Sensory attributes of chicken meat in relation to microbial and physicochemical characteristics

by

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Submitted in partial fulfilment of the requirements for the degree

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DECLARATION

I, Wendy Katiyo declare that the thesis, which I hereby submit for the degree PhD (Food Science) at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

SIGNATURE: ...…………………………....

DATE: ……………………………………..

Ethics Statement

The author, whose name appears on the title page of this thesis, has obtained, for the research described in this work, the applicable research ethics approval (EC161205-087). The author declares that she has observed the ethical standards required in terms of the University of Pretoria's Code of ethics for researchers and the Policy guidelines for responsible research.

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DEDICATION

To Jehovah *El Roi*, the God who sees me

To my beautiful family

To the girl child

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ABSTRACT

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In line with global trends, chicken meat is the most consumed source of animal protein in South Africa. Raw chicken meat is frequently contaminated with *Salmonella* spp. and *Campylobacter* spp., and is highly susceptible to bacterial spoilage if improperly handled. Although the chicken industry is primarily responsible for the quality and safety of chicken meat, consumers have an active role to play as they represent the final line of defence against the occurrence of foodborne illnesses and food waste. This study was undertaken to investigate and assess the practices, knowledge and perceptions of a group of South African consumers with respect to handling raw chicken meat, and to identify the associated risks to meat safety and quality. Subsequently, the odour and appearance attributes of raw chicken meat during refrigerated storage under aerobic packaging were characterised and the relationship with microbial and physicochemical quality changes was established. Finally, the link between consumers' perceptions, handling

practices and sensory, microbial and physicochemical characteristics of chicken meat was elucidated.

A web-based cross-sectional consumer survey (n = 863) was conducted using convenience sampling. The survey questionnaire collected information on consumers' handling practices, knowledge of temperature related factors affecting the safety and quality of chicken meat and perceptions on intrinsic and extrinsic attributes as indicators of the safety and quality of chicken meat. Furthermore, raw chicken legs obtained from a commercial poultry processing plant were stored at 4 °C and microbiological (total viable counts, *Pseudomonas* spp., Enterobacteriaceae and lactic acid bacteria), physicochemical (pH and instrumental colour) and descriptive sensory analyses (odour and appearance) were conducted during storage for 14 days.

Overall, only 38% of the surveyed respondents were rated as following good practices and 28% as having good knowledge about temperature related factors affecting the safety and quality of chicken meat. Gaps in handling practices and knowledge that potentially result in breaking of the chicken meat cold chain, the transmission of pathogenic bacteria and cross-contamination were identified. Moreover, smell, use-by date, sell-by date and colour were perceived by a large majority of respondents as highly important attributes when judging chicken safety and quality at point of purchase and the home. Smell was considered significantly more important than colour. Extrinsic attributes such as absence of brine use and growth-promoting hormones in chicken feed were also considered as relatively important.

The storage study revealed that odour attributes of chicken meat (fresh chicken, bloody, pungent, fishy, rotten egg, ammonia-like and intense overall odour) changed at a faster rate than colour (L* and saturation) and appearance attributes (creamy skin, pink flesh, green/blue colouration and slimy). Odour attributes were also highly correlated ($r > 0.8$) with microbial growth. On the other hand, no correlations were found between colour and appearance attributes and microbial growth in chicken meat.

Consumers' handling practices and knowledge levels suggest that there is potential for unacceptable growth of spoilage and pathogenic bacteria in chicken meat. Additionally, the smell of chicken meat is perceived as a more important attribute than colour probably due to the significant differences in the rate of deterioration and relation with microbial growth during storage.

The results from this study reflect a need for educational interventions focused on microbial risks in chicken meat and the consequences of mishandling on safety and quality, guidelines to prevent temperature abuse, the transmission of bacteria and cross-contamination.

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CHAPTER ONE

GENERAL INTRODUCTION

Chicken meat consumption has increased immensely over the past three decades worldwide, with a 3-fold increase as compared to beef and veal (1-fold), pork (2-fold) and sheep (1-fold) (OECD, 2019). Chicken meat is an important source of animal protein, particularly in developing countries where many households rely on grains and tubers as staple foods. South Africa is the largest producer of chicken meat in the African region, and the poultry sector is the main agricultural industry in the country (SAPA, 2018). The average per capita consumption of chicken meat in South Africa in 2017 was 39 kg, and this was more than double that of other animal protein sources consumed during the same period (SAPA, 2018). Chicken meat is therefore an important part of the diet of South Africans.

Bacterial contamination of chicken meat along the value chain is a pertinent challenge to the chicken industry as it affects product quality and safety (Dainty, 1996). Spoilage bacteria are ubiquitous in nature. The growth of psychrotrophic spoilage bacteria in raw chicken meat during cold storage, particularly *Pseudomonas* spp., Enterobacteriaceae and lactic acid bacteria affects the shelf life and consumers' decisions to purchase, prepare or consume the meat (Vasconcelos, Saraiva, & de Almeida, 2014). The development of microbial spoilage in chicken meat is connected to the metabolism of nutrients in the meat and the release of undesirable volatile organic metabolites coupled with the deterioration of colour and texture (Dainty, 1996). Mismanagement of the chicken meat cold chain at any stage of the value chain can result in excessive bacterial growth, unacceptable products and ultimately lead to food waste. The Council for Scientific and Industrial Research (CSIR) estimated the financial burden of meat waste at the consumer level in South Africa in 2012 to be about 2.1 billion Rands (Nahman & de Lange, 2013).

Besides spoilage bacteria, it is well established that raw chicken meat is frequently contaminated with *Salmonella* spp. and *Campylobacter* spp., which are human pathogens. *Salmonella* spp. and *Campylobacter* spp. are natural inhabitants of the gastrointestinal tract of chickens and thus can easily be transmitted to chicken skin and meat during processing, and ultimately to humans if the meat is improperly handled. Studies in South Africa and other countries have shown a high prevalence of *Salmonella* spp. and *Campylobacter* spp. on raw chicken meat at retail (Carron et al., 2018; Mabote, Mbewe, & Ateba, 2011; Nguyen et al., 2016; Shrestha et al., 2017; Zishiri, Mkhize, & Mukaratirwa, 2016). In South Africa, 132 foodborne disease incidences and 8 hospitalisations associated with the consumption of chicken meat were reported during the period 2014 - 2015 (Muvhali, Smith, Rakgantso, & Keddy, 2017; NICD, 2015). A recent study on foodborne diseases that occurred between 2009 and 2015 in the USA showed that most outbreak-associated illnesses were attributed to chicken meat; 123 outbreaks, 3114 illnesses and 372 hospitalisations (Dewey-Mattia, Manikonda, Hall, Wise, & Crowe, 2018).

The primary responsibility for food quality and safety lies with the food industry, but consumers have an active role to play in maintaining the quality and safety of food through proper handling practices (Al-Sakkaf, 2013). However, little is known about chicken meat handling practices and food safety knowledge of consumers in South Africa.

It is widely accepted that consumers' behaviour is influenced by their perceptions. Consumers' perceptions of meat quality and safety are highly subjective and deviate from the objective aspect as understood by meat scientists. It was proposed that consumers draw inferences about the quality and safety of meat from the intrinsic and extrinsic characteristics (Glitsch, 2000; Olson & Jacoby, 1972). At the consumer level, the sensory attributes of chicken meat are the most apparent and thus vital because they are linked to product acceptability (Troy & Kerry, 2010). There is limited information regarding consumers' perceptions of the quality and safety of chicken meat in South Africa and yet it is the most consumed meat.

It was found that chicken meat handling practices and perceptions of consumers differ among countries mainly due to cultural and situational factors (Chamhuri & Batt, 2013). Several consumer behaviour studies concerning chicken meat have been conducted, although mostly in developed countries (Bearth, Cousin, & Siegrist, 2014; Hessel et al., 2019; Koppel et al., 2016; Kosa, Cates, Bradley, Chambers IV, & Godwin, 2015). However, no study has yet further extended the findings by establishing and elucidating consumers' perceptions and handling practices in relation to microbial, physicochemical and sensory characteristics of chicken meat.

Research on the quality and safety of chicken meat at the consumer level requires particular attention as it will equip the chicken industry, public health authorities as well as food quality and safety legislators. For the chicken industry to improve, it is necessary to understand consumers' perspectives on the quality and safety of chicken meat. For public health authorities and food quality and safety legislators to effectively and appropriately respond to consumers' practices, perceptions and knowledge levels, science-based evidence on these aspects needs to be available.

Therefore, this study will investigate and assess the handling practices, food safety knowledge levels, and safety and quality perceptions of South African consumers with respect to raw chicken meat. Importantly, the link between consumers' perceptions, handling practices and microbial characteristics of chicken meat will be established and elucidated.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The purpose of this review is to assess the importance of chicken meat as a source of animal protein globally and in South Africa, and microbial safety and quality challenges associated with its production, processing and retailing. The prevalence of bacterial pathogens in raw chicken meat at retail, particularly *Salmonella* spp. and *Campylobacter* spp., and foodborne disease outbreaks linked to the consumption of contaminated chicken meat are reviewed. The predominant bacteria associated with the spoilage of raw chicken meat and the resulting physical, chemical and sensory changes are also reviewed. Since consumers are part of the food chain, consumer behaviour with respect to handling practices for chicken meat and perceptions of the safety and quality of chicken meat is reviewed as well.

2.2 Global chicken meat production and consumption trends

Global production of poultry meat has increased by more than 3-fold over the past three decades from 37.7 million tonnes in 1988 to 120.5 million tonnes in 2017 (FAOSTAT, 2019). Currently, the largest poultry meat producing countries in the world are the United States of America (USA), China and Brazil, producing about 22, 18 and 14 million tonnes in 2017, respectively (FAOSTAT, 2019) (Figure 2.1). Collectively, the European Union also makes a noteworthy contribution to global poultry meat production. In the African region, South Africa and Egypt dominate the poultry sector with an output of 1.7 and 1.2 million tonnes in 2017, respectively. Poultry production volumes in many African countries are relatively low primarily due to adverse climatic conditions, high feed costs, frequent disease outbreaks and inadequate infrastructure (Mottet & Tempio, 2017). Global annual poultry meat production is projected to expand by 1.3% over the coming decade (OECD/FAO, 2019).

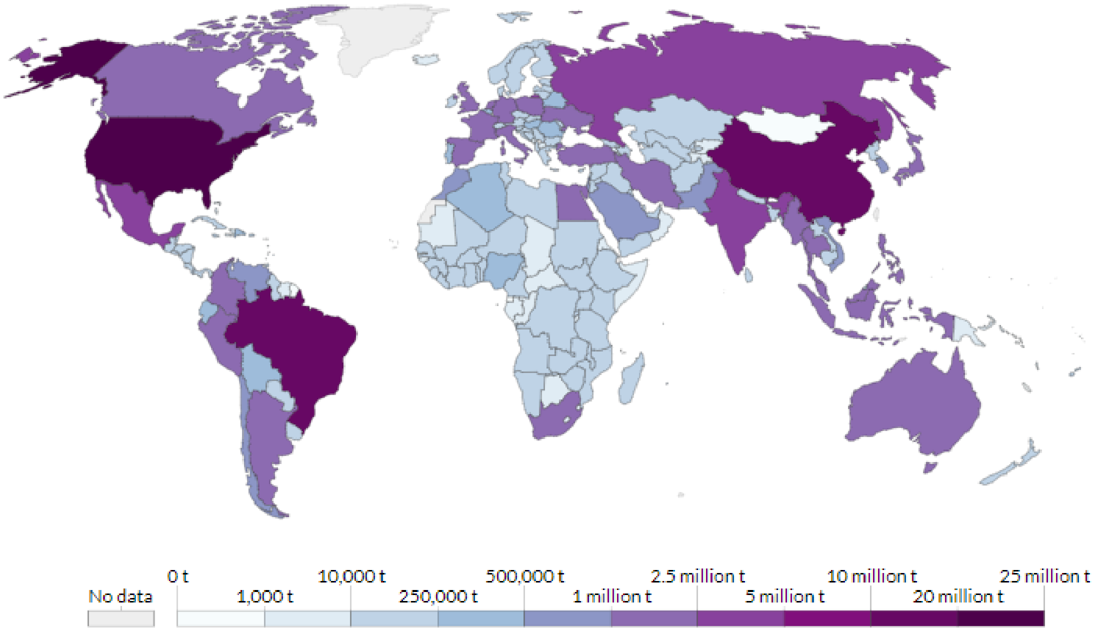


Figure 2.1: World poultry meat production by country (tonnes) in 2017 (FAOSTAT, 2019)

Of the total poultry meat produced and consumed worldwide, approximately 88% is chicken meat (FAO, 2019). The modern broiler chicken industry is a global animal husbandry success story. The greater part of this success is attributed mainly to the genetic selection of broiler chickens for rapid growth, efficient feed conversion and better immunity against diseases (Barbut, 2016). Additionally, dramatic advancements in broiler nutrition have been evident in the last decades. Nutritional research has shown that, to maximise the growth rate of broilers, typical broiler feed formulations should include a major energy source (e.g., corn), a protein source (e.g., soya bean), vitamins and minerals for a stronger immune system, and enzymes to aid in phosphorus and protein digestion (Ahiwe, Omede, Abdallh, & Iji, 2018; Beski, Swick, & Iji, 2015). Improved environmental conditions such as chicken housing designs with lighting and temperature control have also contributed to faster growth by reducing stress in broiler chickens throughout the grow-out period. The feed conversion ratio (FCR) for broiler chickens is lower (that means higher efficiency) than that of other livestock raised using commercial feeds and intensive production methods (Fry, Mailloux, Love, Milli, & Cao, 2018). The FCR is calculated as the ratio of feed intake by the animal to weight gain (Fry et al., 2018). Live weight FCR values ranging from 1.7 - 2.0 for broiler chickens (Zuidhof, Schneider, Carney, Korver, & Robinson, 2014), 2.7 - 5 for pigs (Agostini et al., 2014), 4 - 5 for sheep (Knott et al., 2003), 6.4 - 9 for goats (Sheridan, Ferreira, & Hoffman, 2003) and 6 - 10 for beef cattle (Shike, 2013) have been reported. These and other factors have allowed the modern broiler chicken industry to become more competitive and cost-efficient in comparison with other livestock sectors. Thus, chicken meat has become the cheapest of all livestock meats, and global demand has grown substantially. According to OECD (2019), the world per capita consumption of poultry increased more rapidly than that of pork, mutton, and beef and veal over the past two decades (Figure 2.2). The per capita consumption of poultry, pork, mutton, and beef and veal increased by approximately 57.4%, 7.4%, 8.4% and 3.5%, respectively, during the period 1998 to 2018. Apart from relatively low prices, drivers for the increase in chicken meat consumption include population growth, urbanisation, rising disposable incomes, changes in meat preferences, associated low-fat health claims, and lack of cultural and religious barriers on its consumption (FAO, 2019). It is expected that by the year 2027, global poultry consumption will increase by a further 3.5% (OECD/FAO, 2019).

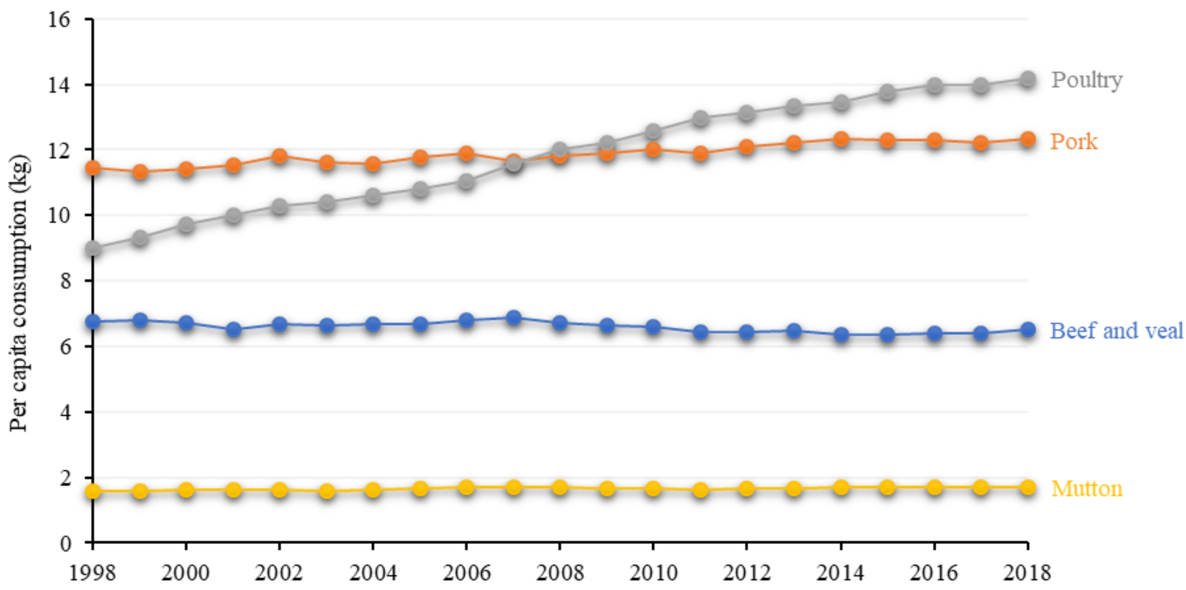


Figure 2.2: World per capita consumption of meat, 1998 - 2018 (OECD, 2019)

Although per capita poultry consumption is relatively high in developed countries, the most rapid increases have been attributed to developing countries (Tan, De Kock, Dykes, Coorey, & Buys, 2018). For instance, the average annual increase in poultry consumption between 2005 and 2015 in developed countries was approximately 1.6%, compared with 2.9% in developing countries (FAO, 2019). Chicken meat has become an essential source of high biological value proteins and contributes substantially to household food security in developing countries, especially in sub-Saharan Africa (SSA) where many populations depend on cereal grains and tubers as staple foods. Chicken meat is also a good source of polyunsaturated fatty acids (especially omega (n)-3 fatty acids), niacin, vitamin B6 and B12, zinc, selenium and phosphorus (INSRJ, 2006, as cited in Pereira and Vicente (2013)). FAO (2013) highlighted the importance of chicken meat in improving nutrition in low-income households in developing countries.

2.3 Chicken meat production and consumption trends in South Africa

South Africa is the largest producer of chicken meat in SSA, accounting for approximately 80% of total production in the region (DAFF, 2018). The poultry sector is the primary agricultural industry in the country, representing 19.6% of the total gross value of agricultural products and 40% of animal product gross value in 2017 (SAPA, 2018a). Chicken meat production increased from 1.5 million tonnes by approximately 47.4% during the period 2007 to 2017 (SAPA, 2018a). Chicken meat is produced throughout South Africa. North West, Mpumalanga and Western and Northern Cape provinces were the largest producers in 2016, accounting for approximately 63% of total production (Figure 2.3).

Figure 2.3: Percentage distribution of broiler chicken meat production in South Africa by province in 2016. *Collectively, Northern and Western Cape provinces produced 21% of total production (DAFF, 2018)

Three chicken farming methods are practiced in South Africa, namely intensive, free-range and organic farming, although intensive farming accounts for the bulk of production (Ncube, 2018). The chicken production systems in place can be categorised into three, namely backyard, commercial and integrated industrial production (Louw, Davids, & Scheltema, 2017) (Figure 2.4). Backyard chicken production is home-based and generally for household food demands, with limited sales for income generation. The chickens are usually sold to close-by neighbours live or dressed. Commercial production is conducted by small and medium-scale chicken farmers. The birds are raised in better-structured houses, given proper feed and the farmers sometimes seek veterinary services. However, according to a review by FAO (2013), small to medium-holder farmers most often have little or no experience in poultry farming, resulting in the misuse of antimicrobial and antibiotic drugs. Due to lack of processing infrastructure, small and medium-holder chicken farmers tend to slaughter the birds manually or pay independent chicken abattoirs to do the processing. The chickens are sold to consumers live or dressed, mainly through the informal market. Small-scale farmers most often face challenges in accessing formal markets in which to sell their produce. Hence, the informal market is an essential sector of the South African chicken meat supply chain (Figure 2.4). An integrated industrial system is whereby a company owns and controls multiple stages of the chicken production process, such as breeder flocks, hatcheries, feed mills, grow-out flocks, processing facilities, transportation and marketing (Ncube, 2018). Additionally, the company produces more chickens through independent farmers by using a formal contract production system (Ncube, 2018). Consequently, the chicken production capacity of integrated industrial systems is very high. The chicken products are marketed locally and some are exported.

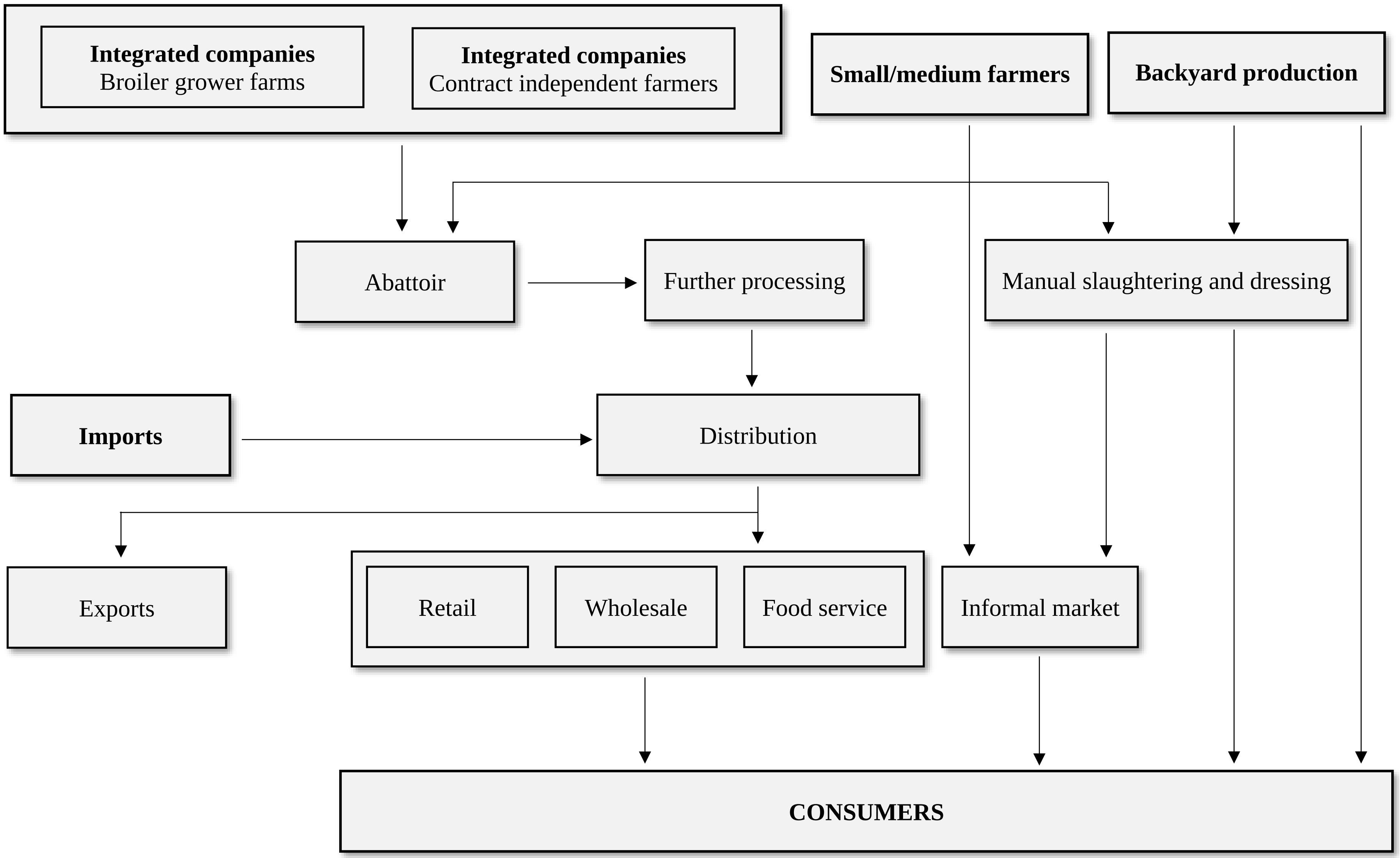


Figure 2.4: A typical chicken meat supply chain in South Africa (adapted from DAFF (2018) and SAPA (2018a))

In South Africa, seven fully integrated companies account for about 75% of total chicken production and the rest is supplied by hundreds of small and medium-scale farmers (Louw et al., 2017). The largest share of local chicken meat products is purchased by the 5 main retail supermarkets (Pick n Pay, Shoprite, Spar, Woolworths and Massmart), and the rest by formal and informal small, medium and micro-sized enterprises (SMMEs) (Louw et al., 2017). Individually quick-frozen chicken (IQF) portions make up the bulk of locally produced chicken products, accounting for about 52% of the formal market in 2018 (SAPA, 2019) (Figure 2.5). Frozen sundry portions, that is chicken offal, were the second most produced (about 14%).

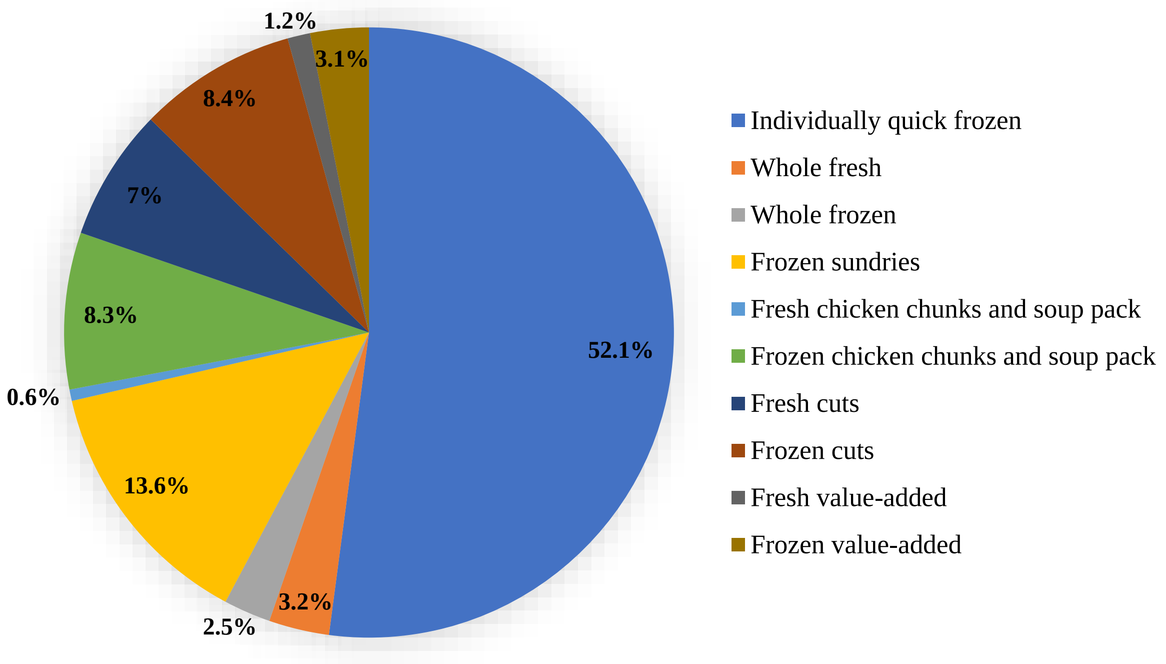


Figure 2.5: Market composition of chicken meat products in South Africa according to volume, 2018 (SAPA, 2019)

Although there has been a dramatic increase in chicken production in South Africa over the past decades, chicken meat imports have increased annually by an average of 10% since 2001 as a consequence of shortfalls in local production (SAPA, 2018b). In 2017, imported chicken meat accounted for about 24% of the total domestic consumption (SAPA, 2018b). Of the total chicken meat imported during 2017, 99.8% was in frozen form (bone-in chicken portions, whole chicken and mechanically deboned chicken). Brazil, the European Union and the USA are the leading exporters of chicken meat to South Africa. Overall, chicken is sold to consumers live, refrigerated, frozen or in further processed form in South Africa.

Similar to global trends, poultry meat is a relatively cheap source of animal protein in South Africa and hence has continuously dominated the meat market over the past decade. While the average annual producer price for chicken meat in 2017 on a South African rand per kilogram basis was 21.44, that of class A2/A3 beef was 45.41, class C2/C3 beef 39.26, pork 27.57 and eggs 21.40 (SAPA, 2019). According to DAFF (2018) estimates, 2.2 million tonnes of poultry meat were consumed in 2017. Of this, 96% was chicken meat. The average per capita consumption of poultry meat from the year 2005 to 2017 was 38 kg, and this was more than double that of other animal protein sources consumed during the same period (DAFF, 2018) (Figure 2.6). An average of 17.3 kg beef, 8 kg eggs, 4.4 kg pork and 3.5 kg mutton and goat were consumed per capita within the stated period. The per capita consumption of poultry meat in South Africa is projected to be more than 45 kg by the year 2027 (OECD/FAO, 2019).

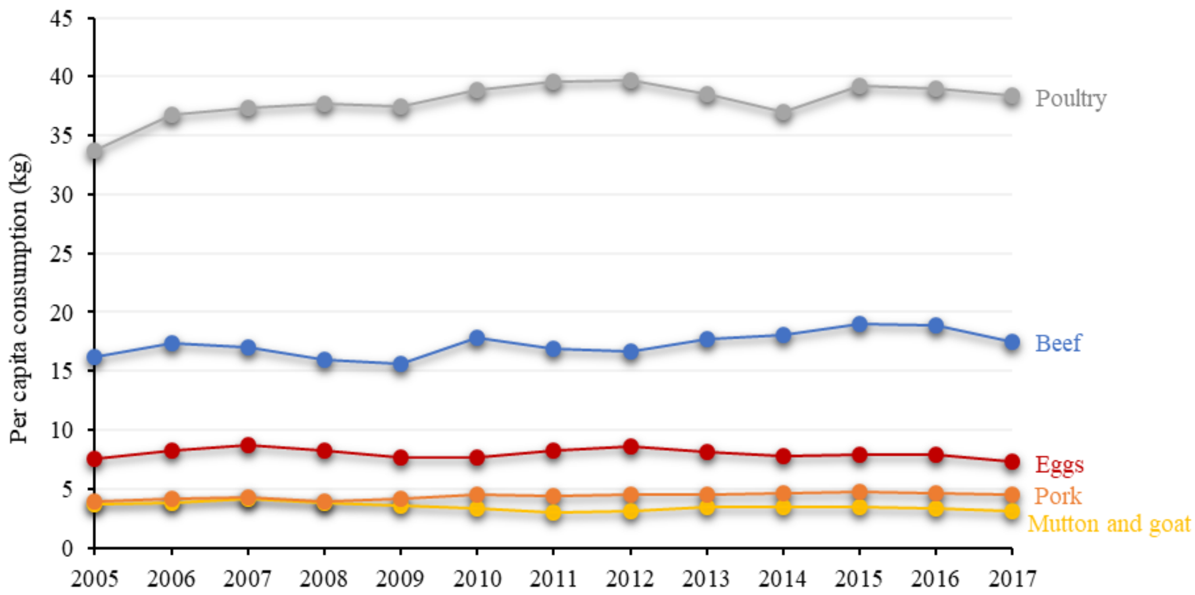


Figure 2.6: Per capita consumption of animal protein in South Africa, 2005 - 2017 (DAFF, 2018)

2.4 Food safety and quality in the chicken industry

2.4.1 Pathogenic bacteria and chicken-borne diseases

Food safety refers to "the practices and conditions that preserve food in order to prevent contamination and foodborne illnesses" (WHO, 2015a). A foodborne disease outbreak is defined as "two or more cases of a similar illness resulting from the ingestion of a common food or beverage" (NICD, 2012). Of the contaminants of chicken meat, the most prominent are bacterial pathogens (WHO/FAO, 2009). Bacteria exist in the environments in which chicken is produced, processed, packaged and stored. Chicken meat is rich in protein and contains a variety of other nutrients, has a slightly acidic pH and high water activity, making it an ideal medium for the growth of many pathogenic and spoilage bacteria (Muchenje et al., 2009). Since chicken meat is the most consumed animal protein in many countries, both developed and developing, ensuring consumer safety against chicken-borne bacterial pathogens is of paramount importance. While many foodborne illnesses may be self-limiting, some can be lethal and result in death. The prevention of foodborne illnesses and deaths associated with chicken meat consumption remains a significant public health challenge (WHO/FAO, 2009).

Numerous studies across the world have detected bacterial pathogens of public health concern in raw chicken meat both at the processing and retail level. Table 2.1 presents the prevalence of foodborne pathogens isolated from raw chicken obtained from retail, reported over the past decade (2009 - 2018) in developed and developing countries. The prevalence of these bacterial pathogens in raw chicken meat, including *Salmonella* spp., *Campylobacter* spp., *Escherichia coli*, *Listeria monocytogenes*, *Staphylococcus aureus*, *Yersinia enterocolitica*, *Arcobacter* spp. and *Shigella* spp., vary widely between studies mostly due to varying production and processing systems, distribution and storage conditions, and types of retailers. Moawad et al. (2017) detected significantly higher contamination rates in refrigerated chicken meat by *Salmonella* spp. and *E. coli* than in previously frozen chicken, while similar contamination rates by *S. aureus* in refrigerated and previously frozen chicken were reported by Boost, Wong, Ho, and O'Donoghue (2013). Other studies showed differences in pathogenic bacteria populations with respect to raw chicken meat with or without skin. For instance, Cook, Odumeru, Lee, and Pollari (2012) reported higher populations of *Campylobacter* spp., similar populations of *Salmonella* spp. and verotoxigenic *E. coli*, and lower populations of *L. monocytogenes* on skinless chicken meat than with skin on. None of the differences exceeded 1 log colony forming units per gram (CFU/g), however. According to Donado-Godoy et al. (2012), no associations were found between the type of retailer (supermarkets, butcheries and wet markets) and the prevalence of *Salmonella* spp. in raw chicken. In contrast, Odwar, Kikuvi, Kariuki, and Kariuki (2014) reported significant differences in the prevalence of *E. coli* in raw chicken obtained from supermarkets and butcheries, with butcheries posing a higher risk. Regarding chicken production methods (free-range and intensive farming), no differences in the prevalence of *Campylobacter* spp. and *Salmonella* spp. were found between free-range and conventionally produced chicken meat (Donado-Godoy et al., 2012; Economou et al., 2015).

Generally, foodborne illnesses are much more of a concern to governments and public health authorities recently than a few decades ago. Kiilholma (2007), Motarjemi and Käferstein (1999) and Newell et al. (2010) highlighted food safety concerns in the poultry sector and factors that may contribute to the high incidence of chicken-borne diseases. The factors likely to play a major role include dramatic changes in the chicken supply system. The mass production of chickens, confined indoors in limited airspaces and producing significant amounts of waste, may allow for the enhanced and easy transmission of bacterial pathogens and disease among birds. This, in turn, may significantly increase the chances of contamination of chicken skin and meat during processing. Modern intensive chicken husbandry practices were also proposed to have promoted the massive prophylactic use of antibiotic drugs, giving rise to the increased risk of antibiotic resistance in bacterial pathogens from broiler chickens. Additionally, due to globalisation, longer and more complex food chains may lead to greater opportunities for contamination, survival and growth of bacterial pathogens in chicken meat products. International trade may also result in the distribution of potentially contaminated chicken products, causing larger multinational foodborne outbreaks.

Table 2.1: Prevalence rates of bacterial human pathogens isolated from raw retail chicken meat, reported in developed and developing countries (2009 - 2018)

Bacterial pathogen	Foodborne disease	Prevalence rates in raw chicken (%)	Reference
***Salmonella* spp.**	Salmonellosis	2.0 - 65.3	(Adesiji, Alli, Adekanle, & Jolayemi, 2011; Ahmed & Shimamoto, 2014; Cook et al., 2012; Huang, Zong, Zhao, Zhu, & Jiao, 2016; Madden, Moran, Scates, McBride, & Kelly, 2011; Moawad et al., 2017; Nguyen et al., 2016; Shrestha et al., 2017; Zadernowska & Chajęcka-Wierzchowska, 2017; Zishiri et al., 2016)
***Campylobacter* spp.**	Campylobacteriosis	34.9 - 100.0	(Carron et al., 2018; Cook et al., 2012; Guyard-Nicodème et al., 2015; Huang et al., 2016; Mabote et al., 2011; Madden et al., 2011; Nobile, Costantino, Bianco, Pileggi, & Pavia, 2013; Wieczorek, Szewczyk, & Osek, 2012)
***Escherichia coli* (O157:H7 and non-O157:H7)**	Haemorrhagic colitis, haemolytic uremic syndrome	1.5 - 88.0	(Adesiji et al., 2011; Ahmed & Shimamoto, 2014; Cook et al., 2012; Davis et al., 2018; Moawad et al., 2017; Park et al., 2015; Shrestha et al., 2017)
Listeria monocytogenes	Listeriosis	9.4 - 34.0	(Cook et al., 2012; Goh et al., 2012; Osaili, Alaboudi, & Nesiar, 2011; X. Wang et al., 2013)
Staphylococcus aureus	Staphylococcal enterotoxin	6.8 - 39.6	(Adesiji et al., 2011; Boost et al., 2013; Sallam, Abd-Elghany, Elhadidy, & Tamura, 2015; X.-M. Wang et al., 2013)
Yersinia enterocolitica	Yersiniosis	2.1 - 32.5	(Bonardi et al., 2010; Momtaz, Davood Rahimian, & Safarpoor Dehkordi, 2013; Zadernowska & Chajęcka-Wierzchowska, 2017)
***Arcobacter* spp.**	Arcobacteriosis	19.0 - 56.0	(Adesiji et al., 2011; Fallas-Padilla, Rodriguez-Rodriguez, Jaramillo, & Echandi, 2014; Nieva-Echevarria, Martinez-Malaxetxebarria, Girbau, Alonso, & Fernández-Astorga, 2013)
***Shigella* spp.**	Shigellosis	0.8 - 3.9	(Ahmed & Shimamoto, 2014; Shrestha et al., 2017)

During the period 2009 to 2018, several disease outbreaks implicating chicken meat were reported across the world (Table 2.2). Generally, outbreaks of gastroenteritis are often not reported to health authorities (Jahan, 2012). This results in current data under-representing the actual burden of enteric disease outbreaks worldwide (Jahan, 2012). There is no adequate capacity to track foodborne diseases in most developing countries although many outbreaks have occurred (Bisholo, Ghuman, & Haffejee, 2018). Moreover, during foodborne disease outbreak investigations, attribution of the disease to specific food sources is rare, let alone the identification of the etiological agent. However, several foodborne outbreak reports in developed countries indicate that Salmonellosis and Campylobacteriosis accounted for more outbreaks than other chicken-borne diseases (Table 2.2). A study on the causes of foodborne disease outbreaks between 2009 and 2015 in the USA revealed that chicken meat was responsible for the most outbreak-associated illnesses, causing 123 outbreaks, 3114 illnesses and 372 hospitalisations (Dewey-Mattia et al., 2018). Although public health risk of bacterial pathogens in chicken meat varies worldwide according to control measures and practices implemented along the chain from primary production to final preparation for consumption, the risk is considered by the WHO and FAO to be significant (WHO/FAO, 2009).

Tables 2.1 and 2.2 indicate that *Campylobacter* spp. and *Salmonella* spp. are the predominant foodborne bacterial pathogens associated with chicken meat and are most frequently implicated in human illnesses (WHO/FAO, 2009). These pathogens are commonly found as part of the natural gastrointestinal tract flora of food animals such as poultry, cattle and pigs. Hence, they can readily contaminate meat and meat products during slaughtering and processing. Challenges associated with *Campylobacter* spp. and *Salmonella* spp. in chicken meat remain prominent even in developed countries where chicken production and processing technologies, and food safety and quality systems are advanced (CDC, 2018; OzFoodNet, 2018).

Table 2.2: Foodborne disease outbreaks associated with chicken meat consumption (2009 - 2018)

Etiological agent	Signs and symptoms	Country	Year	Foodborne outbreak details	Reference
***Salmonella* spp.**	Fever, diarrhoea, headache, abdominal cramps	USA	2009 - 2015	49 outbreaks, 1941 illnesses, 372 hospitalisations	(Dewey-Mattia et al., 2018)
		Australia	2014	15 illnesses, 6 hospitalisations	(OzFoodNet, 2018)
		South Africa	2014	65 illnesses, 8 hospitalisations	(Muvhali et al., 2017)
		South Africa	2015	4 illnesses (children aged 4, 7, 8 and 11)	(Muvhali et al., 2017)
		European Union	2017	7 outbreaks	(EFSA/ECDC, 2018)
		USA	2018	753 illnesses, 186 hospitalisations, 3 deaths	(CDC, 2018)
		Canada	2017 - 2018	474 illnesses, 79 hospitalisations, 3 deaths	(PHAC, 2019)
***Campylobacter* spp.**	Fever, muscle pain, nausea, abdominal cramps, vomiting, diarrhoea with or without blood, headache	USA	2010 - 2015	33 outbreaks	(CDC, 2017)
		Australia	2013	83 illnesses	(OzFoodNet, 2018)
		New Zealand	2014	85 illnesses	(MPI, 2017)
		European Union	2017	8 outbreaks	(EFSA/ECDC, 2018)
Staphylococcus aureus	Nausea, vomiting, abdominal cramps, with or without fever and diarrhoea	Australia	2013	8 illnesses	(OzFoodNet, 2018)
		South Africa	2015	63 illnesses	(NICD, 2015)
		New Zealand	2017	5 illnesses	(MPI, 2017)
***Escherichia coli* (O157:H7 and non-O157:H7)**	Diarrhoea, nausea, vomiting, abdominal cramps, kidney failure	USA	2015	19 illnesses, 5 hospitalisations, 2 developed haemolytic uremic syndrome	(CDC, 2015)
***Clostridium* spp.**	Watery diarrhoea, fever, nausea, abdominal cramps, vomiting, fatigue, headache	USA	2012	666 illnesses	(London, Payne, & Hartl, 2017)
		Australia	2014	28 illnesses	(OzFoodNet, 2018)
		New Zealand	2014	19 illnesses	(MPI, 2017)
Vibrio cholerae	Severe watery diarrhoea, muscle cramps, nausea, fever, fatigue, vomiting	Thailand	2010	28 illnesses	(Swaddiwudhipong, Hannarong, Peanumlom, Pittayawonganon, & Sitthi, 2012)
***ns**		USA	2009 - 2015	74 outbreaks, 1173 illnesses	(Dewey-Mattia et al., 2018)

*ns - etiological agents in chicken meat not specified in the epidemiological report

2.4.1.1 *Campylobacter* spp.

Campylobacter spp. are small (0.2 - 0.8 μm × 0.5 - 5 μm) gram-negative, non-sporulating bacilli that have a curved or spiral shape (Figure 2.7a). They belong to the family Campylobacteraceae (Van Vliet & Ketley, 2001). The bacterial cells of *Campylobacter* spp. are highly motile through unipolar or bipolar flagella at one or both ends of cells. The microorganisms are microaerophilic, growing best at low oxygen atmosphere of approximately 5 - 10% oxygen, 10% carbon dioxide and 85% nitrogen (ICMSF, 1996). *Campylobacter* spp. grow optimally at pH 6.5 - 7.5, and will not survive below a pH of 4.9 and above pH 9.0 (ICMSF, 1996). *Campylobacter* spp. are fastidious bacteria that are unable to ferment carbohydrates. Instead, they obtain energy from amino acids, or tricarboxylic acid cycle intermediates (Van Vliet & Ketley, 2001). The temperature range for the growth of thermotolerant *Campylobacter* spp. is 34 - 44 °C, with an optimal temperature of 42 °C (ICMSF, 1996). Nevertheless, Lee, Smith, and Coloe (1998) found that *Campylobacter jejuni* retained a high level of viability at -70, -20, 4 °C and at room temperature (25 °C) after artificial inoculation onto the skin of raw chicken meat and storage for eight weeks. Additionally, freeze-thawing (3 freeze-thaw cycles) similar to that which may occur in the domestic home, significantly reduced the viable cell numbers but did not eliminate the pathogen from the contaminated chicken meat.

Of the reported *Campylobacter* spp., *C. jejuni* is most often implicated as the causative agent of Campylobacteriosis, while *Campylobacter coli* seems to be less frequent in causing acute human diarrhoea (CDC, 2017; EFSA/ECDC, 2018; OzFoodNet, 2018). Commonly reported symptoms of patients with laboratory-confirmed *Campylobacter* infections include bloody diarrhoea, fever and abdominal cramping. The incubation period is 3 - 5 days with symptoms lasting 5 - 7 days (Fischer & Paterek, 2019). Generally, in order for a foodborne bacterial pathogen to cause infection or intoxication, it must colonise the intestine or adhere to the epithelial surface before exerting its pathogenic action (Bhunia, 2018). The infectious dose of *Campylobacter* spp. varies depending on the immunological status of the host. Consequently, dose-response studies have reported varying results. However, ingestion of as few as 500 *C. jejuni* cells resulted in illness in human experimental infections (Tribble et al., 2009). Although *C. jejuni* infections are usually self-limiting, antibiotics may be prescribed for immunocompromised patients, patients with bloodstream infections and those whose symptoms worsen or persist from the onset of illness or time of diagnosis (Altekruse, Stern, Fields, & Swerdlow, 1999). When treatment is delayed therapy may not be successful. However, resistance of *C. jejuni* and *C. coli* to antibiotic drugs normally used to treat human illnesses has increased markedly in recent years (Newell et al., 2010; Wieczorek et al., 2012). Deaths from *Campylobacter* infections occur primarily in infants, the elderly and patients with underlying illnesses. Infection with *C. jejuni* is also a known antecedent of the development of Guillain-Barre Syndrome (GBS), a polio-like form of paralysis that can result in respiratory and severe neurological disorder and even death (Skarp, Hänninen, & Rautelin, 2016). Less frequently, *C. jejuni* infections produce bacteraemia and septic arthritis.

2.4.1.2 *Salmonella* spp.

Salmonella spp. are another leading cause of foodborne illnesses associated with chicken meat (WHO/FAO, 2009). *Salmonella* spp. are a group of non-sporulating, gram-negative bacteria in the family Enterobacteriaceae (Jay, Davos, Dundas, Frankish, & Lightfoot, 2003). They are rod-shaped bacteria with cell diameters approximately 0.7 - 1.5 μm × 2 - 5 μm (Figure 2.7b). The bacterial cells are predominantly motile with peritrichous flagella. Unlike *Campylobacter* spp., they are classified as non-fastidious bacteria. *Salmonella* spp. are facultative anaerobes. They are capable of generating adenosine triphosphate (ATP) by utilising oxygen when present in the environment and switch to anaerobic respiration in the absence of oxygen (Jay et al., 2003). Moreover, they have relatively simple nutritional requirements. Most of *Salmonella* spp.

grow at a broad temperature range of 5 - 47 °C with the optimum at 35 - 37 °C (ICMSF, 1996). They grow in the pH range 4 - 9 with the optimum between 6.5 and 7.5 (ICMSF, 1996). Similar to *Campylobacter* spp., *Salmonella* spp. have the ability to survive refrigeration and frozen storage of chicken meat. Pradhan et al. (2012) showed that frozen storage of raw chicken breasts at -20, -12 and 0 °C for 25 days did not produce significant changes in the populations of *Salmonella* Typhimurium, indicating that the bacteria could not replicate but survived. However, growth was observed at 4 and 8 °C. Dominguez and Schaffner (2009) also indicated the survival of *S*. Typhimurium and *Salmonella* Kentucky in processed raw chicken products frozen at -20 °C for 16 weeks. Both refrigerated and frozen raw chicken meat has been found to harbour high levels of *Campylobacter* spp. and *Salmonella* spp. (Table 2.1). The ability of *Salmonella* spp. and thermotolerant *Campylobacter* spp. to survive cold storage is of concern to food safety and public health authorities because strict adherence to the recommended refrigeration temperatures (4 °C or less) along the meat supply chain is generally a challenge (Ndraha, Hsiao, Vlajic, Yang, & Lin, 2018). This suggests that the pathogens could multiply if temperature conditions are to be conducive.

While there are more than 2400 *Salmonella* serotypes, outbreaks of *Salmonella* Enteritidis and *S.* Typhimurium have been frequently associated with the consumption of chicken meat (CDC, 2018; EFSA/ECDC, 2018; OzFoodNet, 2018). Other reported serotypes, although less prominent, include Heidelburg, Kentucky, Infantis, Dublin, Newport and Virchow. It is estimated that the ingestion of about 10^5 bacterial cells of *Salmonella enterica* could cause human illness (Bhunia, 2018). The incubation period is relatively short, 6 - 24 hours, with symptoms lasting 2 - 7 days. Symptoms of Salmonellosis include nausea, vomiting, watery diarrhoea with blood and mucus, prostration and slight fever. Infants, the elderly and immunocompromised individuals are at a higher risk of *Salmonella* spp. infection and generally have more severe symptoms (Jay et al., 2003). Treatment in healthy individuals is by electrolyte replacement and rehydration, without the need for antibiotics. However, health risk groups may receive antibiotic therapy. Similar to *Campylobacter* spp., the increasing occurrence of antibiotic-resistant *Salmonella* spp. isolated from chicken meat is also now a major global concern (Newell et al., 2010). It is important to note that for both bacterial infections, continued faecal excretion of the bacteria may occur asymptomatically for an extended period after recovery, and some individuals may become carriers (Jay et al., 2003). Although unaffected, asymptomatic carriers of *Campylobacter* spp. and *Salmonella* spp. may transmit the bacteria during food handling, highlighting the need for effective hand hygiene (Jay et al., 2003).

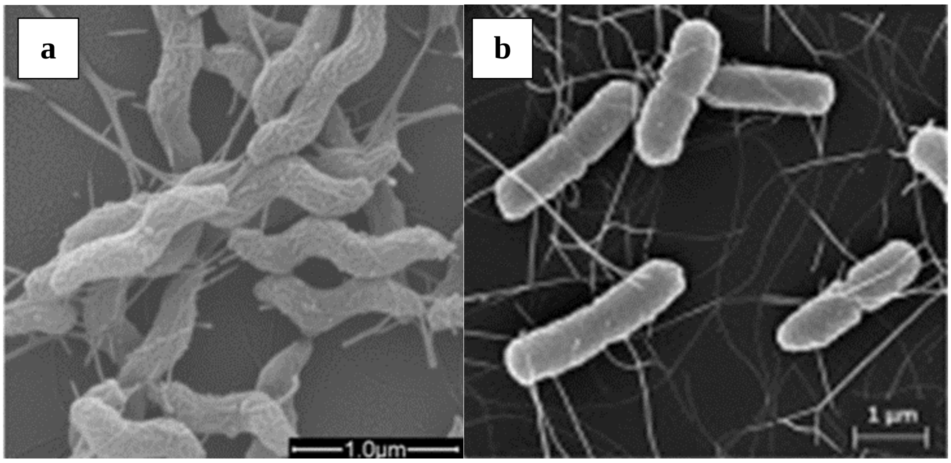


Figure 2.7: Scanning electron micrographs of *Campylobacter jejuni* (a) and *Salmonella* Typhimurium (b) cells (Spöring et al., 2018; Xie, He, Irwin, Jin, & Shi, 2011)

It is believed that infections by *Salmonella* spp. leading to severe gastroenteritis are more common in developing countries but rarely reported. In instances where foodborne disease outbreaks are reported, they are usually improperly investigated. The National Institute for Communicable Diseases (NICD) reviewed the reported foodborne disease outbreaks during the period 2013 - 2017 in South Africa (NICD, 2018). It was found that *Salmonella* spp. were most commonly isolated from stool (19.7%) and food samples (11.4%). Unfortunately, the specific foods associated with the outbreaks were not specified in the report. It was highlighted, however, that one of the major limitations of the study was failure by the NICD to obtain detailed descriptions of the majority of the foodborne disease outbreaks, particularly food exposure information. In another South African study, Muvhali et al. (2017) reported *S.* Enteritidis outbreaks from the year 2013 - 2015. Again, the foodborne disease outbreaks under study were not fully described. Out of the seven *S.* Enteritidis outbreaks reported, only two were attributed to a food source (chicken meat and goat meat). Generally, ineffective monitoring and surveillance of foodborne diseases are prevalent in the African region (WHO, 2015a).

2.4.2 Psychrotrophic bacteria and chicken meat spoilage

The vast majority of bacteria that contaminate raw chicken meat are non-pathogenic. However, they are of importance because their growth leads to quality deterioration and sensory defects in chicken meat, specifically colour, odour and texture, resulting in product rejection by the consumer. High bacterial loads have a direct negative effect on the shelf-life of chicken meat. Microbial spoilage of raw chicken meat is complex and there are multiple spoilage mechanisms to which different spoilage bacteria can contribute depending on the storage temperature, packaging conditions, product composition and storage period (Casaburi, Piombino, Nychas, Villani, & Ercolini, 2015). The groups of bacteria that become best adapted to the meat environment and outgrow others are referred to as specific spoilage organisms (SSOs) (Dainty, 1996). As is the case with pathogenic bacteria, frozen storage generally inhibits the reproductive capacity of spoilage bacteria regardless of the type of packaging (Coorey et al., 2018). During refrigerated storage of chicken meat, psychrotrophic bacteria are of particular importance because they are cold tolerant and thrive in the temperature range of 4 - 25 °C (Russell, 1990). The most extensively reported microbial spoilers of refrigerated chicken meat are *Pseudomonas* spp., *Brochothrix thermosphacta*, lactic acid bacteria (LAB) and different genera of the Enterobacteriaceae family (Doulgeraki, Ercolini, Villani, & Nychas, 2012; Ercolini et al., 2010; Pothakos, Devlieghere, Villani, Björkroth, & Ercolini, 2015). Survival and growth of these psychrotrophs during storage are greatly affected by the gaseous composition of the atmosphere surrounding the raw chicken meat.

2.4.2.1 *Pseudomonas* spp.

Pseudomonas spp. are gram-negative, rod-shaped and motile bacteria by one or multiple polar flagella. They are obligate aerobes, requiring oxygen to survive and replicate. Under aerobic conditions, *Pseudomonas* spp. invariably predominate spoilage of raw chicken during refrigerated storage (Hulankova, Borilova, Abdullah, & Buchtova, 2018; Mikš-Krajnik, Yoon, Ukuku, & Yuk, 2016; Vasconcelos et al., 2014). *P. fluorescens, P. fragi, P. putida* and *P. lundensis* were reported to be the most frequently found species (Arnaut-Rollier, De Zutter, & Van Hoof, 1999; Bruckner, Albrecht, Petersen, & Kreyenschmidt, 2012; Wickramasinghe, Ravensdale, Coorey, Chandry, & Dykes, 2019). *Pseudomonas* spp. are ubiquitous, commonly found in soil, water and plants, and thus originate from the live chicken environment.

It is now well established that there are three groups of *Pseudomonas* spp. growth substrates, namely (i) compounds in the glycolytic pathway such as glucose, glucose-6-phosphate, pyruvic acid and lactic acid, (ii) metabolic products such as gluconate-6-phosphate, and (iii) nitrogen energy sources such as amino acids and proteins (Nychas, Skandamis, Tassou, & Koutsoumanis, 2008). In general, glucose, lactic acid, certain amino acids, nucleotides and water-soluble proteins are catabolised by almost all spoilage bacteria (Doulgeraki et al., 2012). The concentration of these and other compounds in raw chicken affects the type of bacterial spoilage, e.g., saccharolytic or proteolytic (Dainty, 1996; Lin et al., 2004). It is proposed that spoilage by *Pseudomonas* spp. generally occurs by sequential utilisation of substrates in meat. Glucose was found to be the most preferred energy source and a precursor of other microbial growth substrates in refrigerated meat under aerobic, MAP or vacuum packaging, despite its negligible quantity with respect to proteins (Alexandrakis, Brunton, Downey, & Scannell, 2012;

Nychas, Dillon, & Board, 1988). Alexandrakis, Brunton, et al. (2012) observed that the surface concentrations of glucose decreased significantly by about 77% after aerobic storage of raw chicken fillets at 4 °C for eight days. Once the concentration of glucose on the chicken meat surface is depleted, *Pseudomonas* spp. metabolise secondary substrates such as lactic acid and amino acids. It is widely confirmed that the switch by *Pseudomonas* spp. from a saccharolytic to amino acid catabolism leads to the characteristic physical and chemical changes associated with spoiled chicken meat (Dainty, 1996; Lin et al., 2004).

2.4.2.2 Lactic acid bacteria, Enterobacteriaceae and *Brochothrix thermosphacta*

LAB such as *Lactobacillus* spp., *Carnobacterium* spp. and *Leuconostoc* spp. are predominantly involved in the spoilage of chicken meat stored in modified atmosphere packaging (MAP) and vacuum packaging (Höll, Behr, & Vogel, 2016; Koort et al., 2005; Susiluoto, Korkeala, & Björkroth, 2003). *B. thermosphacta* is another important spoilage bacterium found in refrigerated chicken meat stored in MAP and vacuum packaging (Höll et al., 2016). Both LAB and *B. thermosphacta* are anaerobic but aerotolerant. Hence, they contribute to spoilage in chicken meat under aerobic conditions as well (Mikš-Krajnik et al., 2016; Vasconcelos et al., 2014). Regarding the chicken meat spoilage potential of Enterobacteriaceae, *Serratia liquefaciens*, *Enterobacter agglomerans* and *Hafnia alvei* were identified as the most important species (Samelis, 2006). Among the Enterobacteriaceae, *S. liquefaciens* was found in chicken meat stored in air, MAP or vacuum packaging. *H. alvei* was frequently isolated from MAP or vacuum packaged chicken meat while *Enterobacter agglomerans* was found in chicken stored aerobically or in MAP (Lee, Kwon, Heo, Kim, & Kim, 2017; Säde, Murros, & Björkroth, 2013). Under aerobic conditions, these other spoilage bacteria tend to grow relatively slowly and are thus out-competed by *Pseudomonas* spp. The order in which substrates are catabolised by the raw chicken meat spoiling bacteria is summarised in Table 2.3.

Table 2.3: Substrates used by psychrotrophic bacteria during raw chicken meat storage under aerobic conditions, vacuum packaging (VP) and modified atmosphere packaging (MAP) (Casaburi et al., 2015)

Substrates[1]	***Pseudomonas* spp.**		**Enterobacteriaceae**		***Br. thermosphacta***		**Lactic acid bacteria**	
	Aerobic	**MAP and VP**	**Aerobic**	**MAP and VP**	**Aerobic**	**MAP and VP**	**Aerobic**	**MAP and VP**
Glucose	1	1	1	1	1	1	1	1
Glucose-6-P	2	2	2	2	2	2	2	2
Lactic acid	3		3					
Pyruvic acid	4	3						
Gluconic acid	5	3						
Gluconate-6-P	6							
Acetic acid		3		3				
Amino acids	7	3	4		3			3
Ribose					4			
Glycerol					5			

[1]Numbers indicate the order of substrate utilisation by spoilage bacteria

2.4.2.3 Sensory defects associated with spoilage bacterial growth

During the logarithmic phase of spoilage bacterial growth in refrigerated raw chicken meat under aerobic conditions, glucose metabolism results in the formation of a complex mixture of short-chain fatty acids, ketones and alcohols, none of which are malodorous (Dainty, 1996). The commonly identified non-malodorous volatile organic compounds include butanol, acetoin, butanoic acid and ethyl esters. These inoffensive odours were mainly described as ‘dairy’ and ‘fruity’. It is widely proposed that malodorous compounds are formed after the post-glucose utilisation of amino acids, particularly the sulphur-containing amino acids such as methionine, cystine and cysteine, by mainly *Pseudomonas* spp. (Senter, Arnold, & Chew, 2000). The detected offensive organic compounds include acetic acid, hydrogen sulphide, dimethyl sulphide, dimethyl disulphide, dimethyl trisulphide, phenyl sulphide, carbon disulphide, methyl thioacetate, methyl benzoate, 3-methyl-1-butanol, heptane, hexanal and toluene

(Alexandrakis, Brunton, et al., 2012; Lovestead & Bruno, 2010; Mikš-Krajnik et al., 2016; Senter et al., 2000). The contribution of different classes of volatile organic compounds such as fatty acids, aldehydes, ketones, alcohols, esters, sulphur and nitrogen compounds to the olfactory characteristics of raw chicken during refrigerated storage was reported by Mikš-Krajnik et al. (2016). Each of the chemical contributors become more or less dominant depending on the abundance of bacterial species and strains in the meat matrix, and the storage period.

Once amino acids have been depleted and bacterial cells enter the stationary growth phase, it has been proposed that bacterial proteolysis and lipolytic activity occur by the production of extracellular enzymes by *Pseudomonas* spp. (Dainty, 1996). Extracellular lipases decompose lipids and produce free fatty acids and ketones, thus further contributing to the characteristic malodorous odours. Sliminess or slippery texture generally occurs shortly after the appearance of off odours and is attributed to the bacterial synthesis of exopolysaccharides (Vihavainen & Björkroth, 2010). The ability of *Pseudomonas* spp. to produce proteases and lipases is partly the reason they become dominant in the long run.

In MAP and vacuum packaged meat, typical sensory changes caused by LAB spoilage include sour off odours, the formation of CO_2 resulting in bulging of packages, slime formation and discolouration (Nychas et al., 2008). Generally, LAB do not produce malodorous odours. Similar to *Pseudomonas* spp., Enterobacteriaceae particularly *S. liquefaciens* and *H. alvei*, are capable of producing hydrogen sulphide, malodorous diamines (putrescine and cadaverine) and green discolouration in meat (Kameník, 2013). During aerobic metabolism, *B. thermosphacta* mainly produces acetic acid, butyric acid, acetone, alcohols and a range of fatty acids while lactic acid is the major product in anaerobic packaging (Samelis, 2006). Commonly occurring volatile organic compounds in refrigerated raw meat and their descriptions are presented in Table 2.4. The odour descriptions were developed using model chemical solutions.

Table 2.4: Commonly identified malodorous and non-malodorous volatile organic compounds in raw meat during refrigerated storage and the odour descriptions (www.thegoodscentscompany.com, as cited in Casaburi et al. (2015))

Odour compound	Odour description
Alcohols	
Butanol	Fruity
3-Methyl-1-butanol	Fermented, alcoholic, pungent
1-Octanol	Waxy, floral with a sweet, fatty, coconut nuance
1-Octen-3-ol	Mushroom, oily, vegetative and fungal
2-Octen-1-ol	Green vegetable
2-Ethyl-1-hexanol	Citrus, fresh, floral, oily, sweet
2,3-Butanediol	Fruity, creamy, buttery
1-Hexanol	Pungent, fruity and alcoholic, sweet
Heptanol	Musty, pungent, fruity nuances of apple, banana
Phenylethyl alcohol	Floral, rose, dried rose, rose water
Aldehydes	
Hexanal	Fresh, fatty, leafy, fruity, sweaty
Nonanal	Waxy, rose fresh, orange peel, fatty, cucumber
Heptanal	Fresh, fatty, herbal, wine-lee
Benzaldehyde	Strong, sharp, sweet, bitter, almond, cherry
Ketones	
Acetoin	Buttery, creamy, dairy, milky, fatty sweet
Diacetyl	Strong, butter, sweet, creamy, pungent, caramel
3-Octanone	Musty, mushroom, moldy and cheesy, fermented
2-Butanone	Acetone-like, ethereal, fruity, camphor
2-Heptanone	Cheesy, creamy, fruity, spicy, sweet, herbal
Esters	
Ethyl acetate	Fruity, grape, sweet, weedy, green
Ethyl butanoate	Fruity, juicy, fruit pineapple
Ethyl - methyl butanoate	Fruity, sweet, apple, pineapple
Ethyl octanoate	Fruity wine, waxy, sweet, apricot, banana
Ethyl hexanoate	Sweet, fruity, pineapple, waxy, green, banana
Ethyl decanoate	Sweet, waxy, fruity, apple, grape
Volatile fatty acids	
Acetic acid	Pungent, acidic, cheesy, vinegar
Butanoic acid	Sharp, acetic, cheese, butter, fruit
Hexanoic acid	Sour, fatty, sweat, cheese
Nonanoic acid	Waxy, dirty, cheese, cultured, dairy
2- Methyl butanoic acid	Pungent, acid, Roquefort cheese
3- Methyl butanoic acid	Sour, stinky feet, sweaty, cheese
Sulphur compounds	
Dimethyl sulphide	Sulfurous, onion, vegetable cabbage, tomato
Dimethyl disulphide	Sulfurous, vegetable, cabbage, onion
Dimethyl trisulphide	Sulfurous, cooked onion, savory, meaty
Methyl thioacetate	Sulfurous, eggy, cheesy, vegetable cabbage

2.4.2.4 Descriptive sensory profiling of raw chicken meat

Descriptive sensory analyses are conducted to provide detailed word descriptions of food (sensory attributes). They involve the identification, description and quantification of sensory attributes of food by a trained panel (Meilgaard, Carr, & Civille, 2015). Descriptive sensory analyses can assist food processors at almost every stage, including research and development, quality control, defining product attributes, product comparison and shelf life studies (Lawless & Heymann, 2010).

According to Casaburi et al. (2015), there are fewer studies on descriptive sensory profiling of raw meat in comparison with cooked meat presumably because meat is generally consumed after cooking. Several studies have conducted descriptive sensory analyses of chicken meat with objectives other than quality analysis at the final cooking phase for consumption. Franke, Höll, Langowski, Petermeier, and Vogel (2017) investigated the sensorial quality of raw chicken breasts packaged under two different modified atmospheres during storage at 4 °C with the objective to relate with SSOs. The panel described the visual impression of the chicken breasts as gloss, smeary, red and grey and the olfactory impression as spoiled, pungent, bloody, cheesy, plastic, oily, butter-like, sourish, fermented, honey-like, fruity, bad egg and fishy. The results showed that the composition of the modified atmospheres affected the sensory perception. The chicken meat packaged in CO_2 (30%) was characterised by a sensorial longer shelf life, than the one stored in CO_2 (15%). Other studies have applied descriptive sensory analysis to determine the impact of chicken diets, processing methods such as decontamination treatments using chemicals or radiation, and bioactive ingredients on the sensory quality of raw chicken meat products. Meredith, Walsh, McDowell, and Bolton (2013) examined the sensory impact of dipping and spraying artificially contaminated raw chicken legs (skin-on) and fillets (skin less) with trisodium phosphate, lactic acid, citric acid, peroxyacetic acid and acidified sodium chlorite. Six attributes were identified by the assessors for raw chicken (skin - dry, moist, thin, thick; odour - fresh poultry, off odour; colour and shine). There were no significant differences between the treatments for any of the attributes measured in raw drumsticks and fillets, except for the visual colour of fillets treated with both trisodium phosphate (14%, w/v) and citric acid (5%, w/v) which was significantly lighter than that of control samples. Polyphenolic-rich plants have become of interest in enhancing the nutritional properties and shelf life of meat. Upon treating ground chicken breasts and thighs with grape seed extract (0.1%, w/w), Brannan (2009) analysed the sensory changes that occurred during 12 days of refrigerated storage. The developed sensory profile consisted of six descriptors, namely chicken brothy, fishy, sulphury, musty, rancid and overall surface colour. In ground chicken breasts, grape seed extract significantly inhibited the intensity of musty and rancid odour but altered the visual colour during refrigerated storage, compared to control patties. In ground chicken thighs, grape seed extract did not reduce any of the negative sensory odour and had a negative effect on visual colour. Regarding modification of chicken diets, Ruiz, Guerrero, Arnau, Guardia, and Esteve-Garcia (2001) evaluated the sensory effect of supplementing diets of chickens with different fat sources (lard, sunflower oil and refined olive oil) and antioxidants (α-tocopheryl acetate and β-carotene). The resulting raw chicken legs were described as having white, yellow, pink and dark colour with rancid, raw and bloody odours, and fat with hard texture. The main differences detected between treatments were visual attributes. Broilers supplemented with β-carotene had lower values in white to yellow skin colour, lightness to darkness of meat, and colour uniformity of meat compared to the other treatments.

2.4.3 Sources and contamination routes along the chicken value chain

Pathogenic and spoilage bacterial contamination of chicken may occur during any of the steps in the farm-to-table continuum from animal, environmental or human sources and increase the risk of foodborne illnesses and chicken meat spoilage at the consumer level.

2.4.3.1 Chicken processing plant

Generally, broiler chickens arrive at processing plants carrying high numbers of different bacteria, both externally and in the alimentary tract (WHO/FAO, 2009). During chicken processing, it is recognised that the microbial load of chickens is progressively reduced. However, because of the proximity of carcasses on the processing line and the nature of processing operations, it was established that several opportunities exist for bacterial contaminants to spread among the carcasses (Rouger, Tresse, & Zagorec, 2017). Each processing step can influence the levels of both spoilage and pathogenic bacteria on the exterior of chicken carcasses. A schematic of typical operations in a chicken processing plant is presented in Figure 2.8. During the successive steps, scalding, defeathering, evisceration, washing, chilling, portioning and secondary processing have been considered as potential routes of *Salmonella* spp., *Campylobacter* spp. and spoilage bacteria transmission (Rouger et al., 2017). Additionally, air, equipment and chicken meat handlers can also be sources of contamination.

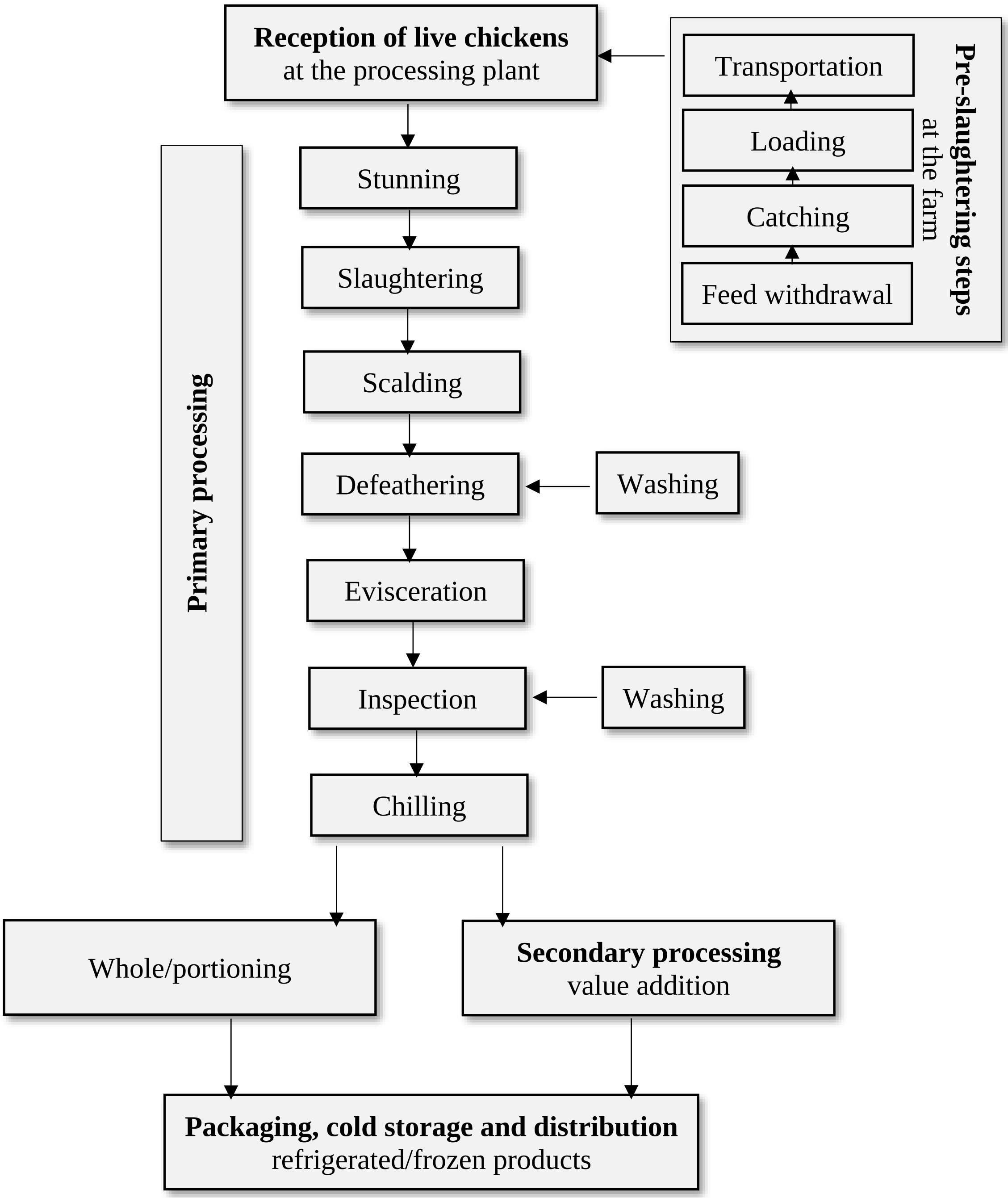


Figure 2.8: Typical unit operations in a chicken processing plant (Sams & McKee, 2010)

After stunning, slaughtering and bleeding, chicken carcasses are immersed in a scald tank. The primary purpose of scalding is to facilitate the removal of feathers. Scalding temperatures differ depending on whether chicken carcasses are to be soft (50 - 53 °C), medium (54 - 58 °C) or hard scalded (59 - 61 °C) (Fernandez-Lopez, Sendra-Nadal, & Sayas-Barbera, 2010). These water temperatures have important implications for the survival of pathogenic and spoilage bacteria. During scalding, faeces and dirt from chicken feathers and feet are released into the water and contaminate it. At low temperatures (50 - 53 °C), spoilage and pathogenic bacteria may remain viable and the water becomes a source of contamination for subsequent birds unless it is continuously replaced (Barbut, 2016). After changing scald water only once per day, Abu-Ruwaida, Sawaya, Dashti, Murad, and Al-Othman (1994) reported a significant increase in *Salmonella* spp., *Campylobacter* spp., *E. coli* and *S. aureus* levels following scalding of chickens at 51.5 - 53 °C at a modern commercial processing plant. It was concluded that immersion scalding at low temperatures could be a hazardous operation, particularly in cases where there is an inadequate flow of fresh water into the scald tank (example shown in Figure 2.9a). Nonetheless, although hard scalding (59 - 61 °C) leads to a more significant reduction in bacteria, Slavik, Kim, and Walker (1995) demonstrated that it causes modifications to the chicken skin by damaging the epidermal layer, thereby exposing a new skin surface. The authors proposed that the new skin surface, with microscopical channels and crevices, allows higher attachment of bacteria during subsequent processing steps. The attached bacteria could be more difficult to remove by decontamination procedures later on. Furthermore, it has been reported that increased amounts of faecal material in scald water results in a decrease in the water pH because of the presence of uric acid, and thus may influence heat resistance of *Salmonella* spp. and *Campylobacter* spp. (Pacholewicz, Lipman, Swart, Havelaar, & Heemskerk, 2016). Both *Salmonella* spp. and *Campylobacter* spp. are most heat resistant at neutral pH (6.5 - 7.5) (USDA-FSIS, 2015).

The next step, defeathering, is considered as a major source of cross-contamination. Rotating rubber fingers used to remove feathers from scalded chickens can easily become contaminated if they are not regularly cleaned, disinfected and replaced when worn out. Bacteria could attach onto the rubber fingers and contaminate carcasses as they move through the defeathering line.

Arnold (2007) investigated the bacterial load on defeathering rubber fingers from three commercial plants before, during and after processing. The author found that, for the three plants, bacterial loads on the rubber fingers varied significantly with processing time. Counts as high as 7.33 CFU/disk were recovered after processing. In another study by Abu-Ruwaida et al. (1994), *Campylobacter* spp. and *E. coli* loads on chicken carcasses increased significantly to 5.5 and 4.8 CFU/g, respectively, after the defeathering step. It was suggested that carcass-to-carcass contamination could also be a contributing factor, as chicken carcasses are always close to each other in the feather picking machines. Importantly, the rotating movements of defeathering fingers could cause considerable dispersion of bacteria in all directions in the machine through the generation of aerosols (Rouger et al., 2017).

During evisceration, there is a higher risk of *Salmonella* spp. and *Campylobacter* spp. contamination of carcasses, especially when the viscera rupture (example shown in Figure 2.9b). These bacterial pathogens occur in relatively high numbers in the gastrointestinal tract of infected birds (Altekruse et al., 1999; Antunes, Mourão, Campos, & Peixe, 2016). Besides contaminating the affected bird, the contents of the damaged viscera may also leak onto underlying carcasses. It was established that mis-cuts and rupturing of intestines commonly arises when the evisceration machines are unable to adjust to the natural variation in carcass size within and between flocks (Projahn et al., 2018). Additionally, failure to thoroughly clean and sanitise evisceration machines between shifts could lead to the build-up of bacteria and eventually cause cross-contamination. In semi-automated production processes, bacterial contamination may also be due to handling of carcasses during manual transfer from the defeathering to evisceration line (USDA-FSIS, 2015). After evisceration, carcasses are washed and chilled. Spray washing poses the risk of generation of aerosols that can disseminate bacteria to other carcasses. Interestingly, Wang, Li, Slavik, and Xiong (1997) found that very high spray pressure (above 800 kPa) may actually force bacteria deep into the skin of carcasses rather than washing it off. On the other hand, carcass washing using immersion tanks may cross-contaminate carcasses that were initially pathogen-free. Similarly, air or cold water used for chilling can act as cross-contamination vehicles between carcasses if hygiene conditions are not adequately maintained (USDA-FSIS, 2015). There is also the possibility of bacterial growth if the carcasses are not rapidly chilled to 4 °C or lower.

After primary processing, chicken meat may be subjected to further processing (value addition). It may thus be potentially exposed to bacterial contamination from contact with equipment, work surfaces, food ingredients and the hands of chicken meat handlers (Buncic & Sofos, 2012). After analysing all the chicken processing operations, Abu-Ruwaida et al. (1994) and Goksoy, Kirkan, and Kok (2004) concluded that the highest levels of both spoilage and pathogenic bacteria were detected after scalding and defeathering of carcasses. The next most critical step was evisceration. In contrast, Mpundu, Munyeme, Zgambo, Mbewe, and Muma (2019) found the highest levels of *E. coli* and *Salmonella* spp. downstream after carcass washing, and this was due to excessive reuse of water. Therefore, it is widely acknowledged that individual chicken processing plants may perform the aforementioned operations differently and to different hygiene levels. Thus, there is variation in the reported prevalence and levels of spoilage and bacterial pathogens in final chicken carcasses at the end of processing among countries (Goncalves-Tenorio, Silva, Rodrigues, Cadavez, & Gonzales-Barron, 2018).

Figure 2.9: Examples of chicken processing situations that potentially result in highly contaminated products. Carcasses immersed in a scald tank with excessive faecal material due to inadequate fresh water flow (a) and faecal contamination on the carcass tail area due to ruptured viscera (b) (USDA-FSIS, 2015).

2.4.3.2 Distribution, storage and retail

After freezing or refrigeration, the packaged raw chicken meat products are stored briefly at the processing plant or immediately dispatched for retail. At this post-processing phase of the food chain, maintenance of the chicken meat cold chain is critical to preserve its safety and quality. Most bacterial pathogens are characterised as mesophilic, that is, they are adapted to moderate temperatures with optimal growth conditions ranging from about 15 - 45 °C (ICMSF, 1996). The temperature conditions to which the products are exposed during truck loading, transport, delivery and retail can influence bacterial contamination levels of individual raw chicken meat products by the time consumers purchase them. During product transportation, heterogeneity of airflow within refrigerated trucks has been reported as one of the challenges. Raab et al. (2008) investigated temperature fluctuations, using data loggers, within a refrigerated truck during transportation of raw chicken breasts over 11 hours. Temperature measurements at different locations within the truck showed fluctuations between -5 and 15 °C. The highest temperature was detected close to the truck door. Furthermore, measurements of the core temperature of chicken breasts placed at different heights on a single pallet in the truck (at the top, middle and bottom) revealed that more temperature fluctuations occurred at the top level. However, higher temperatures were observed for chicken breasts located at the middle and bottom levels. Additionally, it was highlighted that delayed loading and unloading of chicken meat in unrefrigerated delivery areas contribute to a disrupted cold chain.

Chicken meat retailers represent the front line of the chicken industry to consumers. Cold storage, particularly refrigerated storage, at retail points is considered as the most inefficient step in the cold chain of raw chicken meat. Open display cabinets are commonly used in supermarkets, butcheries and grocery stores for refrigeration of fresh chicken meat products, and to a lesser extent for frozen products. It was established that although open display cabinets have the benefit of being more appealing and allow unrestricted product access by consumers, they are not energy efficient (Kou, Luo, Ingram, Yan, & Jurick II, 2015). Temperature measurement studies indicate that display cabinet temperatures frequently rise above the ideal limit of 4 °C during refrigerated storage. Evans, Scarcelli, and Swain (2007) found that temperature abuse (> 4 °C) was prevalent for the majority of products (97%) placed at the front in open refrigeration cabinets, with products at the base (60%) being affected the most. This suggests that temperatures at the cabinet rear were colder than at the front. The technical challenge cited for open display cabinets was establishing thermostat settings for keeping raw chicken products at the front rows at the ideal temperature of 4 °C or lower, and products at the back above freezing temperatures. Mercier, Villeneuve, Mondor, and Uysal (2017) pointed out that some meat retailers tend to exacerbate the problem by overloading the front shelves of display cabinets or placing the shelves at the highest position to attract potential customers while jeopardising meat safety and quality. As aforementioned (section 2.4.1), numerous studies worldwide have reported a high prevalence of bacterial pathogens in both refrigerated and frozen raw chicken meat from retail. Contaminated raw chicken meat can result in a reduced product shelf life and foodborne infection or intoxication if improperly handled by consumers.

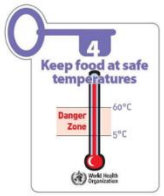
2.5 Food safety and quality at the consumer level

Consumers represent the ‘fork’ in the farm-to-fork food safety and quality continuum. Previous research, mostly in developed countries, suggests that most sporadic cases of foodborne illness are due to improper handling of food by consumers (Al-Sakkaf, 2013). Gustavsson, Cederberg, Sonesson, Van Otterdijk, and Meybeck (2011) estimated that 2% of the meat produced in SSA is lost at consumer level. This indicates that consumers are an integral part of the food chain, they represent the final step for the prevention of foodborne illnesses and food waste and have an active role to play to ensure food safety and quality. Failure by consumers to recognise that food safety and quality is a shared responsibility spanning from food production to the consumption stage at home can increase the risk of foodborne illnesses and food waste. Improper food handling by consumers can also negate efforts put by the food industry to minimise contamination and supply safe and good quality food.

The home is considered as the place associated with a significant risk of foodborne illnesses for several reasons. Firstly, although eating away from home has become increasingly common worldwide, it is believed that a higher proportion of food consumed by people is still prepared at home (Fiedler & Yadav, 2017). Secondly, many people are in population groups that are at higher risk of contracting foodborne illnesses. These include pregnant women, children under 5 years of age, the elderly, patients with HIV/AIDS, organ transplant recipients and cancer patients (Altekruse et al., 1999). For example, in 2018, about 8.5% of the population in South Africa was 60 years or older, 10% was less than 5 years old and about 13% were suffering from HIV/AIDS (STATS SA, 2019). This data suggests that at least 30% of the South African population were at high risk of contracting foodborne illnesses, as well as more severe illness outcomes. Thirdly, in some countries, there has been a dramatic shift in healthcare delivery whereby home-based health care is increasingly playing a role in complementing or replacing in-patient care (Mashau, Netshandama, & Mudau, 2016). It is estimated that 4.5 million patients were cared for at home in the USA in 2015 (CDC, 2016).

In response to the global increase in foodborne diseases, the World Health Organisation (WHO) initiated a public health campaign in 2015 entitled '*How safe is your food? From farm to plate, make food safe'* (WHO, 2015b). The campaign focused on raising awareness about the importance of every sector in the food chain in ensuring that food is safe to eat. Emphasis was also placed on the need for national governments and local organisations to improve food safety at the consumer level through consumer education. Globally relevant recommendations on how consumers can ensure food safety were also included in the campaign. The highlighted key principles to food safety were known as the 'Five keys to safer food'. The core messages of the 'Five keys to safer food' principles were to promote food safety through (i) keeping clean, (ii) separating raw and cooked food, (iii) cooking food thoroughly, (iv) keeping food at safe temperatures and (v) using safe water and raw materials. Generally, the WHO food safety principles apply to any foodstuff, particularly that which is identified as a major vehicle for pathogens such as chicken meat. Additionally, the principles also ensure preservation of food quality, particularly recommendations on temperature control. A summary of how the principles can be implemented by consumers and the rationale behind each one is presented in Table 2.5.

Table 2.5: The World Health Organisation key food safety principles, actionable steps and rationale behind each recommendation (Fontannaz-Aujoulat, Frost, & Schlundt, 2019)

Recommendation (key)	Actionable steps to achieve recommendation	Rationale behind recommendation
	Wash your hands with soap and water after going to the toilet Wash your hands with soap and water before, during and after food preparation Wash and sanitise all surfaces, equipment and utensils used for food preparation Protect kitchen areas from insects, pests and other animals	While most microorganisms do not cause disease, dangerous microorganisms are widely found in soil, water, animals and people. These microorganisms are carried on hands, wiping cloths, utensils and equipment, especially cutting boards and the slightest contact can transfer them to food and cause foodborne illness.
	Separate raw meat, poultry and seafood from other foods Use separate equipment and utensils such as knives and cutting boards for handling raw foods Store food in containers to avoid contact between raw and prepared foods	Raw food, especially meat, poultry and seafood and their juices, can contain dangerous microorganisms that may be transferred onto other foods during food preparation and storage (cross-contamination).
	Cook food thoroughly, especially meat, poultry, eggs and seafood Bring foods like soups and stews to boiling to make sure that they have reached 70 °C For meat and poultry, use a thermometer Reheat cooked food thoroughly	Proper cooking can kill almost all dangerous microorganisms. Studies have shown that cooking food to a temperature of 70 °C can help ensure it is safe for consumption. Foods that require special attention include minced meats, rolled roasts, large joints of meat and whole poultry.
	Do not leave perishable and cooked food at room temperature for more than 2 hours Refrigerate promptly all cooked and perishable food (below 5 °C) Keep cooked food hot (more than 60 °C) prior to serving Do not store food too long even in the refrigerator Do not thaw frozen food at room temperature	Microorganisms can multiply very quickly if food is stored at room temperature. By holding at temperatures below 5 °C or above 60 °C, the growth of microorganisms is slowed down or stopped. Some dangerous microorganisms still grow below 5 °C.
	Use safe water or treat it to make it safe Select fresh and wholesome foods Choose foods processed for safety, such as pasteurised milk Wash fruits and vegetables, especially if eaten raw Do not use food beyond its expiry date	Raw materials, including water and ice, may be contaminated with dangerous microorganisms and chemicals. Toxic chemicals may be formed in damaged and mouldy foods. Care in the selection of raw materials and simple measures such as washing and peeling may reduce risk.

2.5.1 Consumers' handling practices for chicken meat

The primary purpose of consumer food safety and quality research is to understand how consumers handle food at retail and in their homes, to establish what consumers know about food safety and quality and why some safe food handling practices are implemented but some are not (Redmond & Griffith, 2003). Once the risky food handling practices are established, educational programs are then designed to address them. For food safety and quality educational interventions to be most effective, they need to target correcting consumer practices that are most likely to result in foodborne illnesses and food waste (Redmond & Griffith, 2003). Moreover, a review by Al-Sakkaf (2013) established that food handling practices might differ by culture, gender, age, education level, income and other socio-demographic characteristics of consumers. Thus, the behavioural differences between various subpopulations must also be understood in order to communicate food safety and quality risks accordingly.

A frequently contaminated chicken meat supply potentially contributes to foodborne outbreaks and a high initial bacterial load increases the likelihood of meat spoilage. However, consumers' risky practices during purchasing, domestic storage and preparation of chicken meat, and lack of knowledge about food safety may exacerbate the problem (Käferstein, 2003). Several studies have assessed consumers' self-reported practices for handling chicken meat, whereas others have investigated actual chicken meat handling behaviour of consumers in model kitchens or their homes. Summaries of the findings of consumer studies on chicken handling practices based on self-reporting and actual observations are presented in Tables 2.6 and 2.7, respectively. Findings concerning consumer refrigeration practices for chicken meat revealed that many consumers do not place raw chicken on the bottom shelf of the refrigerator to prevent it from dripping down on prepared, ready to eat foods or foods eaten raw (Bruhn, 2014; Kosa et al., 2015; Murray et al., 2017). Additionally, many consumers were unaware of the standard temperature for refrigeration of chicken meat (4 °C) and did not know the temperatures of their refrigerators (Bruhn, 2014; Hoelzl et al., 2013; Nesbitt et al., 2009). As simple as hand washing may seem, several of the observational surveys reported that a large majority of consumers did not wash their hands with soap and water before and after handling raw chicken meat (Bruhn, 2014; DeDonder et al., 2009; Hoelzl et al., 2013; Kennedy et al., 2011; Maughan et al., 2016). Another commonly self-reported and observed food handling error was consumers reusing kitchen utensils that had been used to prepare raw chicken, such as cutting boards and knives, without adequate washing (Hessel et al., 2019; Kennedy et al., 2011; Koppel, Suwonsichon, Chitra, Lee, & Chambers, 2014; Koppel et al., 2015). Concerning food thermometers, the studies reported that many consumers do not use thermometers when cooking chicken meat to check for doneness (Bruhn, 2014; DeDonder et al., 2009; Hoelzl et al., 2013; Kennedy et al., 2011; Kosa et al., 2015; Maughan et al., 2016; Murray et al., 2017; Nesbitt et al., 2009). However, Kosa et al. (2015) proposed that educational programs should focus first on food thermometer ownership, as most consumers did not own one. According to the studies, maintenance of the chicken meat cold chain, hand washing, avoiding cross-contamination and using a thermometer when cooking chicken meat may be the main food handling principles that needed more attention during risk communication to the studied populations.

It is important to note that most of the aforementioned consumer studies were carried out in developed countries, particularly the USA and Canada. In the African region, there is limited published information on consumer studies on chicken handling practices. According to Mwamakamba et al. (2012), public health promotion campaigns using WHO's 'Five keys to safer food' principles were implemented in several African countries for food handlers in settings such as schools, hospitals, food markets, street vending sites and other food establishments. This may explain why there are numerous published studies focused on food handling practices in food establishments and not at the consumer level.

Table 2.6: Summary of results from surveys conducted in different countries on consumers' self-reported practices for handling chicken meat (2009 - 2019)

Consumers' self-reported risky chicken handling practices (%)		
Purchasing	**Thawing**	**Cross-contamination**
24% do not separate raw chicken from other food in grocery cart[5]	30% (Canada)[1]; 25% (USA)[5]; 37% (Brazil)[8] do not thaw frozen chicken in the refrigerator, cold water or microwave	6% (Canada)[1]; 24% (India), 32% (Korea), 30% (Thailand)[2]; 23% (Russia), 16% (Estonia), 24% (Italy), 39% (Spain)[4]; 6% (USA)[5]; 8% (Canada)[7]; 23% (Brazil)[8] do not wash chopping board with soap and water after cutting raw chicken
30% do not separate raw chicken from other food at check out[5]	49% thaw frozen chicken at room temperature[3]	81% (India), 71% (Korea), 51% (Thailand)[2]; 18% (Russia), 75% (Estonia), 61% (Italy), 85% (Spain)[4]; 69% (USA)[5]; 63% (USA), 98% (Colombia), 88% (Argentina)[6] wash raw chicken before cooking
14% took more than 2 hours to reach home after buying chicken[8]	12% do not cook chicken immediately after thawing[5]	49% do not have a separate chopping board for raw chicken meat[3]
Refrigeration	31% do not know that thawing chicken at room temperature is risky[7]	20% put raw chicken and cooked chicken on the same plate during barbecue[3]
65% do not know the ideal refrigeration temperature[1]	**Hand washing**	91% think washing completely removes bacteria from chicken meat[3]
83% do not know their refrigerator temperature[1]	33% do not always wash hands before handling raw chicken[1]	9% do not use a separate chopping board for raw chicken[7]
26% (India), 41% (Korea), 25% (Thailand)[2]; 26% (Russia), 54% (Estonia), 46% (Italy), 44% (Spain)[4]; 83% (USA)[5]; 73% (Canada)[7] do not place raw chicken on the bottom shelf	34% (India), 62% (Korea), 45% (Thailand)[2]; 35% (Russia), 50% (Estonia), 34% (Italy), 37% (Spain)[4]; 7% (Canada)[7] do not wash hands with soap and water after handling raw chicken	do not wash chopping board with soap and water after cutting raw chicken[8]
81% think refrigeration inactivates bacteria on chicken[3]	12% do not wash hands after handling raw chicken[5]	**Cooking**
29% refrigerate raw chicken for more than 2 days[5]		86% (Canada)[1]; 49% (Switzerland)[3]; 71% (Canada)[7] do not use a thermometer to check chicken doneness
19% do not refrigerate chicken within 2 hours[7]		38% do not own a thermometer[5]
		43% did not use a thermometer the last time they cooked chicken[5]
		15% did not know that eating undercooked chicken is risky[7]

[1](Nesbitt et al., 2009) - Canada study, 2332 consumers
[2](Koppel et al., 2014) - Asia study: India (115), Thailand (100), Korea (101)
[3](Bearth et al., 2014) - Switzerland study, 465 consumers
[4](Koppel et al., 2015) - Europe study: Italy (94), Russia (100), Estonia (113), Spain (102)
[5](Kosa et al., 2015) - USA study, 1504 consumers
[6](Koppel et al., 2016) - America study: USA (227), Colombia (98), Argentina (100)
[7](Murray et al., 2017) - Canada study, 2474 consumers; [8](Hessel et al., 2019) - Brazil study, 1217 consumers

Table 2.7: Summary of results from observational surveys conducted in different countries on consumers' practices for handling chicken meat (2009 - 2016)

Consumers observed following risky chicken handling practices (%)			
Purchasing	**Hand washing**	**Cross-contamination**	**Cooking**
3% took more than an hour to reach home after buying raw chicken[3] 85% did not separate raw chicken from other food in grocery cart[5] 29% did not separate raw chicken from other food at check out[5] **Refrigeration** 20% did not separate raw chicken from other food[3] 55% did not know their refrigerator temperature[3] 35% (Austria)[3]; 56% (USA)[4] did not know the ideal refrigeration temperature 73% did not place chicken on the bottom shelf[4] 36% of refrigerators were above 4 °C[4] 18% removed raw chicken from its original packaging before storage[5]	27% (USA)[1]; 85% (Ireland)[2]; 95% (Austria)[3]; 64% (USA)[4] did not wash hands with soap and water before handling raw chicken 59% (USA)[1]; 83% (Ireland)[2]; 65% (Austria)[3]; 38% (USA)[4] did not wash hands with soap and water after handling raw chicken 60% did not wash hands with soap and water after food preparation[6]	29% (USA)[1]; 52% (Ireland)[2] did not wash chopping board with soap and water after cutting raw chicken 69% did not wash knife with soap and water after cutting raw chicken[2] 65% did not discard the chicken packaging immediately after opening[3] 15% reused knife after cutting raw chicken without washing[3] 47% washed raw chicken before cooking[4]	93% (USA)[1]; 100% (Ireland)[2]; 97% (Austria)[3]; 95% (USA)[4]; 67% (USA)[6] did not use a thermometer to check chicken doneness 58% did not know the safe minimum temperature for cooking chicken[1] 40% (USA)[4]; 24% (USA)[6] of chicken was undercooked (below 74 °C)

[1](DeDonder et al., 2009) - USA study, 41 consumers
[2](Kennedy et al., 2011) - Ireland study, 60 consumers
[3](Hoelzl et al., 2013) - Austria study, 40 consumers
[4](Bruhn, 2014) - USA study, 120 consumers
[5](Donelan, Chambers, Chambers IV, Godwin, & Cates, 2016) - USA study, 96 consumers
[6](Maughan et al., 2016) - USA study, 101 consumers

2.5.2 Consumers' perceptions of the safety and quality of chicken meat

From a consumer behaviour perspective, perception is defined as "the process by which consumers select, organise and interpret product information or stimuli in order to apprehend and make decisions about that product" (Keast, 2009). Consumer quality and safety perceptions of food are fundamental to the food industry because these are linked to food choice and consumer demand (Troy & Kerry, 2010). A review by Korzen and Lassen (2010) established that consumer perceptions of food not only relate to the basic senses but to experience with the food and learned information about the food as well. Korzen and Lassen (2010) also described how consumer perceptions of meat might vary depending on the context, such as during purchasing, preparation at home and consumption at home.

Various theories on the consumer quality perception process have been proposed (Troy & Kerry, 2010). However, in all the proposed theories, the utilisation of product 'cues' or indicators by consumers during decision making has been taken into account (Troy & Kerry, 2010). The concept of cue utilisation in the quality perception process was introduced by Cox, 1962 (as cited in Olson and Jacoby (1972)). The concept was then modified and broadened by Olson and Jacoby (1972). The cue utilisation theory proposes that products consist of an array of cues which provide the basis for quality judgements by consumers (Olson & Jacoby, 1972). Cues can further be categorised as intrinsic or extrinsic to the product. The theory seeks to establish how product cues are selected by consumers and their relative importance in the quality perception process. It was proposed that intrinsic and extrinsic cues are utilised according to their predictive and confidence values. The predictive value (PV) was defined as "the extent to which consumers associate a given cue with product quality". In contrast, the confidence value (CV) refers to "the degree to which consumers are confident in their ability to accurately use and judge that cue". Hence, the higher the PV and CV of a cue, the more important it is to the consumer in the quality perception process and the greater effect it has on the final decision, and vice versa. Olson and Jacoby (1972) assumed that PV and CV have an interactive effect on the probability of cue utilisation by consumers, rather than an independent, additive effect. Similar to quality perception, consumers also use cues to predetermine the safety of food products, and this is also a hypothetical construct (Becker, Benner, & Glitsch, 2000; Glitsch, 2000). Cue utilisation studies provide valuable insight into consumer perceptions of the quality and safety of food products.

Since it is widely believed that consumers base their decisions on perceived product cues, the chicken meat industry must understand what the cues for chicken meat are and their importance to consumers. Several consumer surveys have investigated various intrinsic and extrinsic characteristics of chicken meat and their relative importance in evaluating the quality and safety of chicken meat. The identified cues and quality and safety assessment of chicken meat varied among countries (Table 2.8). However, for most of the surveys, colour was found to be more important as an indicator of chicken meat quality during purchasing, while price was less important. Perceived freshness seemed to play a significant role in indicating the safety of chicken meat during purchasing (Becker et al., 2000; Glitsch, 2000). During eating, flavour (Becker et al., 2000; Glitsch, 2000), taste (Sismanoglou & Tzimitra-Kalogianni, 2011) and tenderness (Imran, Kamarulzaman, Latif, & Mohd Nawi, 2014) were found to be relatively important to consumers. Interestingly, Irish consumers reported all the presented cues for eating quality of chicken meat to be equally important (Glitsch, 2000). The studies suggest that consumers consider more than one cue during the quality/safety perception process, and their perceptions are subjective and dissimilar among countries. Keast (2009) highlighted that, in addition to sensory factors, country differences in consumer quality and safety perceptions of food are highly influenced by differences in food production and processing technologies, food labelling, ethical concerns regarding animal welfare, culture, food traditions and situational factors.

Table 2.8: Summary of cues as indicators of quality and safety of chicken meat as assessed by consumers in different countries

Country of study (*n*)	Intrinsic and extrinsic cues in evaluating chicken meat			Reference
	Quality at place of purchase	Safety at place of purchase	Eating quality	
Ireland, Italy, Spain, Sweden, United Kingdom (500 consumers from each)	colour, leanness, place of purchase, country of origin, label, price	freshness, free-range, country of origin, feed, label, producer, price	flavour, smell, tenderness, colour, texture, leanness, gristle, juiciness	(Glitsch, 2000)
Germany (500 consumers)	place of purchase, country of origin, leanness, colour, label, price	freshness, free range, feed, country of origin, label, producer, price	flavour, smell, tenderness, juiciness, colour, leanness, texture, gristle	(Becker et al., 2000)
Greece (240 consumers)	feed, rearing method, country of origin, place of origin, price, retailing store, producer, brand, beautiful packaging	Not investigated	taste, odour, colour, texture, tenderness, leanness	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Indonesia (80 consumers)	Not investigated	smell, freshness, colour, texture, pesticide use, chemical processing, packaging, labels government licencing	Not investigated	(Yusuf, 2011)
Malaysia (569 consumers)	Not investigated	Not investigated	tenderness, springiness, colour, sweetness, fatty/oily taste, fibrousness, aroma, visible fat, size	(Imran et al., 2014)
Italy (93 consumers)	appearance, label, traceability, packaging type, retailing store, quality certification, leanness, organic, cooking usage, brand, price, breed, nutritional information	Not investigated	Not investigated	(Borgogno, Favotto, Corazzin, Cardello, & Piasentier, 2015)

2.6 Conclusions and research gaps

This review established that chicken meat plays a significant role as a source of animal protein in the diets of South Africans and populations across the globe. However, the processing, distribution and retailing of chicken meat can lead to contamination and growth of pathogenic and psychrotrophic spoilage bacteria, particularly *Salmonella* spp., *Campylobacter* spp. and *Pseudomonas* spp. Thus, contaminated chicken meat is a potential public health risk and high initial bacterial loads can lead to food spoilage. Unfortunately, consumer behaviour studies in different countries (mostly developed countries) show that a vast majority of consumers do not follow safe practices when handling raw chicken meat. Additionally, consumer behaviour studies reveal that consumers' perceptions of the safety and quality of chicken meat are not objective but subjective and are based on the sensory and non-sensory characteristics of chicken meat (cues), which can differ country wise. However, there is no information available on South African consumers' practices and knowledge on handling chicken meat, and perceptions of the safety and quality of chicken meat. A good understanding of consumers' practices and knowledge on handling chicken meat and perceptions of the safety and quality of chicken meat is critical in designing evidence and science-based public health campaigns to alleviate the risk of foodborne diseases and food waste in South Africa. Additionally, the link between consumers' practices and perceptions of the safety and quality of chicken meat and its microbial, chemical, physical and sensory characteristics still needs to be established and elucidated.

CHAPTER THREE

HYPOTHESES AND OBJECTIVES

3.1 Hypotheses

i. A large majority of the surveyed South African consumers will indicate risky chicken meat handling practices, a lack of food safety knowledge and inaccurate safety and quality perceptions.

   Consumer-based research studies, both self-report and observational, have shown that substantial numbers of consumers frequently implement improper handling practices for purchasing, storing and preparing chicken meat and exhibit a general lack of food safety knowledge (Bearth et al., 2014; Koppel et al., 2016; Kosa et al., 2015; Murray et al., 2017). Mismanagement of the chicken meat cold chain, cross-contamination, poor hygiene and undercooking of chicken meat were identified as the most significant areas of consumer non-compliance and unawareness. Furthermore, studies have proposed that consumers use attributes of chicken meat to infer the safety and quality (Becker et al., 2000; Borgogno et al., 2015; Glitsch, 2000), which do not reflect the accurate microbiological status of chicken meat (Henson & Northen, 2000).

ii. From a microbiological viewpoint, the colour of raw chicken meat will not be perceived as the most important sensory attribute for the assessment of quality and safety during purchasing and preparation at home by consumers.

   Aerobic bacterial growth plays a role in the discolouration of meat by reducing the level of oxygen in the surface tissue leading to the oxidation of myoglobin, resulting in the formation of metmyoglobin (Mancini & Hunt, 2005; Suman & Joseph, 2013). This pigment gives meat a brown-red colour. Further utilisation of oxygen by bacteria decreases the oxygen partial pressure at the meat surface and promotes the formation of deoxymyoglobin, resulting in purple-red meat colour (Mancini & Hunt, 2005). However, myoglobin concentration in raw chicken meat muscle is relatively low (Miller, 2002), thus these phenomena may not be visually apparent to consumers.

iii. Consumers’ handling practices and knowledge levels on temperature related factors affecting bacterial growth in chicken meat will reflect a potential risk of undesirable pathogenic and spoilage bacterial growth in chicken meat.

Management of the chicken meat cold chain and chicken meat safety and quality are intimately linked. It was established that one of the weakest points in the food chain with regard to temperature control is at the consumer level (Mercier et al., 2017). Several consumer behaviour studies have reported insufficient knowledge about temperature control and breaking of the chicken meat cold chain by a substantial proportion of consumers (Bearth et al., 2014; Bruhn, 2014; Hoelzl et al., 2013; Nesbitt et al., 2009). This can result in excessive growth of both pathogenic and spoilage bacteria, potentially leading to food safety risk and undesirable physicochemical and sensory changes.

3.2 Objectives

i. To assess South African consumers’ handling practices, food safety knowledge levels, and safety and quality perceptions with respect to raw chicken meat and to identify risks to meat safety and quality.

ii. To characterise the odour and appearance attributes of raw chicken meat during refrigerated storage under aerobic packaging and to establish the relationship with microbial, pH and instrumental colour changes.

iii. To establish and elucidate the relationship between consumers’ perceptions, handling practices and sensory, microbial, pH and instrumental colour characteristics of chicken meat.

CHAPTER FOUR

Assessment of safety risks associated with handling chicken meat as based on practices and knowledge of a group of South African consumers

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4.1 Abstract

Chicken meat has been identified as one of the most important food vehicles for pathogens, particularly *Salmonella* spp. and *Campylobacter* spp. Consumer food safety knowledge and behaviour can substantially contribute to the prevention of foodborne illness. The main objective of this study was to assess the practices and knowledge of a group of South African consumers with respect to handling raw chicken meat, and the associated safety risks with the aim of reducing the risk of foodborne illness at the consumer level. Data were collected through a web-based cross-sectional survey (n = 863). The survey respondents consisted of consumers responsible for buying raw chicken meat and preparing meals in their households. Results showed that a substantial proportion of consumers do not handle raw chicken correctly during purchasing (55%) and thawing (44%); and do not wash their hands correctly before (31%) and after (36%) handling raw chicken. With regard to consumers' knowledge on factors affecting the safety of chicken meat, 48% of the respondents believed that refrigeration prevents the growth of bacteria in raw chicken, 93% did not know the maximum safe temperature for refrigerating raw chicken, 26% would refreeze raw chicken once thawed and 45% indicated that chicken that looks and smells fresh could not make them sick. Although the majority of consumers (at least 85%) indicated concerns about the safety risks associated with chicken meat, only 38% were rated as following good practices and 28% as having good knowledge about factors affecting the safety of chicken meat. Overall, consumers aged 40 years and older reported following more safe chicken handling practices and had more knowledge thereof than consumers below 40 years. The findings reflect safety risks related to consumers' knowledge and practices when handling chicken meat and highlight the need for consumer education. Targeted communication of safe chicken handling guidelines to prevent temperature abuse of chicken meat, transmission of pathogenic bacteria and cross-contamination are needed.

4.2 Introduction

In South Africa, there is great reliance on poultry meat as the main source of animal protein (Ncube, 2018). According to the South African Poultry Association (SAPA), 2.2 million tonnes of poultry meat were consumed in South Africa in 2016, of which approximately 98% was chicken meat (SAPA, 2017). In fact, over the past decade more chicken meat has been consumed than beef, pork, mutton and goat combined (SAPA, 2017). Unfortunately, raw chicken meat is recognised as an important reservoir for *Campylobacter* spp. and *Salmonella* spp., which are human pathogens (WHO/FAO, 2009). The prevalence of these bacterial pathogens in raw chicken meat both at processing and retail level in South Africa has been reported (Mabote et al., 2011; Olobatoke & Mulugeta, 2015; Rani, Hugo, & Muchenje, 2013; Van Nierop et al., 2005; Zishiri et al., 2016). Even though data on the epidemiology of salmonellosis and campylobacteriosis specifically due to contaminated chicken is scarce, the health risk is considered to be significant (WHO/FAO, 2009).

In general, foodborne illnesses are an important public health challenge globally (WHO, 2015a). The South African National Institute for Communicable Diseases (NICD) defines a foodborne disease outbreak as "a food poisoning incident involving two or more people epidemiologically linked to a common food or beverage source" (NICD, 2012). In 2016, 85 foodborne disease outbreaks were reported to the NICD. In total, 2096 people were affected, leading to 1651 hospital visits, 139 hospitalisations and 12 deaths (NICD, 2018a). The devastating listeriosis outbreak which occurred recently in South Africa whereby 1038 confirmed cases and 208 deaths were reported during the period January 2017 to May 2018 (NICD, 2018b) further highlights the need for good food safety practices. It is generally accepted that the actual prevalence and incidence of foodborne illness is markedly higher than the documented data mainly due to under-reporting and limited surveillance capacity, especially in developing countries (Jahan, 2012).

The emergence of foodborne illness has been mostly attributed to a contaminated food supply, mishandling of products at manufacture and food service facilities (Käferstein, 2003). Consumers' limited knowledge concerning microbial food hazards, unsafe food handling at home and risky consumption behaviours also adds to the incidence of foodborne illness (Käferstein, 2003). Food handlers, including those in charge of food preparation in the home, are considered the last and most critical 'line of defence' for preventing the occurrence of foodborne illness (Murray et al., 2017). In 2015, the World Health Organisation (WHO) launched a campaign urging governments to improve food safety by educating the general public on proper food handling, storage and preparation practices (WHO, 2015b). Raising consumer food safety awareness, particularly targeting foods that are widely consumed and those identified as major vehicles for pathogens, could prevent or minimise food poisoning cases.

Previous studies in developed countries have gained insight into consumers' level of food safety practices and knowledge on poultry meat and identified gaps that may pose health risks (Bearth et al., 2014; Bruhn, 2014; Donelan et al., 2016; Koppel et al., 2015; Kosa et al., 2015). In South Africa, research on food handlers' practices and knowledge relating to food safety has largely focused on ready-to-eat street-vended food and street vendors (Asiegbu, Lebelo, & Tabit, 2016; Campbell, 2011; Hill, Mchiza, Puoane, & Steyn, 2018; Kok & Balkaran, 2014; Lues, Rasephei, Venter, & Theron, 2006; Mjoka & Selepe, 2017), and food service personnel in delicatessen sections of retail outlets (Human & Lues, 2012; Van Tonder, Lues, & Theron, 2007), academic institutions (Sibanyoni, Tshabalala, & Tabit, 2017) and fast food outlets (Murwira, Nemathaga, & Amosu, 2015). Consequently, information on consumers' level of food safety practices and knowledge on chicken meat is limited. Therefore, the objective of this study was to assess the practices and knowledge levels of a subset of South African consumers with respect to the handling of raw chicken meat and to identify safety risks, consumers' concerns and areas requiring intervention to prevent or limit risks. The aim of this study was to reduce the risk of foodborne illness at the consumer level.

4.3 Materials and methods

4.3.1 Questionnaire design

A structured questionnaire was designed by modifying questions from existing surveys by Bearth et al. (2014), Jevšnik, Hlebec, and Raspor (2008), Koppel et al. (2015) and Kosa et al. (2015). Ten consumers, recruited via convenience sampling, were asked to verbalise their understanding of questions and response options to determine if these were as intended (Haeger, Lambert, Kinzie, & Gieser, 2012). The questionnaire was revised accordingly. The online questionnaire was reviewed to determine ease of selection of response options and logic of branched questions. An online pilot test to verify the functionality of the questionnaire and estimate the survey completion time was then conducted with 94 participants. The questionnaire was finalised on the basis of the pilot study results. The final questionnaire obtained information on (i) consumers' self-reported practices when handling raw chicken from retail to the home, (ii) consumers' knowledge of factors affecting the safety of raw chicken, (iii) consumers' concerns about safety risks linked to handling chicken meat in and out of the home and (iv) consumers' socio-demographic characteristics (age, gender and education level).

4.3.2 Large-scale survey

Respondent recruitment and questionnaire administration for the large-scale survey was conducted through online lead generation (Egentic Asia Pacific Pte Ltd, Bukit Merah, Singapore). The survey was advertised on publicly accessible websites by inviting consumers to participate voluntarily. The consumers consented by agreeing to participate anonymously in the survey. Respondents were directed to the survey generated on Compusense® Cloud (Compusense Inc., Guelph, ON., Canada). Approval of the research protocol was granted by the ethics committee of the Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa (EC161205-087) (see Appendix A).

4.3.3 Respondents' socio-demographic characteristics

The screening criteria required that respondents should be at least 18 years of age, responsible for buying raw chicken meat and preparing meals in their households. Respondents who did not meet all the criteria were eliminated from the survey. A total of 863 participants met the eligibility criteria and completed the survey. Among the surveyed consumers, 71% were women (Table 4.1). The largest group of respondents were in the age range of 18 - 29 years, and 99% of the respondents were educated to high school or tertiary level.

Table 4.1: Socio-demographic characteristics of survey respondents (*n* = 863)

Demographic segmentation	Number of respondents, *n* (%)
Gender	
Male	247 (28)
Female	612 (71)
Not disclosed	4 (1)
Age (yr.)	
18 - 29	360 (42)
30 - 39	183 (21)
40 - 49	137 (16)
50 - 59	114 (13)
60 and older	69 (8)
Education level	
Primary school	4 (1)
High school	386 (44)
Tertiary	473 (55)

4.3.4 Statistical analysis

Consumers' responses to questions on chicken handling practices were grouped into two according to food safety guidelines in literature (those following recommended practices and those following risky practices). The two proportions were then compared using the chi-square test. Consumers' answers to questions on factors affecting the safety of chicken meat were also grouped into two (correct and incorrect answers), and the two proportions subsequently compared using the chi-square test. Chi-square test was also employed to compare the proportions of consumers who usually consider safety risks linked to handling chicken meat in and out of the home with those who do not.

Depending on their chicken handling practices and knowledge about factors affecting the safety of chicken meat, respondents were categorised using a scoring and categorisation system following a modification of the method described by Gizaw, Gebrehiwot, and Teka (2014). Six questions on chicken handling practices (practices questions 1 - 7, excluding question 3; see Appendix B) and 5 questions on chicken safety knowledge (knowledge questions 8 -12) were included in the analysis. All the questions were assigned the same weight. A score of one (1) was awarded for each correct response and a score of zero (0) was given for incorrect responses. Scores for practices and knowledge questions were summed separately. Scores for each respondent were converted to percentages. Respondents were then grouped into three categories based on their practices and knowledge about handling chicken meat: 'poor' (0 - 59%), 'moderate' (60 - 79%) and 'good' (80 - 100%).

Spearman's correlation coefficient was calculated between consumers' practices percentage scores and knowledge percentage scores. In order to determine the effect of socio-demographic factors on consumers' practices and knowledge scores for handling chicken meat, the Mann-Whitney U test (for gender and education level) and the Kruskal-Wallis H test (for age) were employed. Multiple linear regression analysis was used to model the associations of socio-demographic factors with consumers' practices percentage scores and knowledge percentage scores, respectively. During multiple linear regression analysis, indicator variables were developed, whereby the categorical predictor variables (age, gender and education level) were coded with values of 0 and 1 indicating the 'absence' and 'presence' of a characteristic, respectively (Bower, 2013). The categories 'male', 'high school' and '18 - 29 years' were used as reference categories for gender, education level and age, respectively. The analyses were carried out using SPSS software (version 20.0, IBM SPSS Statistics Inc., Armonk, NY, USA) at 95% confidence level.

4.4 Results and discussion

4.4.1 Consumers' self-reported practices for handling raw chicken from retail to the home

Consumers' practices for handling raw chicken are presented in Table 4.2. Responses in bold are the recommended practices.

4.4.1.1 Purchasing and period prior to home storage

During grocery shopping, a significant proportion of the respondents (55%) did not follow the recommended practice of selecting raw chicken when they are about to check out ($\chi^2 = 10.02$, $p = 0.002$) (Table 4.2). A similar study by Jevsnik et al. (2008) revealed that, when shopping, 90% of Slovenian consumers also did not select raw meat when they were about to check out. Not following this practice could lead to temperature abuse of the chicken product and increase the potential for pathogenic bacterial growth, if present. Regarding this practice, it is highly probable that most consumers could be influenced more by where the chicken products are located in the retail store than concern for safety. In a standard supermarket layout, meat products are usually situated across the rear and away from the entrance or exit (Aloysius & Binu, 2013). However, no information on the layout of supermarkets as frequented by respondents in this study was collected.

After purchasing chicken meat, 95% of the respondents reported taking on average at most 2 hours before refrigerating or freezing raw chicken at home (χ^2 = 695.97, $p < 0.001$). This included travel time from the retailer to home. This result is comparable with a survey reporting that about 93% of Irish consumers freeze or refrigerate raw meat within 2 hours after purchasing (Kennedy et al., 2005). Interrupting the chicken meat cold chain for extended periods could increase the risk of proliferation of pathogenic microorganisms to unacceptable levels, posing a health risk to consumers (Von Loeper, Musango, Brent, & Drimie, 2016). As per the South African Department of Agriculture, Forestry and Fisheries (DAFF) food preparation guidelines, the meat cold chain should not be broken for over 2 hours (Department of Agriculture Forestry and Fisheries, 2002).

4.4.1.2 Home storage

At home, a large majority of the consumers surveyed (86%) store raw chicken in the freezer (χ^2 = 441.12, $p < 0.001$) (Table 4.2). The rest (14%) keep it in the refrigerator. Both these practices are acceptable for domestic storage of raw chicken. It is well established that freezing (below -10 to -12 °C) has an inhibitory effect on the growth of both pathogenic and spoilage microorganisms and has the advantage of extended storage time (Coorey et al., 2018). As opposed to freezing, refrigeration of raw chicken for extended periods can pose a risk as bacteria can still grow but at a slow rate, especially at temperatures above 4 °C (Koutsoumanis & Taoukis, 2005; Tuncer & Sireli, 2008). It is challenging to investigate the ideal maximum refrigeration period for raw meat because the microbial load of meat differs widely at the time of purchasing (Coorey et al., 2018). Nonetheless, the United States Department of Agriculture

(USDA) recommends refrigeration of raw poultry for a maximum of 2 days at 4 °C or below (USDA-FSIS, 2014). In this survey, a significant proportion of the respondents (81%) reported refrigerating chicken meat for at most 2 days before cooking ($\chi^2 = 316.65$, $p < 0.001$). However, 15% of the respondents indicated that they refrigerate chicken meat for more than 2 days and up to 7 days (Table 4.2). Following this practice could cause microbial pathogen growth in chicken meat thereby putting consumers at risk of food poisoning.

4.4.1.3 Thawing methods

Since a large majority (86%) of the consumers in this study freeze raw chicken after purchasing, it was important to ascertain their thawing practices prior to cooking. For domestic thawing, using the refrigerator, thawing under running cold water or in cold water that is changed regularly, or thawing in a microwave as part of the cooking process, is recommended in the South African Food Preparation and Home Food Safety guidelines (Department of Agriculture Forestry and Fisheries, 2002). In this study, 44% of the respondents reported risky practices, that is, either thawing raw chicken on the kitchen countertop (24%), in hot water (13%) or cooking it whilst still frozen (7%) ($\chi^2 = 12.78$, $p < 0.001$) (Table 4.2). A similar study by Bearth et al. (2014) revealed that 49% of Swiss consumers thaw frozen chicken on the countertop. Thawing at ambient temperature or in hot water might expose the chicken meat to temperatures enhancing microbial growth, whilst cooking meat without thawing might result in undercooking of the innermost portions (Food Advisory Consumer Service, 2016). According to Roccato et al. (2015), thawing raw chicken meat overnight at room temperature caused significant increases in *Salmonella* Typhimurium numbers in comparison with thawing overnight in the refrigerator. Research on other meat species (fish) demonstrated that refrigerator and cold-water thawing, in comparison with ambient temperature and microwave thawing, resulted in meat with the lowest total aerobic mesophilic bacterial counts (Ersoy, Aksan, & Özeren, 2008; Javadian, Rezaei, Soltani, Kazemian, & Pourgholam, 2013).

Consequently, the recommendation to thaw raw chicken meat in a refrigerator or in cold water is pertinent to minimise the growth of both pathogenic and spoilage microorganisms.

4.4.1.4 Hand washing

In this study, 31% of the respondents reported not washing their hands with soap and water before handling raw chicken (Table 4.2). After handling raw chicken, 36% of the respondents reported not washing their hands using soap and water. Several other studies, both observational and self-reporting, have also revealed that most consumers fail to comply with the hand hygiene guideline of washing hands with soap and water before and after handling raw chicken during food preparation (Bruhn, 2014; Donelan et al., 2016; Jevšnik et al., 2008). Hand washing has been recognised as an important but easily overlooked public health practice that may considerably mitigate the transmission of pathogens to food and the risk of diarrheal diseases (Ejemot-Nwadiaro, Ehiri, Arikpo, Meremikwu, & Critchley, 2015). The South African Department of Health (DoH) hand washing guidelines to the general public recommend firstly wetting hands with clean running water, lathering hands with soap and then thoroughly rubbing the palms, back of hands, in-between fingers, thumbs, wrists and nails before rinsing with clean water and finally drying using a clean cloth or by air (Department of Health, 2016). Even though antibacterial soaps are the most effective, Toshima et al. (2001) and Burton et al. (2011) demonstrated that using plain soap and water is viable as it could remove more than 91% of bacteria of potential faecal origin from hands. Non-conformance by consumers to this hygienic practice could lead to cross-contamination, especially when consumers touch other utensils, kitchen surfaces or prepare other foods after handling raw chicken without first washing their hands with soap and water (Bruhn, 2014).

Table 4.2: Consumers' purchasing, storage and preparation practices for handling raw chicken meat (*n* = 863)

Question and response options	Number of respondents, *n* (%)	Summation of number of respondents, *n* (%)[1]	*p*-value[1]
At what stage do you usually select raw chicken during grocery shopping?			
At the end, when I have selected all the other items	**385 (45)**	**385 (45)**	**0.002**
Straight away when I enter the shop	85 (10)	478 (55)	
Sometime during the shopping	141 (16)		
I don't have a particular pattern	252 (29)		
On average, how long do you leave raw chicken out (including the time you take to travel from the shop to your home) before storing it in a refrigerator or freezer at home?			
Less than 1 hour	**565 (66)**		
1 hour	**180 (21)**		
2 hours	**74 (9)**	**819 (95)**	**< 0.001**
3 hours	21 (2)	44 (5)	
4 hours	4 (1)		
5 hours	2 (0)		
More than 5 hours	17 (2)		
Where do you usually store raw chicken at home?[2]			
In the refrigerator	**123 (14)**	-	**< 0.001**
In the freezer	**740 (86)**		
What is the maximum time period you keep raw chicken in the refrigerator before cooking? (*n* = 702)[3]			
I don't keep raw chicken in the refrigerator[4]	25 (4)		
1 day or less	**470 (67)**		
2 days	**100 (14)**	**570 (81)**	**< 0.001**
3 days	39 (6)	107 (15)	
4 days	12 (2)		
5 days	10 (1)		
6 days	2 (0)		
1 week	44 (6)		

Question and response options	Number of respondents, *n* (%)	Summation of number of respondents, *n* (%)[1]	*p*-value[1]
When thawing frozen raw chicken for cooking, how do you usually do it?			
I thaw it in the refrigerator	**120 (14)**		
I thaw it using the microwave	**171 (20)**		
I thaw it in cold water	**193 (22)**	**484 (56)**	**< 0.001**
I thaw it on the kitchen countertop	210 (24)	379 (44)	
I thaw it in hot water	113 (13)		
I do not thaw it; I cook it frozen	56 (7)		
When preparing raw chicken, how do you usually wash your hands before handling the meat?			
I use soap and water	**592 (69)**	**592 (69)**	**< 0.001**
I use water	232 (27)	271 (31)	
I wipe my hands with a paper towel, dishcloth or apron	23 (3)		
I don't wash my hands	16 (2)		
When preparing raw chicken, which of the following do you usually do immediately after handling the meat?			
I wash my hands with soap and water	**554 (64)**	**554 (64)**	**< 0.001**
I wash my hands with water	251 (29)	309 (36)	
I wipe my hands with a paper towel, dishcloth or apron	46 (5)		
I continue cooking without washing my hands	12 (1)		

[1]Consumer responses were grouped into two (those following recommended practices and those following risky practices). Responses reflecting recommended practices appear in bold. The two proportions were then compared by the chi-square test at $p < 0.05$.
[2]Responses to this question were not grouped into recommended and risky practices.
[3]Only responses indicating time units were considered.
[4]Respondents who reported that they do not keep raw chicken in the refrigerator were excluded from statistical analysis.

4.4.2 Consumers' knowledge of factors affecting the safety of chicken meat

Consumers' knowledge about the recommended safe storage and preparation practices related to chicken meat was determined (Figures 4.1 and 4.2). A significant proportion of the respondents (93%) did not know the ideal refrigeration temperature for raw chicken (χ^2 = 388.46, $p < 0.001$). Of these, 55% reported temperatures higher than 4 °C as suitable (ranging from 5 - 45 °C), and 3% indicated that they were uncertain (Figure 4.1). The recommended temperature by the South African Food Advisory Consumer Service (FACS) is 4 °C (Food Advisory Consumer Service, 2016). In the current study, the temperature of domestic refrigerators was not determined. A literature review by James, Onarinde, and James (2017) concluded that the practical application of consumers' knowledge about refrigeration temperatures is limited because of the general lack of refrigerator thermometers in homes. Consequently, most consumers do not know the temperature in their own refrigerators. The authors recommended that refrigerator manufacturers should include built-in sensors that may help consumers know and monitor the temperature of their refrigerators to minimise bacterial growth in food during storage, and ultimately reduce the occurrence of foodborne diseases.

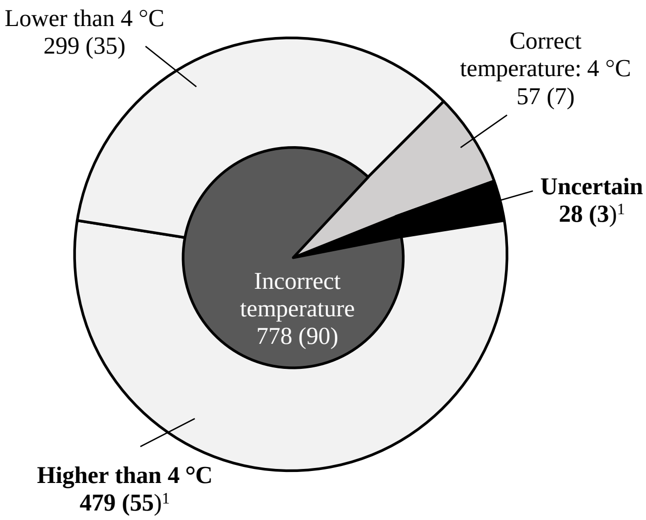

Figure 4.1: Comparison of the number of respondents (% in brackets) who gave the correct maximum refrigeration temperature for raw chicken (4 °C) with those who did not (n = 863)
[1]Number of respondents at risk of unsafe chicken meat appear in bold.

About half of the respondents (45%) were unaware that sensory indicators of raw chicken freshness (appearance and smell) are not accurate indicators of safety ($\chi^2 = 7.23$, $p = 0.007$) (Figure 4.2). Unlike with spoilage bacteria, the growth of foodborne pathogens to hazardous levels in meat is impossible to detect through sensory assessment of meat freshness (Henson & Northen, 2000). Hence consumers should be made aware of the need to be constantly vigilant when handling and preparing chicken meat to avoid the risk of infections.

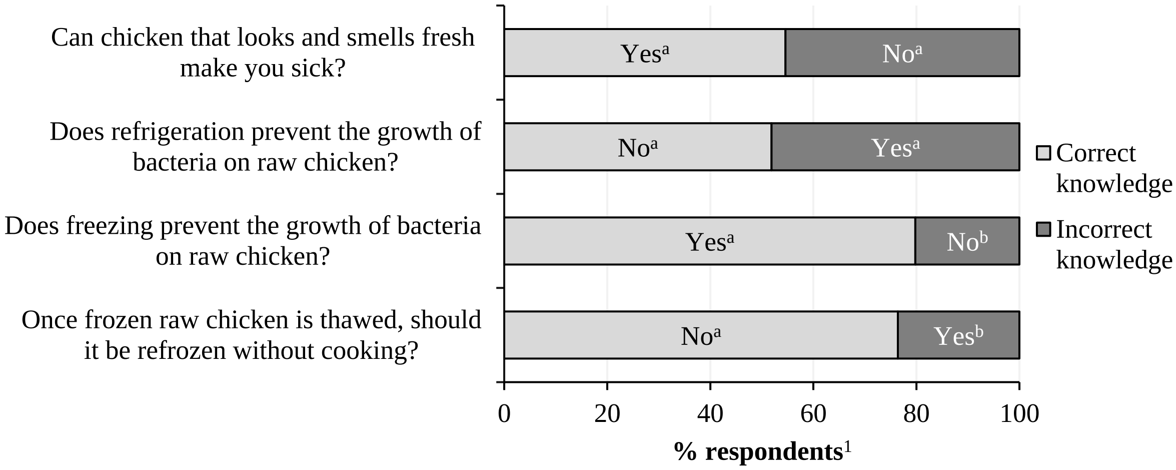

Figure 4.2: Consumers' knowledge about factors affecting the safety of chicken meat

[1]Consumers' responses to dichotomous questions (Yes/No). Responses with different superscripts were significantly different (chi-square test, $p < 0.05$, $n = 863$).

Besides their lack of knowledge of the ideal chicken meat refrigeration temperature, about half (48%) of the consumers were of the impression that bacteria in chicken meat become dormant during refrigeration storage ($\chi^2 = 1.26$, $p = 0.261$) (Figure 4.2). In a similar study, Bearth et al. (2014) found that 49% of Swiss consumers were also of the misconception that pathogenic bacteria in poultry meat cannot reproduce at refrigeration temperatures. The findings of the current study are concerning because consumers indicate a lack of knowledge related to temperatures that inhibit bacterial growth. This could lead to improper storage of chicken meat at home. Thus, consumers should be educated on the effect of refrigeration temperatures on bacterial growth in meat.

Regarding freezing of chicken meat, 80% of the respondents correctly indicated that freezing prevents the growth of bacteria in raw chicken meat. After thawing, 24% of the consumers reported that raw chicken meat should be refrozen if not cooked immediately ($\chi^2 = 239.89$, $p < 0.001$) (Figure 4.2). However, of the 24% that reported that thawed chicken meat should be refrozen if unused, almost all (92%) do not use a refrigerator for thawing. It is proposed that during thawing of foods, bacterial growth could be enhanced due to the increased moisture and nutrients available from the formed exudate (Leygonie, Britz, & Hoffman, 2012). A study by Rahman, Hossain, Rahman, Hashem, and Oh (2014) showed that beef samples thawed at 4 °C had the lowest bacterial load after each freeze-thaw cycle (a total of 3 cycles), in comparison with those thawed at room temperature and in cold water. This implies that the practice of refreezing meat after thawing at temperatures higher than 4 °C could potentially compromise its safety and increase the chances of foodborne illness.

4.4.3 Categorisation of consumers based on practices use and knowledge of factors affecting the safety of chicken meat

Respondents were categorised into three groups based on poor, moderate or good chicken meat handling practices and poor, moderate or good knowledge levels of factors affecting the safety of chicken meat (Table 4.3). Only 38% of the respondents were categorised as following good chicken meat handling practices and 28% as having good knowledge of factors affecting chicken meat safety. Most consumers followed moderate or poor practices (62%) and had moderate or poor knowledge levels (72%).

Table 4.3: Categorisation of respondents according to their practices and knowledge of factors affecting the safety of chicken meat (*n* = 863)

	Categorisation system[1]			Mean score (%)
	Poor (0 - 59%)	Moderate (60 - 79%)	Good (80 - 100%)	
Chicken handling practices	310 (36)	228 (26)	325 (38)	66 ± 22
Chicken safety knowledge	349 (40)	273 (32)	241 (28)	56 ± 22

[1]Data is presented as *n* (%).

These results are concerning because almost all of the surveyed consumers in this study were educated to high school or tertiary level. However, their limited awareness could be attributed to lack of emphasis on food safety in the South African basic education curriculum (Department of Basic Education, 2011, 2017). The findings suggest that a large majority of the surveyed consumers need education to improve their practices and knowledge on chicken meat safety to alleviate the risk of foodborne disease infections. Intervention is needed from the Inter-departmental Food Safety Coordinating Committee (IDFSCC) in South Africa to develop consumer education programmes to improve consumer awareness on food safety matters. The IDFSCC could be more effective in the implementation of consumer food safety education programmes as it is a collaboration of three government departments: Department of Agriculture, Forestry and Fisheries (DAFF), Department of Health (DoH) and Department of Trade and Industry (DTI) (DAFF, 2016). Chicken meat processors could also raise consumer awareness by including clear safe handling instructions on chicken meat product labels. Currently, the safety information on raw chicken products is inadequate and unstandardized, that is, the amount of information provided differs from one chicken brand to another and is completely absent on other brands. This is probably because South African labelling regulations do not mandate the inclusion of safe handling practices on poultry products (Department of Health, 2014a). Disclosure of safety risks associated with poultry on product labels could improve consumer knowledge and practices. Additionally, retailers could assist consumers to be conscious of food safety through several ways, for example, providing food safety information in the supermarket during in-store advertising, in catalogues, in retailer-owned magazines and on grocery bags; and colour coding of grocery bags to prevent cross-contamination during grocery packing at check out (as it is in the case of colour-coded chopping boards).

4.4.4 Effects of socio-demographic factors on consumers' practices and knowledge of factors affecting the safety of chicken meat

Socio-demographic factors possibly influencing consumers' practices and knowledge related to handling chicken meat were investigated (Table 4.4). In this study, women respondents reported following more safe practices than men (U = 62.01, $p < 0.001$), though their knowledge levels were similar (U = 70.70, p = 0.125). This may be due to the fact that in South Africa women prepare food in the home more often than men hence they have more practise and experience (Altman, Hart, & Jacobs, 2009). Furthermore, it was found that the education level of respondents had no impact on their chicken meat handling practices (U = 89.54, p = 0.621), but respondents with tertiary education were more knowledgeable about factors affecting the safety of chicken meat than those with high school education (U = 100.74, p = 0.007). The results suggest that there could be instances whereby consumers who are knowledgeable about the safety of chicken meat do not always conform to safe practices for handling chicken meat. In this study, consumers' knowledge about factors affecting the safety of chicken meat did not substantially impact their practices for handling chicken meat (Spearman's correlation $\rho = 0.23$, $p < 0.001$). The phenomenon of consumers failing to put their knowledge into practice is usually attributed to psychological factors, most commonly optimistic bias and habit (Al-Sakkaf, 2013).

Table 4.4: Effects of socio-demographic factors on consumers' practices and knowledge of factors affecting the safety of chicken meat

	Gender	Mean score (%) ± SD (n = 859)[1, 2]	Education level	Mean score (%) ± SD (n = 859)[1, 3]	Age (yr.)	Mean score (%) ± SD (n = 863)[1]
Chicken handling practices	Male	$60.9^a \pm 20.9$	High school	$66.6^a \pm 21.8$	18 - 29	$58.6^a \pm 21.2$
	Female	$67.5^b \pm 22.0$	Tertiary	$65.6^a \pm 22.0$	30 - 39	$65.9^b \pm 21.0$
					40 - 49	$72.3^c \pm 21.4$
					50 - 59	$75.3^c \pm 19.5$
					60 and older	$74.6^c \pm 21.1$
Chicken safety knowledge	Male	$54.3^a \pm 23.2$	High school	$53.5^a \pm 22.6$	18 - 29	$52.6^a \pm 23.2$
	Female	$56.8^a \pm 21.8$	Tertiary	$57.7^b \pm 22.2$	30 - 39	$53.9^a \pm 20.4$
					40 - 49	$59.1^b \pm 21.8$
					50 - 59	$60.9^b \pm 22.0$
					60 and older	$63.2^b \pm 21.6$

[1]Means with different superscripts within columns, for each score category, were significantly different (Mann-Whitney U and Kruskal-Wallis H test, $p < 0.05$).
[2]Consumers who preferred not to disclose their gender (1%) were not included in the statistical analyses.
[3]Consumers with primary school education (1%) were not included in the statistical analyses.

A study by Bearth et al. (2014) reported that consumers did not realise that their behaviour at home could lead to contracting foodborne illness (optimistic bias) and acknowledged that they found it challenging to break their risky habits. In addition to educating consumers, publicising foodborne disease outbreaks bold and clear (scare tactics) might help consumers to better understand the aetiology and severity of food poisoning and motivate them to change their attitudes and habits and adopt safe food handling practices. An example whereby scare tactics have been effective is in the United States of America (USA). Since 2012, the Centres for Disease Control and Prevention (CDC) has periodically launched anti-smoking campaigns featuring compelling real stories of former smokers living with smoking-related diseases and disabilities (CDC, 2018). The CDC estimates that during 2012 to 2015, approximately half a million smokers in the USA successfully quit smoking definitively as a result of the campaign. With respect to age, it was found that the youngest group of respondents (18 - 29 years) reported more risky practices than the rest of the consumers ($p < 0.05$). Consumers in this age group (18 - 29 years) demonstrated that they were significantly less knowledgeable than respondents in the other age groups ($p < 0.05$), except those in the 30 - 39 years age group ($p > 0.05$).

Models developed to determine the strength of socio-demographic factors to predict consumers' practices when handling chicken meat (Table 4.5) and knowledge about factors affecting the safety of chicken meat (Table 4.6) also revealed that the age of respondents better predicted both practices and knowledge than gender and education level, as evidenced by the larger predictor variable coefficients.

Table 4.5: Multiple linear regression model for the association of socio-demographic factors with consumers' practices for handling chicken (*n* = 855)

Socio-demographic factors	Categories	Unstandardized coefficients	Standard error	t-statistic	*p*-value[2]
Constant		55.228	1.707	32.337	< 0.001
Gender	*Male*[1]	-	-	-	-
	Female	5.696	1.557	3.667	< 0.001
Education level	*High school*[1]	-	-	-	-
	Tertiary	-0.923	1.414	-0.652	0.515
Age (yr.)	*18 - 29*[1]	-	-	-	-
	30 - 39	6.763	1.879	3.596	< 0.001
	40 - 49	12.482	2.069	6.036	< 0.001
	50 - 59	16.213	2.215	7.321	< 0.001
	60 and older	17.289	2.715	6.373	< 0.001

[1]Reference category. Dependent variable: percentage scores for consumer practices.
[2]Association significant at $p < 0.05$, $R^2 = 0.116$. Consumers who preferred not to disclose their gender (1%) and with primary education (1%) were not included in the statistical analysis.

Table 4.6: Multiple linear regression model for the association of socio-demographic factors with consumers' knowledge of factors affecting the safety of chicken meat (*n* = 855)

Socio-demographic factors	Categories	Unstandardized coefficients	Standard error	t-statistic	*p*-value[2]
Constant		49.310	1.825	27.024	< 0.001
Gender	*Male*[1]	-	-	-	-
	Female	2.104	1.665	1.263	0.207
Education level	*High school*[1]	-	-	-	-
	Tertiary	4.080	1.512	2.698	0.007
Age (yr.)	*18 - 29*[1]	-	-	-	-
	30 - 39	0.931	2.009	0.463	0.643
	40 - 49	5.878	2.213	2.656	0.008
	50 - 59	8.517	2.368	3.596	< 0.001
	60 and older	10.917	2.903	3.761	< 0.001

[1]Reference category. Dependent variable: percentage scores for consumer knowledge.
[2]Association significant at $p < 0.05$, $R^2 = 0.042$. Consumers who preferred not to disclose their gender (1%) and with primary education (1%) were not included in the statistical analysis.

Similar studies conducted in other countries, such as Slovenia and Turkey, also showed that food safety knowledge and safe practices tend to improve with consumer age (Jevšnik et al., 2008; Sanlier, 2009). In accordance with the findings in the present study, young adults particularly aged 18 - 29 years were identified as the most susceptible to foodborne illness, followed by those aged 30 - 39 years. Byrd-Bredbenner, Abbot, and Quick (2010) speculated that this could be due to changes in school curricula leading to marginalisation of life skills subjects. As a result, a large proportion of young adults could have limited knowledge and skills on the safe purchase, preparation and storage of food. Life skills subjects such as home economics should be a standard and compulsory part of the basic education curriculum. Home economics could be an important tool to impart essential food safety knowledge and skills to children and youths with possible long-term effects on individuals after their schooling has been completed. Another reason cited by the author was that more mothers have careers nowadays and hence have less time to spend preparing meals at home together with their children. Children and teenagers could acquire food safety knowledge and learn safe practices for handling food as a result of frequently observing and assisting their parents (or family members) when preparing meals at home. The food safety skills learned could develop into life-long habits thereby preventing the incidence of foodborne illness. In order to increase food safety awareness among young adults, consumer educators could employ the internet, social media and relevant social pressure (Young & Waddell, 2016). These modes of food safety education could be more interesting to young adults than conventional methods such as print-based material and lectures.

4.4.5 Consumers' concerns about safety risks linked to handling chicken meat

Lastly, it was important to investigate whether consumers consider the safety of chicken meat in the first place (Figure 4.3). Basically, at least 85% of the respondents indicated that they think about the safety of chicken meat when shopping, during storage and preparation of chicken meat at home and when consuming chicken meat outside of their homes ($p < 0.05$). Furthermore, a large majority (82%) knew that their practices for handling chicken meat from retail to the home could impact its safety ($p < 0.05$). However, the respondents' concerns were inconsistent with their self-reported practices, discussed earlier in this paper. A possible explanation could be that the respondents were concerned about the safety of chicken meat but lack knowledge on safe handling practices, hence the need for consumer education. On a more positive note, their concerns could also be an indication that they would be receptive to education about the safety of chicken meat.

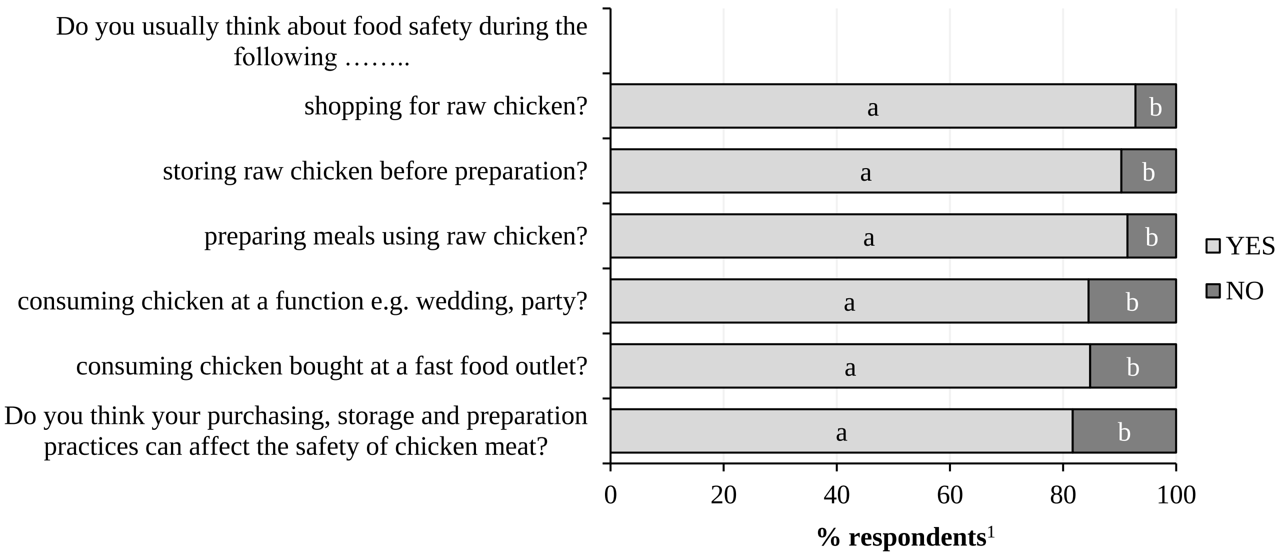

Figure 4.3: Consumers' concerns over the safety of chicken meat

[1]Consumers' responses to dichotomous questions (Yes/No). Responses with different letters were significantly different (chi-square tests, $p < 0.05$, $n = 863$).

Incidences of foodborne illness implicating chicken meat have been reported in South Africa. For instance, 65 people reported ill after consuming contaminated chicken meat served in a lodge in Limpopo province in 2014 (Muvhali et al., 2017). Similarly, 63 people were affected after eating contaminated chicken meat served at a hotel in Tshwane District in 2015 (NICD, 2015). A recent report by the NICD on foodborne disease outbreaks in South Africa revealed that there is generally great variability in the investigation and reporting of foodborne disease outbreaks throughout the country (NICD, 2018a). It was highlighted that food samples are not always collected and when collected, inappropriate testing methods are usually applied. Hence investigations towards establishing the sources of infections are often hindered (NICD, 2018a). There is, therefore, need to standardise and improve surveillance and reporting of foodborne disease outbreaks. In addition, the obtained foodborne disease outbreak information, coupled with guidelines to prevent safety risks, could be publicised to increase consumer food safety awareness.

4.5 Conclusions

This study investigates the safety risks associated with practices and knowledge of a subset of South African consumers related to handling raw chicken meat. Major gaps in practices and knowledge that could lead to temperature abuse of chicken meat, transmission of pathogenic bacteria and cross-contamination are identified. Based on these findings, there is potential for foodborne illness due to mishandling of chicken meat and a serious lack of knowledge about factors affecting the safety of raw chicken by a large proportion of consumers. Consumer practices and knowledge when handling chicken meat can be improved through educational interventions by the IDFSCC and non-governmental scientific organisations such as FACS, with emphasis on the basic science explaining the rationale behind recommended practices to increase consumer understanding and motivation. The inclusion of specific food safety guidelines for consumers within the labelling regulations followed by poultry processors in South Africa (Foodstuffs, Cosmetics and Disinfectants Act No. 54 of 1972) is also recommended. Furthermore, retailers can contribute in raising consumer awareness by providing food safety information during chicken product advertisement. For effectiveness, the employed risk communication strategies must be multifaceted in order to cater for consumers with different socio-demographic characteristics.

CHAPTER FIVE

How a group of South African consumers perceives intrinsic and extrinsic attributes as indicators of safety and quality of chicken meat: actionable information for public health authorities and the chicken industry

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Redrafted from:

Katiyo, W., Coorey, R., Buys, E. M., & de Kock, H. L. (2020). Consumers’ perceptions of intrinsic and extrinsic attributes as indicators of safety and quality of chicken meat: Actionable information for public health authorities and the chicken industry. *Journal of Food Science, 85*(6), 1845-1855.

5.1 Abstract

Understanding consumers' perceptions towards chicken meat safety and quality could provide valuable information to public health educators and the chicken industry since it is the most consumed meat. This study explores perceptions of a group of South African consumers on the safety and quality of chicken meat based on intrinsic and extrinsic attributes and identifies related safety risks. Data were collected through a web-based survey (863 participants). A substantial proportion of consumers considered supermarkets as the most trusted outlets to sell safe and good quality chicken (compared with butcheries, wholesalers, farmers' markets, street vendors or 'other retailers'). A significant majority of respondents (53%) most trusted refrigerated chicken to be of good quality compared with 36% trusting frozen chicken or 11% chicken at room temperature. Frozen chicken was considered to be most safe by 48% of consumers while 43% regarded refrigerated chicken as most safe. At point of purchase and home, smell, use-by date, sell-by date and colour were perceived as highly important attributes when judging chicken safety and quality. Consumers also considered the absence of brine use and growth-promoting hormones in chicken feed as relatively important. It is essential that consumers apply safe chicken handling practices from point of purchase to consumption, irrespective of the type of retailer, perceived sensory characteristics and date labels to reduce or eliminate microbial risks. Addressing factors such as brining, growth-promoting hormones and free-range by the chicken industry may improve consumer knowledge and meet expectations.

5.2 Introduction

In line with global trends, chicken meat consumption in South Africa has expanded rapidly, supported by rising incomes, dynamic social class mobility and urbanisation (BFAP/NAMC, 2018). Per capita consumption of chicken in South Africa in 2017 was 39 kg and it is expected to exceed 45 kg by 2027 (SAPA, 2018). In contrast, only 18 kg beef, 5 kg pork and 3 kg mutton and goat were consumed per capita in the same year (SAPA, 2018).

In contrast to the objectively defined views on safety and quality by meat science experts, consumers' perceptions of the concepts are highly subjective. Consumers' perceptions of the safety and quality of chicken meat are of interest to farmers, processors and retailers because the consumers' perceptions are linked to what is expected and how products are chosen (Troy & Kerry, 2010).

Meat quality is defined by consumer preferences, that is, what consumers want in a meat product with regards to different attributes. The quality of fresh meat "indicates its usefulness to the consumer and its acceptability for cooking" (Joo, Kim, Hwang, & Ryu, 2013). Consumers form inferences regarding the quality of meat using cues (Sepúlveda, Maza, & Pardos, 2011). The cues are stimuli that provide information about the product leading to a particular behaviour by the consumer, e.g. an evaluation or a choice. Intrinsic cues relate to physical characteristics of the meat product (e.g., colour, smell, texture) whereas extrinsic cues relate to the meat product but are not physically part of it (e.g., brand, quality stamp, date label, origin, packaging, production and processing information, price, place of purchase, media information, anecdotes) (Djekic, Skunca, Nastasijevic, Tomovic, & Tomasevic, 2018; Font-i-Furnols & Guerrero, 2014). Studies report that consumers use colour and freshness as the leading quality cues when selecting chicken meat (Djekic et al., 2018; Skunca et al., 2016). For many European consumers, it was noted that the impact of price has reduced significantly and health, animal welfare and environmental factors have become more critical (McCarthy, O'Reilly, Cotter, & de Boer, 2004; Pouta, Heikkilä, Forsman-Hugg, Isoniemi, & Mäkelä, 2010). However, the relative importance of extrinsic factors seems to vary by country.

According to the Codex Alimentarius Code of Hygienic Practice for Meat (CAC/RCP 58-2005), meat that is safe and suitable for human consumption is characterised as having been processed under adequate hygiene control, not containing chemical residues in excess of established limits, not been treated with illegal substances as specified in relevant national legislation, free of physical contaminants and not causing foodborne infection or intoxication when properly handled and prepared (Codex Alimentarius Commission, 2005). Unfortunately, chicken meat is an important vehicle for human pathogenic bacteria, particularly, *Salmonella* spp. and *Campylobacter* spp. causing a food safety challenge (Magwedere, Rauff, De Klerk, Keddy, & Dziva, 2015). Foodborne disease outbreaks are a common occurrence in South Africa (Niehaus, Apalata, Coovadia, Smith, & Moodley, 2011). Numerous consumer studies, mostly conducted in developed countries, have concluded that consumers play an essential, active role in the safety of poultry products and they represent the final step for the prevention of foodborne illnesses (Donelan, Chambers, Chambers IV, Godwin, & Cates, 2016; Koppel et al., 2015; Kosa, Cates, Bradley, Chambers IV, & Godwin, 2015). In the previous study investigating South African consumers' knowledge and handling practices for chicken meat (section 4), it was established that there is potential for foodborne illnesses due to mishandling of chicken meat and a lack of knowledge about factors affecting the safety of chicken meat by many consumers (Katiyo, de Kock, Coorey, & Buys, 2019). The development of safe chicken handling guidelines for consumer education interventions was recommended. Similar to quality perceptions, consumers also use cues to predetermine the safety of chicken meat, with freshness being reported as the most important indicator (Becker, Benner, & Glitsch, 2000; Glitsch, 2000). Investigating consumers' perceptions towards the safety of chicken meat can also provide additional information for the development of comprehensive public health education programs.

Therefore, this study (i) explored perceptions of a subset of South African consumers on the safety and quality of chicken meat based on intrinsic and extrinsic attributes, and (ii) identified perceptions that may lead to safety risks.

5.3 Materials and methods

5.3.1 Questionnaire design and online survey

Structured questions from an existing survey by Sismanoglou and Tzimitra-Kalogianni (2011) were modified. The questions were part of the questionnaire described in section 4.3. The questionnaire was pilot-tested (94 participants), revised and administered for a large-scale online survey (863 participants) following the method outlined in section 4.3. Socio-demographic characteristics of the respondents were described in section 4.3.3.

The final questionnaire (see Appendix B) obtained information on (i) consumers' habits for purchasing and consumption of chicken meat (questions 15-17), (ii) consumers' quality and safety perceptions of intrinsic and extrinsic attributes of chicken meat at point of purchase and before preparation at home (questions 18-23), and (iii) consumers' socio-demographic characteristics, namely age, gender and education level (questions 24-26). Intrinsic and extrinsic attributes of chicken meat for section (ii) of the questionnaire (questions 18-23) were selected based on existing literature (Glitsch, 2000; Sismanoglou & Tzimitra-Kalogianni, 2011) and label information on primary processed refrigerated and frozen raw chicken from six different South African retail supermarkets. Question 18 related to the type of retailer that respondents most trusted to sell good quality and safe chicken meat (see Appendix B). Question 19 related to the chicken product, with respect to temperature state, that respondents most trusted to be of good quality and safe when purchasing. For questions 20 and 21, the respondents were asked how important were twelve different attributes of chicken meat to them when judging the quality and safety of raw chicken at point of purchase. The attributes considered were smell, colour, amount of visible fat, damaged packaging, price, sell-by date, use-by date, brand name, free-range, no growth hormones in feed, no brine injected into meat and country of origin. Similarly, for questions 22 and 23, the respondents were asked how important were five attributes of chicken meat to them when judging the quality and safety of raw chicken before preparation at home. The attributes were smell, colour, how the meat feels to the touch (texture), sell-by date and use-by date. Responses to questions 20 and 22 were rated on a scale from 1 (not important at all) to 7 (extremely important). Question 21 requested ranking of the attributes from 1 being most important to 12 being least important, and question 23 requested ranking of the attributes from 1 being most important to 5 being least important. The attributes were presented to different respondents in a randomised order to prevent possible rating and ranking bias.

5.3.2 Statistical analysis

The chi-square test was employed to compare proportions of consumers according to purchasing and consumption habits for chicken meat (questions 15-17; see Appendix B). The chi-square test was also used for comparisons between proportions of consumers according to perceptions of the quality and safety of chicken meat from different types of retailers and temperature state of chicken meat (questions 18 and 19). Consumers' mean ratings and rankings on the importance of attributes of chicken meat when assessing its quality and safety were compared using the Friedman's test followed by the Dunn-Bonferroni post hoc test (questions 20 - 23). SPSS software was employed (version 20.0, IBM SPSS Statistics Inc., Armonk, NY, USA). K-means cluster analysis with determinant (W) clustering criterion was also performed to distinguish different consumer groups based on their quality and safety perceptions of attributes of chicken meat. The optimal number of clusters was determined using the elbow method (Liu et al., 2018). Differences between clusters in terms of socio-demographic characteristics and consumers' perceptions were assessed through the chi-square test and analysis of variance (ANOVA) followed by the Fisher's Least Significant Difference (LSD) test, respectively. XLSTAT software was employed (version 2019, Addinsoft XLSTAT, NY, USA). All the analyses were conducted at 95% confidence level.

5.4 Results

5.4.1 Purchasing and consumption habits

Prior to investigating consumers' perceptions of chicken meat, it was important to make an assessment of their purchasing and consumption habits. It was found that more than 75% of the respondents consume chicken meat in their households twice a week or more (Figure 5.1). Many of the respondents (76%) mostly purchase raw chicken at supermarkets. Respondents (1%) who selected the 'other retailers' option specified that they buy raw chicken at home-based stores ('spaza shops' and tuck shops) and/or directly at chicken abattoirs. A 'spaza shop' or tuck shop refers to a small, informal grocery shop most often run from a section of a residential home in order to supplement household income (Ligthelm, 2013). The results also showed that raw chicken meat sold frozen or refrigerated is the most popular form (94%).

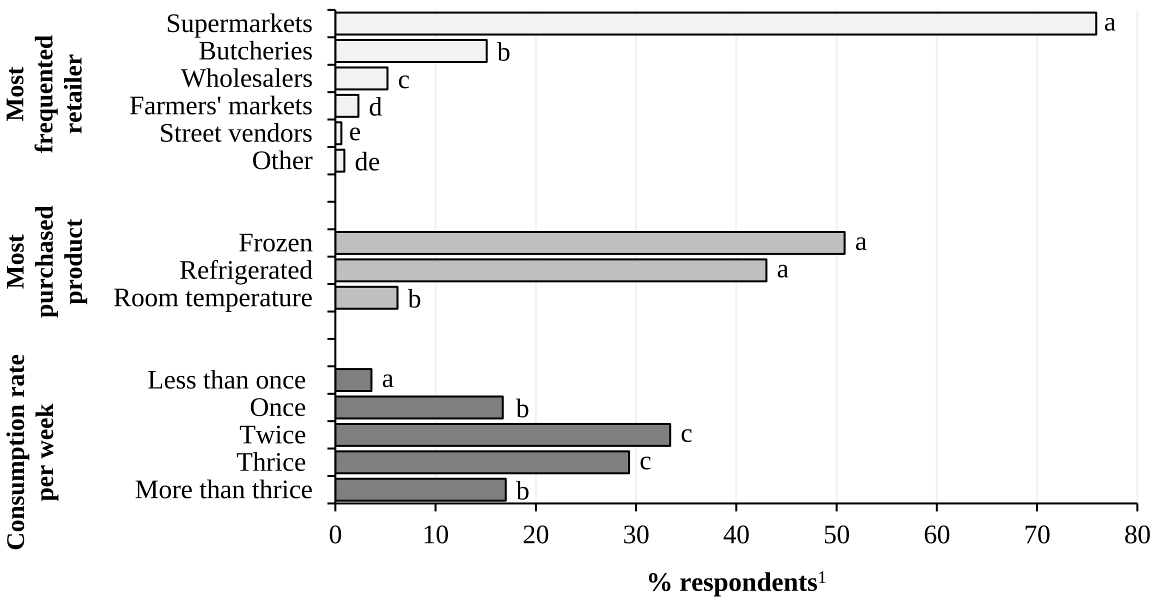


Figure 5.1: Consumers' habits for purchasing and consumption of chicken meat

[1]Proportions of respondents with different letters between categories for each question are significantly different (chi-square test, $p < 0.05$, $n = 863$).

5.4.2 Perceptions of intrinsic and extrinsic attributes of chicken meat

Fifty-five percent of the respondents reported that they most trusted supermarkets to sell safe chicken meat while 47% most trusted supermarkets to sell good quality chicken meat (Figure 5.2). Twenty-six percent of the respondents most trusted butcheries for safe chicken meat while 28% most trusted butcheries for good quality chicken meat. Street vendors were most trusted by less than 1% of the respondents for safe and good quality chicken meat.

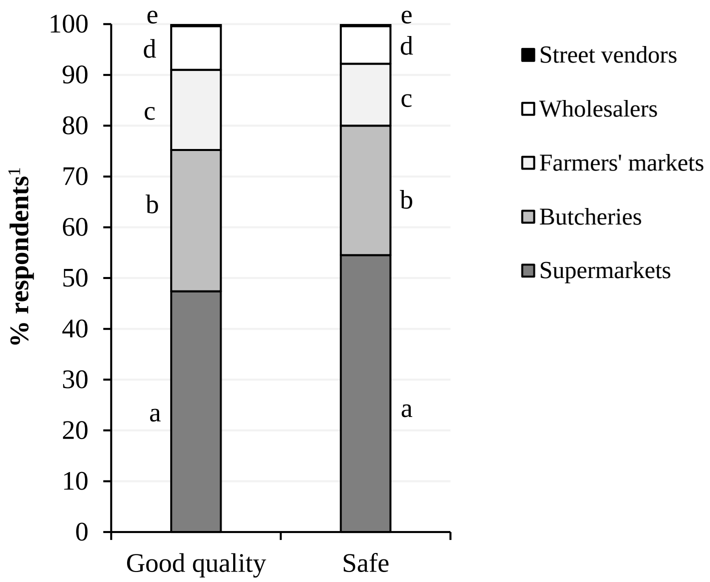


Figure 5.2: Type of retailers most trusted by respondents to sell safe and good quality chicken meat

[1]Proportions of respondents with different letters for each parameter are significantly different (chi-square test, $p < 0.05$, $n = 863$).

Respondents (53%) mentioned that they most trusted refrigerated chicken to be of good quality (Figure 5.3). A significantly lower number of the respondents (36%, $p < 0.05$) most trusted frozen chicken to be of good quality. Only 11% of the respondents most trusted chicken meat sold at room temperature to be of good quality. There was no significant difference between the number of respondents who most trusted frozen chicken to be safe (48%) and those who most trusted refrigerated chicken to be safe (43%). The rest of the respondents (9%) most trusted chicken sold at room temperature to be safe.

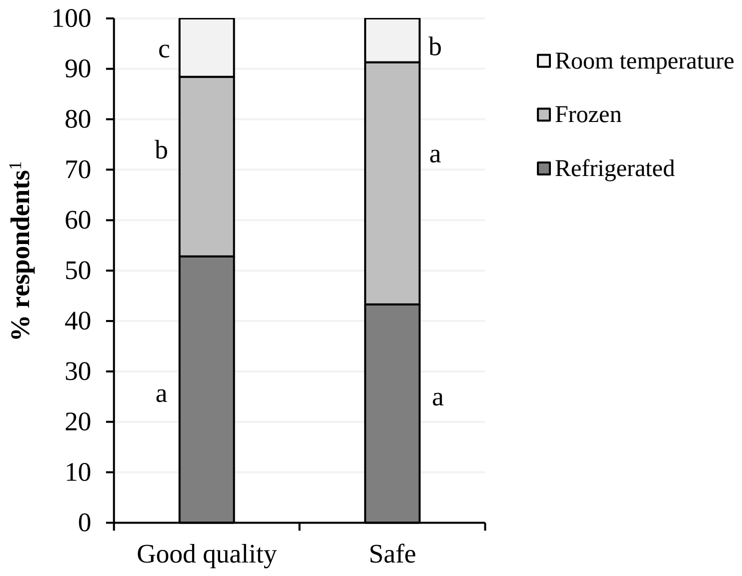
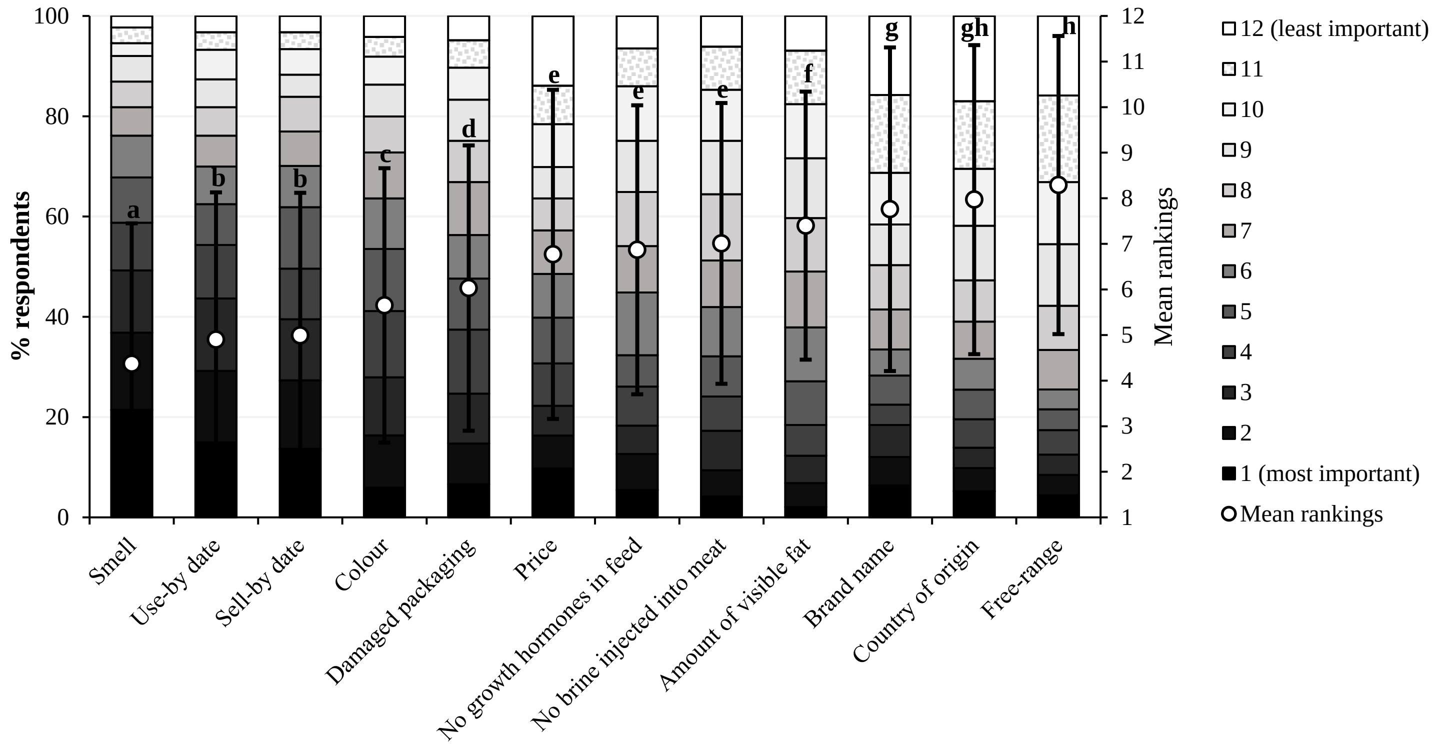


Figure 5.3: Temperature state of chicken meat most trusted by respondents to be safe and of good quality

[1]Proportions of respondents with different letters for each parameter are significantly different (chi-square test, $p < 0.05$, $n = 863$).

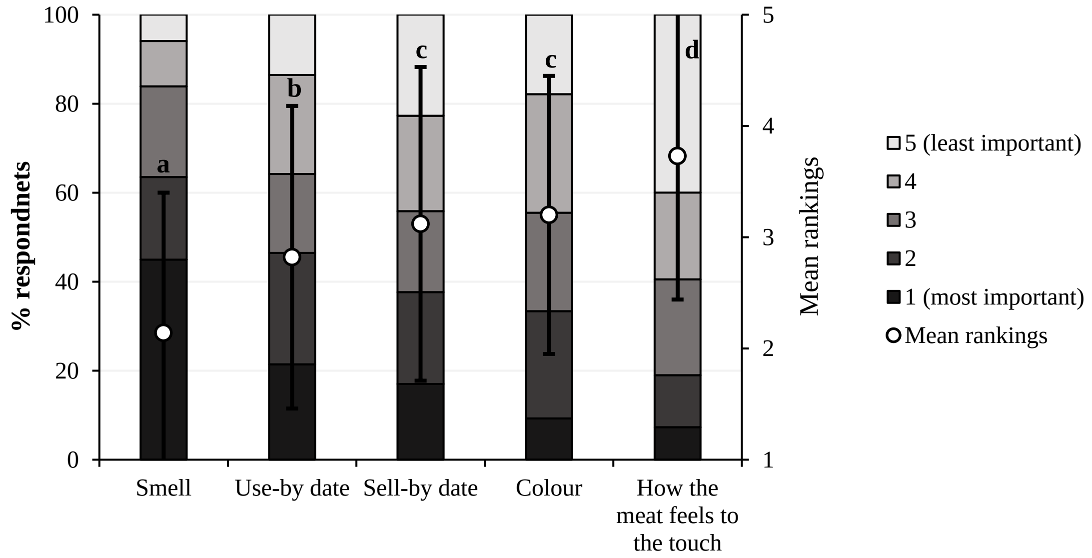
The most important attribute when assessing the safety of chicken meat at point of purchase was smell, with a mean ranking of 4.37 ($p < 0.05$) (Figure 5.4a). More than half of the respondents (67%) ranked this attribute lower than the central rank position (< 6), indicating its importance. Use-by date and sell-by date were the second most important attributes, followed by colour. The attributes, price, no growth hormones in feed and no brine injected into meat were considered equally important. The attributes considered to be least important were country of origin and free-range. Before preparation of chicken at the home, smell was also ranked as the most important attribute (Figure 5.4b). How the meat feels to the touch was considered as least important.

(a)



Attributes of raw chicken at retail

(b)



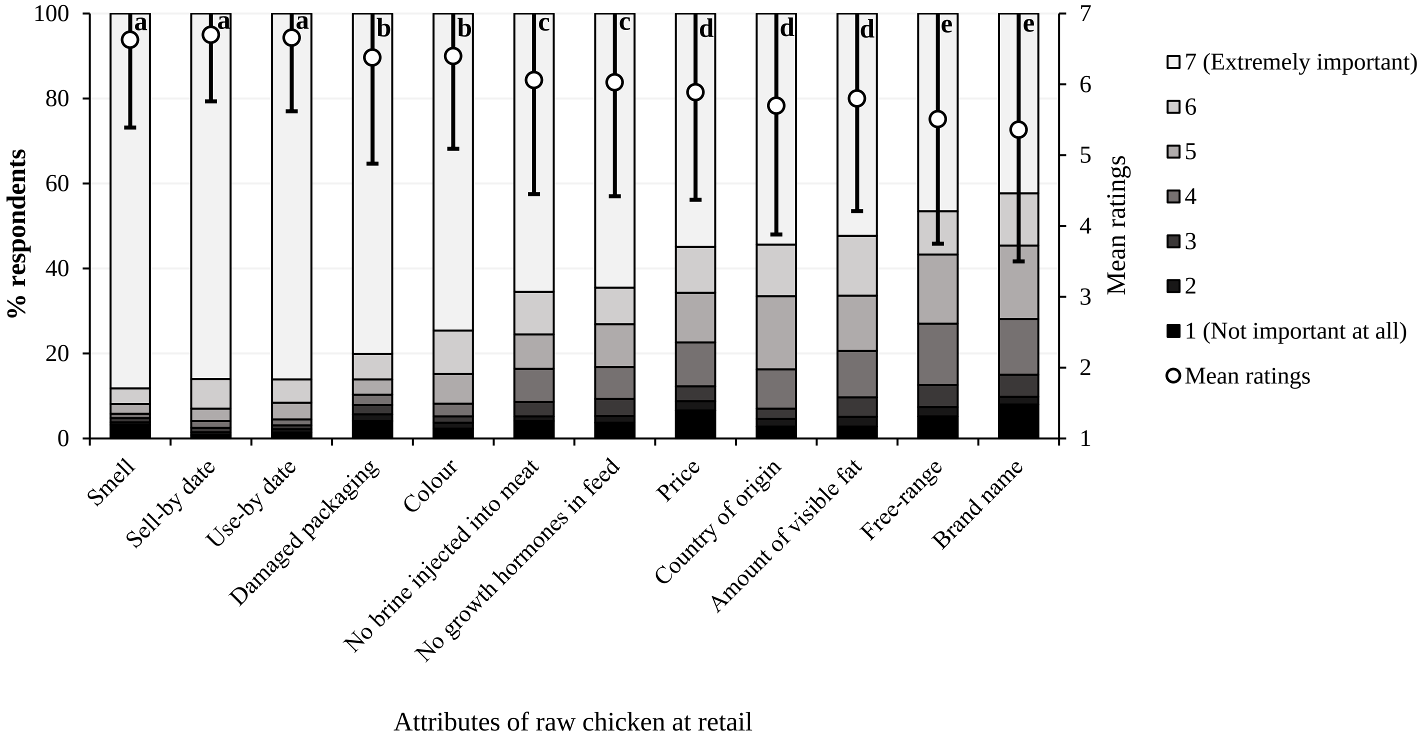
Attributes of raw chicken at home

Figure 5.4: Ranking of the importance of attributes of chicken meat when assessed by consumers for safety at retail (a) and the home (b)

At retail, attributes of chicken meat were ranked from 1 for the attribute considered most important to 12 for the attribute considered least important. At home, they were ranked from 1 for the attribute considered most important to 5 for the attribute considered least important. An attribute with the lowest mean ranking was the most important. Mean rankings with different letters were significantly different (Friedman's test, p < 0.05, n = 863).

Smell, use-by date, and sell-by date were rated equally and as highly important for judging quality of chicken meat at point of purchase ($p < 0.05$), with mean ratings almost 7 (> 6.6) (Figure 5.5a). More than 80% of the respondents rated these three attributes as extremely important. Damaged packaging and colour were rated as the next important attributes, followed by no brine injected into meat and no growth hormones in feed. Brand name and free-range appeared to be considered less important. When assessing chicken meat quality before preparation at the home, the respondents rated smell and use-by date as extremely important and how the meat feels to the touch as less important (Figure 5.5b).

(a)



(b)

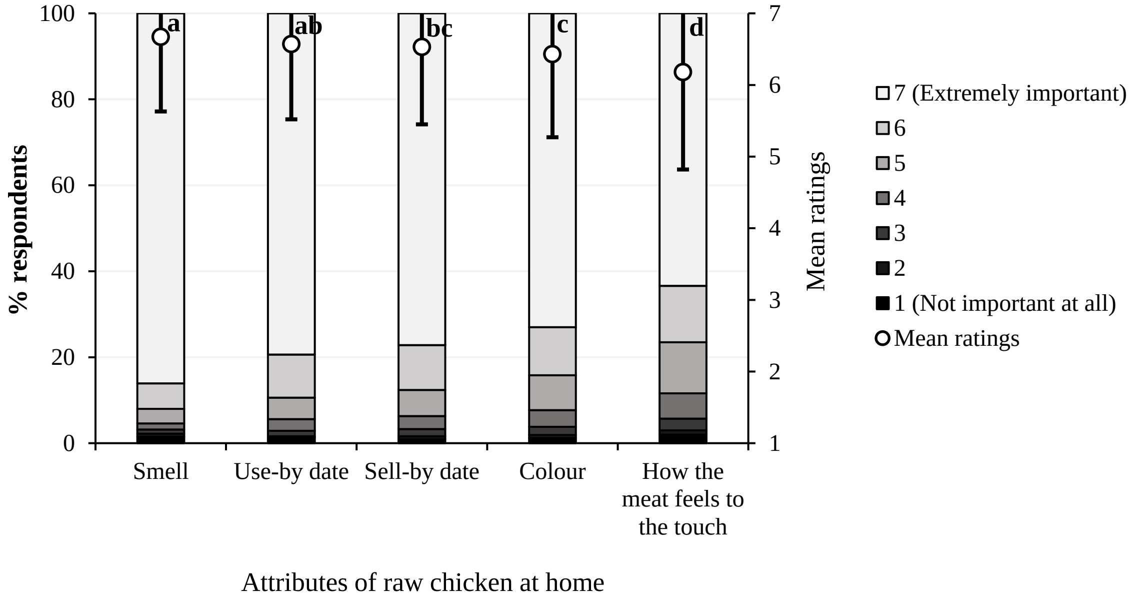


Figure 5.5: Rating of the importance of attributes of chicken meat when assessed by consumers for quality at retail (a) and the home (b)

Attributes of chicken meat were rated on a scale from 1 (not important at all) to 7 (extremely important). An attribute with the highest mean rating was more important. Mean ratings with different letters were significantly different (Friedman's test, $p < 0.05$, $n = 863$).

5.4.3 Consumer clustering based on perceptions of chicken meat

For both safety at retail and the home, 3 consumer clusters were identified, respectively (Table 5.1). A summary of the socio-demographic characteristics of the different clusters is presented in Table 5.2. For safety at retail, cluster 1 (37% of consumers) considered smell and use-by date as the most important, cluster 2 (30%) ranked packaging integrity, use-by date and country of origin as the most important, while sell-by date was assigned the highest importance by cluster 3 (33%) (Table 5.1). About a third of the consumers were in each cluster, with significant differences identified only for the percentage of females and consumers aged 30 - 39 years (Table 5.2). For safety at home, cluster 1 (40% of consumers) attached more importance to use-by date, cluster 2 (35 %) considered smell and texture as most important, while smell was relatively important to cluster 3 consumers (25%) (Table 5.1). Clusters 1 and 2 were similar in size for each socio-demographic category but significantly larger than the percent in cluster 3, except for consumers aged 30 - 39 and 60 years and older (Table 5.2).

Table 5.1: Rank order of importance of attributes of chicken meat when assessed for safety at retail and home (n = 863)

Rank order	At retail[1]			At home[1]		
	Cluster 1 (*n* = 318)	Cluster 2 (*n* = 258)	Cluster 3 (*n* = 287)	Cluster 1 (*n* = 344)	Cluster 2 (*n* = 303)	Cluster 3 (*n* = 216)
Most important	Smell, use-by date	Damaged packaging, use-by date, country of origin	Sell-by date	Use-by date	Smell, how it feels to the touch	Smell
↓	Colour	Smell, brand name, price, no growth hormones in feed, no brine injected into meat, sell-by date	Smell	Smell, sell-by date	Colour	Colour
↓	Sell-by date	Colour, amount of visible fat	Price	Colour	Sell-by date, use-by date	Sell-by date, use-by date
↓	Damaged packaging	Free-range	Use-by date, colour	How it feels to the touch		How it feels to the touch
↓	No growth hormones in feed, no brine injected into meat		Damaged packaging, brand name, no brine injected into meat			
↓	Amount of visible fat, country of origin		Amount of visible fat, free-range, no growth hormones in feed			
↓	Free-range, price		Country of origin			
Least important	Brand name					

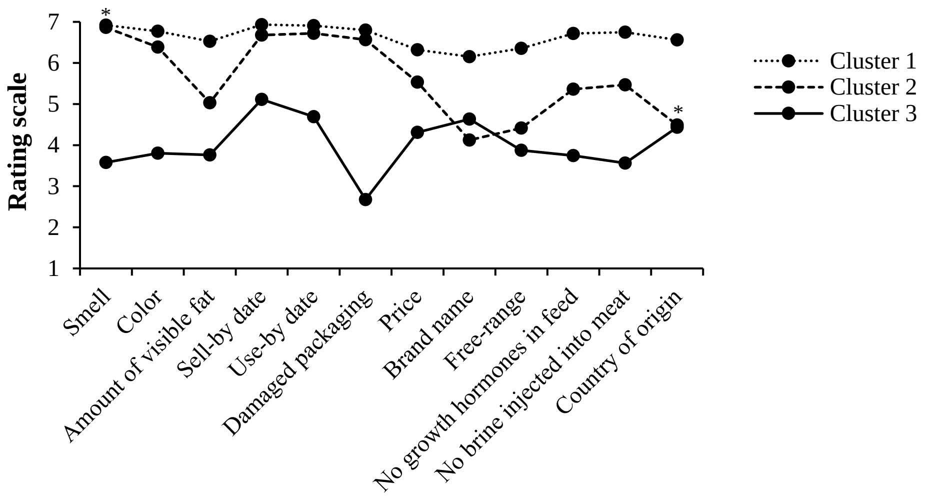
[1]At retail, attributes of chicken meat were ranked from 1 for the attribute considered most important to 12 for the attribute considered least important. At home, they were ranked from 1 for the attribute considered most important to 5 for the attribute considered least important. Attributes on different levels of importance are significantly different (ANOVA, $p < 0.05$).

Table 5.2: Socio-demographic cluster profiles for perceptions of the safety of chicken meat at retail and home (*n* = 863)

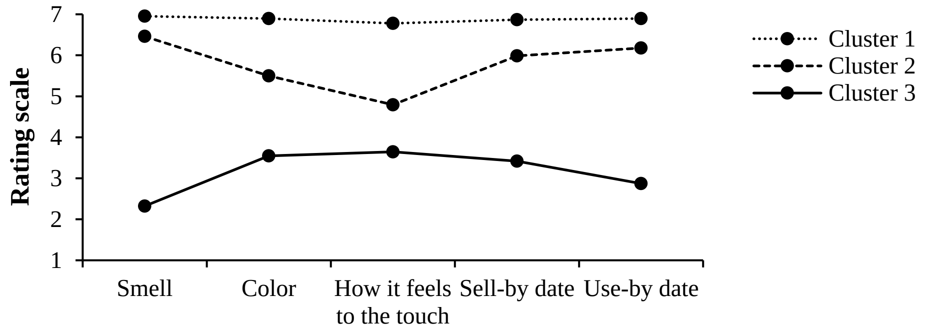
Socio-demographic factors	Categories (*n*)	At retail[1]			At home[1]		
		Cluster 1 318[a] (37)	Cluster 2 258[b] (30)	Cluster 3 287[ab] (33)	Cluster 1 344[a] (40)	Cluster 2 303[a] (35)	Cluster 3 216[b] (25)
Gender[2]	Male (*n* = 247)	72[a] (29)	86[a] (35)	89[a] (36)	93[a] (38)	96[a] (39)	58[b] (23)
	Female (*n* = 612)	245[a] (40)	170[b] (28)	197[ab] (32)	249[a] (41)	206[a] (34)	157[b] (26)
Age (yr.)	18 - 29 (*n* = 360)	120[a] (33)	121[a] (34)	119[a] (33)	157[a] (44)	118[ab] (33)	85[b] (24)
	30 - 39 (*n* = 183)	75[a] (41)	47[b] (26)	61[ab] (33)	70[a] (38)	53[a] (29)	60[a] (33)
	40 - 49 (*n* = 137)	52[a] (38)	36[a] (26)	49[a] (36)	48[ab] (35)	58[a] (42)	31[b] (23)
	50 - 59 (*n* = 114)	44[a] (39)	38[a] (33)	32[a] (28)	44[a] (39)	47[a] (41)	23[b] (20)
	60 and older (*n* = 69)	27[a] (39)	16[a] (23)	26[a] (38)	25[a] (36)	27[a] (39)	17[a] (25)
Education level[3]	High school (*n* = 386)	136[a] (35)	116[a] (30)	134[a] (35)	149[a] (39)	141[a] (37)	96[b] (25)
	Tertiary (*n* = 473)	181[a] (38)	141[a] (30)	151[a] (32)	192[a] (41)	161[a] (34)	120[b] (25)

[1]Cluster data presented as *n* (% of respondents). Total % per category may not add up to 100 due to rounding off of figures. Values in a row with different superscripts are significantly different (chi-square test, $p < 0.05$).
[2]Consumers who preferred not to disclose their gender (1%) were not included in the statistical analyses.
[3]Consumers with primary school education (1%) were not included in the statistical analyses.

For both quality perception at retail and the home, 3 clusters of consumers were also identified, respectively (Figure 5.6). The socio-demographic characteristics of the different clusters are summarized in Table 5.3. For quality at retail, the consumers in cluster 1 (almost 60% of respondents) considered all the attributes of chicken meat as extremely important (Figure 5.6a). Cluster 2 (33% of consumers) rated freshness indicators of chicken meat (smell, colour, use-by date, sell-by date) and packaging integrity as extremely important and the rest of the attributes of low importance. The 8% of consumers in cluster 3 rated the attributes of lower importance ($p < 0.05$). For each socio-demographic group, a large majority of the consumers were in cluster 1 except for males and consumers aged 18 - 29 years (less than 50% of consumers). Similar results were obtained for consumers' perceptions of the quality of chicken meat at the home (Figure 5.6b). Respondents in cluster 1, the largest group, considered all 5 attributes as extremely important, while those in cluster 2 rated smell and date labels more important than colour and texture. The remaining 4% of the respondents (cluster 3) rated all the attributes low (mean < 4) ($p < 0.05$). For each socio-demographic group, a large majority of the consumers were in cluster 1 (Table 5.3).



(a) At retail



(b) At home

Figure 5.6: Consumer clustering based on importance-rating of attributes of chicken meat when assessed for quality at retail (a) and home (b)

Attributes of chicken meat were rated from 1 (not important at all) to 7 (extremely important). An attribute with the highest mean rating is more important. Mean ratings without an asterisk (*) are significantly different (ANOVA, $p < 0.05$, $n = 863$).

Table 5.3: Socio-demographic cluster profiles for perceptions of the quality of chicken meat at retail and home (*n* = 863)

Socio-demographic factors	Categories (*n*)	At retail[1]			At home[1]		
		Cluster 1 507[a] (59)	**Cluster 2 285[b] (33)**	**Cluster 3 71[c] (8)**	**Cluster 1 619[a] (72)**	**Cluster 2 213[b] (25)**	**Cluster 3 31[c] (4)**
Gender[2]	Male (*n* = 247)	117[a] (47)	95[a] (38)	35[b] (14)	153[a] (62)	78[b] (32)	16[c] (6)
	Female (*n* = 612)	389[a] (64)	188[b] (31)	35[c] (6)	463[a] (76)	134[b] (22)	15[c] (2)
Age (yr.)	18 - 29 (*n* = 360)	177[a] (49)	134[b] (37)	49[c] (14)	239[a] (66)	99[b] (28)	22[c] (6)
	30 - 39 (*n* = 183)	109[a] (60)	60[b] (33)	14[c] (8)	133[a] (73)	47[b] (26)	3[c] (2)
	40 - 49 (*n* = 137)	89[a] (65)	48[b] (35)	-	100[a] (73)	35[b] (26)	2[c] (1)
	50 - 59 (*n* = 114)	83[a] (73)	24[b] (21)	7[c] (6)	93[a] (82)	18[b] (16)	3[c] (3)
	60 and older (*n* = 69)	49[a] (71)	19[b] (28)	1[c] (1)	54[a] (78)	14[b] (20)	1[c] (1)
Education level[3]	High school (*n* = 386)	224[a] (58)	123[b] (32)	39[c] (10)	284[a] (74)	86[b] (22)	16[c] (4)
	Tertiary (*n* = 473)	281[a] (59)	161[b] (34)	31[c] (7)	333[a] (70)	126[b] (27)	14[c] (3)

[1]Cluster data presented as *n* (% of respondents). Total % per category may not add up to 100 due to rounding off of figures. Values in a row with different superscripts are significantly different (chi-square test, $p < 0.05$).
[2]Consumers who preferred not to disclose their gender (1%) were not included in the statistical analyses.
[3]Consumers with primary school education (1%) were not included in the statistical analyses.

5.5 Discussion

5.5.1 Purchasing and consumption habits

This study substantiates reports that chicken meat is widely consumed in South Africa. Many consumers mostly buy raw chicken for preparation in their households at supermarkets, in a refrigerated or frozen state. In a similar South African study (*n* = 466), Xazela, Hugo, Marume, and Muchenje (2017) also found that a high proportion of consumers from the Eastern Cape province (65%) most often buy meat at supermarkets. Supermarkets are most popular probably because they dominate about 65% of the South African meat market (Ncube, 2018). Moreover, supermarkets offer convenience with regard to both location and availability of a broad range of household groceries, the 'one-stop-shop' concept (D'Haese & Van Huylenbroeck, 2005), compared with other meat retailers such as butcheries and farmers' markets. Information about the number of butcheries and farmers' markets in South Africa is limited. The most cited reasons by consumers from Gauteng province in South Africa for not frequenting farmers' markets for vegetables, fruits, meat, eggs, and dairy foods was that they were inconveniently located and occurred irregularly (Vermeulen & Biénabe, 2010). These could also be the reasons why the majority of consumers in the present study do not mostly purchase chicken meat at farmers' markets. Likewise, many consumers did not purchase chicken meat at wholesalers. It is possible that a substantial number of the consumers were single or do not have big families since many (63%) were aged 18 - 39 years, and hence may not buy chicken meat in quantities in excess of a few kilograms. No information on the respondents' marital and family status was collected, however. In this study, it is also reasonable to assume that a large proportion of the surveyed consumers were middle and high-income earners since only a few mostly purchase chicken meat from informal retailers (street vendors and 'other retailers') and chicken meat sold at room temperature. Generally, meat from the informal sector is relatively affordable hence it is an essential retail channel in South Africa, particularly to low-income earners in townships and informal settlements (Willemse, 2011). Informal retailers usually sell food products that are neither frozen nor refrigerated, even if the goods are perishable. No information on consumers' household income was collected, however.

5.5.2 Perceptions of the safety of chicken meat

The findings indicated that many consumers considered supermarkets as the most trusted outlets to sell safe chicken meat. A focus group study by Behrens et al. (2010) revealed that supermarkets were most trusted by Brazilian consumers as well because standards of cleanliness and hygiene were viewed as high. This could mean that most consumers equate the cleanliness and hygiene standards of a meat retail outlet with the safety of the meat products on sale. In another study, Verbeke and Ward (2006) found that certification of meat products found in supermarkets has a positive impact on Belgian consumers' perceptions. Consumers may feel confident of the safety of chicken meat from supermarkets due to guarantee seals which are used as proof by processors that the meat was inspected by authorized government veterinarians and certified. In South Africa, according to the Meat Safety Act, it is mandatory that poultry carcasses be inspected for disease conditions and abnormalities during processing (DAFF, 2006). Before leaving the abattoir, each poultry product is sealed with a label approving that it is fit for human consumption (DAFF, 2006). Nevertheless, it is important to highlight that certification labels do not reflect the microbial status of poultry products, a fact which most consumers may be unaware of. Therefore, it is possible for chicken meat from supermarkets to contain high levels of pathogenic bacteria, with the potential of causing foodborne illnesses if improperly handled by supermarket personnel and consumers.

A few of the respondents most trusted street vendors and chicken meat sold at room temperature to be safe. Meat from informal retailers is generally considered as posing health risks to consumers. A focus group discussion by Oguttu, McCrindle, Makita, and Grace (2014) with chicken meat street vendors in Gauteng province in South Africa revealed that the vendors sometimes obtained live broiler chickens directly from chicken farmers and slaughtered and dressed them at their homes before selling to consumers. The hygiene conditions during chicken slaughter and vending might not meet specifications in the Meat Safety Act, hence the meat is potentially unsafe. Moreover, the street vending environment usually does not permit maintenance of the cold chain. Frozen or refrigerated chicken meat is thus relatively safe because the maintenance of cold temperatures at retail ensures no or minimal bacterial growth. In cases whereby consumers purchase live chicken for slaughter at home, there could also be a microbial risk especially when the intestinal contents contaminate the meat during evisceration of the carcasses and if the chicken slaughter waste is not properly disposed of. It is therefore paramount to raise consumer awareness of food safety practices, irrespective of their perceptions of chicken meat retailers.

Smell, use-by and sell-by dates, and colour were ranked as more important indicators of chicken safety in the present study. According to the Codex Alimentarius Commission, the use-by date refers to "the date which signifies the end of the period under any stated storage conditions, after which the product should not be sold or consumed due to safety and quality reasons" (FAO/WHO, 2018). It has been cautioned though that use-by dates do not guarantee meat safety because the maintenance of cold temperatures along the supply chain cannot be assured (Newsome et al., 2014). Besides, recent allegations of some retailers in South Africa altering date labels to extend the shelf life of meat could further increase the risk of consumers contracting foodborne illnesses (Times LIVE, 2017, 2019). Smell and colour are considered as inaccurate indicators of the microbial safety of meat because bacterial pathogen growth does not result in sensory changes in meat and can cause human illnesses at low concentrations, even when the meat is unspoiled (Henson & Northen, 2000). Consequently, it is essential that consumers practice food safety from point of purchase to consumption at the home, regardless of date labels and sensory characteristics of chicken meat to reduce or eliminate microbial risks.

Consumers also perceived the absence of growth hormones in chicken feed to be an important attribute when judging chicken meat safety. The use of hormonal substances as growth promoters in food animals has provoked many concerns on the impact on human health (Jeong, Kang, Lim, Kang, & Sung, 2010). It is possible that some consumers may assume that the rapid growth of broiler chickens is due to the use of feed containing growth-promoting hormones by commercial farmers. This misconception could have arisen from the fact that the use of growth-promoting hormones is permitted in the beef industry (DAFF, 2008), and that some chicken meat products are labelled as having been processed from chickens that were raised without growth-promoting hormones. Nevertheless, the use of growth-promoting hormones in feed during chicken farming is not allowed in South Africa and thus is not stipulated in the regulations for labelling and advertising of foods (DAFF, 2008; Department of Health, 2014a). The 'raised without growth-promoting hormones' claim could be a marketing strategy and may result in consumers supposing that all other chicken meat products without this label would have been processed from chickens raised using feed containing growth-promoting hormones. In the USA, this claim is permitted only if it is accompanied by a statement informing consumers that the use of hormones in the production of poultry is prohibited (Yang, Raper, & Lusk, 2017). Poultry farmers, agricultural extension officers, and SAPA could assist by increasing consumer awareness on how chickens are raised and address consumer concerns and inquiries. Moreover, it is advisable that food regulators monitor chicken meat product labels at retail to protect consumers against misleading claims.

On the same note of product labelling, it is mandatory for processors to declare on the packaging where chicken meat products were produced, processed or packaged for transparency and traceability purposes. Some developed countries such as Australia also require country of origin labelling (Country of Origin Food Labelling Information Standard, 2016). This regulation is even more critical in South Africa now that chicken meat imports have increased substantially as a consequence of shortfalls in local production (SAPA, 2018). Of interest in this study were consumers' safety perceptions of the country of origin of chicken meat following allegations of unsanitary practices by some Brazilian chicken processors (DAFF, 2017). The scandal generated substantial media publicity because Brazil is one of the major suppliers of raw chicken meat in South Africa (SAPA, 2018). Surprisingly, the country of origin was perceived by respondents as one of the least important attributes when inferring the safety of chicken meat. Verbeke and Ward (2006) also found the importance of country of origin of meat to be significantly less than that of other attributes. Consumers may find the country of origin of chicken meat less important, especially when purchasing imported products, because they may not be knowledgeable of the production processes employed by the exporting countries. Thus, they may find it challenging to make confident decisions based on this attribute. It is also possible that some consumers do not check information about the source of chicken products when purchasing.

Previous studies conducted in the United States of America (USA) and Australia have reported that consumers perceived free-range chicken to be safer than conventional chicken as they believed that less/no growth-promoting hormones and antibiotics were used during its production, and the prevalence of pathogenic bacteria was lower (Bernard, Pesek, & Pan, 2007; Erian & Phillips, 2017). In the present study, free-range was one of the least important attributes to consumers when assessing the safety of chicken meat. In South Africa, there is currently no legislated national standard governing free-range chicken farming, hence production conditions amongst farmers are diverse (Tung, 2016). There is presently no published research (according to our knowledge) investigating if consumers of free-range chicken are aware of this fact. Moreover, there is currently no published research (according to our knowledge) investigating the association between consumers' expectations and understanding of free-range chicken, and the actual production practices by farmers. Though this attribute was one of the least important, it is advisable for free-range poultry production regulations to be promulgated to guarantee the authenticity of products and for consumer protection.

5.5.3 Perceptions of the quality of chicken meat

Consistent with supermarkets being the most frequented retailers for raw chicken meat by many consumers, the findings suggested supermarkets were also the most trusted outlets to sell good quality chicken. A study by Behrens et al. (2010) reported that supermarkets are usually preferred rather than informal retailers because consumers trust that the meat is sourced from reputable suppliers and hence would have been produced and processed following stipulated regulations, including labelling. On the other hand, other studies found that consumers frequent butcheries (McCarthy & Henson, 2005), wet markets and farmers' markets (Chamhuri & Batt, 2013) more as they perceived the meat to be freshly slaughtered and thus of better quality in comparison with that from supermarkets. The reported differences could be partly due to dissimilar chicken meat market structures between countries, with traditional markets more prevalent in developing countries. Regarding the temperature state of chicken meat, significantly more of the consumers most trusted refrigerated chicken meat to be of good quality than those who most trusted frozen chicken. However, frozen chicken meat is generally lower priced than its refrigerated counterpart. Frozen chicken meat accounts for about 70% of all retail chicken meat sales in South Africa (NAMC, 2018). Consumers may not prefer frozen chicken products as they are usually injected with brine during processing. Another possible reason could be that consumers may find it easier to detect irregularities in the colour and smell of chicken meat when it is sold in a refrigerated than frozen state.

In the present study, smell, use-by and sell-by dates were rated as highly important attributes, followed by colour for assessing the quality of chicken meat at retail and before preparation at the home. Visual appearance has been reported to be a very important meat attribute at retail probably because consumers use colour as an indicator of freshness or spoilage (Kennedy, Stewart-Knox, Mitchell, & Thurnham, 2004; Skunca et al., 2016). The overall visual appearance of chicken meat includes skin colour, flesh colour and any defects such as bruises and blood clots. Chicken meat is perishable and loss of freshness during storage is mainly caused by bacterial growth (Rukchon, Nopwinyuwong, Trevanich, Jinkarn, & Suppakul, 2014). In the current study, the smell of chicken meat at point of purchase was highly important possibly because meat from butcheries, farmers' markets and street vendors can be sold unpackaged in South Africa. It is also possible that some of the consumers indicating that they purchase chicken meat from supermarkets may buy it from butchery sections of the supermarkets. Consumers may be able to detect slight spoilage odours emanating from chicken meat during purchasing, causing them not to buy it even if the colour and overall appearance are still acceptable. In such cases, the appearance may become secondary to smell. Considering that if the raw chicken meat was marinated or heavily spiced, then the above-mentioned argument would not be valid as it would be challenging for consumers to detect any signs of spoilage in such meat.

Date labels, irrespective of their meaning, generally give consumers confidence in the quality of meat products (Verbeke & Ward, 2006). Though use-by and sell-by dates are good indicators of meat freshness, they may not be helpful to consumers where the chicken meat cold chain is broken along the supply chain. Some researchers have proposed using intelligent packaging instead, with the ability to monitor the quality status of chicken meat in terms of bacterial deterioration and communicate it to consumers (Yam, Takhistov, & Miltz, 2005). It was surprising that the sell-by date was considered of high importance by consumers when assessing the quality of chicken meat before preparation at home. One would expect that the sell-by date would not matter anymore. This could suggest that many consumers may be unaware of what the sell-by date indicates. According to the Foodstuffs, Cosmetics and Disinfectants Act, the sell-by date is "the last date of offer for sale to the consumer after which there remains a reasonable storage period at home" (Department of Health, 2014b). It is highly probable that many consumers confuse the sell-by date with use-by and expiry dates. Leib et al. (2014) proposed that sell-by dates on food products are mainly for stock control by retail personnel and should be incomprehensible or invisible to consumers as they may be incorrectly interpreted. Misinterpretation of date labels by consumers could result in food loss. Consumers could benefit from education about date labelling terminology to improve their capability to assess the quality of chicken meat and other food products.

Brining of chicken meat to enhance its flavour and tenderness during cooking has been practiced by poultry processors for many years in South Africa (Tan, De Kock, Dykes, Coorey, & Buys, 2018). In developed countries such as the USA, injection of flavour enhancers into poultry meat is also allowed (United States Department of Agriculture, 1999). However, in South Africa, there were disagreements between local chicken processors and regulators concerning the appropriate levels of brine for injection into chicken meat (South African Poultry Association v. Minister of Agriculture, 2016). Some reports highlighted that high salt concentrations in brine could put consumers' health at risk, hence non-brined chicken meat could be healthier in this regard (Mashishi, 2016). The legal brining limits were eventually set at 10% and 15% for whole chicken carcasses and portions, respectively (DAFF, 2016). It is unfortunate that there was controversy and extensive media coverage concerning the appropriate brining levels for chicken meat, but there is to date no published research (according to our knowledge) giving insight into consumers' perceptions and expectations regarding brined chicken. This study indicates that consumers perceived the absence of brine in chicken meat as an important attribute reflecting its quality. It is advisable for poultry processors to conduct market research and incorporate consumers' views regarding brining of chicken meat. A possible solution could be for poultry processors to supply both brined and non-brined chicken products to cater for consumers with differing preferences. In other developing countries such as Zambia, brining of chicken meat is not practiced as this is what consumers prefer. It was found that Zambian consumers perceive non-brined chicken meat as 'wholesome' (Bagopi et al., 2014).

Price, visible fat content and country of origin appeared to be of low importance for the evaluation of chicken meat quality during purchasing by consumers. This study did not explore the economic status of the respondents, but it is reasonable to assume that price would be of high importance to consumers with lower income. However, there is sometimes social bias and some consumers do not reveal that price is relatively important to them with regard to quality. Visible fat content may not be a quality issue for most consumers because some processors in South Africa trim off excess fat from raw chicken meat and label the products as such. The importance of country of origin to Belgian consumers has also been reported by Verbeke and Ward (2006) to be lower than that of other extrinsic attributes of chicken meat. In contrast, Ehmke, Lusk, and Tyner (2008) revealed that consumers from China, Niger, France and the USA generally prefer meat products from their own countries, suggesting ethnocentric tendencies.

Brand name and free-range were considered as the least important attributes. This could mean that the quality of chicken meat is a generic concept to consumers and not brand specific. In Brazil (Farina & de Almeida, 2003) and Vietnam (Ifft, Roland-Holst, & Zilberman, 2012), free-range chicken meat was perceived to be tastier, healthier and more natural, and these appeared to be the key quality considerations for purchases. As previously discussed, the extent to which South African consumers are aware of different chicken production practices is unknown. Thus, consumers may not find free-range chicken highly important due to a lack of knowledge.

5.5.4 Consumer clustering based on perceptions of chicken meat

A large majority of consumers tend to rely on freshness indicators for the assessment of safety of chicken meat during purchasing and preparation, but a substantial proportion perceived factors such as country of origin, packaging integrity and texture as most important. The surface texture of raw chicken meat deteriorates at advanced stages of microbial spoilage (Russell, 2000), hence this attribute may not be as reliable as smell. The origin of chicken meat has been increasingly regarded by European consumers as an important safety cue, with the majority buying meat of domestic origin (Vukasovic, 2011). It was noted that geographical origin is highly influential on consumers' purchasing decisions especially during meat safety crises such as avian influenza outbreaks.

A large majority of consumers in this study were clustered together because they perceived both intrinsic and extrinsic attributes of chicken meat to be extremely important for the assessment of quality at retail and home. Research suggests that consumers who value attributes of meat tend to be more involved with the product and invest more cognitive effort into the decision-making process (Ripoll & Panea, 2019). High involvement leads to an extensive search and use of meat product information by the consumer before decision making. Another cluster with a substantial proportion of consumers, in the current study, seemed to value intrinsic more than extrinsic attributes. Roe and Bruwer (2017) proposed that consumers with high meat product involvement rely on intrinsic rather than extrinsic attributes. However, it can be argued that consumers may need to make an effort to gain prior knowledge on extrinsic attributes of chicken meat in comparison with intrinsic attributes, thus indicating more product interest.

5.6 Conclusions

Though smell, use-by dates, and colour are good indicators of the quality of chicken meat, they do not reflect the presence or levels of bacterial pathogens in chicken meat which can cause foodborne illnesses even when the meat is unspoiled. Since human pathogenic bacteria are almost always present in raw chicken, knowledge about microbial risks and safe handling practices for chicken meat needs to be communicated effectively to reduce or eliminate risks from pathogenic bacteria at the consumer level. Consumer education on the correct interpretation of date labels is also recommended. The findings also suggest that chicken meat processors and regulators revisit the issue of brining of chicken meat by approaching it from a consumer preference perspective, and poultry farmers and other industry stakeholders address the misconception about the use of feed containing growth-promoting hormones by raising consumer knowledge on chicken production. Food legislators can also contribute by monitoring chicken product labels at retail to protect consumers from misleading 'raised without growth-promoting hormones' claims. The information from this study can assist public health authorities to design targeted food safety awareness programs and the chicken industry to meet consumer expectations. The limitation of the study was that consumers who mostly purchase chicken meat from street vendors and 'other retailers' were probably underrepresented hence the results may not accurately reveal their perceptions. Further research should focus on these groups.

CHAPTER SIX

Sensory implications of chicken meat spoilage in relation to microbial and physicochemical characteristics during refrigerated storage

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Adapted from:

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2020). Sensory implications of chicken meat spoilage in relation to microbial and physicochemical characteristics during refrigerated storage. *LWT - Food Science and Technology*, 128, https://doi.org/10.1016/j.lwt.2020.109468

6.1 Abstract

Consumer perception of chicken meat spoilage is linked to sensory, microbial and physicochemical changes of raw chicken during storage. The objective of this study was to characterise the sensory attributes of raw chicken meat and to establish the relationship with the microbial and physicochemical changes during refrigerated storage under aerobic packaging. Chicken legs obtained from a commercial poultry processing plant were stored at 4 °C and microbiological (total viable counts, *Pseudomonas* spp. Enterobacteriaceae, lactic acid bacteria), pH, colour and descriptive sensory (odour and appearance) analyses were conducted during storage for 14 days. Chicken meat stored for 1, 3 and 7 days was characterised by having pink flesh and creamy skin, with a bloody and fresh chicken smell, and high skin L*, flesh L* and flesh colour saturation values. Chicken meat stored for longer than 7 days was described as having all the negative sensory attributes (green/blue colouration, slimy, pungent, fishy, rotten egg, ammonia-like and intense overall odour), high microbial levels and pH beyond 7. Skin colour saturation did not differentiate well chicken meat samples stored for different days, hence would be a poor indicator of spoilage. Odour attributes of chicken meat deteriorated at a faster rate than instrumental colour and appearance attributes and were highly correlated ($r > 0.8$) with microbial growth. In contrast, no correlations were found between instrumental colour (except for skin L*) and appearance attributes and microbial growth in chicken meat. The findings suggest that, to consumers, the smell of raw chicken meat would be a more reliable signal for microbial spoilage than appearance.

6.2 Introduction

Chicken meat is the most commonly consumed animal protein source in many countries (OECD, 2019). Besides relatively low cost, factors that have been cited for the increased demand for chicken meat include changes in consumers' dietary preferences, consumers' perception of chicken meat as a healthy alternative to red meat due to its low fat content, the versatility of chicken meat (Henchion, McCarthy, Resconi, & Troy, 2014; Tan et al., 2018) and the limited religious restrictions related to its consumption (Mehta & Nambiar, 2007). As is the case with other meats, fresh chicken meat is highly perishable and it has a limited shelf life regardless of refrigerated storage. Deterioration in quality or freshness of refrigerated chicken meat is largely due to psychrotrophic microbial growth and physicochemical changes (Rukchon, Nopwinyuwong, Trevanich, Jinkarn, & Suppakul, 2014). The ready availability of proteins, free amino acids, fats, vitamins, mineral salts and moisture makes chicken meat an ideal medium for the survival and growth of microorganisms during processing, storage and distribution, and at retail and consumer level (Muchenje et al., 2009). Although research has proven that vacuum and modified atmosphere packaging result in a marked extension of the shelf life of refrigerated chicken meat, conventional aerobic packaging using material such as polyvinyl chloride (PVC) film continues to be the dominant type of packaging for fresh chicken meat (McMillin, 2017). During aerobic storage of chicken meat at refrigeration temperatures, the most frequently isolated psychrotrophic bacteria contributing to spoilage include *Pseudomonas* spp., Enterobacteriaceae, *Brochothrix thermosphacta* and lactic acid bacteria (LAB) (Casaburi et al., 2015; Doulgeraki et al., 2012; Ercolini et al., 2010; Pothakos et al., 2015). Their metabolic activities result in the formation of metabolites which bring about physical and chemical changes in the chicken meat, sensorially perceived as off-odours, discolouration and slime (Dave & Ghaly, 2011). At the consumer level, the sensory aspect of raw chicken meat is of paramount importance because it is the most apparent and hence linked to consumer acceptance during purchasing or preparation (Troy & Kerry, 2010). Chicken meat spoilage is not always evident though and perception of sensory spoilage may be influenced by the severity of meat spoilage and sensory acuity of the individual (Nychas et al., 2008).

Many studies have been conducted to analyse storage dependant microbial growth processes and the associated chemical and physical changes in raw chicken meat (Balamatsia, Paleologos, Kontominas, & Savvaidis, 2006; Balamatsia, Patsias, Kontominas, & Savvaidis, 2007; Doulgeraki et al., 2012; Guevara-Franco, Alonso-Calleja, & Capita, 2010; Wang et al., 2017). However, the relationship between microbial growth, pH, changes in instrumentally measured colour and sensory attributes of raw chicken has not yet been established. Therefore, the specific objective of this study was to characterise the odour and appearance attributes of raw chicken meat during refrigerated storage under aerobic packaging and to establish the relationship with the microbial and physicochemical quality changes. The aim of this study was to understand how the implications of microbial spoilage of chicken meat relate to consumers' sensory perception of chicken meat spoilage.

6.3 Materials and methods

6.3.1 Sample collection and storage conditions

Raw chicken legs were collected from the production line of a processing plant in Gauteng province, South Africa, immediately after aerobic packaging with PVC film (oxygen transmission rate - *c*. 5000 mL/m^2 per 24 h atm at 22 °C and 75 % relative humidity). At each sample collection date, 20 packs of chicken meat were collected, each with 6 chicken legs. The chicken was transported to the laboratory under chilled conditions within 6 h after slaughtering and stored at 4 ± 0.5 °C. Samples were analysed after 1, 3, 7, 10 and 14 days of storage. Two independent trials of storage experiments were carried out over a period of 1 month.

6.3.2 Bacteriological analysis

Raw chicken leg samples were prepared for microbial analysis as described by Mikš-Krajnik et al. (2016). Total viable counts (TVC) were determined on Plate Count Agar (PCA) incubated at 25 °C for 3 days, *Pseudomonas* spp. on selective Cetrimide-Fucidin-Cephaloridine (CFC) agar incubated at 25 °C for 2 days, Enterobacteriaceae on Violet Red Bile Glucose (VRBG) agar incubated at 37 ^{o}C for 1 day and lactic acid bacteria (LAB) on De Man, Rogosa and Sharpe (MRS) agar incubated at 25 ^{o}C for 3 days.

6.3.3 pH determination

The pH of chicken samples was measured as described by Zhang, Wu, and Guo (2016). A 10 g sample of the meat was homogenised at room temperature for 3 min in 100 mL distilled water using a stomacher bag. The pH of the mixture was then measured using a calibrated digital pH meter (Hanna pH meter 211, Hanna Instruments Inc., USA).

6.3.4 Colour measurements

Colour of the flesh and skin of raw chicken meat during storage were assessed at room temperature (25 °C) using a colorimeter after calibration with a white ceramic tile as per the manufacturer's instructions (Chroma Meter CR-400, Konika Minolta Inc., Japan). The colour was measured as CIE L* (lightness), a* (redness/greenness) and b* (yellowness/blueness) colour coordinates. The a* and b* colour coordinates were reported as S (saturation) after calculation using the formula, $\sqrt{a^{*2} + b^{*2}}$ (Buys, 2004). Saturation measures the colour intensity (Buys, Nortjé, Jooste, & Von Holy, 2000). Measurements were made perpendicular to the surface of the flesh and skin of the chicken legs at 3 different locations on each leg (Choo et al., 2014). Areas on the chicken surface that were selected for colour measurements were free from obvious defects such as bruises, blood clots or scalding and defeathering damage.

Images of chicken meat samples were taken using a digital camera (Canon PowerShot SX 50 HS, 12.1 megapixels).

6.3.5 Quantitative descriptive sensory analysis

Quantitative descriptive sensory analysis of the odour and appearance of refrigerated raw chicken meat was carried out by a trained panel of 10 members (3 males and 7 females), aged between 24 and 42 years. The panel was composed of people who regularly bought raw chicken and prepared it in their households. The sensory acuity of the panellists was assessed prior to training through a 12 plates colour test by Ishihara (1987) (see Appendix C) and aroma identification test as per the International Organisation for Standardisation 8586:2012 (2014) (see Appendix D). Chicken samples stored for different time periods (1, 6 and 12 days), using a reversed storage design as described by Hough (2010), were used during 4 h of panel training. Panel training was conducted as described by Lawless and Heymann (2010). During training, the panel developed a vocabulary of terms with which to describe the odour and appearance of the range of chicken samples in the study. A group discussion was then held to agree upon the descriptors, their definitions and references to use in order to calibrate the panellists' judgements. The finalised list included 4 terms describing the appearance (pink flesh, creamy skin, green/blue colouration and slimy layer) and 6 terms describing the odour of chicken meat (fresh chicken, bloody, pungent, fishy, rotten egg and ammonia-like) (Table 6.1). Evaluation of the test samples was conducted in the Department of Consumer and Food Sciences, University of Pretoria food preparation pilot plant, at room temperature (25 °C) under white fluorescent light. The chicken samples were placed in their original packaging on white, plastic trays and served monadically, directly from the cold room along with the selected reference standards. However, the two standard references, rotten egg and spoiled tilapia, were excluded from the final sensory evaluation tests as these resulted in carryover effects. Instead, the panellists used mental references of rotten egg and fish (Franke et al., 2017). To prevent assessor recognition bias, each chicken sample was labelled with a randomly selected 3-digit code. The order of sample presentation to each panellist was selected following a Williams design. A blind control sample that was previously frozen at -20 °C and thawed at 4 °C for 18 - 24 h prior to evaluation was presented at each test session. After evaluating the appearance of raw chicken, panellists used stainless steel tongs to open the chicken packages for odour assessment. A 60 s rest period was given between samples for panellists to smell the back of their hands to neutralise their sense of smell. The chicken samples were rated for intensities of odour and appearance attributes on an unstructured 10-cm scale anchored at both ends with words describing the extremes of each attribute. The sensory tests were run using Compusense® Cloud Saas software (Compusense Inc., Guelph, ON., Canada) (see Appendix E). The research protocol was approved by the ethics committee of the Faculty of Natural and Agricultural Sciences, University of Pretoria, South Africa (EC161205-087). Panellists provided informed consent prior to participating in the study (see Appendix F).

6.3.6 Statistical analysis

Experiments were replicated three times. The effect of storage period on microbial growth, pH, instrumental colour and descriptive sensory characteristics of raw chicken meat was determined using one-way repeated measures analysis of variance (ANOVA) followed by the Fisher's Least Significant Difference (LSD) test. SPSS software (version 20.0, IBM SPSS Statistics Inc., Armonk, NY, USA) was employed for the analyses. Principal component analysis (PCA) was used to visualise correlations between the descriptive sensory attributes, microbiological levels, pH and instrumental colour characteristics of raw chicken meat. The PCA was done on the means of each variable. Pearson's correlation coefficients were calculated to examine the significance of the relationships between the data. XLSTAT software (version 2016, Addinsoft XLSTAT, NY, USA) was employed for the analyses. The above analyses were carried out at 95% confidence level. The rate of change of the intensity of odour and appearance of chicken meat during storage was determined by fitting linear equations to the data.

6.4 Results and discussion

A visual display of the changes in the appearance of the raw chicken meat over the storage period is shown in Figure 6.1. A lexicon developed to describe the sensory characteristics of the chicken meat during refrigerated aerobic storage is presented in Table 6.1. Changes in microbial levels, pH, instrumental colour and descriptive sensory characteristics (odour and appearance) of raw chicken meat during storage at 4 °C are shown in Figure 6.2.

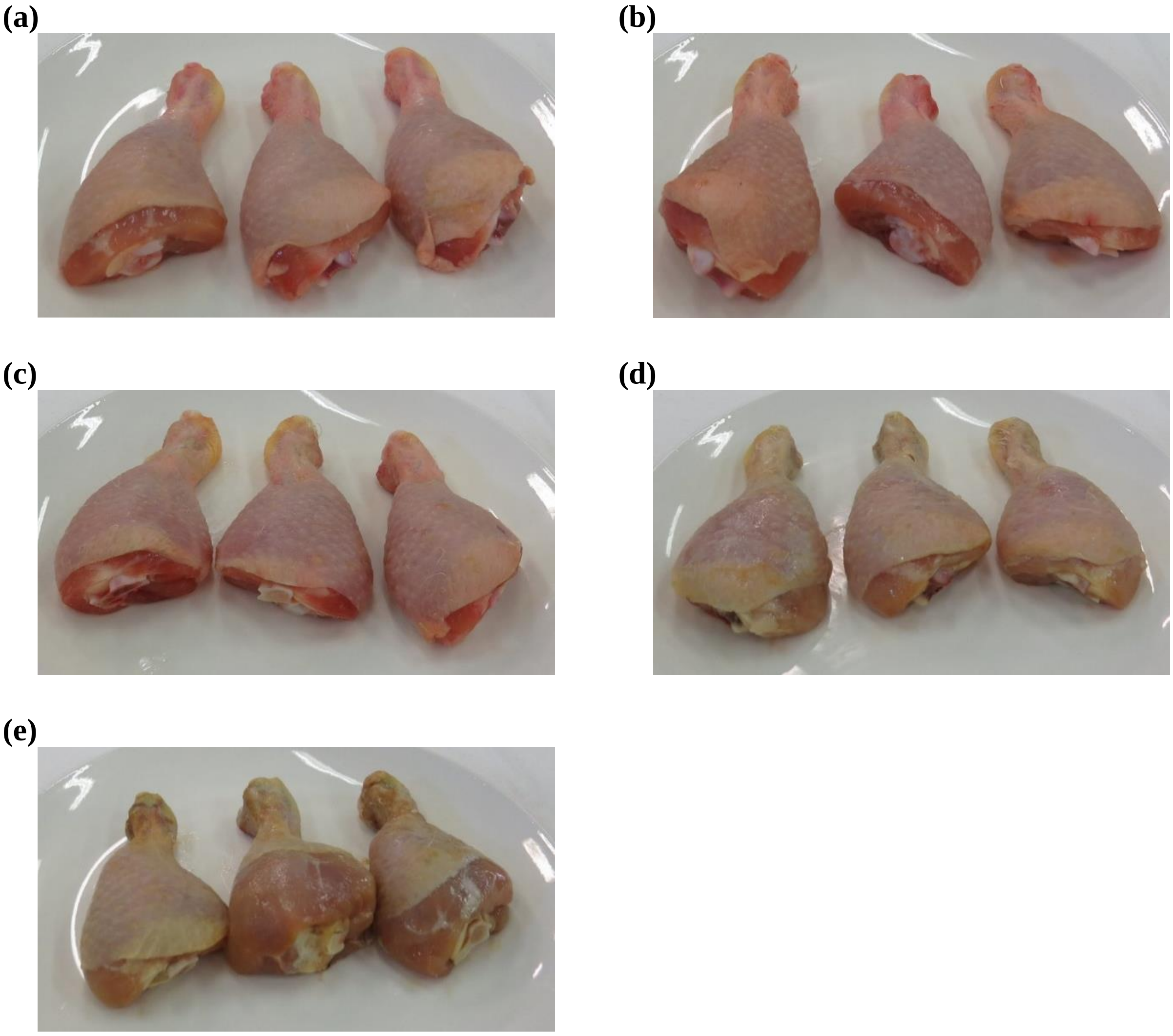

Figure 6.1: Chicken meat samples stored at 4 °C for 1 (a), 3 (b), 7 (c), 10 (d) and 14 days (e)

Table 6.1: Descriptors, definitions and standard references used in descriptive sensory analysis of raw chicken meat during refrigerated storage

Descriptor	Definition	Rating scale	Standard reference (extreme level)
Appearance			
Pink flesh	Pink colour intensity in the flesh of raw chicken legs	0 = no pink flesh 10 = very pink flesh	Photograph of fresh raw chicken legs from abattoir, taken on day zero (Appendix G)
Creamy skin	Cream colour intensity in the skin of raw chicken legs	0 = no creamy skin 10 = very creamy skin	Photograph of fresh raw chicken legs from abattoir, taken on day zero (Appendix G)
Green/blue colouration	Visible green/blue colouration on parts (or all) of raw chicken legs	0 = no green/blue colouration 10 = intense green/blue colouration	Picture of naturally green-blue fish (*Chromis viridis*) (Appendix G)
Slimy layer	Visible growth with a slippery appearance on parts (or all) of the surface of raw chicken legs	0 = absent 1 = present	-
Odour			
Fresh chicken	Distinct aromatic associated with fresh raw chicken muscle	0 = no fresh chicken odour 10 = very fresh chicken odour	Intensity of very fresh raw chicken odour
Bloody	Aromatic associated with raw lean meat, blood, serum or metal/iron	0 = no bloody odour 10 = intense bloody odour	Intensity of an odour of raw beef liver
Pungent	Very strong, sharp smell	0 = no pungent odour 10 = intense pungent odour	Intensity of an odour reminiscent of a rotten freshwater fish
Fishy	Aromatic associated with spoiled fish	0 = no fishy odour 10 = intense fishy odour	Intensity of an odour reminiscent of a rotten freshwater fish
Rotten egg	Aromatic associated with rotten eggs	0 = no rotten egg odour 10 = intense rotten egg odour	Intensity of an odour reminiscent of a rotten egg
Ammonia-like	Aromatic associated with ammonia	0 = no ammonia-like odour 10 = intense ammonia-like odour	Intensity of the odour of 0.2% ammonia in water
Overall odour	-	0 = no odour 10 = intense odour	Intensity of the overall odour perceived whether positive (fresh) or negative (spoiled)

6.4.1 Microbial growth versus descriptive odour changes and slime formation

The results show that the initial (day 1) and final (day 14) TVC in the chicken samples was 5.00 and 9.13 log CFU/g, respectively (Figure 6.2a). *Pseudomonas* spp. were the predominant bacteria present in raw chicken meat throughout the storage period, followed by Enterobacteriaceae and LAB. As storage progressed, microbial levels increased significantly ($p < 0.05$) at each test interval, except for Enterobacteriaceae. There was no difference between the Enterobacteriaceae population in chicken stored for 10 and 14 days. Generally, raw chicken meat that is stored aerobically at refrigeration temperatures develops a microflora confined to the surface of the meat that is usually dominated by *Pseudomonas* spp., most often *P. fragi*, *P. fluorescens* and *P. putida* (Hinton Jr, Cason, & Ingram, 2004; Rouger et al., 2017; Wickramasinghe et al., 2019). It has been proposed that *Pseudomonas* spp. gain a strong competitive advantage over other spoilage bacteria partly due to their ability to metabolise glucose to 2-oxo-gluconate and gluconate through the Entner-Doudoroff pathway (Dainty, 1996). These compounds are not readily assimilated by other spoilage bacteria and thus *Pseudomonas* spp. build up an energy reserve for use when glucose is depleted (Dainty, 1996). In addition, the proteolytic activity of *Pseudomonas* spp. assists their penetration into the meat, enabling them to gain access to new sources of nutrients that are not available to other spoilage bacteria with weaker or no proteolytic properties (Nychas et al., 2008). Consequently, *Pseudomonas* spp. grow rapidly and constitute up to 50 - 90% of the overall bacterial population.

In the present study, slime on the surface of the chicken legs was detected by all the panellists only after 10 and 14 days of storage (Appendix H) when the TVC were 8.66 and 9.13 log CFU/g, respectively (Figure 6.2a). At high cell counts (> 8 log CFU/g), spoilage bacteria secrete exopolysaccharides which gradually form a layer on the surface of the meat, thereby acting as a protective diffusion barrier against desiccation and predation (Vihavainen &

Björkroth, 2010). Russell (2000) described slime as translucent, moist bacterial colonies that increase in size and eventually coalesce and form a layer on the surface of the chicken skin.

As the microbial levels increased, the intensity of the odours also changed, with significant changes ($p < 0.05$) after storage for 7 days (Figure 6.2b). While the intensity of the positive odours (fresh chicken and bloody) decreased with storage time, the negative odours (pungent, fishy, rotten-egg and ammonia-like) and overall odour intensity increased. Storage for 7, 10 and 14 days resulted in significant increases ($p < 0.05$) in the intensity of all the negative odours, except for ammonia-like which significantly increased only after 10 and 14 days. However, chicken meat stored for 7 days smelled significantly different ($p < 0.05$) from that refrigerated for 10 and 14 days for all odour descriptors, including the overall odour. In the present study, the TVC and *Pseudomonas* spp. levels in the chicken meat reached 7.54 and 6.49 log CFU/g, respectively, after 7 days of storage (Figure 6.2a). It is generally agreed that the first signs of off-odours in poultry stored under refrigerated aerobic conditions occur when superficial TVC reach about 7 log CFU/g (Alexandrakis, Downey, & Scannell, 2012; Balamatsia et al., 2006; Lin et al., 2004). It was proposed that at this point glucose, the most preferred energy substrate by bacteria, would have been depleted. The depletion of the glucose supply results in the sequential utilisation of other substrates such as lactate, pyruvic acid and gluconic acid until amino acids are utilised. The sulphur containing amino acids cysteine, cystine and methionine were identified as responsible for the formation of malodorous sulphur containing volatile compounds such as hydrogen sulphide, dimethyl sulphide and dimethyl disulphide at TVC levels higher than 8 log CFU/g (Ellis, Broadhurst, Kell, Rowland, & Goodacre, 2002). Malodorous biogenic amines such as dimethylamine and trimethylamine were also reported to be formed through microbial enzymatic decarboxylation of amino acids (Lázaro et al., 2015). It is reasonable to assume that these chemical compounds were the ones described by the panel in this study as fishy, rotten egg, ammonia-like and pungent.

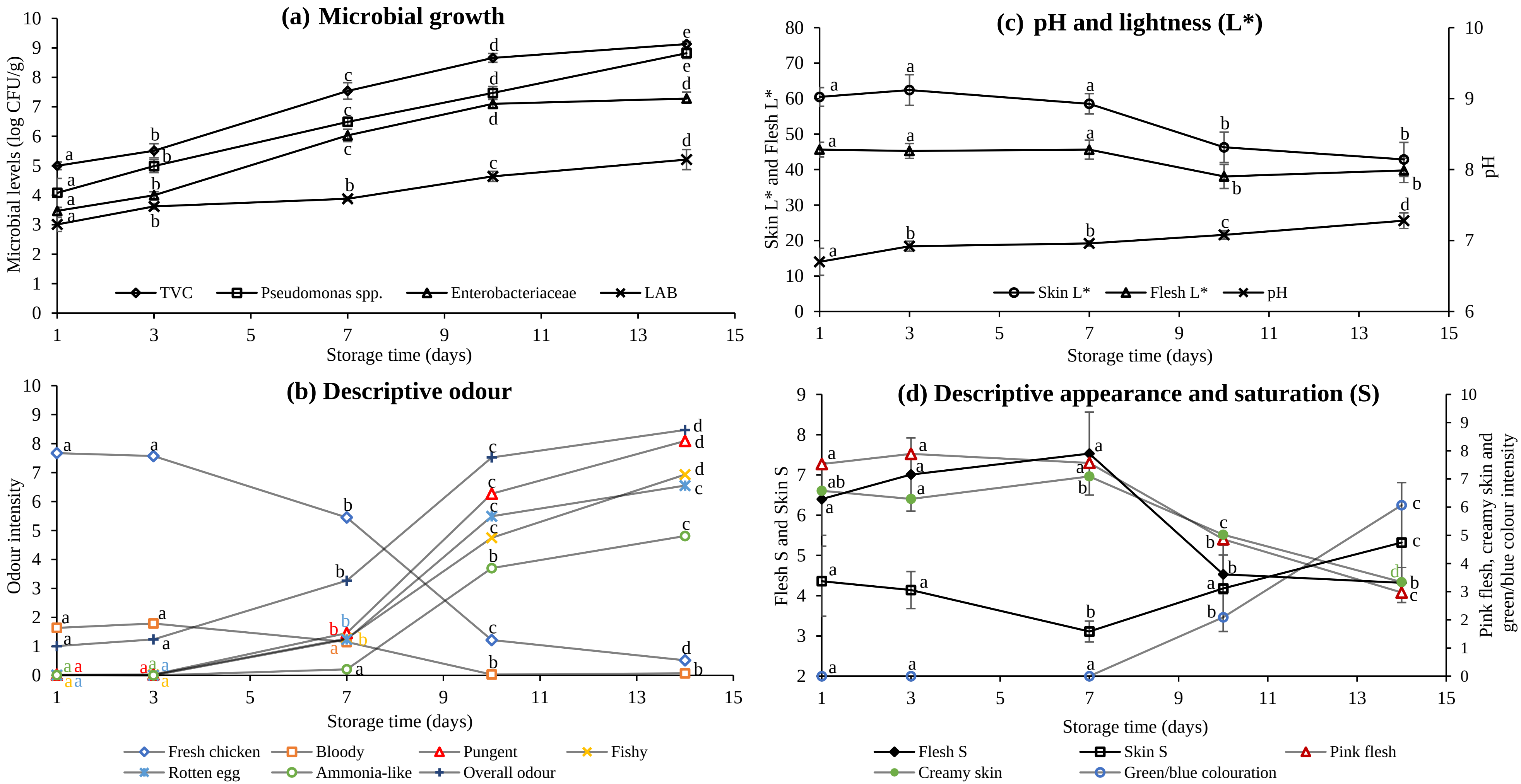

Figure 6.2: Effect of refrigerated storage (4 °C) on microbial levels, pH, instrumental colour and descriptive sensory characteristics (odour and appearance) of chicken meat.

TVC - total viable count; LAB - lactic acid bacteria. Values are expressed as mean ± standard deviation. Values with different letters during storage are significantly different ($p < 0.05$). Descriptive sensory data are shown in colour. For visibility purposes, standard deviations for descriptive sensory data are not shown but presented in Appendix H. The 10-cm scale anchors (0 = absent, 10 = intense) for the different odour and appearance attributes are shown in Table 6.1.

The volatile amines, dimethylamine and trimethylamine, have been detected as giving off the characteristic odour of decomposing fish at low concentrations and an ammonia-like odour at higher concentrations (Byrne, Lau, & Diamond, 2002; Morsy et al., 2016). Hydrogen sulphide has been described as reminiscent of over-boiled or rotten eggs (Guidotti, 1996).

Vasconcelos et al. (2014) reported that at TVC between 7 and 8 log CFU/g, the chicken meat could be categorised as semi-fresh and was still considered as acceptable because the off-odours were slight. Only after the cell counts exceeded 8 log CFU/g could the off-odours be readily perceived, and the meat was categorised as spoiled. This way of categorising meat samples under aerobic refrigerated storage was also applied by Papadopoulou, Panagou, Tassou, and Nychas (2011), but for pork meat. Using microbial levels and the intensity of odours in the present study, chicken legs stored for 7 days could be categorised as semi-fresh. This suggests that it is possible for some consumers, especially those with low olfactory sensitivity, to perceive chicken meat at this stage of microbial growth as still fresh, and only detect spoilage when the microbial levels are too high. Balamatsia et al. (2006) pointed out that consumer perception of meat spoilage is subjective and hence there is no general agreement on the point of incipient spoilage of meat. Some countries, such as South Africa and Australia, do not have regulatory requirements regarding the maximum TVC for raw chicken meat for sale.

6.4.2 Microbial growth, pH and instrumental colour versus descriptive appearance changes

There was a significant difference ($p < 0.05$) in the pH of chicken meat during the first 3 days of storage from 6.70 to 6.92, and then it remained stable up to day 7 (Figure 6.2c). However, there was no significant change ($p > 0.05$) in the lightness values (L*) of both flesh and skin of chicken legs during the first 7 days of storage. After storage for 10 days, the pH increased significantly to 7.08 and finally to 7.28 after 14 days. This increase coincided with darkening of the chicken, with significantly lower ($p < 0.05$) lightness values (L*) of both skin and flesh. At this point, there were more than 8 log CFU/g TVC in the chicken meat. According to literature, during extended storage of refrigerated meat, the accumulation of alkaline nitrogenous compounds such as ammonia and amines results in an increase in meat pH, which leads to unacceptable darkening of the meat (Allen, Russell, & Fletcher, 1997; Zhang et al., 2016). This usually occurs at advanced stages of meat spoilage (about 9 log CFU/g). Consistent with this study, Zhang et al. (2016) also found that the pH of aerobically packaged chicken breast fillets increased significantly during storage for 15 days at 4 °C. In their study, the increase was observed after 9 days of storage. Likewise, del RÍO, Muriente, Prieto, Alonso-Calleja, and Capita (2007) reported a significant pH increase in aerobically packaged chicken legs refrigerated at 3 °C after 5 days of storage. Differences in pH values reported in various studies are most probably due to different chicken portions under study, storage periods, storage temperatures and initial microflora in the chicken meat.

A similar trend to the instrumental colour results (L*) was observed for the changes in the intensity of the pink colour of chicken flesh during storage (Figure 6.2d). Chicken meat stored for 10 and 14 days was significantly less pink ($p < 0.05$) than the rest of the samples. Likewise, the red colour saturation values of chicken flesh (flesh S) decreased significantly only after 10 and 14 days of storage. Another way in which microbial growth is thought to affect the colour of packaged fresh meat is by reducing the level of oxygen at the surface tissue leading to the oxidation of myoglobin, resulting in the formation of metmyoglobin which gives the meat a brownish colour (Mancini & Hunt, 2005; Suman & Joseph, 2013). Further utilisation of oxygen by aerobic bacteria decreases the oxygen partial pressure at the meat surface to essentially zero and hence promotes the formation of deoxymyoglobin, resulting in meat that is purplish in colour (Mancini & Hunt, 2005). However, these phenomena are more obvious in red meat than chicken meat muscle because myoglobin concentration in chicken is reported to be relatively low, even in the dark muscle (thighs and legs). Kranen et al. (1999) and Miller (2002) found myoglobin contents of only 1.17 and 1.50 mg/g in chicken leg muscle, respectively. Regarding skin colour, the creamy appearance of chicken legs stored for 1 day did not differ with that of chicken stored for 3 and 7 days (Figure 6.2d). The colour of the chicken skin deteriorated significantly less creamy after storage for 10 and 14 days. On the other hand, lower saturation values (skin S) were observed up to 7 days of storage and then the values increased (Figure 6.2d). The increase in skin colour saturation could be as a result of the apparent discolouration on day 10 and 14 samples (Figure 6.1). The panel described it as green/blue colouration on both the chicken flesh and skin and it was apparent to all only after 10 and 14 days of storage. The observed blueish hue could have been due to the formation of deoxymyoglobin, as aforementioned. However, the colour of deoxymyoglobin is commonly described as purplish in red meat (Mancini & Hunt, 2005). Previous studies have also indicated that some bacterial species such as *Shewanella putrefaciens*, *Pseudomonas* spp. and bacteria from the Enterobacteriaceae family produce large amounts of hydrogen sulphide from sulphur containing amino acids under restrictive conditions of very low oxygen concentration and high meat pH (Kameník, 2013). Hydrogen sulphide subsequently reacts with myoglobin in the meat tissue forming sulphmyoglobin, which causes green discolouration. Besides contributing to the formation of sulphmyoglobin, early studies have reported that certain *Pseudomonas* strains synthesise greenish pigments during the logarithmic growth phase (Meyer, 2000; Wasserman, 1965). Pigment products such as pyoverdine by *P. fluorescens* and *P. putida* could possibly have also contributed to the greenish tint observed on the chicken meat by the panel. Green/blue discolouration on the chicken legs was observed when TVC, *Pseudomonas* spp. and Enterobacteriaceae levels were at 8.66, 7.47 and 7.10 log CFU/g, respectively. The chicken legs were however not analysed for the presence of deoxymyoglobin, specific hydrogen sulphide-producing bacterial species or microbial pigments in the present study. It is important to mention that the discolouration on the chicken skin and flesh was faint and not uniform and the colorimeter measurements, a* (red/green) and b* (yellow/blue) (results not shown), did not reflect the green/blue colour assessment by the human panel. Thus, for chicken colour, the human panel was more informative than the colorimeter measurements in this regard.

6.4.3 Descriptive odour changes versus appearance and instrumental colour changes

It is apparent from Figure 6.3 that PCA factor 1 (89.0%) explained the variance in the chicken samples more clearly than factor 2 (7.4%). The total variance explained by the two factors for the chicken meat stored for different days was 96.4%. Chicken meat stored for 1 and 3 days was more similar (left side of biplot) but different from samples located to the right side of the biplot (day 10 and 14). Chicken meat stored for 7 days was clearly different from all the other samples but relatively more similar to day 1 and 3 samples.

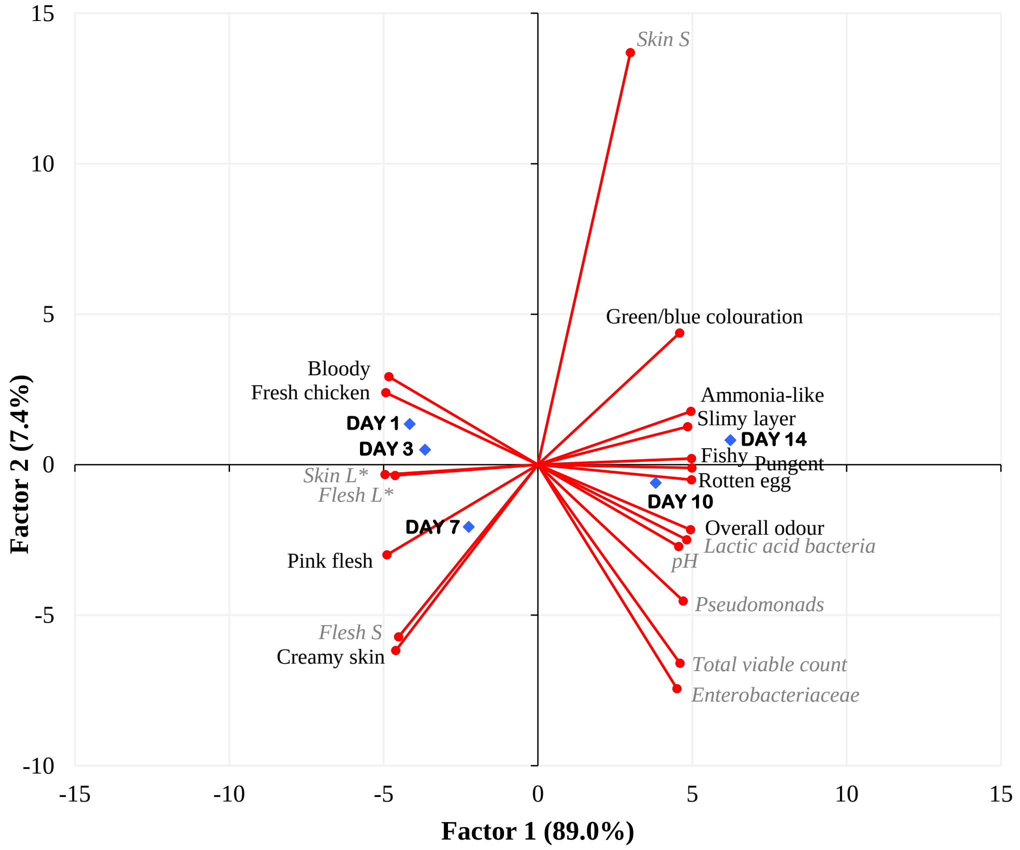

Figure 6.2: Principal component analysis biplot of factors 1 and 2 representing chicken meat sample scores and microbial, physicochemical and descriptive sensory characteristics loadings

Chicken meat stored for 1, 3 and 7 days was characterised by having pink flesh and creamy skin, with a bloody and fresh chicken smell, and high skin L*, flesh L* and flesh S values. Chicken meat stored for 10 and 14 days was described as having all the negative sensory attributes, high microbial levels and high pH. The PCA results also suggest that although chicken meat stored for 7 days still exhibited colour and appearance attributes of fresh chicken, it may not have been as fresh smelling as that stored for 1 and 3 days.

Computation of the rate of change of intensity of odour and appearance during chicken storage also showed that odour deteriorated at a faster rate than appearance, except for the attributes bloody and ammonia-like (Figure 6.4). Overall, this indicates that odour is a critical characteristic of chicken meat during refrigerated storage. Of the descriptive odours under study, overall odour and pungent intensity changed at the fastest rate (Figure 6.4). The results confirm the findings of the previous study whereby consumers (n = 863) were asked to indicate how important intrinsic and extrinsic attributes of chicken meat are when judging the quality and safety of raw chicken during purchasing and preparation (section 5). The consumers indicated that the smell of raw chicken was one of the most important attributes that they consider both at retail and home. The colour of chicken meat was considered as significantly less important. Franke et al. (2017) also reported that the formation of off-odours preceded discolouration, based on sensory analysis of chicken breast packaged in two different modified atmospheres and stored at 4 °C for 8 and 14 days. Thus, off-odours are the signal for microbial spoilage of chicken meat. Colour could be a more discriminating factor for red meat such as beef due to the relatively high myoglobin content.

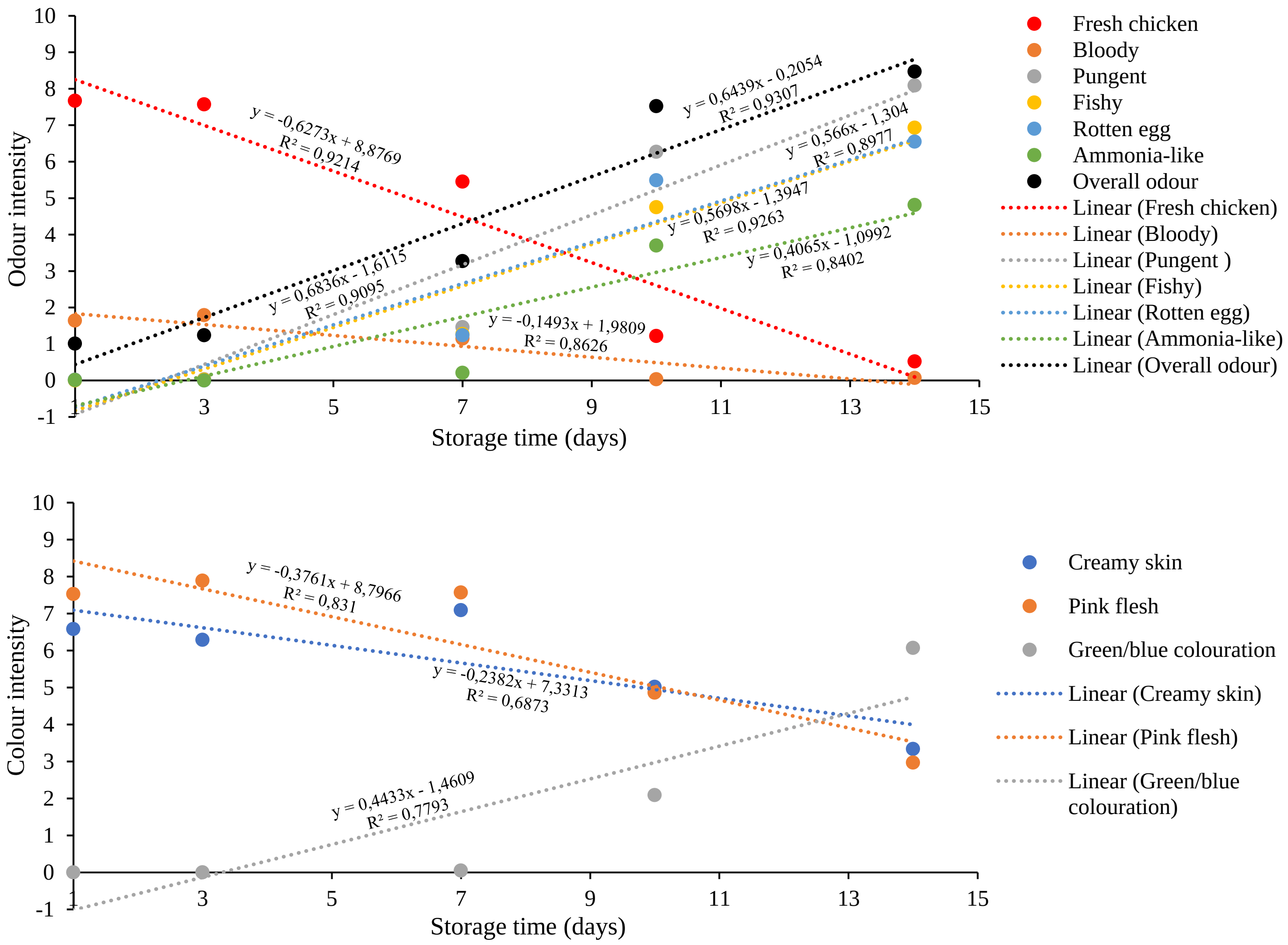

Figure 6.3: Rate of change of intensity of odour (a) and appearance (b) attributes of chicken meat during aerobic storage at 4 °C for 14 days

[1]The 10-cm scale anchors (0 = absent, 10 = intense) for the different odour and appearance attributes are shown in Table 6.1.

6.4.4 Correlations between microbial growth, pH, instrumental colour and descriptive sensory characteristics

There were generally high correlations (r = 0.80 - 1.00) between microbial levels, pH, instrumental colour and human panel intensity ratings of odour and appearance of chicken meat during storage (Table 6.2). As discussed earlier, microbial growth in aerobically packaged and refrigerated chicken meat results in the production of volatile catabolites which affect the odour quality (Casaburi et al., 2015). Colour deterioration during storage is usually attributed to an increase in meat pH and biochemical reactions between oxygen, volatile microbial catabolites and meat colour pigments (Mancini & Hunt, 2005; Suman & Joseph, 2013). Nevertheless, it is important to highlight that although meat spoilage is almost always due to microbial growth, other mechanisms such as lipid oxidation and enzymatic autolysis are responsible as well (Iulietto, Sechi, Borgogni, & Cenci-Goga, 2015). There also could be interactions between microbial growth and enzymatic reactions (Nychas et al., 2008). While there were many moderate to high microbial quality-appearance-colour correlations, the results showed that most correlations were not significant (Table 6.2). This may be due to the non-significant changes observed in the appearance attributes and colour measurements of chicken meat after 1, 3 and 7 days of storage (Figure 1c and d). Correlations between microbial quality and odour attributes were however significant. These results suggest that the appearance attributes and colour of chicken meat may be less reliable indicators of microbial spoilage during storage than odour.

Table 6.2: Pearson's correlation coefficients (*r*) between microbial, physicochemical and descriptive sensory characteristics of chicken meat[1]

Variables	TVC	Pseudomonads	Enterobacteriaceae	LAB	pH	Skin L*	Flesh L*	Skin S	Flesh S	Pink flesh	Creamy skin	Green/blue colouration	Slimy layer	Fresh chicken	Bloody	Pungent	Fishy	Rotten egg	Ammonia-like
Pseudomonads	**0.981**																		
Enterobacteriaceae	**0.998**	**0.968**																	
LAB	**0.949**	**0.968**	**0.933**																
pH	**0.911**	**0.968**	**0.893**	**0.985**															
Skin L*	**-0.907**	**-0.914**	**-0.888**	**-0.930**	-0.859														
Flesh L*	-0.819	-0.798	-0.813	-0.853	-0.762	**0.937**													
Skin S	0.261	0.387	0.207	0.490	0.468	-0.599	-0.528												
Flesh S	-0.693	-0.711	-0.668	-0.779	-0.685	**0.927**	**0.937**	-0.767											
Pink flesh	-0.845	**-0.890**	-0.815	**-0.920**	-0.868	**0.979**	**0.881**	-0.731	**0.930**										
Creamy skin	-0.719	-0.805	-0.681	-0.872	-0.843	**0.905**	0.827	-0.852	**0.914**	**0.966**									
Green/blue colouration	0.773	0.860	0.732	**0.888**	0.874	**-0.901**	-0.744	0.788	-0.837	**-0.967**	**-0.969**								
Slimy layer	0.853	0.855	0.838	**0.901**	0.822	**-0.979**	**-0.985**	0.613	**-0.960**	**-0.949**	**-0.899**	0.845							
Fresh chicken	**-0.960**	**-0.952**	**-0.949**	**-0.956**	**-0.893**	**0.986**	**0.932**	-0.474	0.867	**0.943**	0.849	-0.855	**-0.963**						
Bloody	**-0.949**	**-0.921**	**-0.943**	**-0.918**	-0.838	**0.978**	**0.941**	-0.424	0.867	**0.916**	0.803	-0.804	**-0.960**	**0.993**					
Pungent	**0.924**	**0.940**	**0.905**	**0.958**	**0.901**	**-0.996**	**-0.927**	0.592	**-0.907**	**-0.980**	**-0.915**	**0.915**	**0.973**	**-0.990**	**-0.973**				
Fishy	**0.920**	**0.948**	**0.898**	**0.963**	**0.915**	**-0.990**	**-0.896**	0.614	**-0.891**	**-0.987**	**-0.927**	**0.941**	**0.954**	**-0.980**	**-0.957**	**0.997**			
Rotten egg	**0.928**	**0.935**	**0.911**	**0.953**	**0.890**	**-0.997**	**-0.942**	0.567	**-0.910**	**-0.971**	**-0.899**	**0.893**	**0.980**	**-0.994**	**-0.982**	**0.999**	**0.991**		
Ammonia-like	0.873	**0.899**	0.851	**0.936**	0.875	**-0.992**	**-0.942**	0.670	**-0.946**	**-0.988**	**-0.946**	**0.923**	**0.985**	**-0.970**	**-0.952**	**0.993**	**0.988**	**0.991**	
Overall odour	**0.959**	**0.957**	**0.947**	**0.963**	**0.903**	**-0.987**	**-0.929**	0.490	-0.869	**-0.949**	-0.861	0.867	**0.963**	**-1.000**	**-0.990**	**0.992**	**0.985**	**0.995**	**0.974**

[1]Values in bold were significant ($p \leq 0.05$). The magnitude of correlation coefficients was interpreted according to Hinkle, Wiersma, and Jurs (2003): 0.00 to 0.30 little if any correlation; 0.30 to 0.50 low correlation; 0.50 to 0.70 moderate correlation; 0.70 to 0.90 high correlation; 0.90 to 1.00 very high correlation.

Non-significant low to moderate correlations (r = 0.21 - 0.67) were observed between skin colour saturation (skin S) and microbial levels, pH, skin L*, flesh L* and intensity of odours of chicken meat (Table 6.2). Moreover, skin colour saturation values did not differentiate well the chicken stored for different days (Figure 6.3). Skin colour saturation would have been a reliable indicator of skin discolouration if there was an accumulation of greying on the skin as storage progressed. Instead, according to the panellists, the skin turned blue/green. These results indicate that skin colour saturation may not be a reliable indicator of microbial spoilage in chicken meat. Brewer, Zhu, Bidner, Meisinger, and McKeith (2001) reported that instrumental colour measures are affected differently by meat colour changes during storage, and L* and a* are typically related to meat muscle colour. However, it can be argued that b* measurements could also be appropriate in the case of corn-fed chicken meat which is naturally yellow-hued (Kennedy, Stewart-Knox, Mitchell, & Thurnham, 2005).

6.5 Conclusions

Microbial growth is significantly correlated with odour quality of chicken meat during refrigerated storage, but not colour and appearance. For consumers, the smell of raw chicken meat is a more reliable indicator of microbial spoilage than changes in appearance, and detection of pungent, fishy, rotten egg and ammonia-like odours would be warning signals. However, consumers should be wary of semi-fresh or slightly spoiled chicken as this could be an indication of a broken chicken meat cold chain, thereby posing a food safety risk. Retailers are encouraged to follow good meat retailing practices, such as stock control and maintaining the cold chain, to ensure microbial quality of chicken meat.

CHAPTER SEVEN

GENERAL DISCUSSION

7.1 Introduction

This discussion will critically review some of the methodologies applied in the three research sections of this study. The main findings of this study and application will then be discussed. The findings consist of South African consumers' handling practices, food safety knowledge, and quality and safety perceptions with regard to chicken meat. Additionally, how these aspects relate to the microbial, sensory and physicochemical characteristics of chicken meat will be highlighted. A schematic representation of the overall research findings will be presented.

7.2 Critique of methodology

7.2.1 Online consumer survey

The first two research sections of this study consisted of data obtained from a consumer survey conducted over the internet. Online convenience sampling was used to recruit chicken meat consumers and administer the questionnaire both for the pilot (n = 94) and large-scale (n = 863) survey. Consumers were recruited based on their interest in the advertised survey and the screening criteria. The convenience sampling technique is commonly used in similar studies owing to the following benefits: it is relatively inexpensive, a large sample size can be obtained in a shorter period, it offers the simplicity of sampling and easier data collection (Redmond & Griffith, 2003a). Furthermore, the use of web-based questionnaires allows for automatic survey data input and subsequent data processing (Redmond & Griffith, 2003a).

However, because the survey was internet-based, the sample of consumers in this study was biased towards educated consumers who use the internet and could read and understand English. There could also have been bias towards middle and high-income earners due to low internet access by lower-income groups in South Africa. Another drawback possibly caused by online convenience sampling was that females and consumers in the young age group (18 - 29 years) were more represented. This was not surprising as young adults are generally more interested in the internet, particularly social media. The reason why the percentage of female survey respondents (71%) was much higher than that of male survey respondents (28%) could be that in South Africa women prepare food in the home more often than men (Altman et al., 2009). Thus, women could have been more interested in the chicken meat survey than men. On the other hand, it is possible that a high percentage of men were also interested in the survey but did not meet the eligibility criteria and hence were screened out. The screening criteria required that respondents should be responsible for buying raw chicken meat and preparing meals in their households. Consumers who mostly purchase chicken meat from street vendors and 'other retailers' were also not well represented. The huge differences in sample sizes across the consumer categories presented challenges during statistical analysis of some of the survey data. For instance, in the second research section, a comparison of consumers' quality and safety perceptions of chicken meat based on the place of purchase could not be carried out.

The results obtained in the survey may not truly reflect the chicken meat handling practices, food safety knowledge and perceptions of males, older consumers (> 29 years), consumers with no internet access and lower levels of education. To avoid these limitations, stratified random sampling would have been more appropriate for a survey of this nature because it enables researchers to obtain a sample population that best represents the entire population under study (Acharya, Prakash, Saxena, & Nigam, 2013). However, due to resource and time constraints, online convenience sampling was the most feasible survey research method for the current study.

Concerning questionnaire design, the respondents were presented with an almost entirely closed-ended type of questionnaire. Only two questions were open-ended. Possibly, other handling practices and attributes of chicken meat of importance to consumers were not included in the questionnaire. Although the use of open-ended questions could have provided detailed information, it was reported that the responses are usually non-uniform and challenging to analyse statistically, especially for large surveys (Boynton & Greenhalgh, 2004). There could also be a possibility of some of the respondents providing information that is incomplete or irrelevant to the questions asked, rendering some of the data unusable by the researcher (Boynton & Greenhalgh, 2004). For instance, in the first research section, respondents were asked to indicate the maximum time they keep raw chicken meat in the refrigerator before cooking. Unfortunately, about 19% of the respondents did not include the time units. Hence their responses to this question were excluded in the statistical analyses. Several similar consumer studies regarding chicken meat have also used the closed-ended type of questions (Bearth et al., 2014; Jevšnik et al., 2008; Koppel et al., 2015; Kosa et al., 2015; Sismanoglou & Tzimitra-Kalogianni, 2011).

Furthermore, related questions in the questionnaire were grouped. The survey questionnaire was divided into two; the first part investigated consumers' handling practices and food safety knowledge with respect to chicken meat (first research section), and the second part investigated consumers' perceptions of the quality and safety of chicken meat (second research section). About 75% of the questions in the first section of the survey were about the maintenance of the chicken meat cold chain because it is considered as one of the significant risk factors at the consumer level (Kosa et al., 2015). For the second section, although most of the extrinsic attributes may not be directly linked to microbial growth and contamination of chicken meat from an expert's point of view, they had to be included for the study to be objective. It is well established that the food quality or safety perception process is multidimensional and consumers consider both intrinsic and extrinsic attributes during decision making (Becker et al., 2000; Olson & Jacoby, 1972). It was also envisaged that consumers' views on extrinsic attributes would provide insight into consumers' demands and expectations for the chicken industry.

The greatest limitation in the survey was the use of a self-report questionnaire to gather information on consumer handling practices for chicken meat. Although it is the most widely used tool for conducting large surveys, it was reported that there could be inconsistencies with the actual consumer behaviour due to social desirability bias, whereby the best practices for handling chicken meat could have been over-reported (Redmond & Griffith, 2003b). To minimise possible discrepancies, some researchers have conducted direct or video observations of consumers' food safety practices in home kitchens (Bruhn, 2014), model kitchens (Maughan et al., 2016) or during purchasing (Donelan et al., 2016). However, Evans and Redmond (2014) highlighted that observation methods also have the potential for reactivity bias, a phenomenon whereby some consumers may change their practices as a result of being observed. Observation methods may be more reliable, but their use in consumer food safety and quality studies remains minimal possibly because data collection can be time and resource-intensive (Evans & Redmond, 2014).

Despite all the limitations, the results obtained from the survey are still useful as they provide valuable insight into the handling practices, food safety knowledge, and safety and quality perceptions of adult South African consumers who buy raw chicken meat and prepare it in their households.

7.2.2 Storage conditions for chicken meat

Raw chicken legs, in aerobic packaging, were stored at 4 ± 0.5 °C and bacteriological, pH, instrumental colour and descriptive sensory analyses were conducted during storage for 14 days. The justification for the choice of aerobic packaging was based on the fact that this is the most common type of meat packaging in South Africa. Although it was established that most retail and domestic refrigerators operate at temperatures above the ideal limit of 4 °C (James et al., 2017; Mercier et al., 2017), this temperature was selected in the current study to represent refrigeration storage conditions. At 4 °C, spoilage of chicken meat occurs at a slower rate than at abuse temperatures (> 4°C). A longer storage life was required to detect the different stages of chicken meat spoilage and for the descriptive sensory panel to generate as many odour and appearance attributes as possible to describe the sequence of sensory changes. Regarding the applied storage period, one could point out that, in practice, it is uncommon to store aerobically packaged raw chicken meat for as long as 14 days at refrigeration temperatures. However, the storage period and intervals were predetermined from preliminary experiments observations which indicated observable chicken meat colour changes after about 10 days. With sensory data from 14 days of storage (at 5 intervals), it was possible to estimate the rate of change of intensity of both odour and appearance attributes of chicken meat and make an objective conclusion.

7.2.3 Quantitative descriptive sensory analysis

Descriptive sensory analysis is defined as 'the identification, description and quantification of sensory attributes of a food product using human subjects specifically trained for this purpose' (Meilgaard et al., 2015). Panellists must be able to detect and describe the perceived sensory attributes of a food sample. These qualitative aspects of a product combine to define the product and include all of the appearance, aroma, flavour, texture or sound properties of a product that characterise or differentiate it from others. Moreover, panellists must learn to rate the quantitative aspects of a sample and to define to what degree each characteristic is present in that sample (intensity). Two products may contain the same qualitative descriptors, but they may markedly differ in the intensity of each, which results in different and distinct sensory profiles of each product. Thus, descriptive sensory analysis enables the definition of food characteristics for the prediction of attributes that may influence consumer acceptability.

In the third research section, quantitative descriptive sensory analysis was employed to determine the odour and appearance attributes of raw chicken meat during refrigerated storage under aerobic packaging. Ten panellists were trained to familiarise themselves with the chicken meat samples. They generated the sensory attributes that best described the samples and rated the intensity of the sensory attributes of all the samples during storage. Quantitative descriptive analysis was applied in the current study with the purpose of tracking sensory changes of raw chicken meat over storage time to understand consumers' perceptions of the quality and safety of chicken meat during purchasing and preparation at home. Lawless and Heymann (2010) reported that quantitative descriptive sensory analysis is invaluable, especially when there is a need to define sensory - instrumental relationships. One of the objectives of the current study was to determine sensory - microbial - physicochemical relationships during refrigerated storage of chicken meat. The results from the second research section of this study indicated that consumers consider the smell and colour of raw chicken meat as important intrinsic attributes when judging the quality and safety of chicken meat. Hence, quantitative descriptive analysis technique was applied to characterise the odour and appearance of raw chicken meat during storage.

A few challenges were experienced during the application of descriptive sensory analysis. Firstly, all the analyses in the third research section of this study (including descriptive sensory analysis) were conducted 24 hours after sampling instead of on the day of sampling due to time and logistical constraints. Thus, no data were available for samples on day zero of storage. Similar studies have also followed this approach (Balamatsia et al., 2007; Franke et al., 2017). Secondly, descriptive sensory analyses are ideally conducted by panellists separated by individual booths in sensory laboratories. However, due to the carryover effects of odours, the chicken meat samples in this study were tested in the Department of Consumer and Food Sciences, University of Pretoria food preparation pilot plant. The selected location was relatively bigger and allowed for quicker dissipation of odours from samples. The lighting, temperature conditions and air circulation in this setting were controlled. The tests were conducted at room temperature (25 °C) under white fluorescent light. The panellists were provided with individual tablets (wireless touch screen mobile computers) to access the sensory tests which were run using Compusense® Cloud Saas software (Compusense Inc., Guelph, ON., Canada). Hough (2010) pointed out that a sensory laboratory is ideal for sensory tests due to the controlled and constant conditions, but it should not be a limitation when not available. A quiet and pleasant testing area where panellists can assess food samples without interfering with each other was proposed to be sufficient. Thirdly, when conducting a storage study, it is appropriate to compare samples of different storage times with a sample that is considered fresh, but this is not always possible. In this study, it was impossible to keep a fresh control sample because of the 'current status observation' nature of the research. Therefore, no control sample was included. However, to avoid expectation bias during descriptive sensory analysis, a blind sample previously frozen at -20 °C and thawed at 4 °C for 18 - 24 hours before analysis was presented at each test session. The blind samples were frozen immediately upon arriving at the laboratory, after collection from a chicken processing plant. It has been reported that trained panellists in food storage studies soon catch on that they are involved in a storage study (Hough, 2010). This leads panellists to expect the presence of aged food characteristics (in this case odour and appearance), and once found panellists are likely to repeatedly find them for subsequent storage times even when they are not present. Hence, the term 'expectation bias'. However, it is possible that the use of blind control samples to prevent expectation bias in this study could have introduced contrast effects, whereby panellists could have rated the chicken samples not of their own status but in contrast to the blind control samples. To account for this effect, the chicken meat samples were presented for evaluation monadically, in an order selected following a Williams design and labelled with randomly selected 3-digit codes. The attribute intensity ratings for the blind samples were not included in the data analyses. Lastly, the two standard references rotten egg and spoiled fish were not presented to panellists during testing as their use resulted in crossover effects of odours. In a similar storage study, Franke et al. (2017) also presented some but not all of the standard references for odour attributes of chicken meat. Notwithstanding these challenges, the experimental design was considered satisfactory.

7.2.4 Bacteriological and physicochemical analyses

In the third research section, changes in the microbial load associated with the storage of aerobically packaged raw chicken meat at 4 °C for 14 days were determined using the plate count method. *Pseudomonas* spp., Enterobacteriaceae and lactic acid bacteria (LAB) were each determined on the appropriate selective media, and total viable counts (TVC) were assessed on plate count agar (PCA). *Pseudomonas* spp., Enterobacteriaceae and LAB were selected for analysis because they are identified as common spoilage species during refrigeration of raw chicken meat, with *Pseudomonas* spp. being the specific spoilage organism (Doulgeraki et al., 2012). The plate count technique is a traditional culture-dependant analysis used for the enumeration of microorganisms from food samples. The method is based on the assumption that single bacterial cells replicate on agar medium and produce visible aggregates of cells called colonies, which can be counted. This method is considered to be convenient, easy and inexpensive, thus is widely used. The major drawback with plate counts is that the number of viable cells is underestimated because some bacterial cells may be viable but non-culturable due to cell injury or stress (Cundell, 2015). Moreover, it was suggested that general-purpose media such as PCA might favour rapid growing microorganisms, and thus slow-growing cells may be omitted from the count (Cundell, 2015). Recently, some researchers have resorted to the application of culture-independent approaches such as metagenomics (specifically Next Generation Sequencing) to assess microbial diversity and relative abundance during chicken meat storage (Lee et al., 2017; Nieminen et al., 2012). It would have been insightful to relate microbial diversity and abundance with sensory and physicochemical characteristics of refrigerated chicken meat. Nonetheless, the obtained data still revealed the general microbial growth trends in chicken meat during refrigerated storage.

As aforementioned (section 7.2.2), previously frozen blind control samples were included during descriptive sensory analysis, but not for the rest of the analyses in the third research section. Chicken meat is perishable, and freezing is a good way of preserving its microbial and physicochemical quality. However, the limitation of this approach in storing the control sample is that freezing can cause bacterial cell damage through the formation of ice crystals (Golden & Arroyo-Gallyoun, 1997), thereby affecting the growth rate during culturing and the ultimate plate counts. Glycerol is often used as a cryoprotectant to prevent cell damage during storage of bacterial stocks (Prakash, Nimonkar, & Shouche, 2013). Thus, the previously frozen chicken samples could not be 'true control samples' for the bacterial and physicochemical analyses.

Instrumental colour and pH were also measured during the storage of chicken meat at 4 °C. It would have been interesting to include volatile organic compounds in the analyses and establish the relationship with the panel's odour perception, but this could not be done due to logistical constraints of conducting bacteriological, physicochemical and descriptive sensory analyses of chicken samples on the same day. Regarding colour, measurements were made at 3 different locations on each leg because chicken meat colouration is naturally not uniform.

7.3 Research findings

To practice food safety, consumers are encouraged to separate raw chicken meat from ready-to-eat and cooked food to prevent cross-contamination, to maintain the cold chain by keeping raw chicken at 4 °C or lower to minimise the growth of both pathogenic and spoilage bacteria, and to wash their hands and cooking utensils thoroughly with soap and water during preparation of chicken dishes to prevent cross-contaminataion (Fontannaz-Aujoulat, Frost, & Schlundt, 2019). The consumer survey study (first research section, including *n* = 863 consumers) found that a substantial proportion of the respondents reported practices that could lead to temperature abuse of raw chicken meat, the transmission of bacteria and cross-contamination. There was also a lack of knowledge of temperature-related factors affecting the growth of bacteria in chicken meat. Overall, only 38% of the respondents were rated as following good handling practices for chicken meat and only 28% as having good knowledge relating to temperatures that limit bacterial growth in chicken meat. The large majority of questions in this section of the survey were focused on the maintenance of the chicken meat cold chain at the consumer level, from the time of purchase to home storage and preparation. Management of the chicken meat cold chain and chicken meat safety and quality are intimately linked. A literature review by Mercier et al. (2017) established that the weakest points in the food chain with regard to temperature control are found at the retail and consumer level. Consistent with this study, other surveys indicate seemingly insufficient consumer awareness about temperature control of chicken meat. Bearth, Cousin, and Siegrist (2013) found that 79% of Swiss consumers thought that pathogenic bacteria could not replicate at temperatures below 10 °C, and 65% considered thawing frozen poultry at room temperature to be relatively safe. In another study, Nesbitt et al. (2009) reported that 65% of Canadian consumers did not know the ideal temperature for domestic refrigeration of meat. Since the chicken industry cannot supply bacteria-free chicken meat, significant improvements to consumers' handling practices and knowledge levels are required to limit the growth of bacteria in chicken meat and reduce the risk of foodborne illness and food waste. The major factors giving rise to bacterial contamination and excessive proliferation along the chicken supply chain include poor hygiene practices during processing and temperature abuse at retail (Rouger et al., 2017). Moreover, there is generally minimal monitoring of the quality and safety of meat at the retail level by food regulatory authorities in South Africa.

Another important finding of the consumer survey study (second research section) was that smell, use-by date, sell-by date and colour were perceived by a large majority of the respondents as highly important attributes when evaluating the quality and safety of chicken meat during purchasing and preparation. Consumers rely more on sensory attributes (smell and colour) and date labels (use-by date and sell-by date) probably because they perceive them to be more associated with the quality and safety of chicken meat. From a microbial point of view, the freshness of chicken meat is a better indicator of quality than safety (Henson & Northen, 2000). Nevertheless, from a consumer's perspective, it may be justifiable to use freshness attributes as proxy indicators of safety because consumers cannot objectively assess the microbial status of chicken meat at any point. Unfortunately, retailers also cannot guarantee low microbial loads and the absence of pathogenic bacteria in chicken meat. Hence, there is a need for consumers to be aware of the potential bacterial hazards in chicken meat and the implications of improper handling on food safety and food waste. The findings from the entire survey imply that a large majority of consumers probably rely more on their judgements of quality and safety during purchasing and preparation, and neglect handling practices that prevent foodborne illness and chicken meat spoilage. However, many consumers may not know that their perceptions are inaccurate or that their practices and knowledge levels are inadequate. Another important finding of this study was that age, gender and education level had a significant influence on the respondents' perceptions, handling practices and knowledge levels. Young adults and men reported more risky practices and considered the attributes as less important for judging the quality and safety of chicken meat. Young adults and consumers with high school education had less food safety knowledge.

The survey respondents' handling practices, knowledge levels and perceptions have implications on the quality and safety of chicken meat at the consumer level. The government and food authorities in South Africa need to put more emphasis on food safety and quality education of the general public, as advised by the WHO in the 2015 global food safety campaign (WHO, 2015b). The survey information provided by this study could be used as a guide for the development of future education interventions. The parties responsible for food control in the South African government are the Department of Health (DoH), Department of Agriculture, Forestry and Fisheries (DAFF) and Department of Trade and Industry (DTI). Their functions and responsibilities include the protection of consumers through food legislation and informing and educating consumers about food safety and quality and related matters (Department of Health, 2019). Such legislation includes the Meat Safety Act (No. 40 of 2000), Foodstuffs, Cosmetics and Disinfectant Act (No. 54 of 1972) and Consumer Protection Act (No. 68 of 2008). The Department of Basic Education (DBE), which oversees primary and secondary school education in South Africa, could also play a key role by including food handling theory and practices into the life skills curriculum to educate future consumers and food handlers. It was proposed that targeting school-aged children may have a wider impact as they influence their family members (Young & Waddell, 2016). Intervention is needed from these departments in collaboration with non-governmental scientific organisations such as the Food Advisory Consumer Service (FACS) and the South African Association of Food Science and Technology (SAAFoST). The government should have a robust research base because national food control decisions need to be backed by science-based evidence. Consumers' handling practices, knowledge levels and perceptions of chicken meat could be corrected and improved through the development of science-based messages focusing on temperature control, the transmission of bacteria and cross-contamination as identified in this study. Various stakeholders need to participate in conveying these messages to consumers. Chicken meat processors could educate consumers by including standardised handling instructions for optimum quality and safety on the packaging labels and alerting consumers of the potential risks of mishandling. The instructions should also include information on basic personal hygiene practices such as hand washing. Retailers could also assist consumers by adding food safety and quality tips during in-store product advertisements and promotions. The finding that consumers' socio-demographic characteristics significantly influenced their practices, knowledge levels and perceptions of the quality and safety of chicken meat implies that developing education interventions with a 'one-size-fits-all' approach may not be effective. Research conducted so far points to the importance of and supports using multifaceted intervention programmes (Young et al., 2015). For instance, age-wise, children may find cartoon characters, comic books and interactive games more interesting (Quick, Corda, Chamberlin, Schaffner, & Byrd-Bredbenner, 2013), youth and young adults may be targeted through social media and music parodies, and elderly consumers through more traditional methods such as brochures, radio and television programmes (Young & Waddell, 2016). Future surveys on other consumer demographic groups not represented in this study, such as those without internet access and with lower levels of education, should be able to provide more insight for the development of effective public health education campaigns. Paper questionnaires and face to face interviews in local South African languages could be the best ways to collect information from consumers without internet access and with low levels of education.

Several early and recent studies have cited colour and freshness as important attributes regarded by consumers when assessing quality and safety of chicken meat, respectively (Becker et al., 2000; Cowan, 1998; Djekic, Skunca, Nastasijevic, Tomovic, & Tomasevic, 2018; Glitsch, 2000). Djekic et al. (2018) defined freshness as the visual appearance of chicken meat while the other authors did not indicate what freshness referred to. Based on the results from the consumer survey study (second research section), freshness can be defined as the visual appearance and smell of raw chicken combined with information provided by date labels (use-by and sell-by dates). It is often reported that appearance is the most important criterion available to assess at retail due to sealed packaging of meat, hence smell is excluded when investigating consumers' perceptions of meat quality and safety. However, in this study, both smell and colour were included along with other attributes. Smell was included as an attribute that may affect consumers' perceptions of both quality and safety when purchasing chicken meat because the smell of chicken meat is affected by microbial growth during storage, even at retail. In developing countries including South Africa, maintenance of the chicken meat cold chain along the supply chain is a major challenge and spoilage problems usually occur at retail, particularly downtown retailers. Interestingly, smell and use-by date were considered by the survey respondents as significantly more important than colour, both during purchasing and preparation. This finding implies that the colour of chicken meat is important to consumers but not as important as the smell and use-by date. A novel attempt was made in this study to understand this result from a microbial viewpoint.

It is well known that chicken meat is highly perishable and the leading cause of spoilage is excessive bacterial growth, which can occur at any stage of the food chain including retail and consumer level due to improper handling practices (Bruckner et al., 2012). The growth of spoilage bacteria, especially *Pseudomonas* spp., mainly affects the sensory characteristics of chicken meat (Dave & Ghaly, 2011). The affected sensory characteristics are the perceived intrinsic cues of raw chicken meat; smell (odour), colour and texture. Remarkably, the findings of this study indicated that both the instrumental colour and appearance attributes of raw chicken meat were not correlated with microbial growth in chicken meat during storage, namely *Pseudomonas* spp., Enterobacteriaceae, LAB and TVC. Conversely, there was a high and significant correlation between microbial growth and odour attributes. Importantly, the study also found that the spoilage of chicken meat occurs sequentially, with the odour deteriorating at a faster rate than appearance during refrigerated storage. What could be concluded from this and the consumers' perceptions results was that smell was perceived as more important than colour when assessing the quality and safety of chicken meat possibly because off odours are produced before discolouration appears. Additionally, the respondents perceived the use-by date as more important than colour probably because it is possible for the use-by date of chicken meat to pass while discolouration has not yet appeared. Based on these findings, the study suggests that consumers' perceptions of the quality and safety of chicken meat during purchasing and preparation can be related to the microbial growth, sensory and physicochemical characteristics. The findings imply that the chicken industry particularly retailers, needs to put stringent measures to maintain the cold chain and prevent bacterial growth to levels that cause off odours in chicken meat. When the cold chain is maintained, the risk of bacterial pathogen growth is also reduced. Although it is mandatory to put date labels on packaged meat in South Africa (Department of Health, 2014a), there is a need for monitoring of the quality and safety of meat at retail by regulators to prevent incidences of date mark tampering since consumers seem to rely on use-by and sell-by dates.

The findings from the chicken meat storage study also suggest that microbial growth can result in three distinct categories of chicken meat depending on the perceived sensory characteristics during storage; fresh, semi-fresh and spoiled. Consumers with low olfactory acuity may not be able to detect semi-fresh chicken meat. The use of semi-fresh chicken meat could be risky because it may be an indication of a broken cold chain or exceeded durability, thus has implications on meat safety (Ndraha et al., 2018). A broken cold chain accelerates microbial deterioration and thus defeats the purpose of use-by and sell-by date labels on chicken meat. The findings imply that there is a need for the chicken industry to consider the application of intelligent or 'smart' packaging for chicken meat. Intelligent packaging is a packaging technology designed to sense, record and communicate food deterioration to enhance food quality and safety, and alert of possible challenges encountered during distribution and storage (Yam, Takhistov, & Miltz, 2005). Generally, the application of intelligent packaging in the meat industry is limited. Since this study established that odour is a better measure of microbial spoilage of chicken meat than colour, the incorporation of sensors and colorimetric indicators in chicken meat packaging for real-time monitoring of the emission of malodorous volatile organic compounds could assist consumers in making more accurate judgements during purchasing and preparation. The dominant spoilage associated compounds in chicken meat include volatile biogenic amines, sulphuric and nitrogen compounds (Alexandrakis, Brunton, et al., 2012). The concentrations of these volatiles are often related to progress in chicken meat spoilage. Apart from assisting consumers, intelligent packaging could allow better monitoring and control of the cold chain by distributors and retailers and effective shelf-life management of chicken meat. Improved shelf-life management of chicken meat along the food chain will also ultimately reduce problems of food waste. Future research on the impact of the co-occurrence of volatile organic compounds on odour quality of chicken meat could assist in selecting the best biomarker volatiles for early detection of spoilage.

Consumers' perceptions of the quality and safety of chicken meat revealed in this study also provide valuable insight for the chicken industry from a marketing and profitability viewpoint. What was established from the findings was that the majority of consumers consider the two extrinsic attributes, absence of hormones and absence of brine, as relatively more important as indicators of quality and safety of chicken meat than factors such as price, brand name, free-range and country of origin. This implies that chicken producers and processors may need to conduct market research on reasons consumers seem not to be satisfied with the quality and safety of brined chicken meat and the supposed use of hormones during production. Although chicken meat is relatively cheap and the most consumed in South Africa, consumer trust is still paramount and the chicken industry needs to be transparent regarding production and processing methods to meet consumer demand and expectations. Furthermore, three distinct consumer segments were identified according to perceptions of the quality and safety of chicken meat. Some consumers tended to rely more on either intrinsic or extrinsic attributes, while others indicated that both attributes are extremely important. Overall, the results suggest that the chicken industry must clearly communicate both intrinsic and extrinsic attributes of chicken meat to target consumers who rely on either or both attributes during purchase decisions.

Figure 7.1 presents an overview of the potential application of the study findings by different stakeholders to prevent the risk of foodborne illness and food waste at the consumer level, and improve the chicken industry.

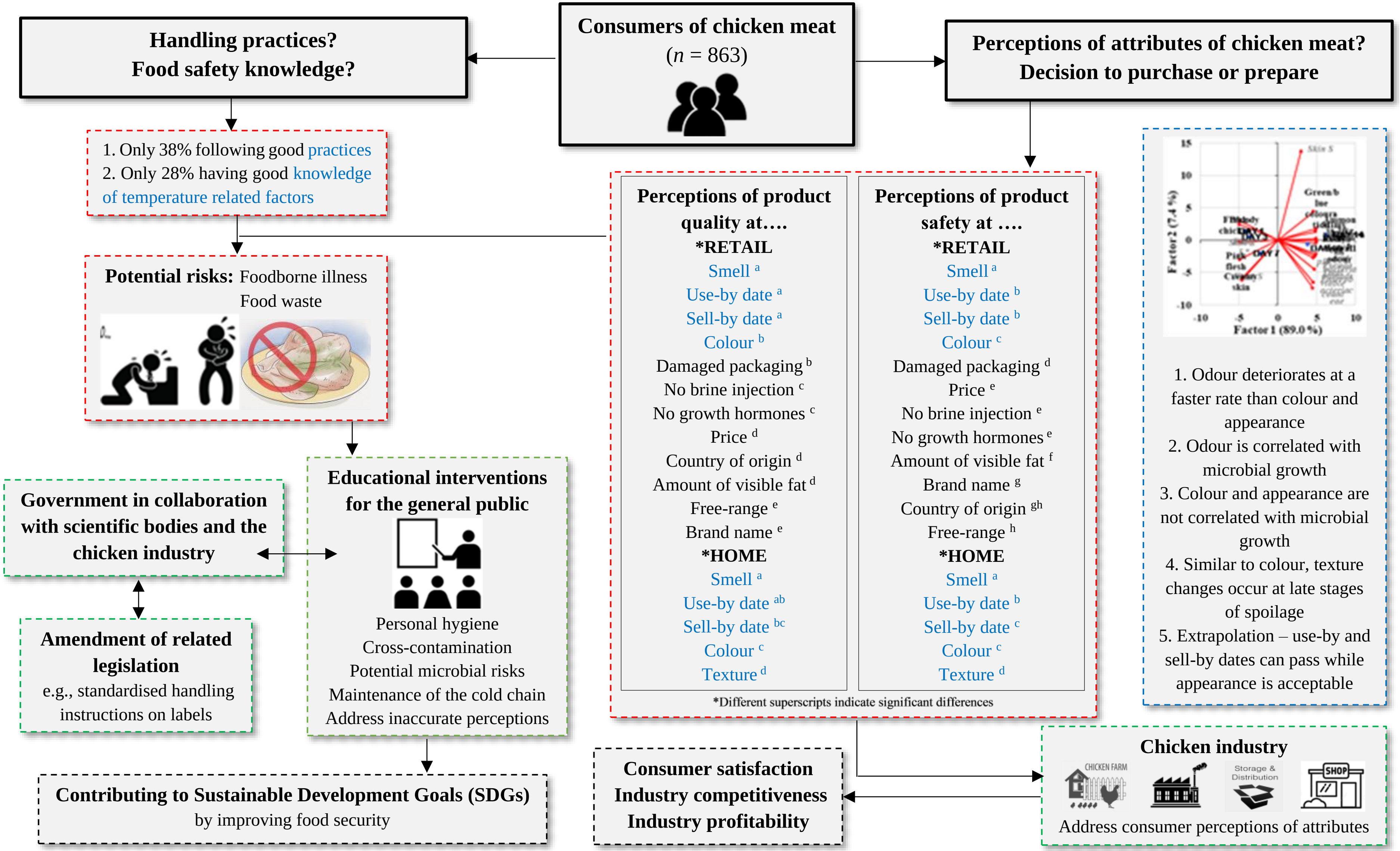

Figure 7.1: Potential application of research findings to prevent the risk of foodborne illness and food waste and improve the chicken industry
Dashed lines: red - potential risks, green - proposed solutions, black - envisaged outcomes, blue - interpretation from a microbial viewpoint

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS

This study reveals gaps in consumers' handling practices and knowledge of temperature related factors affecting the safety and quality of raw chicken meat. The identified gaps may lead to breaking of the chicken meat cold chain, the transmission of bacteria and cross-contamination. Moreover, during purchasing and preparation, consumers rely on smell, use-by date, sell-by date and colour as highly important indicators of the safety and quality of chicken meat. Based on the consumer survey, extrinsic attributes that are not directly related to bacterial growth in chicken meat are considered as less important.

From a microbiological viewpoint, consumers' handling practices and lack of knowledge may lead to excessive growth of both spoilage and pathogenic bacteria in raw chicken meat. Additionally, consumers' perceptions of the safety and quality of chicken meat are relatable to microbial growth during refrigerated storage and the sequence of sensory changes that occur. As an indicator of safety and quality, smell is considered as more reliable than colour since odour attributes of chicken meat deteriorate at a faster rate than colour and appearance attributes. Moreover, high and significant correlations exist between bacterial growth and odour attributes of chicken meat during storage. In contrast, there is no correlation between bacterial growth and colour and appearance attributes.

This study highlights a potential risk of foodborne illness and food waste due to the mishandling of raw chicken meat, inadequate food safety knowledge and inaccurate perceptions of safety and quality of chicken meat by a large proportion of consumers. Additionally, the microbial status of chicken meat is relatable to consumers' handling practices, knowledge levels (linked to behaviour) and perceptions (linked to behaviour) of chicken meat. Thus, increased knowledge about microbial risks associated with raw chicken meat and education on practices to prevent temperature abuse, the transmission of bacteria and cross-contamination are needed.

Based on this study, it is recommended that government bodies responsible for food control in South Africa (DoH, DTI and DAFF) collaborate with education institutions (e.g., DBE), non-governmental scientific organisations (e.g., FACS and SAAFoST) and the chicken industry to develop educational interventions to improve consumers' knowledge, handling practices and perceptions, and raise awareness on foodborne illness and food waste. Inclusion of the rationale behind the recommended handling practices in risk communication strategies may increase consumer understanding and motivation to comply. The educational interventions should be multifaceted to be relevant to consumers with different socio-demographic characteristics. To assist consumers in preventing the occurrence of foodborne illness and food waste, chicken processors could use intelligent packaging and include standardised handling instructions on packaging labels. In addition, retailers could conduct in-store food safety and quality promotions while consumers shop. Refrigerator manufacturers could also include in-built sensors to help consumers store chicken meat at ideal temperatures at home. Although extrinsic attributes of chicken meat were less important to consumers than intrinsic attributes, the chicken industry should address factors such as brine injection, supposed use of hormones and free-range to improve consumer knowledge about chicken production and processing systems. This may indirectly increase consumer satisfaction and chicken industry competitiveness and profitability.

It is also recommended that further research be conducted on socio-demographic groups not represented, that is, those without internet access and with low socioeconomic status. Additionally, investigating consumers' handling practices through participant observation rather than self-reporting methodology could prevent possible social desirability bias and unravel other risky practices that could not be explored in the current study. It would also be interesting to conduct consumer acceptability tests for raw chicken under storage, determine a consumer acceptability point and relate that to microbial, descriptive sensory and instrumental colour and odour (gas chromatography analysis) characteristics of the chicken meat.

CHAPTER NINE

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CHAPTER TEN

PUBLICATIONS AND PRESENTATIONS

10.1 Publications

Katiyo, W., Coorey, R., Buys, E. M., & de Kock, H. L. (2020). Consumers' perceptions of intrinsic and extrinsic attributes as indicators of safety and quality of chicken meat: Actionable information for public health authorities and the chicken industry. *Journal of Food Science, 85*(6), 1845-1855.

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2020). Sensory implications of chicken meat spoilage in relation to microbial and physicochemical characteristics during refrigerated storage. *LWT - Food Science and Technology,* 128, https://doi.org/10.1016/j.lwt.2020.109468

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2019). Assessment of safety risks associated with handling chicken as based on practices and knowledge of a group of South African consumers. *Food Control*, 101, 104-111.

10.2 Conference presentations

10.2.1 Oral presentations

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2019). How South African consumers perceive intrinsic and extrinsic attributes as indicators of safety of chicken meat. 23rd SAAFoST Biennial International Congress and Exhibition. Johannesburg, South Africa. 1-4 September 2019.

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2018). Knowledge and practices related to handling chicken meat by consumers in South Africa. 2nd International Conference for Food Safety and Security. Pretoria, South Africa. 15-18 October 2018.

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2017). Consumer safety perception and practices for raw chicken meat from retail to home: a pilot study. 22nd SAAFoST Biennial International Congress and Exhibition. Cape Town, South Africa. 3-6 September 2017.

10.2.2 Poster presentations

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2018). Raw chicken meat handling practices and safety knowledge of South African consumers. 19th World Congress of Food Science and Technology. International Union of Food Science and Technology (IUFoST). Mumbai, India. 23-27 October 2018.

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2018). Consumer perception of the safety and quality of raw chicken meat in South Africa. 19th World Congress of Food Science and Technology. International Union of Food Science and Technology (IUFoST). Mumbai, India. 23-27 October 2018.

Katiyo, W., de Kock, H. L., Coorey, R., & Buys, E. M. (2018). Descriptive sensory profile of raw chicken meat and its relation to microbial and physicochemical quality during refrigerated storage. International Conference on Agriculture, Food and Aqua. Cape Town, South Africa. 22-23 November 2018. (*Best poster award)*

APPENDICES

Appendix A: Letter of ethical approval for online consumer survey and descriptive sensory analysis of chicken meat

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Natural and Agricultural Sciences
Ethics Committee

E-mail: ethics.nas@up.ac.za

Date: 17/02/2017

ETHICS SUBMISSION: LETTER OF APPROVAL

Ms W Katiyo
Department of Food Science
Faculty of Natural and Agricultural Sciences
University of Pretoria

Reference number: EC161205-087
Project title: Monitoring and Modelling of Consumer Food Safety Practices for Raw Chicken Meat from Retail to Home

Dear Ms Katiyo,

We are pleased to inform you that your submission conforms to the requirements of the Faculty of Natural and Agricultural Sciences Ethics committee.

Please note that you are required to submit annual progress reports (no later than two months after the anniversary of this approval) until the project is completed. Completion will be when the data has been analysed and documented in a postgraduate student's thesis or dissertation, or in a paper or a report for publication. The progress report document is accessible of the NAS faculty's website: Research/Ethics Committee.

If you wish to submit an amendment to the application, you can also obtain the amendment form on the NAS faculty's website: Research/Ethics Committee.

The digital archiving of data is a requirement of the University of Pretoria. The data should be accessible in the event of an enquiry or further analysis of the data.

Yours sincerely,

Chairperson: **NAS Ethics Committee**

Appendix B: Online survey questionnaire collecting information on consumers' handling practices, knowledge of safety factors and perceptions on the safety and quality of chicken meat

Question[1]	**Response options**	**Reference**
Screening questions:[2] Do you buy raw chicken for preparation at home? Do you prepare meals for your household using raw chicken?	❖ Yes ❖ No	-
Q1. At what stage do you usually select raw chicken during grocery shopping?[3]	❖ At the end, when I have selected all the other items ❖ Straight away when I enter the shop ❖ Sometime during the shopping ❖ I don't have a particular pattern	Jevšnik et al. (2008)
Q2. On average, how long do you leave raw chicken out (including the time you take to travel from the shop to your home) before storing it in a refrigerator or freezer at home?[3]	❖ Less than 1 hour ❖ 1 hour ❖ 2 hours ❖ 3 hours ❖ 4 hours ❖ 5 hours ❖ More than 5 hours	Kosa et al. (2015)
Q3. Where do you usually store raw chicken at home?[2]	❖ In the refrigerator ❖ In the freezer	Kosa et al. (2015)
Q4. What is the maximum time period you keep raw chicken in the refrigerator before cooking?[3]	❖ I don't keep raw chicken in the refrigerator ❖ 1 day or less ❖ 2 days ❖ 3 days ❖ 4 days ❖ 5 days ❖ 6 days ❖ 1 week	Kosa et al. (2015)

Question[1]	Response options	Reference
Q5. When thawing frozen raw chicken for cooking, how do you usually do it?[3]	❖ I thaw it in the refrigerator ❖ I thaw it using the microwave ❖ I thaw it in cold water ❖ I thaw it on the kitchen countertop ❖ I thaw it in hot water ❖ I do not thaw it; I cook it frozen	Kosa et al. (2015)
Q6. When preparing raw chicken, how do you usually wash your hands before handling the meat?[3]	❖ I use soap and water ❖ I use water ❖ I wipe my hands with a paper towel, dishcloth or apron ❖ I don't wash my hands	Kosa et al. (2015)
Q7. When preparing raw chicken, which of the following do you usually do immediately after handling the meat?[3]	❖ I wash my hands with soap and water ❖ I wash my hands with water ❖ I wipe my hands with a paper towel, dishcloth or apron ❖ I continue cooking without washing my hands	Kosa et al. (2015)
Q8. Can chicken that looks and smells fresh make you sick?[2]	❖ Yes ❖ No	Koppel et al. (2015)
Q9. Does refrigeration prevent the growth of germs/bacteria in raw chicken?[2]	❖ Yes ❖ No	Bearth et al. (2014)
Q10. Does freezing prevent the growth of germs/bacteria in raw chicken?[2]	❖ Yes ❖ No	Bearth et al. (2014)
Q11. What do you think is the maximum temperature at which raw chicken should be stored in a refrigerator? Please type your response.[6]	-	Jevšnik et al. (2008)

Question[1]	Response options	Reference
Q12. Once frozen chicken is thawed/defrosted, should it be refrozen without cooking?[2]	❖ Yes ❖ No	-
Q13. Do you usually think about food safety during the following?[2] Shopping for raw chicken Storing raw chicken before preparation Preparing meals using raw chicken Consuming chicken at a function, e.g., wedding, party Consuming chicken bought at a fast food outlet	❖ Yes ❖ No	Koppel et al. (2015)
Q14. Do you think that your purchasing, storage and preparation practices can affect the safety of chicken meat?[2]	❖ Yes ❖ No	Koppel et al. (2015)
Q15. On average, how many times per week do you consume chicken in your household?[3]	❖ Less than once a week ❖ Once a week ❖ Twice a week ❖ Three times a week ❖ More than three times a week	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q16. Where do you mostly buy raw chicken?[3]	❖ Wholesalers ❖ Supermarkets ❖ Butcheries ❖ Street vendors ❖ Farmers' markets ❖ Other (please specify)	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q17. In what temperature state do you mostly buy raw chicken?[3]	❖ Frozen ❖ Refrigerated ❖ Room temperature	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q18. Which of the following retailers do you most trust to supply:[3] i. good quality raw chicken? ii. safe raw chicken?	❖ Wholesalers ❖ Supermarkets ❖ Butcheries ❖ Street vendors ❖ Farmers' markets	-

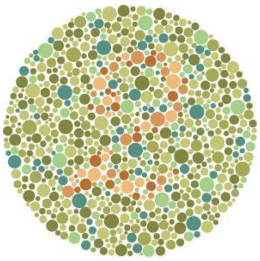
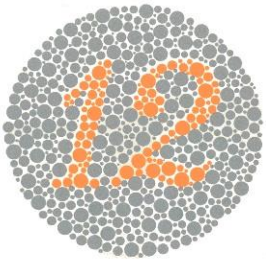
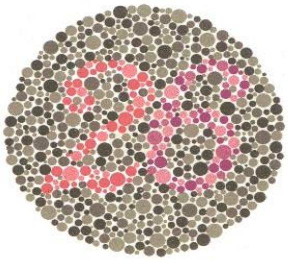
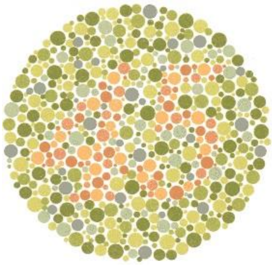
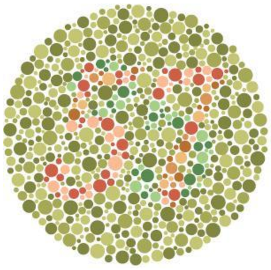
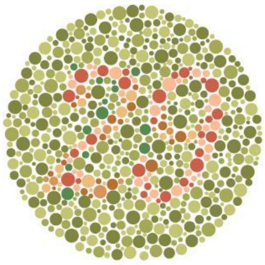
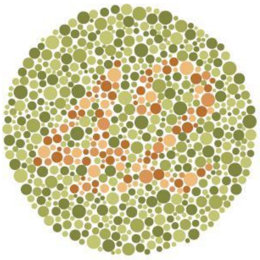
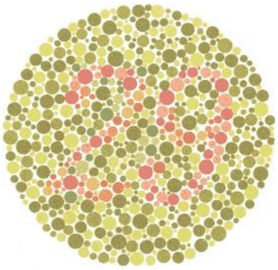
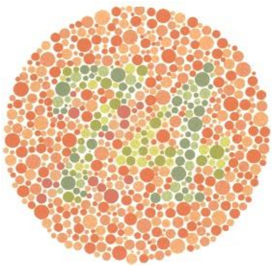
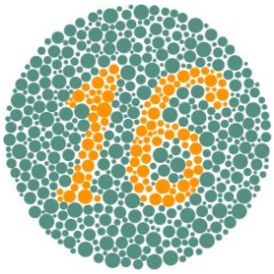
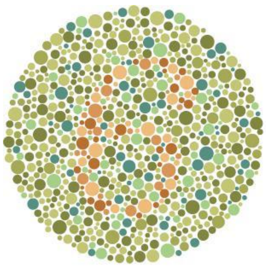
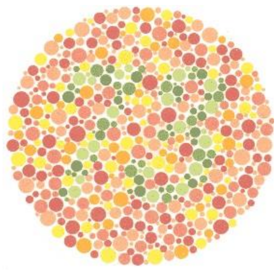
[1]Question	Response options	Reference
Q19. When buying raw chicken, which of the following products do you most trust to be:[3] i. of good quality? ii. safe?	❖ Frozen ❖ Refrigerated ❖ Chicken at room temperature	-
Q20. How important are the following aspects to you when judging the quality of raw chicken at point of purchase? Please rate on a scale of 1 = not important at all, to 7 = extremely important.[3,4]	❖ Smell ❖ Colour ❖ Amount of visible fat ❖ Damaged packaging ❖ Price ❖ Sell-by date ❖ Use-by date ❖ Brand name ❖ Free-range ❖ No growth hormones in feed ❖ No brine injected into the meat ❖ Country of origin	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q21. Twelve aspects of raw chicken meat are listed at the bottom of the screen. How important are they to you when judging the safety of raw chicken at point of purchase? List in order of importance from 1 (most important) to 12 (least important). Drag and drop your responses in the numbered boxes.[3,5]	❖ Smell ❖ Colour ❖ Amount of visible fat ❖ Damaged packaging ❖ Price ❖ Sell-by date ❖ Use-by date ❖ Brand name ❖ Free-range ❖ No growth hormones in feed ❖ No brine injected into the meat ❖ Country of origin	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q22. Before preparing raw chicken at home, how important are the following aspects to you when judging if it is still of good quality? Please rate on a scale of 1 = not important at all, to 7 = extremely important.[3,4]	❖ Smell ❖ Colour ❖ How the meat feels to the touch ❖ Sell-by date ❖ Use-by date	(Sismanoglou & Tzimitra-Kalogianni, 2011)

Question[1]	Response options	Reference
Q23. Before preparing raw chicken at home, how important are the following aspects to you when judging if it is still safe? List in order of importance from 1 (most important) to 5 (least important). Drag and drop your responses in the numbered boxes.[3,5]	❖ Smell ❖ Colour ❖ How the meat feels to the touch ❖ Sell-by date ❖ Use-by date	(Sismanoglou & Tzimitra-Kalogianni, 2011)
Q24. What is your gender?[3]	❖ Male ❖ Female ❖ Other ❖ I prefer not to disclose	-
Q25. What age category do you fall in?[3]	❖ 18-29 ❖ 30-39 ❖ 40-49 ❖ 50-59 ❖ 60 and older	-
Q26. What is your highest education level?[3]	❖ Primary school ❖ High school ❖ Tertiary education	-

[1]All the questions were modified accordingly and the orders of response options were randomised to avoid survey bias due to answer order.
[2]Dichotomous questions
[3]Multiple choice questions
[4]Rating questions
[5]Ranking questions
[6]No response options were provided.

Appendix C: Colour plate test used to assess the ability of prospective panellists to evaluate the colour of food products

Instructions: In the boxes provided, please write the number you see in each circle.

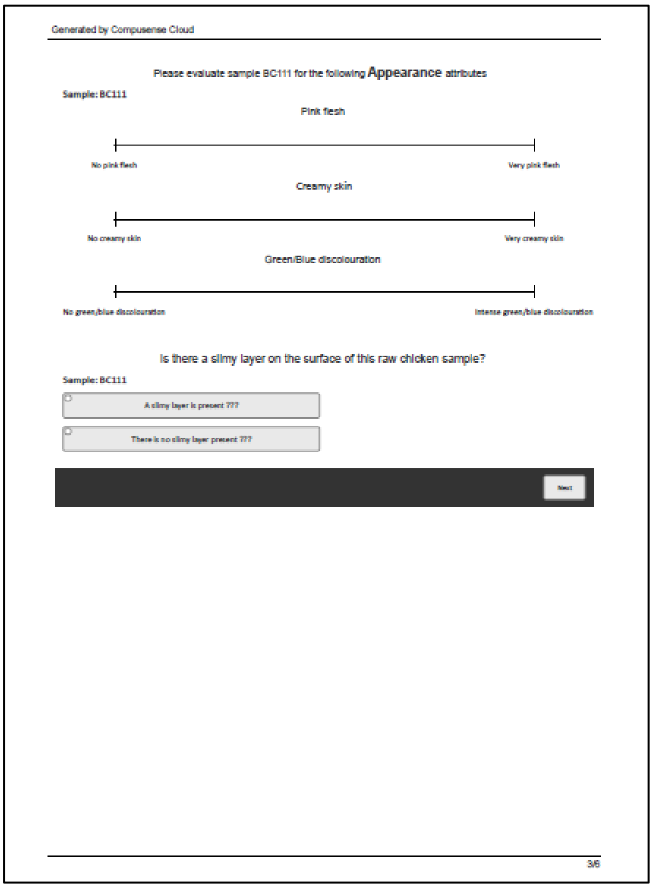
		
		
		
		

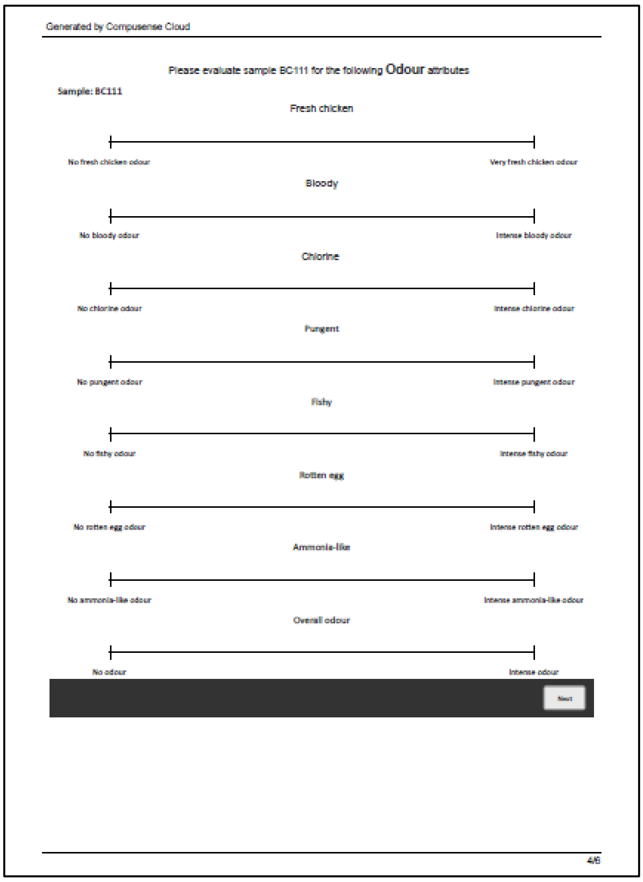
Appendix D: Aroma identification test used to assess the ability of prospective panellists to evaluate the aroma of food products (chicken, grilled beef, bacon, rancid oil, hard-boiled egg, sardines and cabbage)

Instructions: Please go to one of the sample stations as directed by the programme leader. You will find 7 coded bottles containing paper smelling strips. The aromas are of well-known foods and food ingredients. Kindly unscrew each bottle and take a sniff. Please identify and describe each aroma. Remember to smell the back of your hand to neutralise your sense of smell before and in-between smelling the different strips.

- **547** ____
- **433**____
- **701** ____
- **279** ____
- **456** ____
- **600** ____
- **921** ____

Appendix E: Quantitative descriptive sensory evaluation test for raw chicken meat during refrigerated storage





Appendix F: Consent and agreement form for panellists participating in descriptive sensory analysis of raw chicken meat

Consent and agreement form: Descriptive sensory evaluation of raw chicken meat

Wendy Katiyo is a PhD Food Science student at the University of Pretoria. Part of her research focuses on the sensory properties of raw chicken meat.

What will you be asked to do? You will be presented with raw chicken meat samples for sensory evaluation. During the first 2 sessions, you will be trained to describe and evaluate the odour and appearance of the meat samples. After training, you will be asked to evaluate (look at and smell) the raw chicken in 10 separate evaluation sessions (between 9 June 2017 and 11 July 2017).

How long will it take? You are expected to evaluate the raw chicken meat samples during 10 scheduled evaluation sessions lasting approximately 20 minutes per day.

Why should you participate? You will contribute to understanding of the science related to the sensory quality of raw chicken. You will get the opportunity to give an opinion on the sensory properties of raw chicken meat. You may include this acquired skill as a trained sensory panellist on your CV. Panellists will receive a R300 gift voucher as a gesture of appreciation after completing all the sessions.

Are there any risks? You will be asked to smell and look at raw chicken meat. You will not be asked to touch or taste the meat. The risk of smelling and looking at the meat is no higher than that of smelling and looking at raw chicken meat at the retailer or whilst preparing chicken at home.
Note that participation is completely voluntary and at your own risk. The University of Pretoria or any of its representatives cannot be held responsible in the unlikely event of any injury or illness as a direct or indirect result of your participation in these sensory evaluation sessions.

Do you have to participate? You do not have to participate in this project. If you do participate, you are allowed to withdraw at any time. Note that the thank you gift voucher is linked to completing all the training and evaluation sessions. Your participation may be terminated if you do not keep to the terms and conditions explained during recruitment.

What will we do with your answers? Responses to questions are tracked using numerical codes. These codes are not in any way related to your identity. The responses will only be used for research purposes.

If you have any questions about the research, please contact the sensory panel leader Wendy Katiyo or the project supervisor Prof. H. L. de Kock.

I HAD THE OPPORTUNITY TO READ THIS CONSENT FORM, ASK QUESTIONS ABOUT THE TASK AND I VOLUNTEER TO PARTICIPATE.

______________________________ Participant's full name

______________________________ Participant's signature

______________________________ Date

______________________________ Prof. H. L. de Kock (Supervisor of student)

______________________________ Wendy Katiyo (Student / Panel leader)

Appendix G: Standard references for creamy skin, pink flesh (a) and blue/green colouration (b) attributes of chicken meat during refrigerated aerobic storage

(a)

(b)[1]

[1]https://en.wikipedia.org/wiki/Chromis_viridis

Appendix H: Data for appearance and odour descriptive profile of raw chicken meat during refrigerated aerobic storage

Descriptor	Storage time (days)[1]				
	1	3	7	10	14
Appearance					
Pink flesh	$7.53^{a} \pm 1.58$	$7.89^{a} \pm 1.81$	$7.57^{a} \pm 2.02$	$4.86^{b} \pm 2.91$	$2.97^{c} \pm 2.38$
Creamy skin	$6.58^{ab} \pm 2.55$	$6.29^{a} \pm 2.80$	$7.09^{b} \pm 2.35$	$5.02^{c} \pm 3.25$	$3.34^{d} \pm 3.07$
Green/blue colouration	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$0.00^{a} \pm 0.00$	$2.09^{b} \pm 0.39$	$6.07^{c} \pm 0.47$
Slimy layer[2]	0^{a}	0^{a}	0^{a}	100^{b}	100^{b}
Odour					
Fresh chicken	$7.67^{a} \pm 1.81$	$7.57^{a} \pm 1.87$	$5.45^{b} \pm 2.49$	$1.22^{c} \pm 1.59$	$0.52^{d} \pm 0.94$
Bloody	$1.64^{a} \pm 3.27$	$1.79^{a} \pm 3.16$	$1.15^{a} \pm 2.22$	$0.03^{b} \pm 0.11$	$0.07^{b} \pm 0.25$
Pungent	$0.02^{a} \pm 0.06$	$0.03^{a} \pm 0.14$	$1.46^{b} \pm 2.00$	$6.27^{c} \pm 2.57$	$8.09^{d} \pm 1.61$
Fishy	$0.00^{a} \pm 0.00$	$0.02^{a} \pm 0.09$	$1.27^{b} \pm 2.33$	$4.75^{c} \pm 2.97$	$6.93^{d} \pm 2.47$
Rotten egg	$0.01^{a} \pm 0.03$	$0.00^{a} \pm 0.00$	$1.24^{b} \pm 2.32$	$5.49^{c} \pm 2.90$	$6.55^{c} \pm 2.95$
Ammonia-like	$0.01^{a} \pm 0.03$	$0.00^{a} \pm 0.00$	$0.21^{a} \pm 0.70$	$3.70^{b} \pm 3.45$	$4.81^{c} \pm 3.76$
Overall odour	$1.01^{a} \pm 1.03$	$1.24^{a} \pm 1.66$	$3.27^{b} \pm 2.64$	$7.52^{c} \pm 1.92$	$8.47^{d} \pm 1.34$

[1]Values are expressed as mean ± standard deviation. Means with different superscripts within a row were significantly different (repeated measures ANOVA, $p < 0.05$).
[2]Percentage of panellists who observed a slimy layer on the surface of raw chicken meat.