem especially for post-harvesting practices (FDA, 2001). Harvesting equipment, such as pitchforks and spades, provide areas, which have come into contact with soil and other possible preharvest contaminants, and can serve as transferal sites of microorganisms onto fresh produce (Taormina *et al*., 2009; Buchholz *et al*., 2012; Matthews, 2013). Traditionally, harvested fresh produce can become contaminated as a result of improper handling during storage and transportation; an example would be the collection and storage containers which are initially placed directly onto soil and thereafter stacked on top of other storage containers, thus permitting the transfer of contaminants during stacking (Matthews, 2014). Finally, pathogens that may be present on hands of labourers within the farm to fork continuum can be transferred from persons directly to vegetables or indirectly via food contact surfaces (Jimenez *et al*., 2007; Todd *et al*., 2008; Todd *et al*., 2009; Jung *et al*., 2014).

Biofilm Formation

A contributing factor in spreading foodborne diseases is cross-contamination via abiotic surfaces (e.g. farming equipment, processing tables) as well as biotic surfaces (e.g. plant surfaces) which may allow for the formation of so-called biofilms by microorganisms (Rayner *et al*., 2004; Patel, *et al*., 2011; Srey *et al*., 2013). Biofilms can be defined as an organized cluster of bacterial cells within an exopolysaccharide matrix adhered to a surface (Latimer *et al*., 2012; Bjarnsholt, 2013). Biofilms form in a step-wise process and represent a physical state of bacteria, which provide increased resistance to antimicrobial substances and removal mechanisms (Kumar and Anand, 1998; Kostakioti *et al*., 2013). The steps of biofilm formation and adherence are influenced by extrinsic and intrinsic factors (Hood and Zottola, 1995; Kumar and Anand, 1998; Bjarnsholt, 2013). The inherent ability of biofilms to attach to a variety of surfaces including plastic, metal, soil particles, organic material and wood, coupled with their increased resistance abilities, emphasizes their potentially hazardous nature (Kim *et al*., 2006).

Biofilm formation by pathogens

Biofilm formation by numerous bacterial species has been recorded, and it is documented that bacterial biofilm formation is favoured in almost any environment in which nutrients are available (Costerton *et al*., 1978). Unfortunately, several pathogenic bacterial species possess the ability to form biofilms, including foodborne pathogens such as pathogenic *E.coli* strains (e.g. EHEC/STEC), *Salmonella* and *Listeria* species. Foodborne disease outbreaks as a result of biofilms on produce such as lettuce and parsley have been reported (Annous *et al*., 2005; Annous *et al*., 2006). The biofilm formation capability of bacterial food pathogens particularly on minimally processed fresh produce, undergoing only minimal microbiological control steps, indicate an important hygienic quality and safety hazard (Clouser *et al*., 1995; Moretro and Langsrud, 2004; Myszka and Czaczyk, 2011).

Table 2.1: Examples of national and international guideline values specifying the acceptable burden of hygiene indicator microorganisms for water intended for irrigation and domestic use. (Adapted from Gemmell and Schmidt, 2013)**.**

Organization/Government	Water use	Bacteriological quality limit value/range
South African Department of Water Affairs (DWAF)	Irrigation water applied to minimally processed produce	≤1 E. coli/100 ml (DWAF, 1996)
	Drinking water	water 0–100 Heterotrophs/ml 0–5 Total coliforms/100 ml 0 Faecal coliform/100 ml (DWAF, 1996)
World Health Organization (WHO)	Unrestricted irrigation of crops (including produce eaten uncooked)	≤1,000 Faecal coliforms/100 ml (WHO, 2006)
	Drinking water	0 Faecal coliforms/E. coli/100 ml (WHO, 2011)
Canadian Council of Ministers of the Environment (CCME)	Irrigation water applied to vegetables usually eaten uncooked	<1000 total coliforms/100ml <100 E. coli/100 ml (CCME, 2003)
United States Government (guidelines differ between states)	Spray irrigation Guidelines	2.2 -200 faecal coliforms/ 100 ml (Blumenthal *et al*., 2000)
	Surface irrigation Guidelines	10 -1,000 faecal coliforms/ 100 ml (Blumenthal *et al*., 2000)
	Irrigation of foods consumed raw (California and Colorado Government)	<2.2 total coliforms/100 ml (Blumenthal *et al*., 2000; USEPA/USAID, 1992)

Biofilms on food contact surfaces

In addition to the possibility of biofilm formation directly on food commodities, food contact surfaces provide additional areas upon which biofilm formation can occur (Jahid and Ha, 2012) and has been documented in many environments. However, the environment that is of increased concern is that of food processing environments especially with direct food contact (Notermans *et al*., 1991; Blackman and Frank, 1996; Chmielewski and Frank, 2003). Food-processing settings are a “haven” for biofilm formation, and biofilms have been found on multiple food processing surfaces including stainless steel, glass, and plastic (Rivera-Betancourt *et al*., 2004; Samelis *et al*., 2005; Scallan *et al*., 2011; Zhao, 2016). The formation of biofilms on a food contact surface becomes difficult to remove due to the formation of the slime layer of exopolysaccharide, as well as the increased resistance of the bacteria within the biofilm to disinfection (Chmielewski and Frank, 2003). Contamination of food materials by *Salmonella* serovars and *E.coli* O157:H7 strains colonizing food contact surfaces has been reported (Silagyi *et al*., 2009; Wang *et al*., 2013). Interactions between fresh produce, food contact surfaces and biofilm formation as vehicles for disease transmission, via cross-contamination, have been identified and highlighted as an important aspect of food quality and safety (Myszka and Czaczyk, 2011). Consequently this highlights the importance of assessing methods of prevention, effective removal and inactivation of biofilm proliferation in pre- and post-harvest farming practices, to avoid potential contamination.

Antibiotic Resistance

Bacterial resistance describes bacterial organisms no longer responding to a substance that is being used to either inhibit their growth or kill their cells. These substances include antibiotics or biocides (Russell, 1996). Resistance due to natural/intrinsic resistance in specific types of bacteria, arise via genetic mutation or by one species acquiring resistance from another species. The significance of these resistant bacteria is that they are becoming increasingly difficult to treat and are associated with increased risks of hospitalizations or complete failure of treatment in patients. As a result alternative treatments (i.e. medications) or higher dosages are required, introducing ramifications such as increased costing and/or higher levels of toxicity.

Antibiotics have radically transformed the treatment of infectious diseases since their discovery. However, in recent times, the misuse and overuse of antibiotics have resulted in the increased development of antibiotic resistance (Thanner *et al*., 2016). Antibiotic resistance has been deemed a serious health problem; the World Health Organization (WHO) stated in April 2014 that - “this serious threat is no longer a prediction for the future; it is happening right now in every region of the world and has the potential to affect anyone, of any age, in any country.” (WHO, 2014).

Excessive antibiotic use has become one of the top contributors to enhancing the development of antibiotic resistances. South Africa is known to have a high burden of infectious diseases among its population and antibiotics have been widely used to combat these infections (Crowther-Gibson *et al*., 2011). The Centre for Disease Dynamics, Economics and Policy (CDDEP) highlights the escalating concern around antibiotic resistance further by stating that “South Africa’s growing use of antibiotics could lead to resistance against lifesaving treatments.”(CDDEP, 2015).

Antibiotic resistance present in pathogens not only affects health in terms of direct contact but also in terms of food safety (Bester and Essack, 2010; Thanner *et al*., 2016). Antibiotics have long been reported for use in food animals for disease treatment or prevention as well as growth promotion (Aarestrup *et al*., 2001). The use of antibiotics in food animals may result in antibiotic resistant bacteria in faeces/manure, providing routes of transferal to other commodities, such as fresh produce, as in the case of cross-contamination arising from the use of manure as a substitute for fertilizer (Marti *et al*., 2013).

Antibiotic resistance in E.coli and Salmonella spp*.*

In addition to pathogenic strains of *E.coli* and *Salmonella* being recognized as the two most relevant pathogens of concern for safety and quality of fresh produce (Gorni *et al*., 2015), these bacterial pathogens have the potential to be resistant against antibiotics. Multidrug resistant strains of *Salmonella* serovar Typhimurium phage type DT104 from humans and food animals were increasingly observed from the 1980’s, and are now regarded as an epidemiologically predominant strain, which has spread through the United States as well as many European countries (Threfall *et al*., 1997; Glynn *et al*., 1998). This strain displays resistances to ampicillin, chloramphenicol, streptomycin, sulfonamides, and tetracyclines and more recently to trimethoprim, spectinomycin, and ciprofloxacin (Teuber, 1999). Severe cases of salmonellosis require antimicrobial therapy (Marrero-Ortiz *et al*., 2012). Antibiotic resistance within these isolates then makes it more difficult to treat patients with severe infections due to these strains (Marrero-Ortiz *et al*., 2012). *E.coli* isolates originating from humans, commercial poultry, swine and cattle environments were found to display high levels of multidrug resistance (Krumperman, 1983). Possible presence of antibiotic resistant bacteria on minimally processed ready-to-eat fresh produce is an important factor as no further processing may result in increased risks of transferal to humans (Marti *et al*., 2013). The risks associated with antibiotic resistant bacteria in South Africa are further increased as a majority of the population is often using antimicrobial therapy for an array of infections. Antibiotic resistance transmission to other enteric bacteria in persons undergoing antimicrobial therapy may render treatments ineffective (Pezzuto *et al*., 2016). Antibiotic resistant strains of *Salmonella* spp., pathogenic *E.coli* as well as non-pathogenic *E.coli* typically indicating faecal contamination are therefore a major concern for food safety, especially with their potential for antibiotic resistance transmission (Rusul *et al*., 2012).

2.5) Pre- and post-harvest practices employed in smallholder farming

Pre-harvest practices refer to the treatments and practices employed prior to harvesting. These practices include, soil and water treatments, seed storage and seed treatment. In contrast, post-harvest practices are concerned with the treatments and practices carried out after harvesting. Post-harvest technologies include storage, transportation, and processing of agricultural raw materials prior to consumption. There are a variety of pre-and post-harvest practices employed around the world. The factors affecting the choices of pre-and post-harvest practices employed include socio-economic characteristics, such as age, gender and income sources (Mdluli *et al*., 2013).

South African Smallholder Farmer Pre- and Post-harvest Practices

Smallholder farmers within South Africa are known to employ a range of different pre- and post-harvest practices (Cousins, 2016). Reliance on traditional pre-and post-harvest methods is also common and found to be prevalent amongst most smallholder farmers as these techniques often offer cheaper alternatives to modern methods and technologies (Louw *et al*., 2013) The practices employed by smallholder farmers can be described as somewhat mediocre, as these farmers do not have access to adequate infrastructure, transportation and storage facilities thereby increasing risks of adverse effects on produce (Babalola *et al.,* 2010; DAFF, 2012). Such practices may include the use of animal manure as a substitute for fertilizer, the use of pre-mature compost as well as the use of low quality irrigation water sources (Mdluli *et al*., 2013).

Implications of Pre- and Post-harvest Practices

Fresh produce is susceptible to contamination at multiple points in the food production chain (FDA, 2001; WHO/FAO, 2008). The three most important points where potential contamination can arise include: in the field during pre-harvest, during initial production, and during the final preparation in the kitchen (Beuchat, 2002). Contact surfaces along the farm to fork continuum, serve as notable contributors of contamination of smallholder produce thereby emphasizing the need for appropriate hygiene practices within processing. Inappropriate pre- and post-harvest practices are known to have detrimental effects on fresh produce (Brackett *et al*., 1993; Beuchat and Ryu, 1997). Produce exposed to environmental stress factors such as vast temperature differences, inappropriate handling, bruising an abrasions of surfaces are found to be more susceptible to decay and spoilage (Kader and Kitinoja, 2003; Ragaert *et al*., 2007; Francis *et al*., 2012). This in turn may result in produce losses due to spoilage of the product before reaching the market (Buyukbay *et al.,* 2011). Pre- and post-harvest practices in agriculture are often regarded as determinants of the end quality of a commodity (DWAF, 1996).

Studies focused on improving smallholder farmer market access often concentrate on these farmers improving yields thereby obtaining sufficient quantities of products which are required by formal markets. However, whilst improved yields are an instrumental step towards obtaining market access, more important is the initial step of producing good quality produce, able to satisfy the stringent market standards. The quality of fresh produce is determined firstly by the pre-harvest practices employed in production (DWAF, 1996). Furthermore, once good quality fresh produce is produced it is important to ensure that post-harvest practices do not contribute to quality deterioration and product losses. This highlights the importance of pre-and post-harvest practices when aiming to gain market access. Improved awareness and knowledge to bridge the information gap on pre-and post-harvest practices employed in smallholder farming and its subsequent effects on market access and food security are therefore important.

2.6) Socio-economic influences on farming practices

There are many studies which focus on the determinants of adopting farming practices in response to increasing production yields and climate change, such as farmer socio-economic characteristics (Ojiem, *et al*., 2006; Jost *et al*., 2013). The importance of these characteristics and their potential to influence farmer decision making have been highlighted (Ojiem, *et al*., 2006; Stewart *et al*., 2015). Gender is one of the most frequently studied socio-economic characteristics. Mdluli *et al*. (2014) showed both negative and positive impacts of gender on farming practices. The most common observation with regard to agriculture is that a majority of farming practices are carried out by females (FAO, 2013). Higher proportions of females are involved in agriculture, particularly in smallholder farming. Other reported socio-economic characteristics, which potentially impact on farmer decision making include age of the farmers, number of members in a household, household income sources, marital statuses (Matata *et al*., 2010) and exposure to extension services and training (Oni *et al*., 2013; Tshuma, 2014). Agricultural research studies centred on capacitating smallholder farmers in improving farming practices often highlight education as an influential factor on farmer decision making (Mdluli *et al*., 2014; Tshuma, 2014), and consequently a potential avenue through which to improve farming practices (Mdluli *et al*., 2014).

South African smallholder farmers vary in many socio-economic characteristics such as age, gender and educational history (Oni *et al*., 2013; Mdluli *et al*., 2014). Socio-economic characteristics of these resource limited smallholder farmers are therefore important determinants in decision making, especially with regard to farming practices (Tshuma, 2014; Stewart *et al*., 2015). Understanding these characteristics and how they potentially influence smallholder farming pre-and post-harvest and general hygiene practices is thus imperative in providing appropriate and adequate support (Mdluli *et al*. 2014; Stewart *et al*., 2015). Appropriate and effective capacity building and training programmes should recognize the importance, and therefore include, contextual understanding of smallholder farmers.

2.7) Markets

Markets are defined as physical areas where trading is facilitated. Additionally, markets also refer to the set of buyers and sellers whose activities affect the prices at which a particular commodity or commodities are sold as well as the process or system by which the prices of goods or services are established (Mukeere, 2009). Market systems are often complex and require expertise in economics, supply chain management and other commerce related disciplines.

Agricultural Marketing System

A number of factors namely globalization, liberalization, demographics and more specifically urbanization have greatly influenced and continue to influence agricultural marketing systems. This dynamism of the agricultural marketing system has led to the emergence of novel market opportunities and alternate market participants.

Conversely, however, it has also led to challenges in market access and price instability (Onumah *et al*., 2007). With the role of agriculture as a significant contributor to achieve food and nutrition security as well as economic growth (Machethe, 2003; IFAD, 2011), it has been determined as imperative to help farmers address the new challenges and utilize the new opportunities which they are presented with (IFAD, 2012).

Potential Niche Markets for Smallholder Farmers

Smallholder farmers often have access to and supply informal markets. These markets are identified as the ideal niche markets for smallholder farmers as frequency of procurement, and strict hygiene and quality standards are not stipulated (Roesel and Grace, 2015). However, these markets often compensate farmers with only low incomes of sale. Social responsibility and proudly South African drives have led local retail supermarkets and formal markets attempting to source products locally, initiating business with smallholder farmers (Louw *et al*., 2007). Supermarket chains and fresh produce markets may therefore be more lucrative potential niche markets for smallholder farmers to gain a higher and more stable income (Louw *et al*., 2008). Unfortunately, retail supermarket chains and formal fresh produce retail markets are governed by stringent quality and safety standards (Stefano *et al*., 2005; Thamaga-Chitja and Hendriks, 2008; Mdluli *et al*., 2013), which pose one of the greatest market-related challenges for smallholder farmers as they usually lack knowledge of the required quality and safety standards (Stefano *et al*., 2005; Thamaga-Chitja and Hendriks, 2008; Mdluli *et al*., 2013).

2.8) Food safety standards

An array of reasons has led to the heightened attention given to food safety and quality standards in both developed and developing countries (Unnevehr, 2003). These reasons include higher demands for safe and high quality food by households with rapidly rising incomes, technological advancement and improvement in measurement of contaminants, increased diversity of importers and exporters and lastly escalated media exposure and consumer consciousness to the risks of foodborne illnesses and their associated dangers (Lupien, 2007).

Almost every country has their own set of food safety and quality standards and guidelines specifically adapted to their needs (Unnevehr, 2003). However, international guidelines developed by the World Health Organization in conjunction with the Food and Agricultural Organization of the United Nations, such as the Codex Alimentarius, can and are used as baseline standards around the world including South Africa. Additionally, the ISO 22000 is an alternate set of guidelines developed by the International Organization of Standardization, which also deals with aspects of food safety and quality.

Table 2.2: Microbiological limits for raw fruit and vegetables (ready-to-eat) in accordance to the South African, EU, DGHM and Hong Kong regulations or guidelines.

Microorganism	South African Limits (cfu/g)	European Limits (m/M)	DGHM(m/M)	Hong Kong(m/M)
Total coliforms	<200/g	-	-	-
Yeasts and moulds	<100000/g	-	<10000/g (yeasts only)	-
***E.coli* strains**	0/g	100/1000cfu/g	100/1000cfu/g	20/100cfu/g
***Salmonella* spp.**	0/25g	0/25g	0/25g	0/25g

(DOH, 2002; European Commission, 2007; DGHM e. V. 2012; Hong Kong CFS, 2014).

Regulations and Laws Governing Food Safety

Quality and safety management systems, product certification and standardization of food hygiene and quality are still relatively new concepts and often less strict in developing countries and therefore are in need of immediate attention (Henson, 2003). The FCD act No.54 of 1972, is the current regulation standard by which all foods manufactured, processed and sold in South Africa, inclusive of imported food commodities, are governed. There are two regulations under this act that govern microbiological standards for foodstuffs and related matters, namely R.692 and R.1555 under the FCD act (DoH, 2002). Unfortunately, both these regulations do not refer to ready-to-eat fresh produce or similar, indicating a lack of food regulations for this specific category of food commodities in the current national legislation. In such a case the rule of thumb is that foodstuff should ideally not contain any microorganisms (DoH, 2002). Should it contain microorganisms, which is normally the case, their levels should be such that they cause no harm to humans upon consumption. Examples for existing national and international microbiological guideline values for raw fruits and vegetables are given in Table 2.2. The limited and varying guideline values indicate that there is still need for creating microbiological standards for minimally processed fresh produce in order to prevent outbreaks of foodborne diseases and enable market access. (Mdluli *et al*., 2013).

2.9) Control of contamination and deterioration of produce

Preventing the contamination of fresh produce with microbial pathogens and other harmful physical or chemical contaminants can be regarded as the most effective way to ensure the safety of minimally processed fresh produce products (Brackett *et al*., 1999; Sivapalasingam *et al*., 2004; Francis *et al*., 2012). This can be accomplished through key preventive approaches such as Good Agricultural Practices (GAP) on the farm, Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) principles being applied at a processing facility (Unnevehr, 2003; Sivapalasingam *et al*., 2004; Nicola *et al*., 2009)

The reduction of possible food safety hazards using a systematic risk assessment approach for all areas in production chains is known as Hazard Analysis Critical Control Point (HACCP) (Wallace *et al*., 2005; Al-Kandari & Jukes, 2011). This process is recognized by regulatory authorities, industry and academia as an important food safety approach, available to the food industry (USFDA, 2009). HACCP consists of steps assessing the processing line for potential hazards and identifying potential controls to prevent their occurrence (Ropkins and Beck, 2000). International HACCP guidelines are often adopted and implemented in South African retail markets as national regulations (DoH, R908), requiring acceptable standards. Unfortunately, HACCP procedures can be regarded as a “catch 22” situation particularly with regard to smallholder farmers wanting to gain access to high-value markets. The intended high-value markets would like to source produce from the smallholder farmers, as procurement costs may be lower, and in line with socio-economic development, they would facilitate business opportunities. However, bound by laws and HACCP procedures, product sourcing from smallholder farmers will be prevented due to the strict quality and food safety standards which have to be adhered to.

2.10) Challenges of smallholder farming

Smallholder farming although regarded as a potential solution to the rising food demands, is not without challenges (Thamaga-Chitja and Hendriks, 2008). Smallholder farmers face economic challenges as they often do not have enough capital to procure production inputs or if they do, this capital is not sustainable (DAFF, 2012). The economic instability of smallholder farmers also makes them more vulnerable to external factors such a price variability, changes in weather patterns and natural disasters (Mdluli *et al*., 2013).

The process of change in agricultural marketing systems, which is evidently set to continue in the foreseeable future, creates important challenges for smallholder farmers to access markets (Onumah *et al*., 2007). Market access is determined and influenced by a number of factors. Some of these factors include demand for a product, quantities of products available for sale, frequency of product delivery, quality and safety and transaction relationships (Killick *et al*., 2000; Makhura and Mokoena, 2003). Commonly, it is these factors, which pose difficulties for smallholder farmers. Additionally, smallholder farmers face a range of alternate challenges when aiming to obtain market access, which has been the focal aspect of multiple research studies (Louw *et al.,* 2007; Vermuelen *et al.,* 2008; Chikazunga and Paradza, 2012). As mentioned previously the market system is of complex nature. As a result smallholder farmers are faced with challenges related to literacy, language and interaction skills. Two areas wherein smallholder farmers are severely challenged are in literacy and training. Smallholder farmers without proper training are unaware of quality and hygiene standards, which are often required by formal markets (Mdluli *et al*., 2013). Additionally, the literacy component leaves them at a disadvantage when forming relationships with the formal sector, as they are often unable to understand the formalities and functioning of the market system (Louw *et al.*, 2007; Wegner and Zwart, 2011). Consequently, smallholder farmers often cannot compete in terms of markets access with the larger and more experienced commercial farmers.

2.11) Conclusion

Microbial contamination within food production and processing has an important impact on food quality and safety. Minimally processed fresh produce is a possible vector for foodborne illness. The adverse effects on human health and possible market access implications, highlight the importance of smallholder farmers employing good pre-and post-harvest hygiene practices when producing minimally processed fresh produce. Subsequent focus on farmer training can provide a means to assist in the production of minimally processed fresh produce meeting food safety and hygiene quality standards thus helping to gain market access ad contributing to food security. Understanding socio-economic characteristics is therefore imperative when designing appropriate training programmes due to their influences on smallholder farmer decision making.

2.12) References

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CHAPTER 3

The effects of socio-economic characteristics of smallholder farmers on pre- and post-harvest practices: implications for market access, health and household food security.

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The demand of fresh produce is increasing. However, it can become contaminated anywhere along the farm to fork continuum. As one of the determinants of market access, the quality of fresh produce, is dependent on the pre- and post-harvest hygiene practices employed during production and processing. Smallholder farmers from low socio-economic backgrounds, have minimal understanding on how farming hygiene practices affect the quality of products, and entry into regulated high-value markets. The objective of this study was to assess the influences of socio-economic characteristics of smallholder farmers on pre- and post- harvest practices employed in production of fresh produce, in line with attaining market access, health and household food security. Key informant interviews, questionnaires and focus group discussions with smallholder farmers of the Marianhill Agri-hub, KwaZulu-Natal, determined the pre- and post-harvest practices utilized, as well as insight on farmer attitudes on general hygiene. Descriptive statistics revealed a female dominated (80%) and ageing farmer population (79% over 40 years old), the majority of whom (61%) displayed interest in gaining access to regulated high-value markets to supplement household income. Many farmers (>63%) reported pre-treating animal manure used as a substitute for fertilizer. Statistical analysis showed that socio-economic characteristics such as exposure to prior training and education levels of farmers significantly influenced selected pre-and post-harvest practices. Implementation of good hygienic pre-and post-harvest practices, which have the potential to facilitate market access, are therefore reliant on socio-economic characteristics of farmer populations. From this study, it can be concluded that understanding the socio-economic contexts of smallholder farmers is essential when developing market access capacity building within agricultural training programs.

Key words: Smallholder farmer; socio-economic characteristics; pre- and post-harvest; market access; fresh produce; food security

3.1) Introduction and contextual background

Approximately 11% worldwide and 19.4% of all South African households have inadequate food access in varying degrees of severity (FAO, 2015; Statistics SA, 2014). Increased agricultural production and food self-sufficiency have been part of economic growth and development initiatives in countries worldwide, marking agriculture as the foundation of most developing countries (FAO, 2011; Stewart *et al*., 2015). Smallholder farming, particularly in Sub-Saharan Africa, forms the basis of livelihoods for millions of people (Aliber and Hart, 2009; Stewart *et al*., 2015). Generally characterized by owning farmland up to two hectares and employing no external labourers, South African smallholder farming was initially aimed at providing food for the household, with minimal surplus (Denison and Manona, 2007 (a and b); Mdluli *et al*., 2014). A mix of market access barriers hampers South African smallholder farmers, limiting them to perform mainly at a subsistence level (Stewart *et al*., 2015; Chitja and Mabaya, 2016).

The growing global population requires an extra 70% of food production and smallholder farmers have been recognized as having the potential to fulfil this demand, thereby improving household food security (Bruinsma, 2010; Stewart *et al*., 2015). In addition to supporting livelihoods, the smallholder farming sector may potentially contribute to economic growth and development of developing countries (HLPE, 2013). Smallholder farming practiced by a sizeable number of people in South Africa (Statistics SA, 2012), despite its current low contribution to income generation, present's a potential opportunity for improved income generation, while still supporting household food security (Thamaga-Chitja and Hendriks, 2008; Baiphethi and Jacobs, 2009; Mdluli *et al*., 2013).

South African smallholder farmers' general production commodities are varieties of fresh produce (Modi, 2003; Mdluli *et al*., 2013) The health benefits, low expense, high turnover rates and general ease of production of fresh produce make them ideal commodities for smallholder farmer production. Increased interest of consumers in fresh, healthy, and unprocessed foods have led to an increase in demand of the "minimally processed organic/organically grown" food products (Rico *et al*., 2007; Mdluli *et al.,* 2014; Gorni *et al*., 2015). Coupled with the increase in demand for organically produced foods and food produced through low agro-inputs systems, the production of organic produce as well as "organically produced", but not "certified organic" produce from smallholder farmers indicates a potential market niche (Mdluli *et al*., 2013).

In addition informal markets, fresh produce and supermarket/ retail stores are markets which smallholder farmers have the potential to gain access to. Despite being the ideal markets for smallholder farmers (Thamaga-Chitja and Hendricks 2004), informal and fresh produce markets often procure products at lower prices and frequency of procurement lacks stability. Supermarket chains (high-value markets) seem to be an alternate potential niche market for smallholder farmers enabling a higher and stable income source (Louw *et al*., 2008). Unfortunately, these high value markets are governed by stringent quality and safety standards, which pose the greatest market-related challenge for smallholder farmers due to their lack of knowledge on the required quality and safety standards (Thamaga-Chitja and Hendricks, 2004; Louw *et al*., 2008; Mdluli *et al*., 2014).

Smallholder farmers are assumed to display a similarity in socio-economic, demographic, and knowledge traits (Mabaya *et al*., 2011). Socio-economic characteristics have the potential to influence the farming practices employed by the smallholder farmer (Oni *et al*., 2013; Mdluli *et al*., 2014). Smallholder farmers within South Africa are known to employ a range of different pre- and post-harvest practices including their reliance on traditional pre-and post-harvest methods (Louw, 2013). These techniques are prevalent amongst most smallholder farmers, as they often offer cheaper alternatives to modern methods and technologies (van der Heijden and Vink, 2013). Practices employed by South African smallholder farmers can be described as only adequate, as these farmers often have limited or no access to adequate infrastructure, transportation and storage facilities (DAFF, 2012). The adoption of these practices thereby increase risks of adverse effects on produce (Babalola *et al.,* 2010; DAFF, 2012). Pre-and post-harvest practices, according to many studies, have the potential to contribute to contamination of produce at any point along the farm to fork continuum (Nicola *et al*., 2009; Jung *et al*., 2014). Contact surfaces within the farm to fork continuum may also serve as noteworthy contributors of microbial contamination on smallholder farmer fresh produce (Jahid and Ha, 2012).

Thus despite occupying a potential market niche in organic markets, smallholder farmers often have limited or no knowledge on the standards of food and hygiene quality standards and market specifications that are required to have saleable products, due to their previously disadvantaged status (Louw, *et al.,* 2007; Mdluli *et al*., 2013; Mabaya *et al*., 2011). This poses a problem in that it is known that “organically” produced minimally processed fresh produce are often subject to microbiological contamination, in turn affecting the hygienic quality and safety of the products and their potential to be marketed at higher values (Mdluli *et al.*, 2013; Maffei *et al*., 2013). South Africa is also known to display population statistics, wherein a large proportion of consumers are more vulnerable due to increased susceptibilities, to illness via food contamination, as they belong to the “YOPI” group (young, old, pregnant and immune compromised) (Gemmell and Schmidt, 2010; Oni *et al*., 2015). Maintenance of the essential healthy balanced diets for these individuals is dependent on fresh produce meeting minimal hygiene and quality standards (Gemmell and Schmidt, 2012; Pezzuto *et al*., 2016). Fresh produce of unsatisfactory quality, with its potential to cause illness, may render household members unhealthy. Bread winners of the family may become incapable of working/functioning productively, affecting income sources negatively. Additionally if farming was an income source, the ability to generate income to buy more and better quality food would be thwarted.

The safety and quality of minimally processed fresh produce can be ensured through prevention of contamination with microbial pathogens, physical contaminants, chemical residues or bio-toxins (Abadias *et al*., 2008). Key preventative approaches improving the food safety and quality of these products can be accomplished through Good Agricultural Practices (GAP) on the farm, Good Manufacturing Practices (GMP) and Hazard Analysis Critical Control Point (HACCP) principles being applied at processing facilities (CFIA, 2014). South Africa, as with many developing countries, continually focus agricultural research on improving production and production yields, however little attention of research is focused on the importance of pre- and post-harvest practices. Indicating the need for improved awareness and knowledge to bridge the information gap on pre-and post-harvest practices employed in smallholder farming and its subsequent effects on market access, health and household food security. The importance of socio-economic factors in determining how smallholder farmers carry out pre- and post-harvest practices is important, as these practices have the potential to contribute to microbial contamination (Brackett, 1999; Jung *et al*., 2014), in turn impacting on potential market access and household food security.

Improvement of smallholder farmer livelihoods is dependent on the farming systems in Southern Africa increasing production and sustainability. When conducting research regarding the improvement of smallholder agricultural practices, comprehensive attributes of the smallholder farmer should be well understood (Pienaar and Traub, 2015). The complexity of resource limited agriculture, further highlights the importance of understanding the context of smallholder farming, with respect to characteristics such as demographics and socio-economic factors and their subsequent impacts on fresh produce contamination via pre- and post-harvest practices (Ndove *et al*., 2006; Thamaga-Chitja & Morojecle, 2014; Nederlof and Dangbe´gnon, 2007). Without the understanding of demographics and socio-economic characteristics of the smallholder farmers, improvements may not be meaningfully facilitated and realised to meet the requirements of potential high-value fresh produce markets (Betek and Jumbam, 2015).A previous study investigating links between such human dimensions and only general hygiene practices adopted by smallholder farmers' has been carried out (Mdluli *et al*., 2014).

The objective of this study was to explore the socio-economic characteristics of the smallholder farmers', their influences on pre-and post- harvest farming practices and thus implications on market access, health and household food security. In doing so, potential links and impacts on fresh produce safety and quality, in terms of microbial contamination, were determined. This is based on the principle that market access will only be facilitated if minimally processed fresh produce meets relevant food safety and hygiene quality standards, resulting in improved household food security and market access for the smallholder farmers whom are able to meet the required safety and quality standards.

3.2) Methods and Materials

Study Site and Sampling Procedures

A sequential explanatory mixed methods research design, wherein qualitative methodologies are used to assist with describing and interpreting quantitative findings was used in this research study. Data collection tools included key informant interviews (qualitative method) with staff of the Marianhill Agri-hub, a local organic farming NGO, with headquarters situated in Marianhill, KwaZulu-Natal. In addition, questionnaires (see General Appendix 1) administered to 80 smallholder farmers all involved with or supplying the Marianhill Agri-hub, were also utilized. The NGO offers a market platform to farmers, while offering workshops and training in certain farming aspects, in order to achieve an acceptable standardized quality. The Marianhill Agri-hub is not yet certified as an “organic” supplier, and thus supplies vegetables under the “organically produced” and not “certified organic” label. This classification refers to produce that is produced using low agricultural inputs, such as compost and organic fertilizers and limited organic pesticides, but does not meet the strict organic production guidelines outlined by the respective organic certification organizations (e.g. SGS South Africa (Pty) Ltd. and Ecocert South Africa). The Agri-hub constitutes four smaller Agri-hub’s, namely: Hambanati, uMbumbulu, Marianhill and Cliffbux, located in the province of KwaZulu-Natal, South Africa. Open-ended questionnaires (quantitative method) were used to collect information and provided insight into farmers’ attitudes and behaviours, regarding pre- and post-harvest hygiene practices. Trained and untrained farmers, inclusive of farmers supplying the NGO and farmers interested in supplying, but yet to supply the NGO made up the purposively sampled population. The questionnaires were prepared in English and later translated into isiZulu. Visual observations of the practices were also made to validate some of the results.

26/04/2016 at the Cliffbux Agri-hub

12/05/2016 at the Marianhill Agri-hub

Figure 3.1: Semi-formal questionnaire sessions with the Marianhill Agri-hub farmers on two different occasions.

Data Analysis

Data were coded, captured and analysed using IBM's statistical Software Package for Social Scientists (SPSS) (version 24, 2016). Descriptive statistics including frequency analysis were utilized to generate sample descriptions. The Pearson's Chi-Square test of significance, evaluated relationships between selected pre-and post-harvest practices (e.g. pre-treatment of water/compost prior to use etc.) and relevant nominal or categorical socio-economic variables. P-values of <0.05 were considered as significant. Observations made and pictures taken were used to enrich the data and analysis.

3.3) Results & Discussion

This study sought to determine the socio-economic characteristics of the Marianhill Agri-hub smallholder farmers and provide insight on the relationships between these characteristics and the pre-and post-harvest hygiene practices adopted by these smallholder farmers. The first section (Section A-Smallholder farmer demographic and socio-economic characteristics) describes the sample population and their socio-economic characteristics, using frequency analysis. Section B, relationships between socio-economic characteristics and smallholder farmer pre-and post-harvest hygiene practices, assessed the relationships between the socio-economic characteristics of the smallholder farmers and the pre-and post-harvest practices which they employ in the production of fresh produce, using the relationship analysis statistic, Pearson Chi-Square.

Section A: Smallholder Farmer Demographic and Socio-economic Characteristics

In a sample population of 80 smallholder farmers from rural KwaZulu-Natal, results reveal that a majority of the sample population were female (80%) whereas males only accounted for 20% of the sample population (Table 3.1). A correlation between the finding of this study and alternate literature, illustrates that woman are generally the main participants involved in smallholder farming (Altman *et al*., 2009; FAO, 2013). These findings show that improvement initiatives, through training or funding, should be directed towards females, due to their continuous active participation in agriculture (Mdluli *et al*. 2014).

Table 3.1: Frequency table of smallholder farmer demographics and general hygiene responses.

Demographic Variable	Characteristics/Categories	Actual Number(n=80)	Percentages
Gender	Male	16	20%
	Female	64	80%
Age	<20 Years Old	0	0%
	Between 21-39 Years Old	17	21%
	>40 Years Old	63	79%
Level of Education	No formal Education	10	12%
	< Grade 7	30	38%
	Grade 8-12	27	34%
	> Grade 12	13	16%
Income Source	Remittances	0	0%
	Government Social Grants	51	64%
	Farming	23	29%
	Wages/Salary	6	7%
	Combination of additional income and sole source of income	7	9%
Interest level in farming	Interested if there's no alternate	11	14%
	Interested for additional income	49	61%
	Very interested, sole source of income	13	16%
Membership in a farmer's group	Yes	63	78%
	No	17	22%
Involved/exposed to farmer training	Yes	49	61%
	No	31	39%
Knowledge of fresh produce outbreaks as a result of consumption	Yes	5	6%
	No	75	94%
The need for Awareness on Fresh Produce Quality	Yes	11	14%
	No	69	86%
Type of Farming Practiced	"Organic"	64	80%
	Conventional	16	20%

*Percentages were rounded up to the nearest whole number

The results shown in Table 3.1 indicate an ageing sample population, with only 21% of the study population being under the age of 40, and 79% of the participants being over the age of 40, this is found to be in correlation with literature (Heide-Ottosen and Vorbohle, 2014;Tshuma, 2014). According to previous studies, ageing farmer populations are generally a dominant characteristic in farming areas (Bembridge, 1991; Kamara *et al*., 2001; Heide-Ottosen and Vorbohle, 2014). Factors such as limited availability of alternate professions, and opportunities with higher paying sectors impact on the participation of the younger population (Leavy and Smith, 2010). It was also concerning to note that not a single farmer under 20 years of age participated in the study.

Literacy among the sample population was found to be a general characteristic, with only 12% of the participants having no formal education, whereas 38% had at least received primary education, followed by 34% having secondary education and 16% having tertiary education. A number of previously conducted studies depicted that smallholder farmers were relatively illiterate or had not been exposed to any formal education (Fawole and Fasina, 2005; Dearlove, 2007; Babalola, *et al*., 2010 and Mnkeni *et al*., 2010). In contrast, our results depict that a majority of the farmers (88%) belonging to the Marianhill Agri-hub had at least been exposed to a basic level of formal education.

Similarly to previous studies (Aliber and Hart, 2009; Mdluli *et al*., 2014), the main income source of participants involved in this study was government grants (64%), such as pension and social grants, followed by income generated through farming at 29%, and formal salaries and wages accounting for 7% of income. Through content analysis it was apparent that a number of participants obtained income from a combination of sources. A common trend, amongst smallholder farmers is the diversification of income sources, in order to manage and buffer against associated poverty risks (Coetzee, 2003; Aliber and Hart, 2009).

Data with respect to the interest in farming of the sampled population were collected on the basis of interest in farming and on those deriving an income source from agriculture. The farmers were grouped based on interest in farming and market access. The three groups were i.e. (i) – “mildly” interested only if there’s no alternate source of income; (ii) – “moderately” interested for generation of additional income and

(iii) – “very” interested, as it is the sole source of income. Descriptive analyses indicated that a small proportion of the farmers (14%) was only mildly interested in farming, if there were no alternate means of income generation, whereas 16% were very interested in farming, as it was the sole source of income. 9% of smallholder farmers displayed a “moderate” to “very” interested level of interest in farming. The largest percentage of participants (61%) was moderately interested in farming as an additional income source. This interest in farming is common, because farming is an essential part of livelihood strategies among smallholder families (Aliber and Hart, 2009). The minimal indication of “very interested” farmers may be attributed to the fact that most smallholder farmer’s perspectives of farming are not business oriented. Similar observations were made in other research studies, wherein minimal investment, low productivity and less marketable surplus’ were assumed to be a result of lack of interest (Padilla-Fernandez and Nuthall, 2001; Maskey *et al*., 2010). According to Aliber *et al*. (2009), despite smallholder farmers’ output in South Africa currently contributing negligibly to the nations agricultural GDP, they are still regarded important for sustainable food security and self-employment among rural resource-poor households. Results of this study reflect similar wherein a majority of farmers were interested in farming, only for additional income, possibly indicating that farming is viewed first as a food source and only thereafter considered as a possibility for income generation (Aliber *et al*., 2009).

Table 3.1 also indicated that a majority of the smallholder farmers practiced organic farming (80%), this is expected as most farmers did and intended to supply under the Marianhill Agri-hub, which supplies under the label “organically produced, but not certified organic”. This observation is also in line with Louw (2013), which suggests that smallholder farmers use traditional farming practices, which are generally similar to that of organic farming principles.

Section B - Relationships Between Socio-economic Characteristics and Smallholder Farmer Pre-and Post-harvest Hygiene Practices

Relationships between selected socio-economic farmer characteristics and pre-harvest practices

Pre-harvest farming practices employed by the participants of the study were divided into 7 categories. Table 3.2, shows that 3 of the 7 practices had a significant relationship with at least one of the farmer’s demographic characteristics. Treatment of irrigation water (e.g. boiling of water before use; addition of bactericidal chemicals such as Jik), use and type of pesticide, and the nature of pre-harvest equipment were preharvest practices, which had no statistically significant relationship to any of the farmer demographic characteristics. The results further showed only one statistically significant association existed between gender and pre-harvest practices, which was the treatment of manure. A study conducted by Chen *et al*. (2011) found that there was a higher usage of fertilizer (inclusive of manure) in households with more males. Indicating the possibility that the treatment of manure (as a substitute for fertilizer) may be affected as result of being exposed to higher usages of fertilizer, wherein higher usage correlates to understanding that treatment of manure is required before use.

Table 3.2: Relationships between pre-harvest farming practices and socio-economic characteristics of the Marianhill Agri-hub farmers (n=80).

Selected Pre-Harvest Practices	**p-value**					
	Gender	**Age**	**Education Level**	**Income Source**	**Trained**	**Farmer Group Member-ship**
Type of irrigation water used	0.157	0.707	0.055	0.229	0.023*	0.574
Treatment of irrigation water	0.474	0.126	0.112	0.529	0.912	0.896
Type of fertilizer used	0.845	0.136	0.685	0.021*	0.014*	0.424
Treatment of manure	0.027*	0.072	<0.001*	0.257	0.716	0.926
Use of pesticide	0.500	0.848	0.082	0.391	0.982	0.197
Homemade/store-bought pesticide	0.729	0.347	0.159	0.677	0.152	0.071
Nature of pre-harvest equipment	0.339	0.850	0.809	0.142	0.237	0.528

*significant as p-value is <0.05

A significant relationship between the type of fertilizer used and income source was observed (Table 3.2). As the farmers in this study belonged to resource limited backgrounds and most often relied on government grants for income, fertilizer is a potential expense thereby potentially limiting the use and choice of fertilizer. Results also showed that prior training affected current practices in terms of irrigation water source and fertiliser use. This observation is supported by themes outlined in the content analysis from key informant interviews (see Chapter 3- Appendix 2), wherein most training received by the farmers was centred on effective composting and irrigation. Education was found to have a significant association with treatment of manure.

Relationships between selected farmer characteristics and post-harvest practices

Post-harvest farming practices employed by the participants of the study were divided into 2 categories, time of harvest and nature of harvest collection equipment. Relationship analysis between the demographic characteristics and the farmer post-harvest practices indicated only one significant association, being between education levels and time of harvest (Table 3.3). Education levels have indeed been found to impact farming practices adopted by smallholder farmers in previous studies (Ko, 2010; Martins *et al*., 2012; Mdluli *et al*., 2014).

Table 3.3: Relationships between post-harvest farming practices and socio-economic characteristics of farmers of Marianhill Agri-hub (n=80).

Selected Post-Harvest Practices	**P-value**					
	Gender	**Age**	**Education Level**	**Income Source**	**Trained**	**Farmer Group Membership**
Time of Harvest	0.270	0.493	0.033*	0.563	0.393	0.622
Nature of Harvest Collection Equipment	0.339	0.850	0.809	0.142	0.237	0.528

*significant as p-value is <0.05

Table 3.4: Relationships existing between general hygiene practices and awareness and socio-economic characteristics of the Marianhill Agri-hub farmers (n=80).

	p-value				
	Gender	**Age**	**Education Level**	**Trained**	**Farmer Group Member-ship**
General Hygiene Practices					
Washing Hands	0.909	0.817	0.536	0.005*	0.373
Washing gumboots and clothing items	0.001*	0.724	0.945	0.859	0.138
Washing all pre-and Post-harvest equipment	0.412	0.091	0.729	0.373	0.977
Acknowledgement of the following items as potential sources of contamination					
Water	*0.054*	0.584	0.445	0.026*	0.097
Soil	0.789	0.589	0.495	0.001*	0.155
Fertilizer/Compost	0.214	0.668	0.267	0.140	0.326
Farming Equipment	0.576	0.339	0.030*	0.207	0.785
Acknowledgement of the following items as consequences of bacterial contamination					
No Hazard	0.646	0.742	0.637	<0.001*	0.817
Loss of trust of customers	0.179	0.256	0.212	<0.001*	0.613
Health complications	0.433	0.613	0.957	<0.001*	0.967
Awareness on Fresh produce implications	0.871	0.789	0.428	0.132	0.288
Sickness caused by fresh produce	1.00	0.230	0.853	0.066	0.290

*significant as p-value is <0.05

Relationships between selected farmer socio-economic characteristics and general hygiene practices and awareness

The analysis of general hygiene practices and farmer awareness revealed the highest number of significant associations with the demographic characteristics of farmers (Table 3.4). Significant associations between age and membership to a farmer group with general hygiene practices and awareness were not observed. According to a study by Burton (2006), good hygiene practices are a characteristic often associated with farmers above the age of 40. Similarly, Mdluli *et al*. (2014) found that farmers belonging to older age groups displayed good hygiene practices. The results of this analysis are thus surprising with respect to correlations between age and good hygiene, in that majority of the farmers participating were above the age of 40. Alternatively, the results depict the diversity of smallholder farmers, consequently highlighting that context and demographic characteristics have different effects and outcomes on different smallholder farmer populations. This is contrast to a common assumption that smallholder farmers are a homogenous population, displaying similar characteristics (Manderson, 2015). This reiterates the principle that situations are circumstance, place and context specific and initiatives aimed at improving farmer practices should first be geared toward understanding the target populations and their socio-economic heterogeneity and aim to establish baseline data before interventions.

Additionally, it can be seen that associations between gender and general hygiene practices was found to be statistically significant in one case (Table 3.4). The general hygiene practice of washing farming gumboots and clothing after farming activities (p=0.001) may be attributed to the fact that women are generally responsible for the domestic chores of the household, and thus carry out the washing (Raidimi, 2014). The low number of significant associations between gender and pre-, post-harvest and general hygiene practices and awareness of farmers, indicate that most practices in this community are not influenced by gender. Alternatively, the non-disparity between gender roles could be attributed to adoption of similar techniques as a result of interactions between male and female farmers (Mdluli *et al*., 2014).

The data in Table 3.4 imply that farmers with prior exposure to training displayed better insight, especially in view of general hygiene practices and awareness. This is proved by the relationships that exists between the general hygiene practice of washing hands (p=0.005), and awareness in terms of knowledge of contamination sources (p = 0.026

and 0.001) and consequences as a result of bacterial contamination ($p < 0.001$). Similar observations were reported by Ko (2010), Martins *et al*. (2012) and Mdluli *et al*. (2014) ascribing exposure to prior training as a driver of better farming practices.

Additionally, results in table 3.1, show that generally smallholder farmers were not aware of foodborne illness outbreaks as a result of fresh produce consumption (94%), this is line with their poor awareness on prospective fresh produce contamination sources. A majority of smallholder farmers also indicated that there was no need for awareness on fresh produce quality (86%) (Table 3.1). This highlights assumptions that smallholder farmers are usually unaware of fresh produce quality and its potential implications on market access (Mdluli *et al*., 2013).

Figure 3.2 is a summation of significant associations from tables 3.2, 3.3 and 3.4 between socio-economic characteristics and pre- and post- harvest practices employed by smallholder farmers.

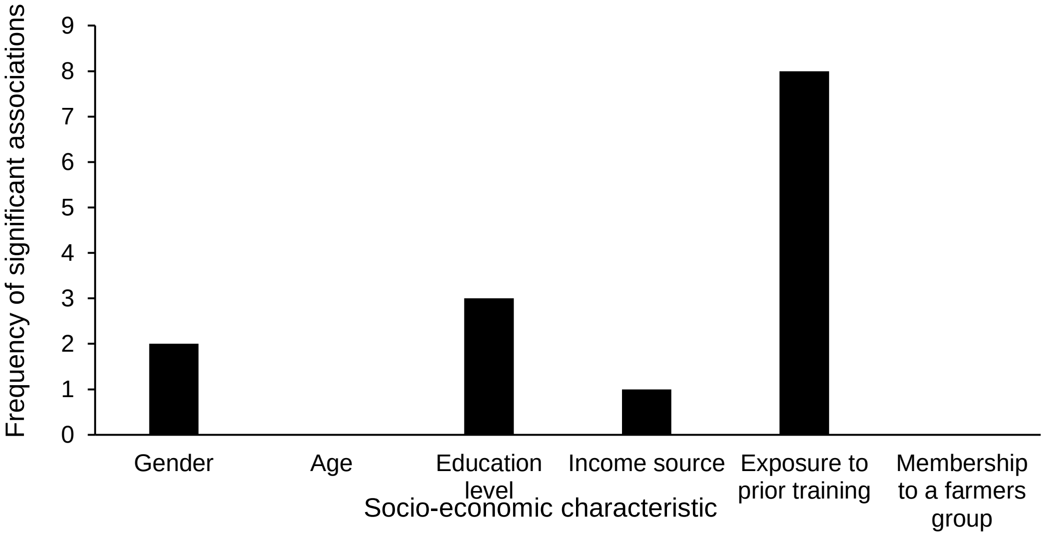

Figure 3.2: Frequency of significant associations between smallholder farmer socio-economic characteristics and pre-, post-harvest and general hygiene practices.

Age

Age was not found to influence any of the categorized farming practices in this study, displaying no significant associations overall (Figure 3.2). Arguably, it can be noted that the sample population of this study represented an ageing population and thus adequate inferences on the hygiene practices adopted by younger populations cannot be assumed. Ageing farmer populations however, may result in the use of primitive less effective methods of farming, which allow the production of fresh produce which does not meet market quality standards (Fasina, 2013). Awareness and extension of the changing market access standards in a country is thus important. Limitation of physical strength is often a characteristic displayed by ageing populations, this may pose challenges to pre-and post-harvest practices in that farmers are not physically able to carry out appropriate and efficient practices to ensure the production of good quality fresh produce (Fasina, 2013). Tang and MacLeod (2006) in Canada, suggested that usually older workers are not as productive in comparison to younger workers, leading to similar assertions made by Li and Zhao (2009) in China, that ageing farmer populations may contribute adversely to agricultural production.

Gender

A majority of the farming practices employed by the Marianhill Agri-hub smallholder farmers were not influenced by gender (Figure 3.2). These results could be attributed, similarly to results found in Mdluli *et al*. (2014), to the fact that most smallholder farmers within this area belong to farmers groups (78%), which allow for male and female interactions, leading to the adoption of similar farming techniques. However, as later described farmer groups were not very active in this farmer community. Despite no gender disparity in employment of farming practices, the number of woman involved in farming in this community (80%) is indicative of the importance of gender analysis in the development of agricultural improvement initiatives. The importance of gender analysis has been recognized as a key step in understanding the differentiated roles, responsibilities and priorities of women, for the creation of targeted development initiatives aimed at improving health and household food security (FAO, 2013; Jost *et al*., 2014).

Education Levels

Education has the potential to influence farm practices and productivity in many manners, such as: enhancement of farm productivity through directly improving the quality of labour; improving the farmer’s ability to acquire and understand new information; evaluation of new production processes and utilization of new agricultural practices, as well as understanding the benefits of appropriate farm practices (Kisaka-Lwayo and Obi, 2012). The results displayed in Table 3.2 and Table 3.3 indicated similar findings, wherein a number of the pre- and post-harvest farming practices employed showed significant associations with the education levels of the farmers. Studies on the impacts of education on farming practices have shown that education increases the probability of a farmer adopting improved practices as it enhances the ability to acquire, understand and efficiently implement prescribed methods, which again substantiate education levels correlating with good hygiene practices (Mdluli *et al*., 2014; Kilpatrick, 2000; Kilpatrick and Johns, 2003). However, it should also be noted that the level of education, and not just education, is a determinant on how well improved farming practices are implemented. A previous study suggested that farmers exposed to higher levels of education are thought to possess a more thorough knowledge of good farming practices (Martins *et al*., 2012). A case in study by Babalola *et al*. (2010) indicated that in many instances, farmers with secondary level education can easily grasp the dynamics of farming for business purposes and can be trained with minimal difficulty, unlike farmers with only primary level education. Farmers with post primary education may also appreciate and effectively use most postharvest technologies available (Babalola *et al*., 2010).

Exposure to Prior Training

Farmers exposed to previous training, had the highest number of significant associations with regard to pre-and post-harvest practices, as well as general hygiene practices and awareness (Figure 3.2). It is clear from the number of significant associations that exposure to training has an effect on farming practices employed. Enhancement in knowledge and human capital are regarded as key contributors which impact on the social welfare, productivity and growth of populations (Serin *et al*., 2009). Training is a proposed method to facilitate the enhancement of knowledge and human capital, especially in agricultural farming populations (IFAD, 2012). In a study conducted by Van Niekerk *et al*. (2011) training was described as a key need by the smallholder farmers of the study, which they deemed essential to the improvement of their farming practices and therefore market access, health and household food security. In a Turkish study recommendations of intensified training and extension services was made, after training through various methods showed positive correlations with adoption of improved farming practices (Uzonna and Qijie, 2013).

Farmer Group Membership

Farmer group membership, surprisingly, displayed no significant associations. Content analysis of focus group discussions revealed that although many farmers belonged to farmer groups, the groups did not have frequent communication and interaction sessions (see Chapter 3- Appendix 2). This provides a potential explanation, as to why membership in a farmers group displayed no significant associations, highlighting that membership has not been advantageous. This is in contrast with assumptions wherein farmer group membership is believed to have provided an additional knowledge basis. A study conducted by Roothaert and Muhanji (2009) argued that participation in farmers' groups or associations helps access markets for both inputs and outputs, such as supply of agricultural inputs, financial assistance, transportation and storage facilities, as well as training services. Preceding this study was a study conducted by Ortmann and King (2007), which illustrated the above input and output examples as reasoning for the formation of farmer group organizations. These examples indicate the potential advantages which can be accessed, if unlike in the current study, farmer group membership provided more frequent meetings, providing platforms for the exchange of information and techniques.

3.4) Conclusion

The results of this study highlight the links between the socio-economic characteristics and smallholder farmer pre-, post-harvest and general hygiene practices and awareness. These socio-economic characteristics, especially exposure to prior training and education levels, have the highest impacts on general, pre- and post-harvest hygiene practices, as well as on hygiene awareness pertaining to fresh produce and its implications. Improved general, pre-and post-harvest practices are thus dependent on exposure to proper training, thereby indicating training as a possible avenue to further improve the outputs and livelihoods of the smallholder farmers. Female dominated smallholder farming, as similarly found in this study, highlights the importance of understanding gender dynamics within farming contexts to derive appropriate initiatives and interventions. Encouragement of the youth to pursue agriculture as a potential career field, is essential, given the socio-economic context of rural KwaZulu-Natal and the need for livelihood options. This suggestion is made bearing in mind the positive correlation of education levels with good farming practices. Indicating that the youth of today, with potentially higher education levels may be better equipped to successfully mitigate the problem of an ageing farmer population, while at the same time successfully producing income earning fresh produce meeting market required safety and hygiene quality standards. Education and training have been proven to be important in pre- and post-harvest practices as these can negatively affect farmer livelihoods, household food security and market access.

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Chapter 3- Appendix 1:

Frequency Tabulations (SPSS v.24)

Gender

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Male	16	20.0	20.0	20.0
	Female	64	80.0	80.0	100.0
	Total	80	100.0	100.0	

Age

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Between 21-39 years old	17	21.3	21.3	21.3
	> 40 years old	63	78.8	78.8	100.0
	Total	80	100.0	100.0	

Income source

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Pension	51	63.8	63.8	63.8
	Farming	18	22.5	22.5	86.3
	Salary/wages	6	7.5	7.5	93.8
	Other	5	6.3	6.3	100.0
	Total	80	100.0	100.0	

Education level

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	<Grade 7	30	37.5	37.5	37.5
	Grade 8-12	27	33.8	33.8	71.3
	>Grade 12	13	16.3	16.3	87.5
	No Formal Education	10	12.5	12.5	100.0
	Total	80	100.0	100.0	

Interest level for farming

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Interested if no alternate	11	13.8	13.8	13.8
	Interested for Additional Income	49	61.3	61.3	75.0
	Very interested, sole source of income	13	16.3	16.3	91.3
	Combination of 2 and 3	6	7.5	7.5	98.8
	Missing Information	1	1.3	1.3	100.0
	Total	80	100.0	100.0	

Membership to a farmers group

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	63	78.8	78.8	78.8
	No	17	21.3	21.3	100.0
	Total	80	100.0	100.0	

Involved/exposed to farmer training

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	49	61.3	61.3	61.3
	No	31	38.8	38.8	100.0
	Total	80	100.0	100.0	

The need for awareness of fresh produce quality

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	5	6.3	6.3	6.3
	No	75	93.8	93.8	100.0
	Total	80	100.0	100.0	

Knowledge of fresh produce outbreaks within the community

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Yes	11	13.8	13.8	13.8
	No	69	86.3	86.3	100.0
	Total	80	100.0	100.0	

Type of farming practiced

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Conventional Farming	16	20.0	20.0	20.0
	Organic Farming	64	80.0	80.0	100.0
	Total	80	100.0	100.0	

Chapter 3- Appendix 2:

Table 3.5: Summary of responses from focus group discussion sessions.

Questions	Responses
Are the farmer groups in your area active?	**Cliffdale**: " we do not see each other very often, unless it is at training/workshops" **Marianhill**: "general preference is to work alone, and sometimes get help from neighbours or friends, but not formal farmer groups" **uMbumbulu**: "not really, not many people like to work together"
Are you interested in gaining market access?	**Cliffdale**: "yes very interested, we all need more income"; **Marianhill**: **uMbumbulu**: " It will be nice, but first we need to have enough for family"
Do you think you produce enough to supply high-value markets	**Cliffdale**: "yes, we would supply all the surplus fresh produce that we have" **Marianhill**: "not unless we supply to Paula, who combines all the produce and then sells it" **uMbumbulu**: N/A
Are you aware of hygiene and quality standards required by high-value markets?	**Cliffdale**: "What are you talking about?" "please explain what is meant" **Marianhill**: " yes , but what are these standards and how can we get more information on them" **uMbumbulu**: N/A

CHAPTER 4

Pre-and post-harvest practices of smallholder farmers in rural KwaZulu-Natal, South Africa: Microbiological quality and potential market access implications

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Increasing demands for “minimally processed” fresh produce, is creating a potential market niche in high-value markets for South African smallholder farmers. Fresh produce not meeting the required microbiological quality criteria, causes consumer health concerns and therefore limits market access. This study determined smallholder farmer pre-and-post-harvest practices and their potential contributions to the microbiological quality of “minimally processed” fresh produce and thus potential implications for market access. Survey results indicated that most smallholder farmers used animal manure as fertilizer (74%) and their knowledge of potential contamination sources was poor. Microbiological analysis showed that a number of irrigation water samples did not meet WHO recommendations for faecal coliform levels. Additionally, most irrigation water samples exceeded the South African standard of ≤ 1 *E.coli/*100ml for irrigation water applied to “minimally processed” fresh produce. Lettuce, parsley, carrots and spinach collected over at least 3-months were frequently of unsatisfactory quality with respect to total coliform levels (ranging from 130 to 79000 MPN/g) and *E.coli* levels (ranging from 2.2 to 49 MPN/g) according to South African Department of Health recommendations. *Salmonella* spp. was not detected in fresh produce or irrigation water samples. Antibiotic susceptibility patterns of 155 randomly selected *E. coli* isolates from both fresh produce and irrigation water were determined using the EUCAST disk diffusion method. The highest percentage of resistance was against the antibiotics streptomycin (95%) and amoxicillin-clavulanic acid (33%). Scanning electron microscopy showed that *E.coli* isolates from fresh produce displayed biofilm formation capabilities. The identification of antibiotic resistant and biofilm forming *E.coli* from fresh produce and within the production and processing environment, highlights the importance of hygienic, pre-and post-harvest practices, especially if smallholder farmers intend on supplying high-value markets.

Key words: Smallholder farmer; market access; pre- and post-harvest; fresh produce; antibiotic resistance; biofilms

4.1) Introduction

Good quality fresh produce is considered as an essential component of the human diet (Rico *et al*., 2007; Berger *et al*., 2010; Baranowski, 2011; Jung *et al*., 2014; Pezzuto *et al*., 2016). Strong positive correlations between fresh produce consumption and health have led to increased demands of good quality fresh produce (De Roever, 1998, Rico *et al*., 2007; Gorni *et al*., 2015). In view of the increasing global demand and value of fresh produce, it contributes substantially to both economy and population health (Narrod *et al*., 2009; Thow and Priyadarshi, 2013). For South Africa, fresh produce is important due to its potential health benefits, availability and its apparent ease of production. With a large proportion of the population constituting of YOPI (Young, Old, Pregnant and Immuno-compromised) individuals (Gemmell and Schmidt, 2010; Oni *et al*., 2015), and specifically KwaZulu-Natal with the highest provincial antenatal HIV prevalence (40.1%) for the year 2013 and Tuberculosis (TB) mortality rates of 81 per 100000, the need for hygienically safe and good quality fresh produce is an essential dietary requirement (Day and Gray, 2016). Furthermore, the widespread use of effective Anti-Retroviral Treatment (ART) in South Africa has led to an increase in survival and ageing of HIV-infected persons for whom hygienically safe and good quality fresh produce is an essential part of a healthy diet (Oni *et al*., 2015)

The analysis of production trends in South Africa shows that a majority of rural households practice smallholder farming (Aliber *et al*., 2006). This farming not only provides fresh produce for families but can contribute to income generation given that produce surplus is safe for consumption and of good quality to be marketed (Thamaga-Chitja and Hendriks, 2008; Mdluli *et al*., 2013).

Fresh produce serves as a natural habitat for a large array of microorganisms (De Roever, 1998; Olaimat and Holley, 2012; Gorni *et al*., 2015). Leafy vegetables are characterized by imbricate leaves and large surface areas and are therefore subject to a higher microbial burden and contamination by spoilage and pathogenic microorganisms (Nguyen-the and Carlin, 1994; Mukherjee *et al*., 2006; Abadias *et al*., 2008; FAO, 2008 (a)). Microbial contamination of fresh produce can arise anywhere along the farm to fork continuum, rendering fresh produce potentially unsafe for consumers if not only spoilage organisms but also pathogenic foodborne disease causing organisms such as pathogenic *Escherichia coli* strains and *Salmonella* spp. are present (Berger *et al*., 2010; Holvoet *et al*., 2015). Potential sources of contamination include pre-harvest practices (including the application of pre-mature compost as fertilizer and usage of poor quality irrigation water) as well as post-harvest practices inclusive of handling produce during harvesting, storage, packaging and transportation (Beuchat, 1996; Harris *et al*., 2003; Francis *et al*., 2012; Holvoet *et al*., 2015). “Minimally processed” fresh produce, such as lettuce, spinach, and parsley, are often consumed raw and therefore pose higher risks to consumers if contaminated with pathogenic microorganisms (Abadias *et al*., 2008; Holvoet *et al*., 2015). The number of reported food-borne disease outbreaks associated with the consumption of raw fruits and vegetables is continually increasing (Berger *et al*., 2010; EFSA, 2015) and have been documented globally (Table 4.1).

Table 4.1: Selected global foodborne disease outbreaks associated with fresh produce within the last decade (2006-2016).

Pathogen	Year	Location	Source	Number of cases of infection	Reference
***Salmonella* spp.**	2016	USA	Alfalfa sprouts	36	CDC, 2016(a); CDC, 2016(b)
***E. coli* O121**	2014	USA	Raw Clover sprouts	19	CDC, 2014
***E.coli* O157:H7**	2012; 2013	USA	Organic Spinach and Spring Mix Blend; Ready-to Eat Salad	33	CDC, 2012 CDC, 2013(a)
***E.coli* O104:H4**	2011	EU, Germany	Sprouts	4075	Buchholz *et al*., 2011; CDC, 2013(b)
***Salmonella* spp.**	2010	USA	Alfalfa Sprouts	140	Harvey *et al*., 2016
***Salmonella* spp.**	2008	USA	Mixed raw Vegetables	1442	CDC, 2008
***Salmonella* spp.**	2007	EU	Alfalfa sprouts	51	Emberland *et al*., 2007; Werner *et al*., 2007
***Salmonella* spp.**	2007	UK	Fresh Herbs (Basil)	30	Pezzoli *et al*., 2007
***E.coli* O157:H7**	2006	US	Fresh Spinach	183	CDC, 2006

“Minimally processed” fresh produce has therefore been identified as a potential food safety hazard, if inappropriate or unsafe pre- and post-harvest practices are employed (European Commission, 2002; Mukherjee *et al*., 2006; EFSA, 2015).

In addition to being able to cause foodborne disease, pathogenic bacteria present on contaminated produce might display antibiotic resistance (Duffy *et al*., 2005; Ruimy *et al*., 2010; Holvoet *el al*., 2013). Such resistances can spread easily from one ecosystem to another by vectors such as humans, animals, food commodities, and insects and aided by weather conditions such as strong winds and flooding (WHO, 2014; Singer *et al*., 2016). Antibiotic resistant bacteria might emerge due to selective pressure from use, overuse and misuse of antibiotics in human and veterinary medicine and agriculture, where antibiotics are used to promote growth in livestock and protect plants from plant pathogens (Threlfall *et al*., 2000; Scherer *et al*., 2013; Durso and Cook, 2014; Gelband *et al*., 2015; Singer *et al*., 2016). Fresh produce has therefore already been identified as a potential vehicle for antibiotic resistant pathogens (EFSA, 2008; Falomir *et al*., 2010; Holvoet *et al*., 2013). This is concerning as such pathogens might be more difficult to treat if they exhibit resistances against key antibiotics (EFSA, 2008; Davies and Davies, 2010; WHO, 2015; EFSA, 2016).

On abiotic surfaces, such as processing tables and farming equipment and biotic surfaces, such as plants, microorganisms tend to form so called biofilms (Rayner *et al*., 2004; Patel, *et al*., 2011; Srey *et al*., 2013)**.** These biofilms represent a physical state of resistance towards cleaning and disinfection displayed by bacteria (Costerton *et al*., 1978), and were involved in an estimated 65% of all microbial related diseases (Joo and Otto, 2012). Although fastidious pathogens do not often form biofilms under nutrient limiting environmental conditions, produce contaminated between farm and fork present an opportunity for pathogen attachment and biofilm formation if nutrients become available due to damaged or injured surfaces of fresh produce (Jahid and Ha, 2012). Biofilms present on fresh produce, contact surfaces or equipment within pre- and post-harvest processing, are generally difficult to remove and serve as a potential means of cross-contamination, further highlighting why biofilms represent a serious threat to food safety and quality (Jahid and Ha, 2012; Srey *et al*., 2013).

Conventional fresh produce processing methods are generally assumed to extend the shelf life of food products because they limit the abundance of microorganisms by controlling their growth, while the limited processing of ready-to-eat “minimally processed” fresh produce often renders this more perishable (Rico *et al*., 2007). The pre- and post-harvest practices employed by South African smallholder farmers are mainly traditional methods, passed down from generation to generation (van der Heijden and Vink, 2013; Louw, 2013). Often these methods, although centred on a good farming principle, are not carried out in the most efficient manner (DAFF, 2012), emphasizing that most South African smallholder farmers still do not have enough information pertaining to hygienic production and good agricultural practices such as emphasized by the USFDA (USFDA, 1998), and the FAO (FAO, 2003). It is contamination through inappropriate methods, which can lead to smallholder farmers producing sub-par fresh produce not meeting market standards (Mdluli *et al*., 2013). The inability of smallholder farmers to supply high-value markets due to not meeting prescribed hygiene standards thereby decreases their potential to generate additional income.

As high-value market access is dependent on fresh produce meeting food hygiene and safety standards (Berdegué *et al*., 2005), appropriate pre- and postharvest practices should be implemented and understood by smallholder farmers.

The aim of this study was to assess the pre- and post-harvest hygiene practices of smallholder farmers and to investigate the potential impact on the microbiological quality of “minimally processed” fresh produce and thus market access challenges. This was done by sampling and analysing irrigation water, fresh produce and surfaces involved in the production and processing of fresh produce for the presence of selected hygiene indicator organisms and a potential pathogen. In addition, the antibiotic resistance patterns of *E. coli* isolates from farming samples and their biofilm formation potential were determined. Furthermore, the pre-and post-harvest practices employed and their relative impacts were determined by key informant interviews and semi-formal questionnaires.

4.2) Methods and Materials

Study Site

Data collection tools included key informant interviews with staff of the Marianhill Agri-hub, a local organic farming non-governmental organization (NGO), and questionnaires administered to 80 subsistence farmers all involved with and supplying the Marianhill Agri-hub. The staff interviews were carried out at the headquarter office of the Agri-hub, located at the Marianhill site. The fresh produce supplied by the Marianhill Agri-hub is labelled “organically produced” and not “certified organic” as no organic certification has been obtained by the organization. The Marianhill Agri-hub consists of 4 Agri-hub’s, namely: Hambanathi, uMbumbulu, Marianhill and Cliffbux (situated in Cliffdale), all located in the province of KwaZulu-Natal, South Africa (Figure 4.1). Questionnaires were used to collect information that would provide insight into the attitudes and behaviours of the small-scale farmers selected for the study. This study included both trained and untrained farmers, as well as farmers supplying the NGO and farmers interested in supplying, but yet to supply the NGO. The questionnaires (see General Appendix 1) were prepared in English and were translated into isiZulu, which provided insight into farmers’ pre- and post-harvest hygiene practices.

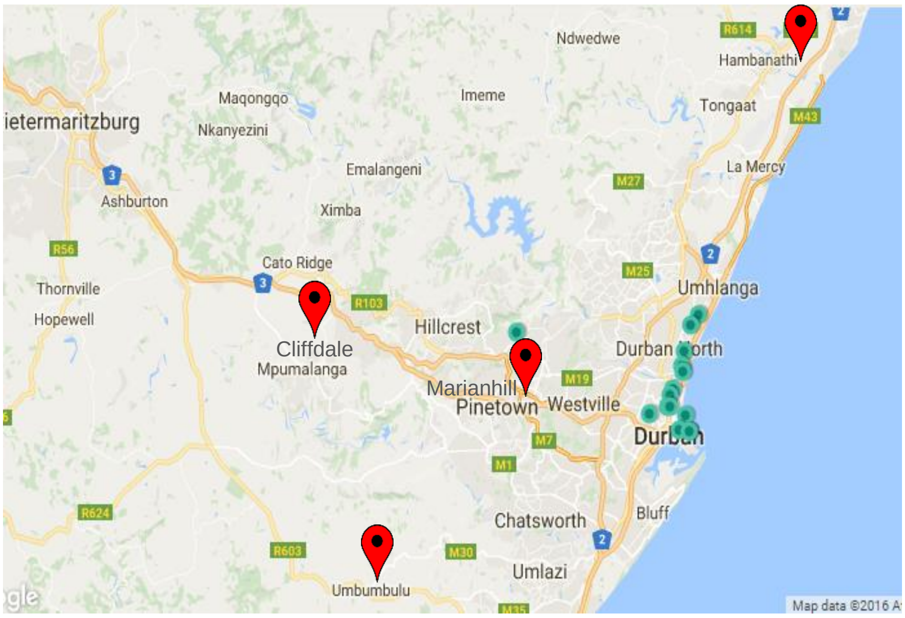


Figure 4.1: Locations of the four Agri-hub facilities in KwaZulu-Natal (Google maps, Accessed 2016, November 9)

Data Analysis

Data was coded, captured and analysed using the IBM SPSS (version 24, 2016) statistical package. Frequency tabulations and mean value calculations for selected pre- and post-harvest practices were carried out to describe samples. The significance of relationships between farmer pre-and post-harvest hygiene practices and selected categorical socio-economic variables were evaluated by the Pearson Chi- Square test. P-values < 0.05 were considered as significant.

Sample Collection for Microbiological Analysis

Vegetable and irrigation water samples were collected and analysed once a month over at least a 3-month period. Irrigation water samples were collected from a Pond (Figure 4.2A) and a rainwater collection device (Figure 4.2B) located in the Mnini District of uMbumbulu. Stream water (Figure 4.2C) was collected from a farmer's yard and river water (Figure 4.2D) was collected from the Mnini communal river, also located in the uMbumbulu area. Municipal tap water was collected from the Marianhill Agri-hub facility (see Chapter 4- Appendix 1).

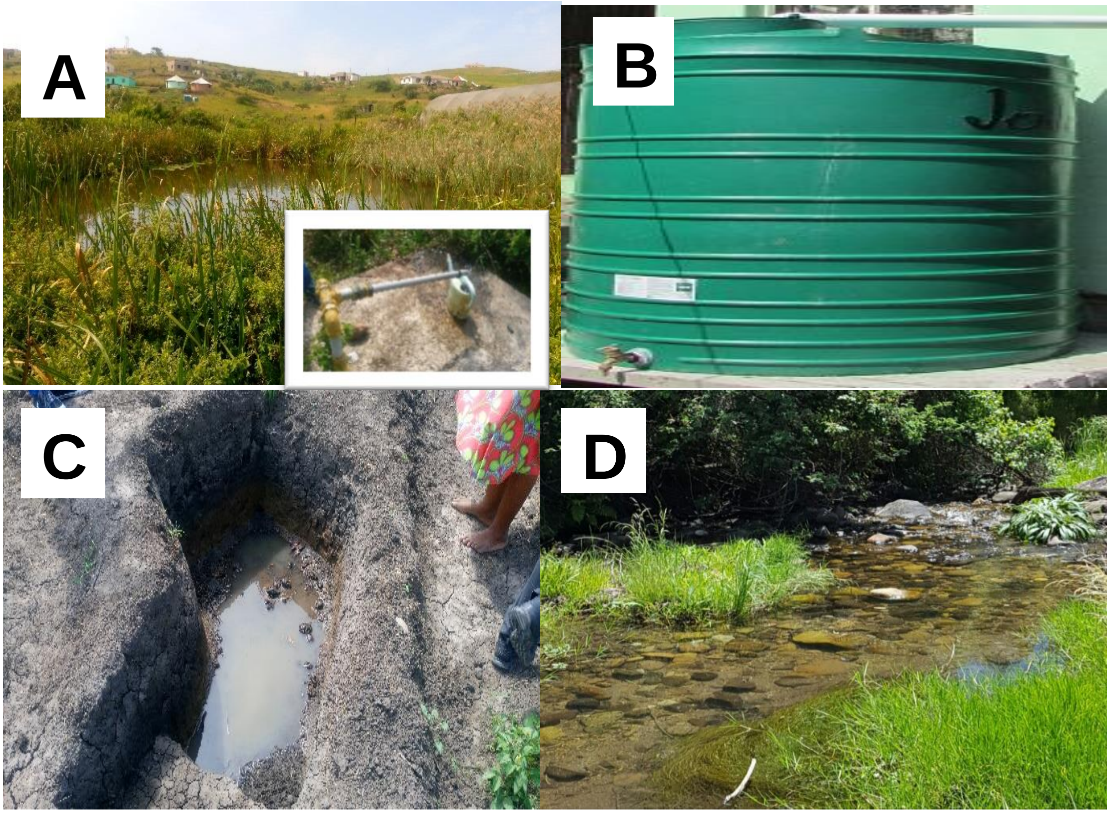


Figure 4.2: Irrigation water sample sites

(4.2A=Mnini Pond (Inset: hand pump); 4.2B=Rain-fed water; 4.2C=Stream water; 4.2D=Mnini River water).

Water sampling

Irrigation water samples were obtained from the above described locations between 8am-12pm, using sterile 500ml Schott bottles. In the case of free flowing irrigation water sources, such as rivers and streams, water samples were collected from areas of fast flow. Generally, water samples were collected at a depth half that of the total, in order to avoid collection of exclusively surface water, as well as debris. Per 100 ml sample volume, 0.1 ml of a $Na_2S_2O_3 \times 5 H_2O$ solution (18 mg/mL) was added to sampling flasks used to collect municipal tap water prior to autoclaving to neutralize free chlorine present in tap water.

Fresh produce sampling

Produce samples of not less than 50g were aseptically collected into sterile stomacher bags (whole carrots and leaves in the cases of lettuce, spinach and parsley), from delivery crates which were stocked with produce sourced from multiple farmers (see Chapter 4- Appendix 2), at the Marianhill Agri-hub facility. Samples were collected from at least three different plants, to ensure a representative sample. Thereafter, samples were transported on ice to the laboratory and analysed within 2 hours.

Microbiological Analysis

Preparation of irrigation water and fresh produce samples

Irrigation water samples were diluted tenfold by aseptically pipetting 1ml of the water sample into 9ml of sterile peptone water (1g peptone and 8.5g NaCl per litre distilled water, pH 7) followed by subsequent decimal dilution (up to 10^{-7}) using the same diluent. Fresh produce samples were prepared for subsequent analyses by aseptically cutting up produce into portions, not exceeding $1cm^2$ for leafy produce samples and transferring 25g samples to Erlenmeyer flasks containing 225ml of sterile peptone water (1g peptone and 8.5g NaCl per litre distilled water, pH 7). Flasks were resealed and gently shaken (50rpm) for 10 minutes at ambient temperature prior to establishing decimal dilutions (up to 10^{-7}) using the same diluent.

Detection and enumeration of total and faecal coliforms and E. coli.

Enumeration of total and faecal coliforms as well as *E. coli* from irrigation water and fresh produce samples was carried out using a well-established MPN procedure (MFHPB-19, Health Canada, 2002). This entailed using an initial presumptive test in Lauryl Sulfate Tryptose broth (LST) (Oxoid) followed by confirmatory testing for total coliforms using Brilliant Green Lactose Bile broth (BGLB) (Merck) and quantifying faecal coliforms through inoculation of gas-positive LST tubes into *E. coli* (EC) broth (Merck) with incubation at 44.5°C. *E. coli* was detected by using gas-positive EC broth tubes to inoculate Levine-Eosin Methylene Blue (L-EMB) agar (Oxoid) and performing the prescribed biochemical confirmation tests (GIMViC). PCR, as described previously (Gemmell and Schmidt, 2012), was used for the additional confirmation of randomly selected biochemically positive *E. coli* isolates. The results are expressed as MPN per 100 ml of river water or MPN per gram of produce sample with 95% confidence intervals based on the MPN tables of de Man (1983).

Detection of Salmonella spp.

Detection of *Salmonella* spp. in irrigation water and fresh produce samples was carried out according to the ISO 6579 (2002) guideline procedure. 25g of sample was transferred to Erlenmeyer flasks containing 225ml sterile buffered peptone water (Merck) for pre-enrichment with incubation at a temperature of 37°C for 24hrs. This was followed by selective enrichment in Tetrathionate broth according to Müller-Kauffmann (Merck) and Rappaport Vassiliadis Soy broth (RVS) (Oxoid), followed by sub-cultivation on Xylose Lysine Desoxycholate (XLD) agar (Merck) and on Brilliant Green agar (BGA) (Merck) according to ISO 6579. The results are expressed as presence/absence of *Salmonella* spp. CFU/ 25 g or 25ml of produce or irrigation water samples, respectively.

Surface Testing (Presence/Absence Test)

Surface testing using sterile transystem culture swabs (Copan) was done of areas of interest (e.g. collection crates, farming equipment, weighing scales, the back of the produce transportation vehicle, and bathrooms) within the processing environment of the Marianhill Agri-hub facility, as well as at on-farm site visits. A 10cm square surface area using a template was sampled using a systematic multi-pass way method, always going from clean to dirty areas, to avoid recontamination (e.g. 10cm side by side vertical strokes, 10cm horizontally and 10 cm diagonally, constantly rotating the swab). Thereafter swabs were used to simultaneously inoculate EMB agar (Oxoid), BGA and XLD agar (Merck) to determine the presence of presumptive *E. coli* and *Salmonella* spp., respectively. Plates were analysed after incubation at 37°C for 24 hours.

Antimicrobial Susceptibility Testing

A total of 155 biochemically confirmed isolates of *E. coli* were subjected to antimicrobial susceptibility testing according to the European Committee on Antimicrobial Susceptibility Testing (EUCAST) Disk Diffusion method (EUCAST, 2015) on Mueller-Hinton Agar (Oxoid) using antibiotic test disks (Oxoid) providing 13 antibacterial agents namely: Ampicillin (10 µg), Amoxycillin-clavulanic acid (20/10 µg (30 µg)), Aztreonam (30 µg), Cefotaxime (5 µg), Ceftazidime (10 µg), Norfloxacin (10 µg), Ciprofloxacin (5 µg) Gentamicin (10 µg), Tobramicin (10 µg), Meropenem (10 µg), Ertapenem (10 µg) Streptomycin (10 µg), and Tigecycline (15 µg).

The *E. coli* isolates were inoculated into nutrient broth and incubated at 37°C for 5-6 h. The broth, if needed, was diluted using sterile 0.85% saline solution to a density of 0.5 McFarland standard turbidity, corresponding to approximately 1-2 x10^8 CFU/mL for *E. coli*. A drigalski spatula was used to spread 100µl of samples evenly over the entire surface of Mueller-Hinton plates. 4-5 antibiotic discs were aseptically placed 30 mm apart and 10 mm away from the edge of the plate within 15 minutes of inoculation. Plates were inverted and incubated aerobically at 35±1 °C for 16 to 20 hours. The zone of growth inhibition was measured using a digital venier caliper to the nearest mm, recorded, and interpreted according to the EUCAST breakpoint tables (Version 6.0) (EUCAST, 2016). Due to no official resistance breakpoints specified for streptomycin by EUCAST, epidemiological cut-off values as described by Scherer *et al*. (2013), were used.

Biofilm Formation Capacity Testing

10 ml cell suspension of nutrient broth (Merck) grown *E.coli* isolates randomly selected from each sample material (20 out of 155) (at 37°C to early exponential phase), were dispensed into 65 mm sterile plastic Petri dishes and incubated for 0, 24, 48, 72 and 96 hours at 25°C. A petri dish that contained only sterile nutrient broth served as negative control. The crystal violet assay to assess biofilm formation capacity was then carried out according to Beukes and Schmidt (2012), with minor modifications as follows. The EtOH solution was collected and the volume adjusted to 5 millilitres and the absorbance measured at 540 nm in 3 ml samples (samples were diluted with 95% EtOH where necessary) using a UV-VIS (UV-Mini 1240) spectrophotometer (Shimadzu, Japan). All samples were analysed in duplicate.

Weight and microscopic analysis of biofilm formation

20ml of nutrient broth (Merck) grown selected *E.coli* overnight culture suspensions were dispensed into 90mm sterile plastic petri dishes. Coupons representing a contact surface (polyvinyl chloride plastic, 10mm X 40mm) were weighed and disinfected with 95% ethanol. Thereafter the dried coupons were aseptically placed into the cell suspension using sterile forceps, followed by incubation for 48 hours at 25°C. After incubation coupons were gently rinsed with 500 µl sterile distilled water. Coupons were left to air dry for 1 hour and then weighed. All coupons were weighed using an ACJ220-4M analytical balance (KERN, Germany). All experiments were carried out in duplicate. The coupons were thereafter subjected to microscopic analysis.

Scanning Electron Microscopy (SEM)

Test coupons (PVC) were mounted onto specimen stubs using carbon tape and thereafter sputter coated using a Quorum Q150R ES sample preparation system (Quorum Technologies, United Kingdom) with gold target prior to examination. Samples were analysed using a Zeiss EVO LS15 Scanning Electron Microscope (Carl Zeiss Microscopy, United States of America). Samples were stored in closed plastic containers until examination to avoid contamination.

4.3) Results and Discussion

This study served to provide insight on the farm to fork hygiene practices adopted by the Marianhill Agri-hub smallholder farmers, and to determine if these practices impact on the quality of fresh produce. Section A (Smallholder farmer hygiene practices and perspectives) reports on the pre-, post-harvest and general hygiene practices and perspectives of the smallholder farmers of the Marianhill Agri-hub, using descriptive statistical analysis. The second section (Section B- Microbiological quality analysis), refers to the microbiological quality analysis, which assesses the fresh produce and irrigation water, as well as pre-, post-harvest and general hygiene practices of the smallholder farmers, using multiple microbiological techniques.

Section A – Smallholder farmer hygiene practices and perspectives

Survey results only include selected practices, which were found to have a statistically significant ($p<0.05$) association with socio-economic factors such as training and education levels, indicating the improvement effect which these factors have and can have on farming practices of smallholder farmers.

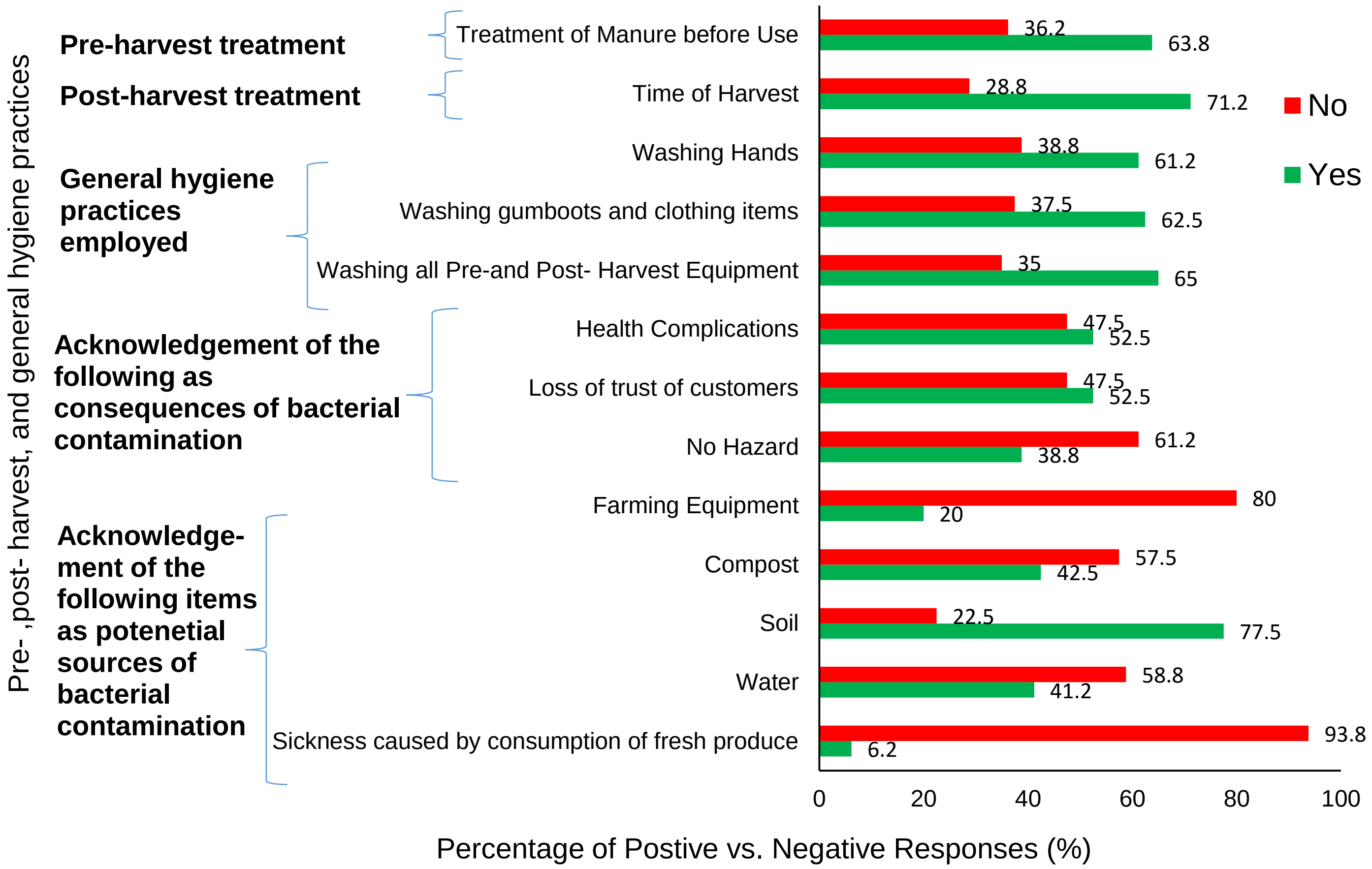


Figure 4.3: Survey responses on pre-, post-harvest and general hygiene practices employed by the smallholder farmers of the Marianhill Agri-hub.

General hygiene practices employed by the smallholder farmers of this study included: washing of hands (61.2%), washing of gumboots and clothing items (62.5%) as well as washing of pre-and post-harvest equipment (65%) either prior to or after conducting farming activities. Thus the majority of farmers (>60%) responded in the positive when asked if they carried out these specific activities. The consequence of bacterial contamination of fresh produce by the smallholder farmers is not often considered and only becomes a concern when hoping to enter regulated high-value markets. However, in this study the majority of farmers recognized consequences such as health complications (52.5%) and loss of trust of customers (52.5%), as potential consequences of bacterial contamination of fresh produce. Acknowledgment of potential sources of bacterial contamination was outlined for the farmers namely, soil, water, compost and farming equipment. Out of the potential contamination sources (e.g. water, compost and farming equipment), only soil was acknowledged by a majority (77.5%) of the smallholder farmers as a potential source of bacterial contamination. Farming equipment was not considered as a potential source of bacterial contamination by 80% of the respondents. This is not surprising as most farmer training appears to focus on improvement yields, but not on the hygiene aspects essential to the production of good quality and hygienically safe fresh produce. In comparison to a study by Mduli *et al*. (2013) wherein most farmers were aware of both water and compost as contamination sources, this study revealed that < 50% of farmers acknowledged water (41.2%) and compost (42.5%) as potential sources of bacterial contamination (Figure 4.3).

Figure 4.4: Types of compost utilized by farmers as fertilizer and percentage of farmers pre-treating manure prior to use.

The term compost as used by the smallholder farmers was used interchangeably and incorrectly with materials such as animal manure, although the latter is not considered compost in a scientific sense. Main compost sources were animal manure (73.8%) followed by self-made compost excluding the use of animal manure (18.8%), with a minority of farmers using store-bought compost (6.3%) (Figure 4.4). Similar to this study, Mdluli *et al*. (2013) found that a number of farmers applied animal manure, both dry and wet, as a source of compost. Multiple studies have identified the use of manure- as opposed to properly generated compost- as one of the main sources of pre-harvest bacterial pathogen contamination (Horby *et al*., 2003; Suslow *et al*., 2003; Islam *et al*., 2005; FDA, 2008; Franz and van Bruggen, 2008). This indicates that although the farmers may understand the need and benefits of using compost in farming, they still do not understand the potential risks involved. Content analysis further revealed that most animal manure used was either of bovine, poultry or goat origin, and only 56% of farmers' pre-treated manure prior to use, often using drying as the main method of pre-treatment. Such faecal matter is established as a potential source of pathogenic bacteria, including shiga-toxin producing *E.coli* (STEC) and *Salmonella* spp. (Venglovsky *et al*., 2009; Falomir *et al*., 2010). These microorganisms have been implicated in numerous foodborne illness outbreaks (Table 4.1).

Section B – Microbiological quality analysis

Hygienic quality of irrigation water sources

Water is an essential resource used daily in tasks such as cooking, cleaning and practicing personal hygiene (WHO, 2011). However, for smallholder farmers it is essential for irrigation when producing fresh produce (FAO, 2008 (b)).

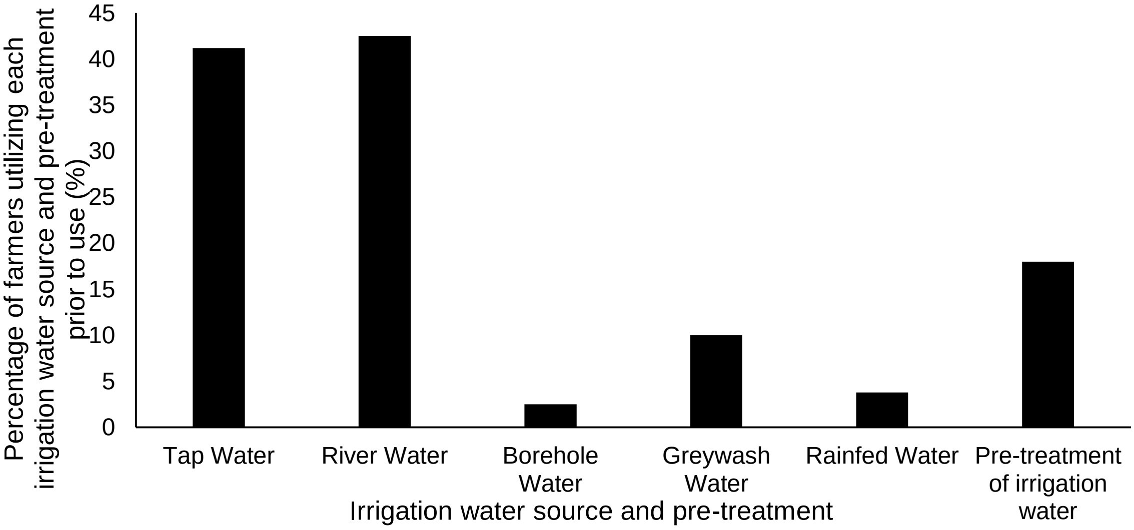


Figure 4.5: Percentage of smallholder farmers utilizing different irrgation water sources and pre-treating irrigation water prior to use.

Questionnaire responses of this study identified five of the most used irrigation water sources to be municipal tap, river, borehole, greywash and rain-fed water (Figure 4.5). In contrast to Mdluli *et al*. (2013), wherein municipal tap water was found to be the primary irrigation water source, river water (42.3%) was the most used irrigation water source. Only 18% of farmers were found to pre-treat irrigation (e.g. boiling of water; addition of bactericidal chemicals such as bleaching agents) water prior to use. The severe drought currently being experienced by a number of the SADC region countries (SADC, 2016) has resulted in 'water-shedding', wherein municipal water supplies are rationed, with water only being freely available for a stipulated time period (Moore, 2016). Discussions with the farmers revealed that although the areas under study had access to municipal water supplies, the water supplies were only functional for a few hours a day due to ‘water-shedding'. As municipal water had to be conserved for the essential needs such as drinking, cooking, and sanitation, river water was therefore used as an alternate for irrigation. A current rising trend is the use of greywash water for irrigation (WHO, 2006). Many studies have reported on the use of greywash water for irrigation and highlighted potential risks (Dixon and Fewkes, 1999; Toze, 2006; Benami *et al*., 2016), similarly the smallholder farmers in this study have also reported using it. Unfortunately, the microbiological quality of greywash water was not analysed due to farmers not having a ready supply when sampling was carried out.

Food production is a sector depending upon high quality water (Wenhold and Faber, 2009; Oberholster and Botha, 2014). The maintenance of safety and quality of food products that are “minimally processed” are reliant on the microbiological quality of irrigation water, irrespective of the source (DWAF, 1996). Therefore river, municipal tap, pond/borehole and rain-fed water, four of the most commonly used irrigation water sources, were subjected to microbiological quality testing. A fifth irrigation water source, a self-constructed stream, was also tested for comparison. The microbial burden was established for irrigation water by targeting selected bacterial hygiene indicators (total and faecal coliforms and *E.coli*) and the presence of a selected pathogen (*Salmonella* spp.).

Analysis of irrigation water sources (excluding tap water) over a three-month period showed total coliforms ranging from 6.8-13000 MPN/100ml while faecal coliform levels for non-tap water irrigation sources ranged from <1.8 -7000 MPN/100ml (Table 4.2). Recommendations from the World Health Organization (2006), stipulate that faecal coliform counts for irrigation water used in the production of “minimally processed” fresh produce should not exceed 1000/100ml. The safety and quality of the irrigation water originating from the stream and river in this study can thus be regarded as unsafe for most of the three-month sampling duration. Gemmell and Schmidt (2013) found similar unsatisfactory water quality results with respect to feacal coliforms when evaluating the quality of the Msunduzi River. However, in contrast Mdluli *et al*. (2013), when evaluating similar irrigation water sources from other locations found that samples met both international and national irrigation water quality recommendations.

Table 4.2: MPN/100ml of total, faecal coliforms, and *E. coli* and presence of *Salmonella* spp. in irrigation water samples from the Marianhill Agri-hub for the months of February, March and April 2016.

*January	February 2016		March 2016		April 2016	
Irrigation Water Sources	MPN/ 100ml	95% confidence interval lower /upper limit	MPN/ 100ml	95% confidence interval lower /upper limit	MPN/ 100ml	95% confidence interval lower /upper limit
Total coliforms						
Mnini Pond water	2700	1000/6600	3300	1000/10000	2600	1000/6600
Mnini Rainwater	49	15/149	33	10/100	6.8	6/34
Stream water	11000	3000/24000	4600	1400/11300	7000	2200/16800
River water	13000	3000/35000	7900	2300/22000	7900	2300/22000
Tap water	< 1.8	-	< 1.8	-	< 1.8	-
Faecal coliforms						
Mnini Pond water	220	70/480	230	70/660	220	70/480
Mnini Rainwater	9.3	3.4/22	< 1.8	-	< 1.8	-
Stream water	4900	1500/14900	2100	0.21/2.20	2300	700/6600
River water	7000	2200/16800	2300	700/6600	700	220/1680
Tap water	< 1.8	-	< 1.8	-	< 1.8	-
E.coli						
Mnini Pond water	220	70/480	230	70/660	93	34/220
Mnini Rainwater	9.3	3.4/22	< 1.8	-	< 1.8	-
Stream water	700	220/1680	110	40/250	110	40/250
River water	1400	600/3400	230	70/660	700	220/1680
Tap water	< 1.8	-	< 1.8	-	< 1.8	-
			Presence in 25ml			
***Salmonella* spp.**	n.d		n.d		n.d	

*n.d - not detected; * Irrigation water was not sampled in January

E.coli levels, with the exception of municipal tap water and Mnini rainwater (March and April), ranged from 9.3-1400 MPN/100ml (Table 4.2). South African standards (DWAF, 1996) recommend that irrigation water applied to “minimally processed” produce should contain ≤ 1 *E.coli*/100ml. Subject to this standard, irrigation water from the Mnini pond, stream and the river for the entire sampling duration was unsatisfactory. The same applies for the rain-fed irrigation water sample for the month of February. The South African guideline appears very strict when compared to alternate water quality standards such as Canadian standards, which recommend that irrigation water used for produce consumed raw should contain <100 *E.coli*/100ml, Mnini pond water in April and again rain-fed water in February would have been of satisfactory quality (CCME, 2003).

Pathogenic organisms contaminating irrigation water, present a definite health hazard due to the possible transferral of these organisms to crops (Steele and Odumeru, 2004). As expected, municipal tap water samples showed no detectable total or faecal coliforms and no *E.coli*, similar to a previous study conducted by Mdluli *et al*. (2013). The highest levels of total coliforms, faecal coliforms as well as *E.coli*, were found in stream and river water. As the microbiological quality of the final fresh produce product may be dependent on the quality of the irrigation water used, the significance of irrigation water quality for the safety of “minimally processed” fresh produce is evident (DWAF, 1996).

However, *Salmonella* spp. was not detected in irrigation water samples, indicating that this potential pathogen was not a contaminating agent at the time of sampling. This is in contrast to other studies which have found that *Salmonella* spp. present in irrigation water served to contaminate irrigated fresh produce (Islam *et al*., 2004; Lapidot and Yaron, 2009).

Hygienic quality of fresh produce

The hygienic quality of any food commodity relates directly to food safety and therefore affects market access (Louw *et al*., 2006). The microbial burden present on “minimally processed” fresh produce, generated by resource-limited smallholder farmers may therefore present a potential risk for consumer health and market access (Mdluli *et al*., 2013). Production of fresh produce in a natural environment is be expected to be burdened with naturally occurring microorganisms (Sagoo *et al*., 2003). In addition, the processing within post-harvest practices, of fresh products is a potential source of contamination, which could further increase the microbial load (Abadias *et al*., 2008; Jung *et al*., 2014). According to South African guidelines set forth by the Department of Health (DoH, 2002), raw fruit and vegetables should not contain total coliforms exceeding 200/g. Microbiological analysis of fresh produce samples (Table 4.3) collected over a four-month period showed a range of 130-79000 MPN/g of total coliforms, thus mostly exceeding the recommendation. As both carrots, being subterranean crops, as well as topsoil crops such as leafy vegetables have contact with soil, irrigation water, fertilizers and manure (Abadias *et al*., 2008), it is not unusual for these crops to show high overall microbial burdens. A number of studies on the microbial burden of “minimally processed” fresh produce found that leafy vegetables had higher overall microbial loads than non-leafy vegetables (Nguyen and Carlin, 1994; Abadias *et al*., 2008). Similarly, the FAO (2008 (a)) identified leafy vegetables being of highest concern with regard to microbial contamination and subsequent cause of foodborne illness. The results obtained (Table 4.3) indicate that on some occasions the leafy vegetables lettuce, parsley, and spinach displayed a lower number of total coliforms than carrots.

Faecal coliform levels ranged between 22 and 1400 MPN/g and a range of 2.2-49 MPN/g was established for *E.coli* (Table 4.3). South African guidelines (DoH, 2002) stipulate that no *E. coli* should be present in 1 g of fresh product intended for consumption, thereby indicating that the fresh produce sampled in this study did not meet these standards. International guidelines, however, accept up to 100 *E.coli* per 1g of fresh produce, indicating that the fresh produce analysed did meet these standards and can be regarded as safe for consumption (European Commission, 2007; DGHM, 2012). The presence of *E.coli* on irrigated fresh produce is not surprising, as similar studies have also found *E.coli* present on fresh produce such as lettuce and parsley (Falomir *et al*., 2010; Holvoet *et al*., 2013). In contrast, Mdluli *et al*. (2013) did not isolate any *E.coli* from lettuce or parsley in a similar study. However, the presence of *E.coli* might indicate the presence of pathogenic *E.coli* strains, relating to foodborne illnesses, such as *E.coli* O157:H7, which would be concerning.

Salmonella spp. was not detected in any of the fresh produce samples tested, indicating that they met national and international quality standards (DoH, 2002; European Commission, 2007) requiring that *Salmonella* spp. is absent in 25g of fresh ready-to-eat-products.

Table 4.3: MPN per g of total, faecal coliforms and *E. coli* and presence of *Salmonella* spp. on the surface of carrot, lettuce, spinach and parsley from the Marianhill Agri-hub for the months January- April 2016.

Fresh Produce	January		February		March		April	
	MPN/g	95% confidence interval lower /upper limit	MPN/g	95% confidence interval lower /upper limit	MPN/g	95% confidence interval lower /upper limit	MPN/g	95% confidence interval lower /upper limit
Total coliforms								
Carrot	79000	230000/22000	220	70/440	1700	600/3900	1700	600/3900
Lettuce	270	100/660	1700	600/3900	240	70/700	240	70/700
Spinach	1100	300/2400	230	70/660	*	N/A	4900	1500/14900
Parsley	*	N/A	1400	600/3400	130	30/350	220	70/440
Faecal coliforms								
Carrot	1400	600/3400	170	60/390	110	30/240	130	30/350
Lettuce	270	100/660	7.9	2.3/22	11	3/24	130	30/350
Spinach	110	30/240	79	23/220	*	N/A	22	7/48
Parsley	*	N/A	45	8/140	130	30/350	140	60/340
E.coli								
Carrot	33	10/100	49	15/149	14	6/34	21	7/41
Lettuce	49	15/149	7.9	2.3/22	3.3	1/10	2.2	0.7/4.8
Spinach	33	10/100	4.9	1.5/149	*	N/A	4.5	0.8/14
Parsley	*	N/A	4.5	0.8/14	4.9	1.5/14.9	3.3	1/10
***Salmonella* spp.**	Not detected in any fresh produce sample over the four month sampling period							

* Sample not obtained due to damage as a result of weather conditions.

Presence/absence testing

As produce contamination can take place via contact surfaces (Wiederoder *et al*., 2012), the presence of hygiene indicator organisms and pathogens on such contact surfaces highlights areas wherein pre- and post-harvest contamination can occur.

Table 4.4: Presence/Absence of *Salmonella* spp. and *E.coli* on selected contact surfaces within the fresh produce processing line of Marianhill Agri-hub assessed over a four month period.

Surface Tested	**January 2016**		**February 2016**		**March 2016**		**April 2016**	
	Salmonella spp.	*E.coli*	*Salmonella* spp.	*E.coli*	*Salmonella* spp.	*E.coli*	*Salmonella* spp.	*E.coli*
Bakkie bin	X	✓	X	X	X	✓	X	X
Plastic Collection Crate	X	X	X	X	X	X	X	X
Metal Scale	X	✓	X	X	X	X	X	X
Steel Pitch Fork	X	X	X	X	X	✓	X	X
Steel Spade	X	✓	X	X	X	X	X	✓
Steel Garden Hoe	X	X	X	X	X	✓	X	X
Staff Bathroom Basin	X	X	X	✓	X	X	X	X
Staff Kitchen Counter	X	X	X	X	X	X	X	X

X= absence; ✓= presence detected

While *Salmonella* spp. was absent from all surfaces tested, *E.coli* was detected on some surfaces on all sampling occasions. The most common surfaces upon which the presence of *E.coli* was detected was farming equipment (Steel Pitch Fork, Steel Spade, and Steel Garden Hoe) and the transportation bakkie bin. The presence of

E.coli is not uncommon on these surfaces, as they are in contact with soil, manure, and organic fertilizers, all of which serve as potential reservoirs of *E.coli* (Franz and van Bruggen, 2008; FDA, 2008). The presence of *E.coli* on these surfaces indicates that contact surfaces within the fresh produce processing line can contribute to contamination of fresh produce (Buck *et al*., 2003).

Antibiotic resistance

Developed and developing countries have recognized antimicrobial resistance in the food chain as an emerging global problem (Threfall *et al*., 2000; Schwaiger *et al*., 2011; Thanner *et al*., 2016). Diverse antimicrobial agents such as antibiotics, sanitizers, and food preservatives are used in food production and processing, aiming to enhance the quality and safety of these products (Davidson and Harrison, 2002). However, usage of these antimicrobial agents at various stages of food production processes may cause selective pressure, thereby promoting resistance within microorganisms (IFT, 2006).

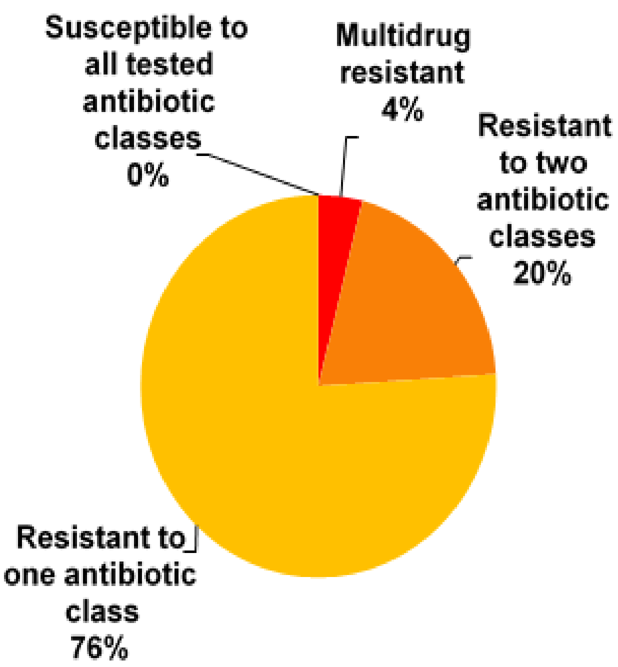


Figure 4.6: Antibiotic resistance distribution in *E.coli* isolated from irrigation water samples (n=25)

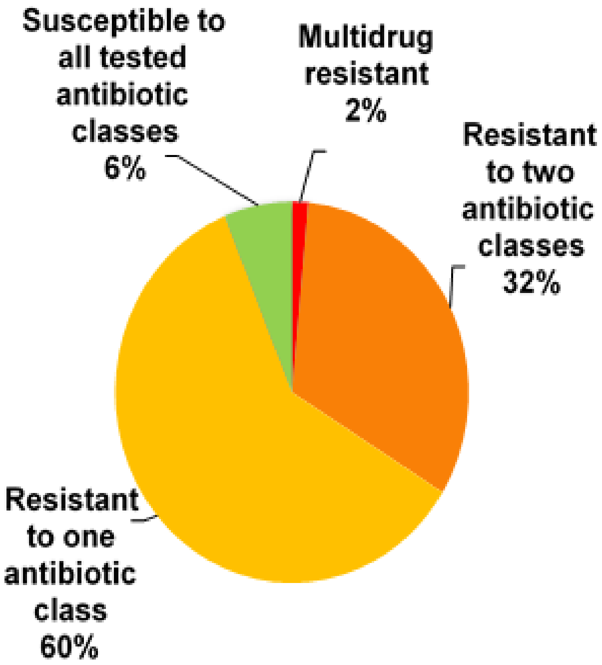


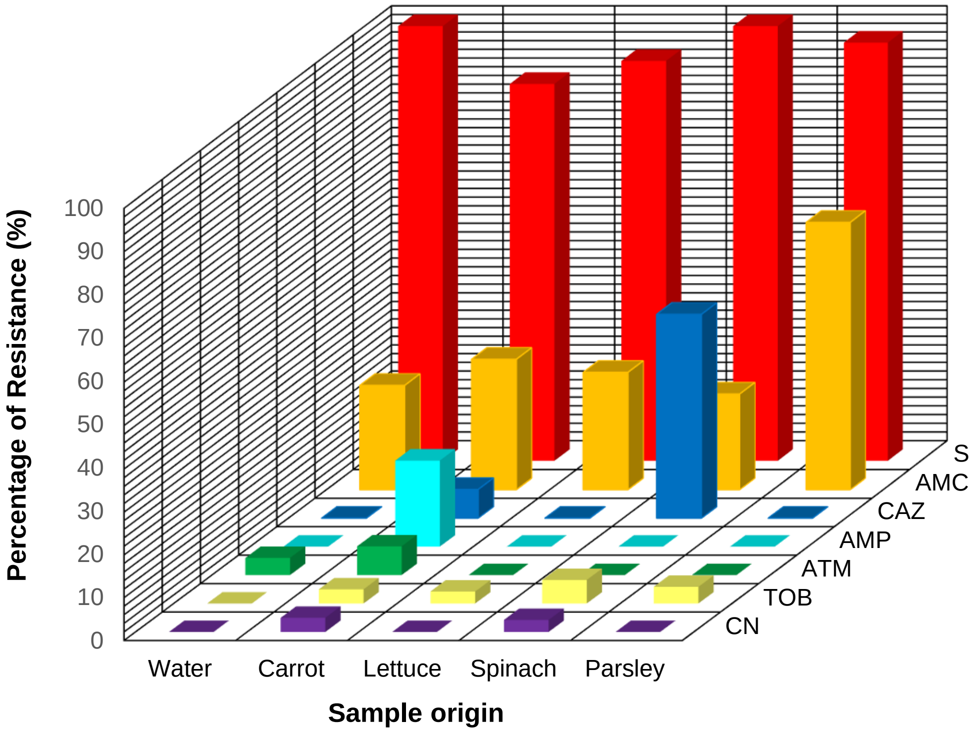
Figure 4.7: Antibiotic resistance distribution in *E.coli* isolated from fresh produce samples (n=130)

In the present study, *E.coli* was isolated from both irrigation water and fresh produce samples (lettuce, spinach, parsley and carrots). The assessment of *E.coli* isolates showed that consistent with other studies of similar nature (Schwaiger *et al*., 2011; Holvoet *et al*., 2013), antibiotic resistant *E.coli* were present on different vegetable types as well as in irrigation water sources. Antibiotic resistance profiles of *E.coli* isolated from irrigation water samples (Figure 4.6) showed that not a single *E.coli* isolate from irrigation water was susceptible to all 13 tested antibiotics. Antibiotic resistance to at least one class of antibiotics was displayed by 76% of isolates, whereas 20% of isolates were found to be resistant to 2 antibiotic classes and 4% isolates displayed multidrug resistance (Figure 4.6). Six percent of *E.coli* originating from fresh produce (Figure 4.7) were susceptible to all antibiotic classes, followed by 60% and 32% of isolates displaying resistance to one and two antibiotic classes, respectively. Only 2% of isolates originating from fresh produce displayed multidrug resistance.

The different types of produce sampled, the different bacterial species targeted and the variation in antimicrobials chosen for testing, render direct comparisons of studies difficult (Schwaiger *et al*., 2011; Marti *et al*., 2013). However, in correlation with other studies of antimicrobial resistance in bacterial isolates from fresh produce, the highest antimicrobial resistance rates for *E.coli* isolated from fresh produce were observed for the antibiotics streptomycin (S) (Schwaiger *et al*., 2011) and amoxycillin-clavulanic acid (AMC) (Marti *et al*., 2013). There was, however, very low rates of resistance to ampicillin (AMP) in contrast to similar studies analysing *E.coli* (Holvoet *et al*., 2013) as well as other bacterial species from fresh produce (Vishwanathan and Kaur, 2001; Boehme *et al.*, 2004; Benzanson *et al*., 2008). In agreement with similar studies, no resistance to antibiotic classes fluoroquinolones (ciprofloxacin (Osterblad *et al*., 1999; Schwaiger *et al*., 2011; Holevoet *et al*., 2013), and norfloxacin), cephaolosporins (cefotaxime (Holvoet *et al*., 2013)), carbapenems (ertapenem, and meropenem) and the glycylcyclines (tigecycline) was observed (see Chapter 4- Appendix 3).

According to EFSA (2016), the *E.coli* isolates obtained from irrigation water and fresh produce (Figure 4.8) of this study displayed “extremely high” (>70%) and “high levels” (>20%-50%) of resistance to streptomycin and amoxycillin-clavulanic acid, respectively. Furthermore, *E.coli* isolates originating from parsley displayed “very high”

(>50%-70%) levels of resistance for amoxycillin-clavulanic acid and *E.coli* from spinach displayed “high” levels of resistance to ceftazidime.



<u>Figure 4.8: Percentage of resistant *E.coli* isolates from different sample origins to 7 representative antibiotics for which resistance was observed.</u>

(CN=gentamicin; TOB=tobramicin; ATM=aztreonam; AMP=ampicillin; CAZ=ceftazidime; AMC=amoxicillin-clavulanic acid; S=streptomycin).

The majority of the analysed *E.coli* isolates displayed a similar overall resistance pattern, with more resistances detected for streptomycin than for any of the other 7 tested antibiotics (Figure 4.8). The similarity between resistance profiles for streptomycin and amoxycillin-clavulanic acid, for water and produce isolates (excluding parsley) might indicate water as a source for these particular resistances. During sampling of irrigation water from the selected river, cattle manure was found all along the river bedside and communication with the farmers revealed that they often allow their cattle to graze in the vicinity of the river. Animal excreta is a known contaminant, introducing antibiotic-resistant bacteria into the environment (Scherer *et al*., 2013; Udikovic-Kolic *et al*., 2014; Wichmann *et al*., 2014). The faecal matter of the grazing cattle may in this case have been the source of antibiotic resistant *E.coli* as

Holvoet *et al*. (2013) postulated, similarly, that cattle faecal matter may serve as a potential reservoir of antibiotic-resistant bacteria.

The presence of antibiotic resistant *E.coli* isolates on fresh produce highlights their role as vehicles for antibiotic resistance transmission (Holvoet *et al*., 2013; Marti *et al*., 2013). The uptake of antibiotics by plants will select for antibiotic resistant microorganisms in and on plants (Boehme *et al*., 2004; Falomir *et al*., 2010), and studies reporting the uptake of antibiotics from water and soil by plants highlight that pre- and post-harvest practices (i.e. use of antibiotic contaminated irrigation water or manure) have the potential to promote the presence of antibiotic-resistant microorganisms in or on fresh produce (Kang *et al*., 2013; Azanu *et al*., 2016). Although the potential risk and implications for plant consumers (e.g. livestock and humans) due to exposure to elevated concentrations of antibiotics is not documented, it is considered as a food safety concern (Marti *et al*., 2013; Singer *et al*., 2016).

Biofilm formation capacity

Bacterial pathogens surviving in manure, irrigation water and soil, have the potential to attach to and colonize plant surfaces (Annous *et al*., 2005). Biofilm formation on plant surfaces is an additional food safety and hygiene risk, by facilitating survival and proliferation of these microorganisms (Seo and Frank, 1999; Rayner *et al*., 2004). To assess this, randomly selected *E.coli* isolates from fresh produce were chosen to determine their biofilm formation capability (see Chapter 4- Appendix 4).

Out of the twenty isolates tested, isolates C6 (S^R, AMC^R; AMP^R; CAZ^R; TOB^R; with an upper R denoting antibiotic resistance), L34 (S^R; AMC^R; TOB^R), and S7 (S^R; AMC^R; TOB^R; CN^R) originally obtained from carrot, lettuce and spinach, displayed the greatest biofilm formation capability based on the crystal violet biofilm assay (see Chapter 4 - Appendix 4). Scanning Electron Microscopy (SEM) (Figure 4.9) showed that *E.coli* biofilms formed on PVC coupons used to mimic contact surfaces showed characteristic layered growth when optimal growth conditions were simulated. The biofilm capabilities displayed by these *E.coli* isolates emphasize their potential as risks in food production and processing environments, where they can increase subsequent cross-contamination, as well as on fresh produce, where increased disease transmission may be facilitated (Chmielewski and Frank, 2003).

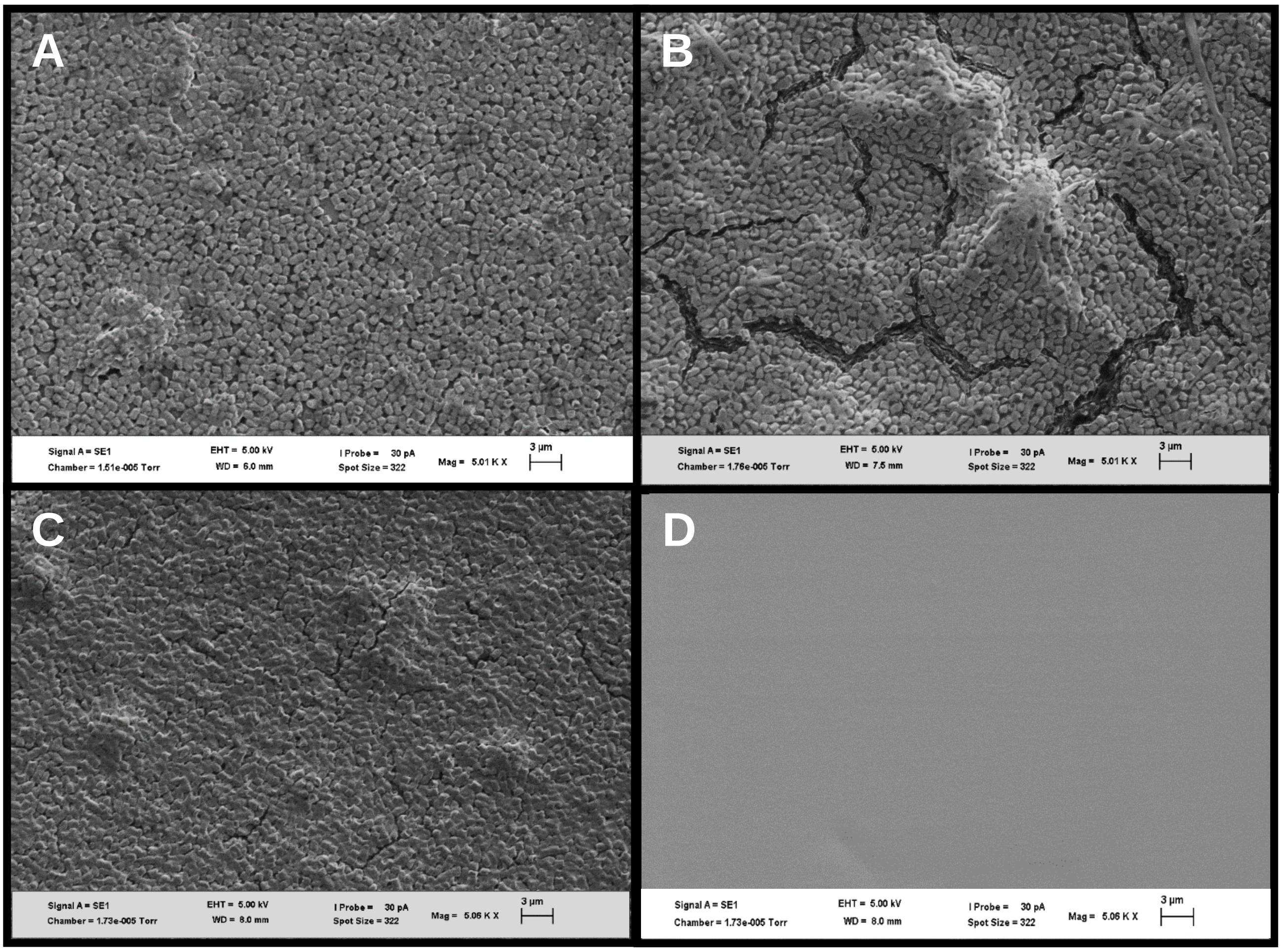


Figure 4.9: SEM analysis of *E.coli* biofilm formation after 48 hours on PVC coupons.

(A = *E.coli* carrot isolate 6; B = *E.coli* lettuce isolate 34; C = *E.coli* spinach isolate 7; D= control)

Coincidently, the *E.coli* isolates displaying greater biofilm formation capacities also displayed greater resistances to the tested antibiotics. Zhang *et al*. (2013) found similar positive correlations between bacterial isolates displaying antibiotic resistances and their biofilm formation capabilities. In contrast Perez *et al*. (2015) found no significant differences in biofilm formation capability between antibiotic resistant and non-antibiotic resistant *Acinetobacter baumanni* isolates. The relationship between biofilm formation capabilities and antibiotic resistance of bacterial isolates is of increasing interest to researchers, especially with respect to the potentially negative implications on health (Qi *et al*., 2016). The biofilm formation capabilities of antibiotic resistant isolates are concerning due to their presence and resilience in food production and processing environments.

4.4) Conclusion

In light of the increased incidence of foodborne disease outbreaks due to contaminated fresh produce, the minimum hygiene and food safety standards demanded by high-value markets have to be adhered to by prospective suppliers (Berdegué *et al*., 2005). This study provides data on the microbiological quality of fresh produce sampled from smallholder farmers from KwaZulu-Natal, South Africa, intent on accessing high-value markets. The microbiological quality of fresh produce samples was frequently found to be unsatisfactory in accordance with South African standards (DoH, 2002) for safe consumption. This could potentially limit market access unless the hygienic quality of the fresh produce were to be improved. Presence of antibiotic resistant and biofilm forming *E.coli* on contact surfaces within the processing line, highlighted the possibility of transferal of spoilage and pathogenic microorganisms to fresh produce. The presence of antibiotic resistance within *E.coli* isolates from irrigation water and fresh produce samples highlights their potential as reservoirs for such resistances within the food chain. Pre- and post-harvest practices such as direct application of animal manure in place of matured compost and use of unsatisfactory quality irrigation water are risky practices that should be avoided. Although the general hygiene practices of smallholder farmers were acceptable, their knowledge of potential contamination sources and resulting consequences was limited. Training initiatives should therefore be focused on improvement of pre-and post-harvest practices as well as general hygiene knowledge throughout the processing chain. This would promote growth and production of high quality fresh produce, which meets market standards thereby enabling high-value market access.

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Chapter 4 -Appendix 1:

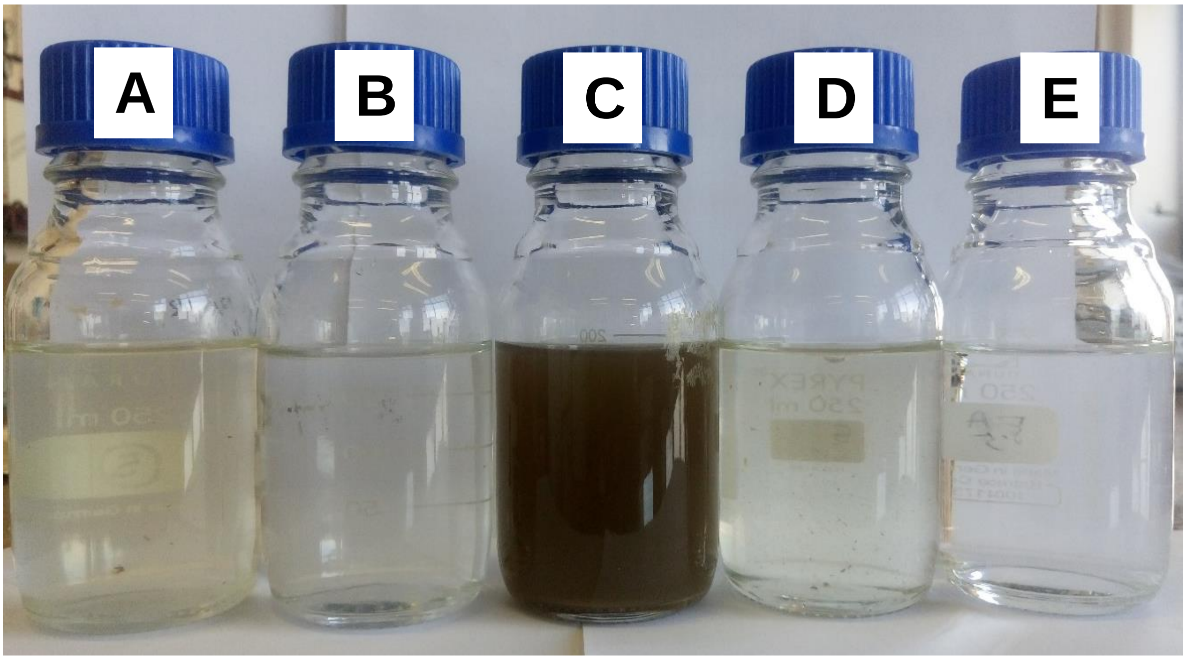

Figure 4.10: Appearance of irrigation water samples after collection

(4.10A=Mnini Pond water; 4.10B= Mnini Rain-fed water; 4.10C=Stream water; 4.10D=River water; 4.10E= Municipal tap water)

Chapter 4- Appendix 2:

Figure 4.11: Pooled fresh produce supplied by the farmers of the Marianhil Agri-hub in collection crates from which fresh produce samples were obtained.

Chapter 4- Appendix 3:

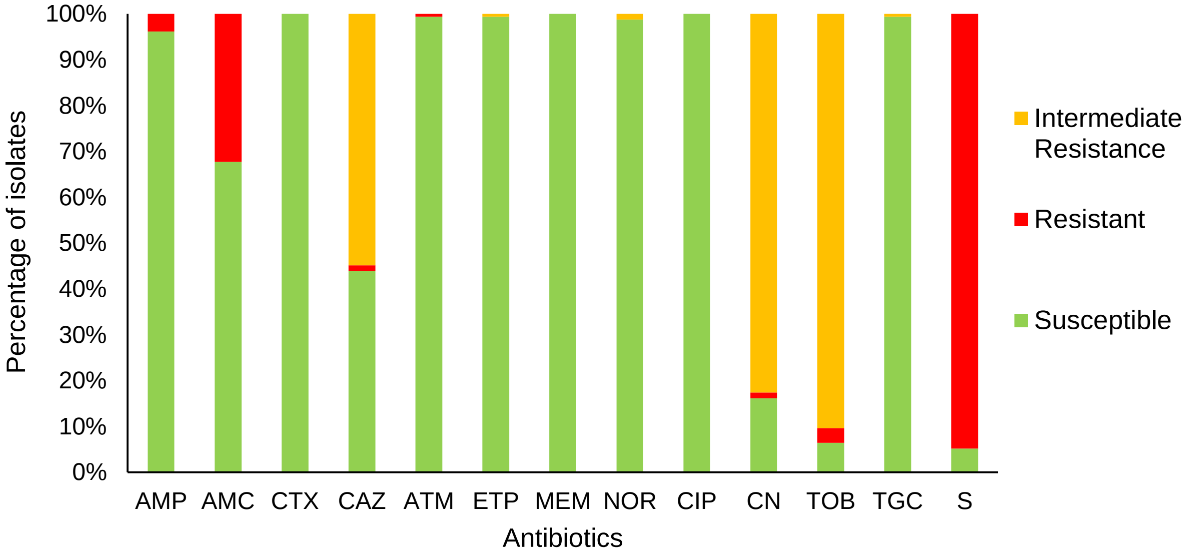

Figure 4.17:Antibiotic resistant profiles of *E.coli* isolated from fresh produce and water samples n=155

(AMP=ampicillin; AMC=amoxycillin clavulanic-acid; CTX=cefotaxime; CAZ=ceftazidime; ATM-aztreonam; ETP=ertapenem; MEM=meropenem; NOR=norfloxacin; CIP=ciprofloxacin; CN-Gentamicin; TOB=tobramicin; TGC=tigecycline; S=streptomycin).

Chapter 4 - Appendix 4:

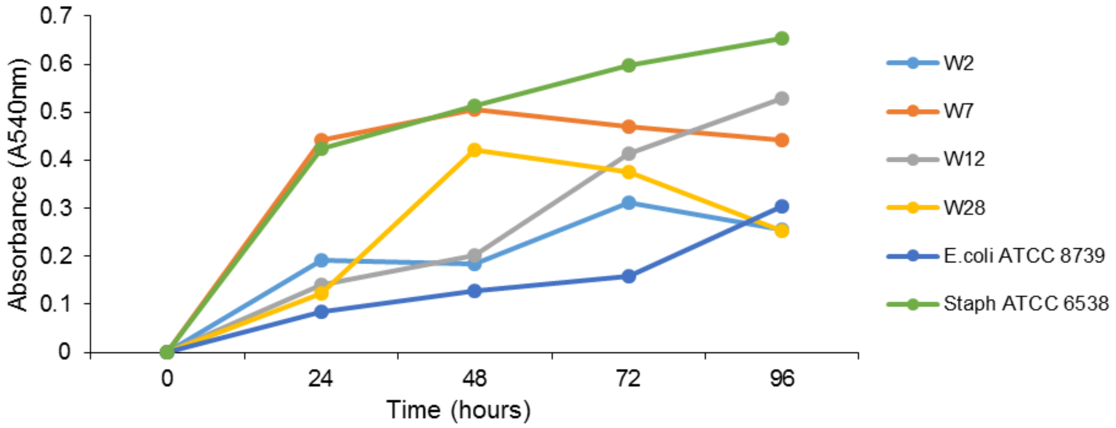

Figure 4.12: Biofilm formation of *E.coli* isolates from irrigation water samples over a 96 hours

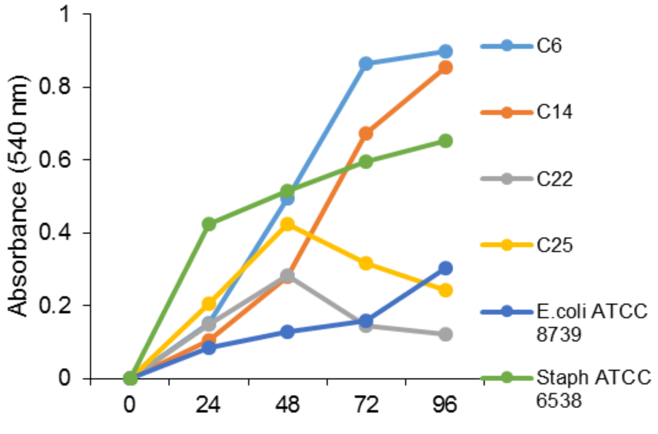

Figure 4.13: Biofilm formation of *E.coli* isolates from carrots over 96 hours

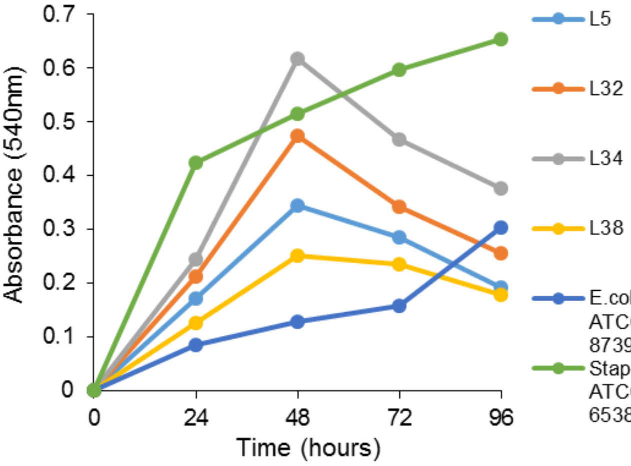

Figure 4.14: Biofilm formation of *E.coli* isolates from lettuce over 96 hours

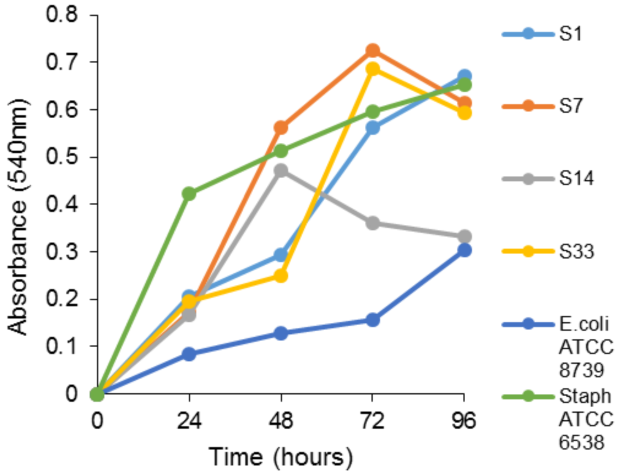

Figure 4.15: Biofilm formation of *E.coli* isolates from spinach, over 96 hours

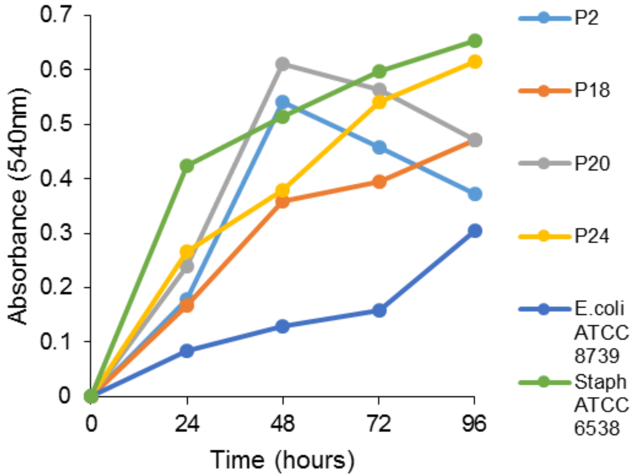

Figure 4.16: Biofilm formation of *E.coli* isolates from parsley over 96 hours

CHAPTER 5

Overview and Conclusions

5.1) Overview

Smallholder agriculture is a key livelihood activity for most rural households in South Africa as well as in many other parts of the developing world (Stewart *et al*., 2015). Despite their large contributions towards household food production, smallholder agriculture in South Africa is currently unable to fully access the potential of income generation from farming due to limited market access (Mduli *et al*., 2014). Successful entry of and integration into (intended) high-value markets, is hampered by numerous constraints and barriers experienced by these resource-limited smallholder farmers (van der Heijden and Vink, 2013).

This study aimed to assess the effects of socio-economic characteristics of smallholder farmers on their farming pre-and post-harvest practices. The potential contribution to microbial contamination from these practices, which in turn affects market access, health and household food security, was also investigated. A transdisciplinary mixed method approach integrating quantitative and qualitative methods was used to address this challenge.

The initial phase of this study included determination of the socio-economic characteristics of the sampled smallholder farmer community, and the pre-and post-harvest practices employed in the production of fresh produce. The links between socio-economic characteristics and smallholder farmer pre-and post-harvest practices were established to discover relative influences. In the second phase of the study, an evaluation of the microbial quality of irrigation water sources and selected fresh produce samples was carried out. Surface swabbing provided insight on potential contamination sources during production and processing. Lastly, antibiotic resistance profiles and biofilm formation capabilities of *E. coli* isolates originating from different sources were determined, to highlight potential risks associated with contaminated minimally processed fresh produce.

5.2) Conclusions and recommendations

Socio-economic factors and attitudes of the Marianhill Agri-hub smallholder farmers, which influence pre-and post-harvest hygiene practices have been outlined and discussed in chapter 3, showing that socio-economic characteristics can impact farming practices employed. Education levels of farmers and their exposure to prior training were the main socio-economic characteristics, which had significant relationships with selected pre- and post-harvest hygiene practices. Employing good pre-and post- harvest practices is important as these practices are determinants of produce quality and thus entry into high-value markets. Furthermore, farmers in this study did not display a good understanding of critical areas of contamination in the production system, and were often unable to recognize potential sources of microbial contamination. Careful assessment of smallholder farmer communities, in order to derive context specific recommendations for improvement of farmer pre-and post-harvest hygiene practices to facilitate market access, is therefore highlighted.

The microbiological quality of the sampled irrigation water sources was analysed for three months, showing that both stream and river irrigation water sources continuously had faecal coliform levels that exceeded DWAF and WHO recommendations for irrigation water intended for the use in production of fresh produce to be consumed raw (DWAF, 1996; WHO, 2006). Fresh produce quality was found to be unsatisfactory according to national guidelines (DoH, 2002), with mostly all produce over the sampling period displaying the presence of *E. coli*. As the microbial quality of both irrigation water and fresh produce were found to be mostly unacceptable, such fresh produce might negatively affect consumer health and market access. Furthermore, *E. coli* isolated from both irrigation water and fresh produce samples were found to display antibiotic resistance and biofilm formation capabilities, which in turn highlight potential for antibiotic resistance transmission and cross-contamination due to biofilms. Presence of bacterial contamination on surfaces involved within pre-and post-harvest processing highlight the potential for storage containers and the like to serve as additional sources of contamination.

Therefore, socio-economic characteristics of smallholder farmers may influence pre- and post-harvest practices. These can contribute to microbial contamination affecting the quality of fresh produce, thereby limiting market access into high-value markets. The results emphasise that all entry and exit points of the farm to fork continuum are critical in terms of potentially introducing microbial contamination.

Ignoring the links between smallholder farmer socio-economic characteristics and farmer practices can undermine agricultural productivity and market access oriented initiatives and thus livelihoods and food security of concerned households. Recommendations derived from this study include the need of extension service departments sensitizing farmers on the importance of employing hygienic pre- and post-harvest practices when producing minimally processed fresh produce. The potential of cross-contamination arising from contaminated surfaces during pre-and post-harvest practices, should be emphasized to increase awareness of smallholder farmers (e.g. rain water to be used for irrigation can become contaminated as a result of microbial contamination persisting on/in storage containers). Continuous advisory on the necessity and importance of good hygiene practices during all stages of fresh produce production should always be emphasized to minimize risk of contamination. Farmer training advocated by policy and practice should enable meeting the quality standards required by high-value produce markets. While education and training are crucial for the improvement of fresh produce quality and safety, alternate market access requirements such as meeting procurement volumes and safe guarding stability of produce supply should also be addressed.

5.3) Policy implications

Heightened attention on the benefits of healthy and nutritional lifestyles, as well as increased reports of fresh produce related foodborne illness outbreaks, have led to consumers and retail markets simultaneously increasing their demand for fresh produce and being more critical about the hygienic quality and safety of fresh produce (De Roever, 1998, Rico *et al*., 2007; Berger *et al*., 2010). South African smallholder farmers producing fresh produce have the potential to contribute to health and household food security as well as to the South African economy (Mdluli *et al*., 2013; van der Heijden and Vink, 2013). The fundamental role of government, private partnerships and the non-governmental sector in supporting smallholder farmers should therefore consider the following:

- Education, awareness and skills on the production and processing of good quality and hygienically safe fresh produce, with special emphasis on pre- and post-harvest practices.
- Provision of extension services which articulate and extend information on current market access standards and market entry related information,

facilitated by the National Department of Agriculture, Forestry and Fisheries (DAFF) to provincial and municipal sectors involved in smallholder farmer support.

- Development and/or adaptations of “farm to fork” guidelines for market access standards, especially for “organically produced” minimally processed fresh produce.

5.4) Further research

Smallholder farming, with its positive connotations for health and household food security, displays great potential for contributing to poverty alleviation. However, research focusing on farmer socio-economic characteristics and its influences on hygiene and quality aspects of production and processing, which are determinants of market access, is limited. Studies documenting the impacts of socio-economic characteristics of farmer populations in relation to their farming methodologies are required, to bridge information gaps and aim to inform policy on how to structure training initiatives appropriately.

Farmer training is often delivered in the form of workshops. These workshops typically run in the way that concepts are theoretically discussed and presented. However, as literature in many South African contexts have revealed, most smallholder farmers are not often well educated (Fawole and Fasina, 2005; Dearlove, 2007; Babalola, *et al*., 2010; Mnkeni *et al*., 2010). The use of written guideline manuals and theoretical presentations may therefore not be the most effective training method, and alternatives such as practical training through the use of models and active participation should be considered. Further research may therefore also include studies on the evaluation of effectiveness of training methodologies.

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General Appendices

General Appendix 1: Research Questionnaire

Questionnaire (in English)

Section A: Demographics and General Information

1.1) Gender

Gender	Mark with an X
a) Male	
b) Female	

1.2) Age

Age	Mark with an X
a) <20	
b) 21-39	
c) >40	

1.3) Highest Level of education completed

Level of Education completed	Mark with an X
a) <Grade 7	
b) Grade 8-12	
c) >Grade 12	
d) No formal education	

1.4) Sources of income

Income Source	Mark with an X
a) Remittance	
b) Social Grant	
c) Pension	
d) Farming	
e) Job wages/ salary	
f) Other	

1.5) If farming is practiced, which markets are supplied practiced

Type of market	Mark with an X
a) Street hawkers	
b) Fresh produce markets	
c) Retail stores	

1.6) Type of farming

Type of farming	Mark with an X
a) Conventional	
b) Organic	

1.7) Potential interest in farming, with the aim of earning an income from sale of products

Interest Scale	Mark with an X
a) Not interested	
b) Interested only if there's no alternate	
c) Interested for additional income purposes	
d) Very interested, sole source of income	

Section B: Pre-and post-harvest methods employed

Pre-harvest Practices

2.1) What vegetables do you plant?

Vegetable	Mark with an X if applicable	Vegetable	Mark with an X if applicable
a) Carrot		f) Beetroot	
b) Green beans		g) Onion	
c) Potato		h) Lettuce	
d) Spinach		i) Cabbage	
e) Tomato		j) Swiss chard	

2.2) What are your reasons for growing these specific vegetables?

2.3) Which vegetables (top 5) generally generate the highest income?

1____________________________ 2____________________________

3____________________________ 4____________________________

5____________________________

2.4) What is the approximate size of your farm or the land that is cultivated (ha)?

2.5) What type of fertilizer is used?

Type of fertilizer	Mark with an X
a) Store bought fertilizer	
b) Animal manure	
c) Self-made compost (excluding animal manure)	
d) No fertilizer	

2.6) What is the source of your irrigation water?

Source of Irrigation water	Mark with an X
a) Tap water	
b) River	
c) Borehole	
d) Greywash (water that has been previously used e.g. water from washing clothes or dishes etc.	

2.7) Name the equipment used in pre-harvest practices?

2.8) What is the nature of the per-harvest equipment used?

Nature of equipment	Mark with an X
a) Metal	
b) Plastic	
c) Other	

2.9) If pesticides are used, what type or brand is used?

Collection

2.10) What tools are used for harvesting?

2.11) What is the nature of the pre-harvest equipment used?

Nature of equipment	Mark with an X
a) Metal	
b) Plastic	
c) Other	

2.12) What time are the crops harvested?

Time of day	Mark with an X
a) Early morning	
b) Midday	
c) Afternoon	
d) Anytime	

2.13) What are the vegetables collected in?

Collection equipment	Mark with an X
a) Baskets	
b) Plastic Dishes	
c) Boxes	
d) Other	

Storage

2.14) How long is the produce kept before transporting to a particular market?

2.15) What type of packaging is used to package vegetables?

2.16) Are the vegetables stored in refrigeration before being transported?

Yes		No	

Transportation

2.17) What type of transport is used to transport your vegetables?

Type of transport	Mark with an X
a) Own	
b) Hired	
c) Trader's transport	
d) Public	
e) Other	

2.18) What is the approximate distance of the market from the farm in km?

2.19) Are there stops (multiple) before transport reaches the markets? (e. g. Alternate collection from other farmers)

2.20) Is the transport system in use, refrigerated?

Yes		No	

Labour

2.21) Do you have enough family labour for your farming activities?

Yes		No	

2.22) if you do not have enough family labour, during which operations is there labour shortage?

Farming operation	Mark with an X
a) Land preparation	
b) Planting	
c) Weeding	
d) Harvesting	

2.23) If there isn't sufficient family labour, how do you deal with the situation?

Solution to labour deficit	Mark with an X
a) Hired labour	
b) Extended hours	
c) Other	

2.24) if the labour is out-sourced, do you train the persons before allowing them to participate in operations?

Yes		No	

Section C: Safety and Hygiene

3.1) Type of animal manure used in farming operations?

Type of manure	Mark with an X
a) No manure	
b) Chicken	
c) Cow	
d) Sheep	
e) Other	

3.2) Is the manure prepared/pretreated?

Yes		No	

3.3) Is water which is used for irrigation and other farming operations treated before it is used?

Yes		No	

3.4) How is the water treated?

3.5) Do you adhere to any of the following with regards to personal hygiene before and after farming operations

Hygiene activity	Mark with an X where applicable
a) Washing hands	
b) Washing gum boots and clothing items	
c) Washing all pre and post-harvest equipment	
d) Go to the farm/garden as you are	
e) Other	

3.6) What is done with bruised or damaged vegetables?

Action	Mark with an X
a) Sold to neighbours	
b) Taken for personal use	
c) Discarded	
d) Sold to the market at a discount price	

3.7) if the vegetables are sold to the market at a discount price, are they separated from the undamaged vegetables before being transported?

Yes		No	

3.8) Are the vegetables subjected to any additional post-harvest treatment?

Section D: Capacity Building

4.1) Are you part of any farmers group?

Yes		No	

4.2) Have you been exposed to or involved in any form of pre- and post-harvest training?

4.3) Who provided the training?

Trainer	Mark with an X
a) Government	
b) NGO	
c) Private company	
d) Other	

4.4) Where was the training held?

Area of training	Mark with an X
Within the district	
Within Durban	
Further than Durban	

4.5) According to your knowledge what can be potential sources of bacterial contamination? (Mark with an X all that are applicable)

Source	Mark with an X
a) Water	
b) Soil	
c) Compost/Fertilizer	
d) Equipment	
e) Other	

4.6) What are the potential hazards of bacterial contamination?

Hazard	Mark with an X
a) No hazard	
b) Loss of trust of customers	
c) Health complications (e.g. getting sick etc.)	
d) Other	

4.7) Do you have any knowledge of outbreaks/sickness linked to harvested fresh produce in your community?

Yes		No	

4.8) According to your knowledge, is there enough awareness about produce quality and safety in your community?

Yes		No	

If no, what do you think should be done to improve awareness?

4.9) What training related to hygienic safety of vegetables do you think you need? Please explain.

What is your mother tongue language?

What language was the training delivered in?

Appendix 2: Representative Pearson Chi-Square Analyses (SPSS v24)

2A) Pre- harvest practices

Table 1: Chi-Square Test: Exposure to previous training* Type of irrigation water used

Crosstab

			Type of Irrigation Water					
			Tap Water	River Water	Borehole Water	Greywash Water	Rain-fed Water	Total
Previous Training	Yes	Count	15	23	2	8	1	49
		Expected Count	20.2	20.8	1.2	4.9	1.8	49.0
	No	Count	18	11	0	0	2	31
		Expected Count	12.8	13.2	.8	3.1	1.2	31.0
Total		Count	33	34	2	8	3	80

	Expected Count	33.0	34.0	2.0	8.0	3.0	80.0

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	11.367[a]	4	.023
Likelihood Ratio	14.719	4	.005
Linear-by-Linear Association	4.163	1	.041
N of Valid Cases	80		

a. 6 cells (60.0%) have expected count less than 5. The minimum expected count is .78.

Table 2: Chi-Square Test: Income source* Type of fertilizer used

Crosstab

			Type of Fertilizer				
			Store Bought Fertilizer	Animal Manure	Self-made Compost (Excluding Manure)	No Fertilizer	Total
Income Source	Pension	Count	3	36	12	0	51
		Expected Count	3.2	37.6	9.6	.6	51.0
	Farming	Count	1	15	2	0	18
		Expected Count	1.1	13.3	3.4	.2	18.0
	Salary/wages	Count	0	5	1	0	6
		Expected Count	.4	4.4	1.1	.1	6.0
	Other	Count	1	3	0	1	5
		Expected Count	.3	3.7	.9	.1	5.0
Total		Count	5	59	15	1	80
		Expected Count	5.0	59.0	15.0	1.0	80.0

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	19.541[a]	9	.021
Likelihood Ratio	10.887	9	.284
Linear-by-Linear Association	.032	1	.857
N of Valid Cases	80		

a. 13 cells (81.3%) have expected count less than 5. The minimum expected count is .06.

Table 3: Chi-Square Test: Education level * Treatment of Manure

Crosstab

			Treatment of Manure		
			Treated	Not Treated	Total
Education level	<Grade 7	Count	21	9	30
		Expected Count	19.1	10.9	30.0
	Grade 8-12	Count	20	7	27
		Expected Count	17.2	9.8	27.0
	>Grade 12	Count	10	3	13
		Expected Count	8.3	4.7	13.0
	No Formal Education	Count	0	10	10
		Expected Count	6.4	3.6	10.0
Total		Count	51	29	80
		Expected Count	51.0	29.0	80.0

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	20.315[a]	3	.000
Likelihood Ratio	23.175	3	.000
Linear-by-Linear Association	8.596	1	.003
N of Valid Cases	80		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 3.63.

2B) Post-harvest practices

Table 4: Chi-Square Test: Education level*Time of Collection

Crosstab

			Time of Collection				
			Early Morning	Midday	Afternoon	Anytime	Total
Education level	<Grade 7	Count	23	3	1	3	30
		Expected Count	21.4	1.5	3.0	4.1	30.0
	Grade 8-12	Count	22	0	4	1	27
		Expected Count	19.2	1.4	2.7	3.7	27.0
	>Grade 12	Count	5	1	3	4	13
		Expected Count	9.3	.7	1.3	1.8	13.0
	No Formal Education	Count	7	0	0	3	10
		Expected Count	7.1	.5	1.0	1.4	10.0
Total		Count	57	4	8	11	80
		Expected Count	57.0	4.0	8.0	11.0	80.0

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	18.152[a]	9	.033
Likelihood Ratio	20.437	9	.015
Linear-by-Linear Association	4.213	1	.040
N of Valid Cases	80		

a. 12 cells (75.0%) have expected count less than 5. The minimum expected count is .50.

2C) General hygiene practices

Table 5: Chi-Square Test: Gender*Washing gumboots and clothing items

Crosstab

			Washing Gumboots and Clothing		
			Yes	No	Total
Gender	Male	Count	4	12	16
		Expected Count	10.0	6.0	16.0
	Female	Count	46	18	64
		Expected Count	40.0	24.0	64.0
Total		Count	50	30	80
		Expected Count	50.0	30.0	80.0

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	12.000[a]	1	.001		
Continuity Correction[b]	10.083	1	.001		
Likelihood Ratio	11.807	1	.001		
Fisher's Exact Test				.001	.001
Linear-by-Linear Association	11.850	1	.001		
N of Valid Cases	80				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 6.00; b. Computed only for a 2x2 table.

Table 6: Chi-Square Test: Education Level * Acknowledgement of farming equipment as a source of bacterial contamination

Crosstab

			Farming Equipment		
			Yes	No	Total
Education level	<Grade 7	Count	4	26	30
		Expected Count	6.0	24.0	30.0
	Grade 8-12	Count	6	21	27
		Expected Count	5.4	21.6	27.0
	>Grade 12	Count	6	7	13
		Expected Count	2.6	10.4	13.0
	No Formal Education	Count	0	10	10
		Expected Count	2.0	8.0	10.0
Total		Count	16	64	80

		Expected Count	16.0	64.0	80.0

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	8.974[a]	3	.030
Likelihood Ratio	9.955	3	.019
Linear-by-Linear Association	.146	1	.702
N of Valid Cases	80		

a. 2 cells (25.0%) have expected count less than 5. The minimum expected count is 2.00.

Table 7: Chi-Square Test: Exposure to previous training * Acknowledgement that there are no hazards as a consequence of bacterial contamination

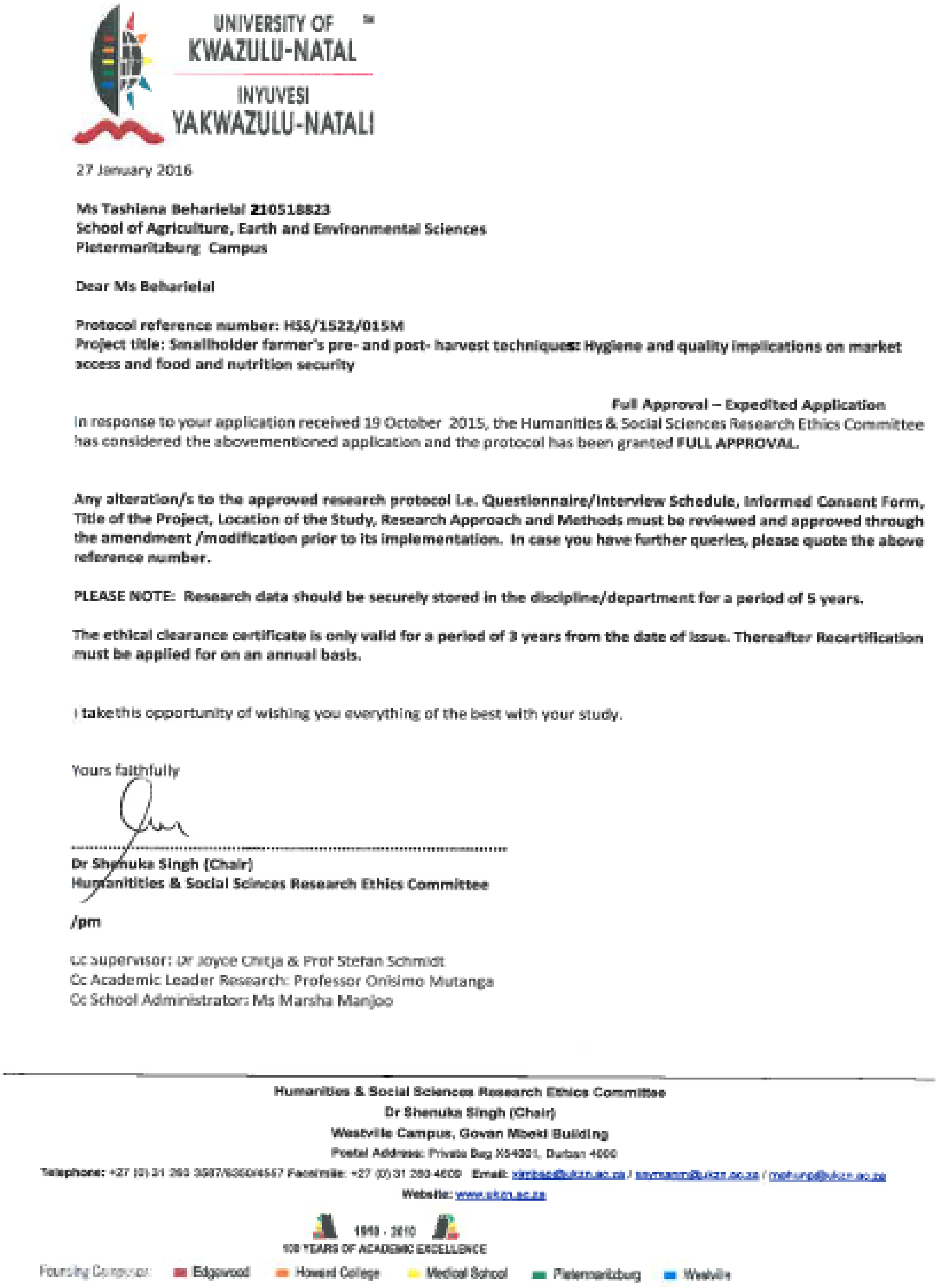
Crosstab

			No Hazard		
			Yes	No	Total
Previous Training	Yes	Count	7	42	49
		Expected Count	19.0	30.0	49.0
	No	Count	24	7	31
		Expected Count	12.0	19.0	31.0
Total		Count	31	49	80
		Expected Count	31.0	49.0	80.0

	Value	df	Asymptotic Significance (2-sided)	Exact Sig. (2-sided)	Exact Sig. (1-sided)
Pearson Chi-Square	31.887[a]	1	.000		
Continuity Correction[b]	29.282	1	.000		
Likelihood Ratio	33.509	1	.000		
Fisher's Exact Test				.000	.000
Linear-by-Linear Association	31.488	1	.000		
N of Valid Cases	80				

a. 0 cells (.0%) have expected count less than 5. The minimum expected count is 12.01; b. Computed only for a 2x2 table

Appendix 3: Approval of Ethical Clearance:



UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

27 January 2016

Ms Tashiana Beharielal 210518823
School of Agriculture, Earth and Environmental Sciences
Pietermaritzburg Campus

Dear Ms Beharielal

Protocol reference number: HSS/1522/015M
Project title: Smallholder farmer's pre- and post- harvest techniques: Hygiene and quality implications on market access and food and nutrition security

Full Approval – Expedited Application

In response to your application received 19 October 2015, the Humanities & Social Sciences Research Ethics Committee has considered the abovementioned application and the protocol has been granted **FULL APPROVAL.**

Any alteration/s to the approved research protocol i.e. Questionnaire/Interview Schedule, Informed Consent Form, Title of the Project, Location of the Study, Research Approach and Methods must be reviewed and approved through the amendment /modification prior to its implementation. In case you have further queries, please quote the above reference number.

PLEASE NOTE: Research data should be securely stored in the discipline/department for a period of 5 years.

The ethical clearance certificate is only valid for a period of 3 years from the date of issue. Thereafter Recertification must be applied for on an annual basis.

I take this opportunity of wishing you everything of the best with your study.

Yours faithfully

....

Dr Shenuka Singh (Chair)
Humanitities & Social Scinces Research Ethics Committee

/pm

Cc Supervisor: Dr Joyce Chitja & Prof Stefan Schmidt
Cc Academic Leader Research: Professor Onisimo Mutanga
Cc School Administrator: Ms Marsha Manjoo

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