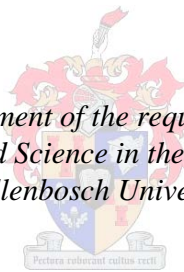


The effect of genotype and rearing system on chicken meat quality

by
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DECLARATION

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SUMMARY

Modern consumers are health conscious and are shifting towards more naturally produced products such as free range chicken. Commercial broiler strains are not suitable for free range rearing and an alternative genotype is needed that will serve the South African market with the acceptable meat quality as a broiler. The objective of this study was to investigate the effect of production system (free range and intensive reared) and genotype (Broiler (COBB™), Ross 308 X Potchefstroom Koekoek hybrid and Potchefstroom Koekoek) on chicken meat quality. This was quantified on the morphological, physical (pH, colour, drip and cooking loss, water holding capacity and tenderness), chemical composition (moisture, protein, fat, ash contents and fatty acid profile), sensory quality and consumer preference of various chicken meat portions.

The results of this study indicate that genotype had a more pronounced effect than production system on the morphological and growth properties of chicken meat, as well as on the sensory characteristics and consumer preference. The broilers had the best ($P \leq 0.05$) feed conversion ratio (FCR), highest average daily gain (ADG) and European production efficiency factor (EPEF), followed by the Hybrid and then the Potchefstroom Koekoek. For each genotype, the free range chickens produced heavier ($P \leq 0.05$) live weights than intensively reared chickens. Despite the poorer growth performance and efficiency of the medium growing Hybrid birds, they had less mortality and fewer leg disorders than the broiler. Additional to these factors, the Hybrid Free Range had higher thigh, drumstick and wing yields ($P \leq 0.05$) than the broiler. When investigating the correlation between the chemical and sensory data, it was observed that the Hybrid scored significantly higher ($P \leq 0.05$) in both flavour and aroma than the Broiler and Koekoek genotypes for both production systems.

For colour, pH and polyunsaturated to saturated fatty acid ratio (PUFA:SFA), the effect of production system was more pronounced than the effect of genotype. Rearing chickens in a free range environment increased the PUFA:SFA ratio ($P \leq 0.05$), making it beneficial to human health. Free range rearing resulted in lower muscle pH_u ($P \leq 0.05$), darker (L* value) ($P \leq 0.05$), less red and yellow (a* and b* value) ($P \leq 0.05$) chicken meat. It also influenced the chemical composition in different carcass portions; for example, a lower fat content in the thigh and higher protein in the breast of the Broiler.

Correlation with the sensory results indicated that juiciness, tenderness, chicken aroma and chicken flavour are the main drivers of liking for consumer's preference towards chicken meat.

The consumers predominantly preferred the Hybrid ($P \leq 0.05$) in a blind tasting session, but when information was given on the production system of a chicken product, the consumers lean more towards a free range reared product than an intensive reared product. This indicates that consumer perception plays an immense role in consumer decision making. Cluster analysis was also performed to ascertain whether the consumers differed in their degree of liking of the intrinsic character of the respective chicken samples. Three different clusters of consumers were identified:

1) Consumers that prefer free range reared chicken meat, 2) Consumers that prefer intensively reared chicken meat, 3) Consumers that prefer both free range and intensive reared chicken meat.

In conclusion, the Hybrid seems to be a viable option for free range production systems in South Africa, without negatively affecting the overall quality of the meat or consumer acceptance.

OPSOMMING

Moderne verbruikers is baie meer gesonheidsbewus en verkies meer natuurlik geproduseerde produkte soos vrylopende (free range) hoenders. Die kommersiële braaikuiken is nie geskik vir vrylopende produksie nie en 'n ander genotipe word benodig wat die Suid-Afrikaanse mark sal kan voorsien met aanvaarbare vleiskwaliteit vergelykbaar met dié van die braaikuiken. Die doel van hierdie navorsing was om die effek van produksiestelsel (vrylopend en intensief) en genotipe (braaikuiken (COBB™), Potchefstroom Koekoek en Ross 308 X Potchefstroom Koekoek kruising) op die morfologiese, fisiese (pH, kleur, drip- en kookverlies, waterhouvermoë en taatheid), chemiese samestelling (vog-, proteïen-, vet-, asinhoud en vetsuurprofiel), sensoriese kwaliteit en verbruikersaanvaarbaarheid van verskeie hoender vleis porsies te bepaal.

Hierdie navorsing het getoon dat genotipe 'n groter invloed gehad het as produksiestelsel op die groei en morfologiese eienskappe van die hoenders, asook op die sensoriese eienskappe en verbruikersaanvaarbaarheid. Die braaikuiken, gevolg deur die Ross X Koekoek kruising en dan die Koekoek, het die beste ($P \leq 0.05$) voeromsetverhouding (FCR), gemiddelde daaglikse toename (GDT) en Europese produksie effektiwiteitsfaktor (EPEF) getoon. Vir elke genotipe het die vrylopende hoenders swaarder ($P \leq 0.05$) lewende massa by slag getoon. Ten spyte daarvan dat die Ross X Koekoek kruising swakker groei en effektiwiteitsresultate getoon het, het hulle laer mortaliteite en minder been breuke en beserings as die braaikuiken gehad. Die Ross X Koekoek kruising wat vrylopend groot gemaak is, het ook swaarder dy, boud en vlerkie massa ($P \leq 0.05$) as die braaikuiken getoon.

Die navorsing het ook getoon dat kleur, pH en die poli-onversadigde tot versadigde vetsuur verhouding (PUFA:SFA) meer beïnvloed is deur die effek van produksiestelsel as genotipe. Die hoenders wat in 'n vrylopende omgewing grootgemaak is se PUFA:SFA verhouding is hoër as dié van intensiewe boerdery, wat dit voordelig maak vir menslike gesondheid. Vrylopende hoenders se vleis is donkerder (L^*) ($P \leq 0.05$) en het ook laer rooi, geel (a^* en b^*) en pH ($P \leq 0.05$) waardes getoon. Produksiestelsel effek het ook variërende chemiese waardes in verskillende karkas porsies tot gevolg gehad: 'n laer vetinhoud is gevind in die dy en 'n hoër proteïeninhoud in die borsies van die braaikuikens wat vrylopend grootgemaak is.

Korrelasies met die sensoriese data het ook getoon dat sappigheid, taatheid en hoendervleis geur die grootste dryfvere is in verbruikersaanvaarbaarheid. Tydens die verbruikerstoetse waar die verbruikers die gaar hoendervleis blind geproe het, het die verbruikers oor die algemeen meer gehou van die Ross X Koekoek kruising in vergelyking met die ander hoender genotipes ($P \leq 0.05$), maar sodra inligting oor die verskillende produksiestelsels gegee is, het die verbruikers aangedui dat hulle hoenders wat vrylopend groot gemaak is, verkies. Dit dui daarop dat persepsies 'n baie belangrike rol speel in die verbruiker se finale besluitnemingsproses. Statistiese segmentasietegnieke is ook op die data uitgevoer ten einde te bepaal of verbruikers in groepe verdeel kan word wat betref hul voorkeur van die sensoriese of intrinsieke eienskappe van die hoenderprodukte. Drie verskillende groepe is geïdentifiseer, nl. verbruikers wat 1) vrylopende

hoender vleis verkies; 2) intensiewe hoender vleis verkies; 3) beide vrylopende en intensiewe hoender vleis verkies.

In die lig van bogenoemde resultate wil dit voorkom of kruisteling tussen die gewone braaikuiken en die Potchefstroom Koekoek 'n moontlike opsie is vir die Suid-Afrikaanse vryloop hoenderbedryf. Hierdeur word daar van vrylopende produksie stelsels gebruik gemaak sonder om die vleiskwaliteit of gebruikers aanvaarbaarheid negatief te beïnvloed.

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LIST OF ABBREVIATIONS

µL	Micro liters
ADG	Average daily gain
AMEn	Nitrogen-corrected apparent metabolizable energy value
Anon.	Anonymous
ANOVA	Analysis of variance
ARC	Agricultural Research Centre
ATP	Adenosine triphosphate
BFR	Broiler free range
BI	Broiler intensive
DA	Discriminant analysis
DFD	Dark, firm, dry meat
DHA	Docosahexaenoic fatty acid
DPA	Docosapentaenoic fatty acid
EPA	Eicosapentaenoic fatty acid
EPEF	European production efficiency factor
FAME	Extraction of the fatty acid methyl esters
FAO	Food and Agriculture Organisation
FCR	Feed conversion ratio
FSA	Food Standards Agency
g	Gram
h	Hour
HFR	Ross X Potchefstroom Koekoek hybrid free range
HI	Ross X Potchefstroom Koekoek hybrid intensive
IMF	Intramuscular fat
KFR	Potchefstroom Koekoek free range
kg	Kilogram
KI	Potchefstroom Koekoek intensive
KN	Kilo Newton
L	Liters
LDL	Low density lipoprotein
LSD	Least significant difference
min	Minuets
MUFA	Monounsaturated fatty acids
N	Newton
n-3	Omega 3 fatty acid
n-6	Omega 6 fatty acid
n-6:n-3	Omega 6 to omega 3 ratio
ND	Non-detected
PCA	Principal Component Analysis
pH _u	pH <i>post mortem</i> (ultimate pH)
PSE	Pale, soft, exudative meat
PUFA	Polyunsaturated fatty acids
PUFA:SFA	Polyunsaturated to saturated fatty acid ratio
r	Coefficient of variance
s	Seconds

SAPA	South African Poultry Association
SD	Standard deviation
SFA	Saturated fatty acids
WBSF	Warner bratzler shear force
WHC	Water holding capacity

NOTES

This thesis is presented in the format prescribed by the Department of Food Science at Stellenbosch University. The structure is in the form of one or more research chapters (papers prepared for publication) and is prefaced by an introduction chapter with the study objectives, followed by a literature review chapter and culminating with a chapter for elaborating a general discussion and conclusion. Language, style and referencing format used are in accordance with the requirements of the *International Journal of Food Science and Technology*. This thesis represents a compilation of manuscripts where each chapter is an individual entity and some repetition between chapters has, therefore, been unavoidable.

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CHAPTER 1

GENERAL INTRODUCTION

Over the past decade poultry production has shown a rapid increase and currently dominates the South African agricultural sector (FAO, 2012; Anon., 2012). This increase is ascribed to higher consumer demand for poultry products and fluctuating red meat prices. In 2011, the total global annual poultry meat production was approximately 101.6 million tonnes compared to 109.0 million tonnes pork, 67.5 million tonnes beef and 13.5 million tonnes mutton (FAO, 2012). The average South African person consumes approximately 66 kg of meat (combined species) annually, of which 32.96 kg is poultry (Anon., 2012). In South Africa, poultry consumption is more than all the other animal protein sources combined (Department of Agriculture, Forestry and Fisheries (DAFF), 2011).

Consumption of fresh meat and meat products are mainly driven by quality but also influenced by meat prices and per capita income (Zhao & Schroeder, 2010). The recession and a decrease in consumer income, has forced consumers to buy and consume cheaper sources of protein such as poultry. In South Africa, chicken breasts/fillets are sold on the retail market for 32% of the price of beef loin steak and 70% of pork fillet. Also, consumers are price sensitive, especially in developing countries and will thus tend to purchase products that are perceived to be value for money.

Chicken meat is a low fat protein source and provides essential vitamins and minerals such as niacin, vitamin A, vitamin E and magnesium. It also has a favourable ratio of polyunsaturated fatty acids to saturated fatty acids (PUFA:SFA) making it beneficial to consumers within a cholesterol lowering diet and thereby helping to reduce the risk of cardiovascular diseases (Charlton *et al.*, 2008). Consumers frequently see chicken meat as a “healthier” option when compared to other meat or protein products on the market (Verbeke & Viane 1999; Charlton *et al.*, 2008 du Toit & Crafford, 2003).

The modern consumer is also more conscious of animal welfare and health; they request products that are environmentally friendly, promote sustainability, have nutritional value, excellent meat quality and that tastes good (Sundrum, 2001; Hoffman & Cawthorn, 2012). Studies on consumer perception of chicken meat and different rearing systems revealed that consumers believe that the meat of free range chickens is healthier and tastier than birds reared in intensive production systems, making their overall perception positive towards free range production systems (Verbeke & Viane 1999; Yeung & Morris, 2001; Harper & Makatouni 2002; Grunert *et al.*, 2004; Greene *et al.*, 2005 as cited by Fanatico *et al.*, 2005a; Fanatico *et al.*, 2007; Castellini *et al.*, 2008; Branciaro *et al.*, 2009). The question arises, however, if these beliefs are true about free range chicken meat or whether it is just a marketing strategy to convince ill-informed consumers? Also, how do South African consumers perceive the meat from extensively reared animals?

The three most important factors that should be taken into consideration with regard to the nutritional information about fat in meat products is the total fat content, the polyunsaturated to saturated fatty acid ratio (PUFA:SFA) and the omega 6 to omega 3 ratio (n-6:n-3) (Enser *et al.*, 1998; Enser, 1999). Free range reared chicken meat is considered to have less saturated fat (SFA), higher polyunsaturated fat (PUFA) and a lower ratio of n-6:n-3 than intensive reared chicken meat (Castellini *et al.*, 2002; Jahan & Paterson, 2007).

Environment and activity level influences the muscle growth and fibre type composition of birds and consequently affect the chemical composition and overall quality of the meat (Lawrie & Ledward, 2006). Free range production systems would expose the birds to fluctuating temperatures and increased exercise on the forage area (Fanatico *et al.*, 2005b). Therefore it would be expected that free range reared birds reach maturity slower (older in age at slaughter weight) than intensive reared birds, resulting in a more intense flavour of the meat, since more fat can be deposited for flavour development (Lawrie & Ledward, 2006; Elmore *et al.*, 1999). The muscles of free range birds will have had a higher level of physical activity, which will result in tougher meat due to increased intramuscular collagen content (Smith & Carpender, 1970; Lewis *et al.*, 2005)

The future of free range agriculture will, to a large extent, depend on consumer demand. In order for the free range chicken industry to expand their market share, they have to increase the demand for chicken meat through developing convenient, innovative, healthy and high quality products that appeal to the high income consumer.

Castellini *et al.* (2008) and Van de Weerd *et al.* (2009) reported that only slow-growing chicken strains can completely benefit from an extensive rearing system and the fast growing strains are considered slow to adapt to change. During the genetic selection for fast growing animals, their behaviour has changed to reduced kinetic activity (Schütz & Jensen, 2001; Branciarri *et al.*, 2009). Therefore, a slower growing chicken line is needed, that can adapt to the harsh conditions of the South African weather, can eat the forage in an extensive production system (and thus exercise more) and still give the same or better meat quality as the broiler. Numerous studies have been done on production and genotype effects on chicken meat quality, but never before in a South African free range environment with a South African indigenous chicken genotype.

The objective of this study was therefore to investigate the impact of production system (free range and intensive reared) and genotype (Commercial Broiler, Ross 308 and Potchefstroom Koekoek hybrid and Potchefstroom Koekoek) on the morphological, physical meat quality (pH, colour, drip and cooking loss, water holding capacity and tenderness), chemical composition (moisture, protein, fat, fatty acid profiles and ash contents), sensory quality and consumer preference of chicken meat.

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CHAPTER 2

PILOT STUDY ON THE SENSORY PROFILE OF COMMERCIAL AVAILABLE BROILERS MARKETED AS INTENSIVELY OR FREE RANGE REARED

ABSTRACT

Modern consumers are more animal welfare conscious and as a result their interest in free range poultry products is growing. The objective of this pilot study was to investigate the sensory (flavour, aroma, toughness, mealiness, initial and sustained juiciness) and physical (drip loss, cooking loss, water holding capacity) meat quality characteristics of chicken marketed as conventional or free range in the South African market. The cooked *pectolaris* (breast) muscles of commercially supplied conventional and free range chicken were compared by means of descriptive sensory analysis. No significant differences ($P > 0.05$) were found for the attributes chicken aroma, chicken flavour, metallic aroma, metallic aftertaste, initial juiciness and mealiness, although the free range birds scored higher in sustained juiciness and were lower in toughness ($P \leq 0.05$) than the conventional birds. The two groups also differed significantly ($P \leq 0.05$) from each other with regard to percentage drip loss, percentage cooking loss and water holding capacity. The major differences in this study can be ascribed to the higher tenderness and juiciness of the free range sample. This study established that although commercially available free range and conventional chicken breasts differ from each, the reasons for these differences are not clear and thus external factors need to be controlled or standardised in further studies.

Keywords: Free range; Conventional; Sensory analysis; Chicken meat; Poultry

INTRODUCTION

The modern consumer is more conscious of animal welfare and as a result would like to purchase products from animals that are extensively reared. Animal welfare can affect the quality of animal products and has become a strategic marketing tool. Intensive production systems are being criticised, by animal welfare organisations, for not providing adequate welfare to animals. This disparagement has led to the development of poultry meat production under less intensive reared conditions. Although consumers expect a higher degree of welfare in free range animals; this is only true if slow-growing strains are used (Castellini *et al.*, 2008). Furthermore, consumers believe that the meat of free range chickens is healthier and tastier compared to those of birds reared in confinement and their overall perspective is positive towards free range production systems (Fanatico *et al.*, 2007; Branciarri *et al.*, 2009). This consumer perception opens a market for more naturally produced chicken products (Branciarri *et al.*, 2009). Although consumers indicate that

they are willing to pay premium prices for free range or organic products, this is not reflected in the purchasing figures (Sundrum, 2001; IGD, 2007; Van Loo *et al.*, 2011).

Research has shown improved welfare in chickens, i.e. better expression of natural behaviour when having access to free range conditions than those in confined areas (Schütz & Jensen, 2001; Branciaro *et al.*, 2009). In Europe, alternative poultry meat production i.e. free range or organic, has gained wide recognition and resulted in branded products, such as the French label “Rouge”, which has been very successful. Castellini *et al.* (2002) and Jahan *et al.* (2005) reported that broiler birds exposed to more natural rearing conditions had increased activity which led to lower lipid contents in the meat and this, combined with pasture intake, contributed to higher consumer acceptability of the meat (Ponte *et al.*, 2008).

Fast-growing chicken lines are inadequate in extensive management production systems as several health and wellness problems occur, such as lameness, leg disorders and a high mortality rate due to their excessive weight. However, they are still commonly used in extensive conditions for economic reasons (Bokkers & Koene, 2003; Castellini & Mourvaki, 2007; Castellini *et al.*, 2008). Free-range production farmers in South Africa prefer to use the same fast-growing meat chicken genotypes, i.e. ROSS, COBB, etc., used in intensive production systems, as the use of slow-growing strains is not compulsory or economical. These fast-growing birds generally have higher live weight and better carcass conformation, attributing to the widespread use of these birds. Slower growing birds such as the indigenous Potchefstroom Koekoek, have greater leg and lower breast yields than fast-growing birds of similar weight. Additionally, these birds show active foraging behaviour which make them an ideal genotype for free range rearing. Poultry meat quality is a complex phenomenon where the rearing system is but one of the non-genetic factors that can significantly affect meat quality (Bogosavljević-Bosković *et al.*, 2006). The main differences found in literature regarding the assessment of the effect of unconventional production systems on poultry meat quality, frequently are a result of birds from different age and genetic origins being compared, rather than from the production system itself.

The growth of the free range chicken industry in South Africa will largely depend on consumer demand. In order to expand this demand and market share the industry need to market free range chicken meat through developing convenient, innovative, healthy and high quality products that appeal to the high income consumer. The modern consumer wants quality meat, as associated with the intensive meat broiler, but also demand products that are healthy, environmentally friendly, promote sustainability and comply with animal welfare guidelines. These complex and diverse aspects creates an enormous challenge for the industry. A possible solution might be considering hybrids between native species (hardy) such as the Potchefstroom Koekoek, with meat broilers (growth & quality).

Although various authors have considered the effect of rearing system and genotype on meat quality, none have done research on the South African market (Castellini *et al.*; 2002a; Castellini *et al.*; 2002b; Debut *et al.*, 2003; Fanatico *et al.*, 2005a; Fanatico *et al.*, 2005b; Branciaro

et al., 2009; Bogosavljević-Bosković *et al.*, 2009; Fanatico *et al.*, 2007b; Jaturasitha *et al.*, 2008; Abdullah *et al.*, 2010; Poltowicz & Doktor; 2011). The aim of this exploratory study was to investigate the sensory and physical meat quality attributes of chicken meat marketed as conventional or as free range reared.

MATERIALS AND METHODS

Sampling

Twelve chicken breast fillets marketed as free range or conventional (intensive) were purchased from a commercial outlet. It was assumed that the purchased samples were fed the same commercial formulated diet as a telephonic discussion with the free range producer elicited the response that they feed commercially available broiler diets. The experimental units included the breast (*M. pectoralis*) muscles of the two treatments. Each treatment was replicated six times (different breasts). The sensory analysis and physical measurements were performed on the cooked right breasts. The analyses were thus performed on 12 (2 treatments x 6 replications) birds.

Descriptive sensory analysis

The sensory analysis consisted of two meat treatments with six consecutive replications of the sensory test, thus the total number of samples equals 12. The frozen breast samples from each treatment, were removed from the freezer (-18°C) and defrosted in a refrigerator at 4°C for 12 h prior to each sensory analysis session. The defrosted samples were removed from the packaging and placed inside separate marked oven roasting bags (GLAD™, South Africa). The roasting bags with the meat samples were then placed on a stainless steel grid and fitted on an oven roasting pan. Thermocouple probes, connected to a hand-held digital temperature monitor (Hanna Instruments, South Africa) were inserted into the core of each of the meat samples where after, the roasting bags were closed by a metal tie. The samples were placed in two conventional ovens (Defy, model 835), pre-heated to 160°C and roasted until an internal temperature of 75°C was recorded by the thermocouple probes (AMSA, 1995). The two conventional ovens were connected to a computerised monitoring system which regulated the temperature of the ovens (Viljoen *et al.*, 2001). After the samples were removed from the oven and roasting bags, each sample were allowed to cool down for 10-15 min and cut into 1 x 1 x 1 cm cubes. The meat cubes were individually wrapped in aluminium foil squares and placed in glass ramekins (two cubes per ramekin), each marked with a randomised three digit code. Before the samples were served to the panellists for evaluation, the ramekins containing the meat samples were placed in a preheated oven (100°C) and reheated for 10 min.

Descriptive sensory analysis was performed on the two meat treatments by a panel of nine judges, each with previous experience in sensory analysis of meat. The panellists were trained in descriptive sensory analysis of meat according to Lawless and Heymann (2010) and the guidelines for sensory analysis of meat as described by the American Meat Science Association (AMSA, 1995). The panel received four training sessions. During each session the panellists received 1 x 1 x 1 cm cubes of meat from the four different meat treatments. The sensory attributes were analysed using a 100 mm unstructured line scale with zero (equal to low intensity) on the left hand side and 100 (equal to extreme intensity) on the right hand side (AMSA, 1995). Eight sensory attributes were decided on by the panellists (Table 2.1). Panellists were seated at individual sensory booths with artificial light in a temperature controlled (21°C) room, and were provided with the four meat treatments, in a randomised order, with distilled water (21°C), half an apple and water biscuits (CARR, UK) to clean and refresh their palate between each sample evaluation. The samples were analysed by completing the questionnaire on Compusense® (Compusense, Guelph, Canada) compiled during the training sessions.

Table 2.1 Attributes used in the sensory analysis of chicken

Sensory attribute	Description	Scale
Chicken aroma	Intensity of the aroma associated with typical cooked chicken as soon as the foil is removed	0 = Extremely bland 100 = Extremely intense
Metallic aroma	Intensity of the aroma associated with metallic as soon as the foil is removed	0 = Extremely bland 100 = Extremely intense
Initial juiciness	Amount of fluid exuded on the cut surface when pressed between the thumb and forefinger	0 = Extremely dry 100 = Extremely juicy
Chicken flavour	Intensity of the flavour associated with typical cooked chicken prior to swallowing	0 = Extremely bland 100 = Extremely intense
Metallic aftertaste	Intensity of the flavour associated with metallic prior to swallowing	0 = Extremely bland 100 = Extremely intense
Toughness	The impression of toughness perceived after the first 5 chews using the molar teeth.	0 = Extremely tender 100 = Extremely tough
Sustained juiciness	Intensity of the juiciness where juiciness is associated with fluid perceivable while chewing	0 = Extremely dry 100 = Extremely juicy
Mealy / powdery / Crumbly texture	Extreme mealiness is associated with a powdery, dry sensation in the mouth	0 = not mealy 100 = Extremely mealy

Physical measurements

Drip loss

The weight (g) of the breast fillets were documented before being vacuum-packed and frozen (-18°C) for approximately one week. After the breast meat was defrosted in a fridge (4°C) for 24 h,

it was removed from the packaging and blotted dry with tissue paper and weighed again (g). The difference in the weight of each of the samples was calculated as the percentage drip loss.

Cooking loss

The total weight loss during cooking (cooking loss) of the four treatments for the six replications was determined by using the method described by AMSA (1995). The breast muscle from each treatment was weighed (g) and documented before cooking. After the cooking process, the meat was removed from the cooking bag and allowed to cool down for approximately 10-15 min. Before recording the final weight (g), the meat was blotted with paper towel to remove excess moisture. The difference in the weight of each of the samples was calculated as the percentage cooking loss.

Water holding capacity

The water holding capacity was performed according to the method described by Trout (1988). A cooked meat sample from each of the two treatments and six replications were used. The meat was cut into small pieces and a 0.5 g piece was placed on top of a filter paper (Lased, Paper Filter, grade 292, diameter 90 mm, part nr. FLAS3205090). The filter paper together with the meat sample was then placed between two Perspex plates and a standard pressure of 588 N was enforced on the plates for 60 s. A photograph was then taken of the filter paper showing the expelled liquid and meat areas. Image J Software (Version, 1.36b, NIH Image) were used to calculate the ratio between the liquid (outer) and meat (inner) purge area to indicate the water holding capacity of the meat sample.

Statistical analysis of data

Experimentally the study consisted of a randomised block design with two treatments and six replications per treatment. The trained panel consisted of ten judges and the two treatments were evaluated for the six sensory attributes established during the training sessions. The model for the experimental design is indicated by the following equation:

$$Y_{ij} = \mu + \beta_j + t_i + \varepsilon_{ij}$$

where μ is defined as the overall mean, β_j is the effect of the block, t_i is the effect of the treatment and ε_{ij} is the error associated with the effect of the block and treatment. Outliers in the data were identified and removed before statistical analysis using ANOVA. T-tests were used to test for significant differences between treatment means. Least significant differences (LSD) were calculated at a 5% significance level. Results were defined as being significant at $P \leq 0.05$ and not significant at $P > 0.05$. Correlations were made between the sensory attributes, physical characteristics and proximate composition by means of the Pearson's correlation coefficient

(Snedecor & Cochran, 1980). SAS™ statistical software (Statistical Analysis System, Version, 9.2, 2006, SAS Institute Inc., CARY, NC, USA) was used for the analyses of variance (ANOVA). The multivariate statistical analysis and Principal Component Analysis (PCA) were performed using XL STAT statistical software (Version 2011; Addinsoft, New York, USA). Principal component analysis (PCA) is used to ascertain the association between the sensory attributes, instrumental attributes and treatments.

RESULTS

Sensory attributes

The sensory means and standard deviations (\pm SD) of the two different treatments are indicated in Table 2.2. It is clear from Table 2.2 that the mean values indicate that the chicken aroma was quite prominent in both samples although it did not differ between treatments ($P > 0.05$). No differences ($P > 0.05$) were found when comparing the two treatments for metallic aroma, initial juiciness, chicken aroma, metallic aftertaste and mealiness. The mean values for chicken flavour were 50.86 and 48.40, indicating that this attribute was fairly strong but not as strong as chicken aroma (> 64.00). The metallic aroma and aftertaste mean values were below 5, indicating that the panel found this attribute to be extremely low and barely recognisable. The small range within which the mean values fall, indicate that the samples were perceived to be very similar for all of these sensory attributes.

Although the panel scored the free range sample higher for sustained juiciness than the conventional sample ($P \leq 0.05$), the mean values for this attribute were between 39.60 and 47.64, indicating that the samples were perceived as being slightly dry.

With regard to toughness the panel established that the free range sample was significantly ($P \leq 0.05$) more tender than the conventional sample. Although differences were detected, the mean values of < 20 for toughness indicate that the samples were perceived as being quite tender.

Table 2.2 Mean scores (\pm SD) of sensory attributes of two chicken meat samples marketed as conventional and free range

Attributes	Intensive	Free Range	LSD
Chicken Aroma	67.98 ^a \pm 9.69	64.18 ^a \pm 9.00	5.20
Metallic Aroma	1.97 ^a \pm 5.05	1.26 ^a \pm 3.19	2.12
Initial Juiciness	54.57 ^a \pm 15.67	58.33 ^a \pm 15.10	5.31
Chicken Flavour	50.86 ^a \pm 9.19	48.40 ^a \pm 9.99	5.06
Sustained Juiciness	39.60 ^b \pm 11.59	47.64 ^a \pm 12.61	5.54
Metallic Aftertaste	4.11 ^a \pm 6.81	4.28 ^a \pm 7.61	4.47
Toughness	18.36 ^a \pm 15.57	11.07 ^b \pm 17.81	5.24
Mealiness	12.25 ^a \pm 7.13	8.69 ^a \pm 6.85	4.41

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab} Values in the same row with different superscripts are significantly different ($P \leq 0.05$)

Means determined by an unstructured line scale (0 = low intensity, 100 = high intensity)

Physical attributes

The physical attributes measured included drip loss, cooking loss and water holding capacity (WHC) of the breast muscle samples and their means and standard deviations (\pm SD) are presented in Table 2.3. The free range sample showed the lowest ($P \leq 0.05$) percentage drip loss (mean value = 2.27), compared to the conventional sample (mean value = 7.71). The free range sample was also found to have a significantly ($P \leq 0.05$) lower percentage cooking loss when compared to the conventional sample. During the WHC pressure test, the free range sample showed the highest ratio ($P \leq 0.05$), indicating that the highest amount of fluid was released from the free range breast meat sample.

Table 2.3 Mean scores (\pm SD) for the physical characteristics of chicken meat samples marketed as conventional and free range

Measurement	Intensive	Free Range	LSD
% Drip loss	7.71 ^a \pm 1.63	2.27 ^b \pm 0.89	2.24
% Cooking loss	19.85 ^a \pm 5.21	12.12 ^b \pm 0.59	3.83
WHC	3.79 ^b \pm 0.09	4.17 ^a \pm 0.19	0.16

Standard Deviation (SD); Least Significant Difference (LSD) at $P = 0.05$

^{ab} Values in the same row with different superscripts are significantly different ($P \leq 0.05$)

Sensory scale values ranged from Low (0) to Extreme (100)

Correlations

A Principal Component Analysis (PCA) bi-plot of the sensory and instrumental data is depicted in Fig. 2.1. The combination of the two factors F1 and F2 explained 62.38% of the total variance of which F1 and F2 explained 18.84% and 43.54%, respectively. In this bi-plot there is a distinct separation of the two samples by the F1 axes, establishing the free range sample on the left hand side and the conventional sample on the right hand side. In this bi-plot it can be seen that the commercial free range samples associated strongly with initial juiciness, sustained juiciness, as

well as WHC. On the other hand, the conventional sample associated strongly with the attributes toughness, mealy, chicken aroma and flavour and percentage drip loss and percentage cooking loss.

What is also indicated in Fig. 2.1, is that the sensory attributes of juiciness associates with WHC on the left side of the PCA plot and that percentage cooking loss and percentage drip loss associate on the right side of the PCA plot. These results indicate that there is an underlying valid structure in the sensory and instrumental results.

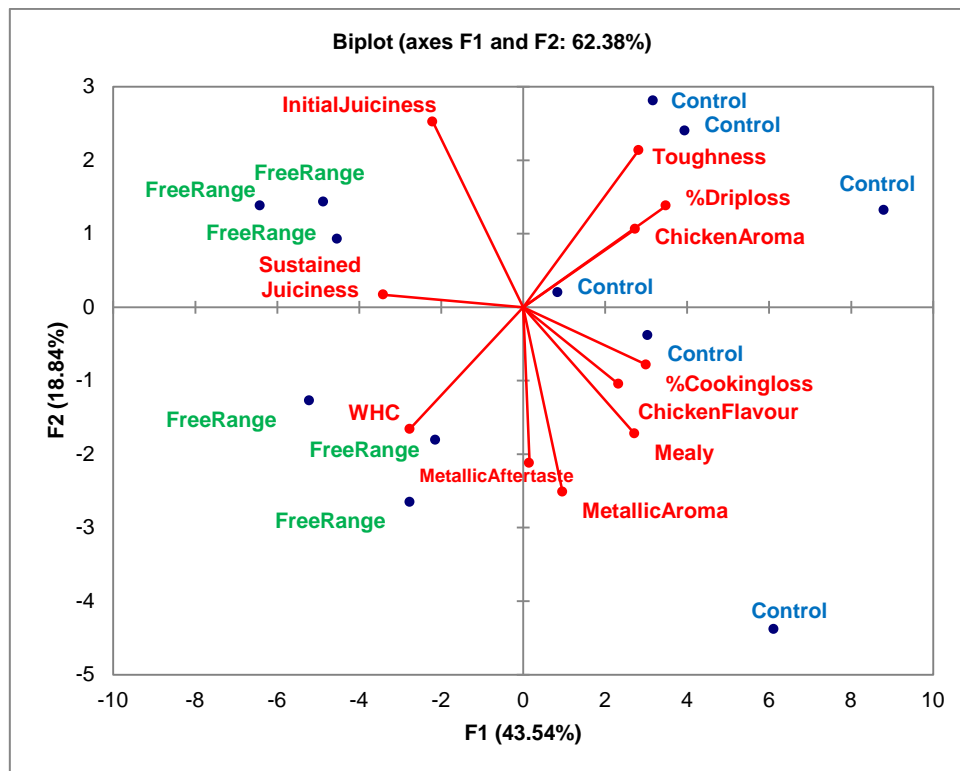


Figure 2.1 Principle Component Analysis of sensory attributes and instrumental attributes combined for broiler breasts marketed as conventional or free range birds.

DISCUSSION

Many factors may have influenced the chicken meat quality in this study, but since juiciness and tenderness were the main effects, these two will be discussed further.

Juiciness

Initial juiciness in meat is defined as the moisture released during mastication, whereas the stimulation of saliva secretion due to the presence of intramuscular fat is defined as sustained juiciness (Lawrie & Ledward, 2006). The free range sample scored significantly higher for sustained juiciness (Table 2.2) compared to the other chicken samples, but not for initial juiciness. This is also illustrated in the PCA bi-plot (Fig. 2.1) where the free range sample associate with

sustained and initial juiciness and the conventional sample are situated on the opposite side indicating a lesser correlation to juiciness. The free range samples also had the lowest cooking and drip loss percentages and showed the highest score for water holding capacity. All these attributes would thus seem to indicate that commercially available free range chickens have a higher water content, which is more strongly bound and which is released once pressure (during chewing or during the WHC test) is applied. This study further indicates that the correlation between initial juiciness and WHC is inconclusive, but there is a moderately positive correlation between sustained juiciness and water holding capacity (WHC) ($r = 0.587$; $P = 0.045$). Water holding capacity is representative of the amount of moisture present within the meat, following the cooking process. Unfortunately no pH measurements were taken and no correlation could thus be made between WHC and pH. Offer and Trinick (1983) concluded that the initial juiciness of meat is positively correlated with the WHC of meat, which is determined by the ultimate pH of the muscle. Intramuscular fat generally contributes to sustained juiciness; the higher the percentage fat present in the meat, the more juicy the meat is perceived to be (Lawrie & Ledward, 2006). However, no proximate analyses were done on the different meat treatments in this exploratory study and therefore no correlations could be made between the different attributes measured and not measured. This is an aspect that warrants further research. It can be argued that when the meat was not juicy (dry), the meat was perceived to be mealier, this is illustrated in the strong negative correlation between mealiness with initial juiciness ($r = -0.557$; $P = 0.060$) and sustained juiciness ($r = -0.792$ $P = 0.002$) and sustained juiciness with drip loss ($r = -0.725$; $P = 0.008$) and cooking loss ($r = -0.680$; $P = 0.015$).

Tenderness

Tenderness is the ease of shearing, cutting or grounding meat during mastication and consumption (Gillespie, 1960; Forrest *et al.*, 1975). The free range meat sample proved to have the lowest toughness (highest tenderness) compared to the other treatment (Table 2.1, Fig. 2.1). According to previous studies, free range meat samples are not as tender as, or no significant differences were found, when compared to intensive reared meat (Castellini *et al.*, 2002; Farmer *et al.*, 1997; Fanatico *et al.*, 2007, Ponte *et al.*, 2008; Wang *et al.*, 2009; Połtowicz & Doktor, 2011). In this study the free range sample scored significantly lower for toughness, this is contradictory to what is found in literature and what is expected. We would have expected the free range to be less tender due to increased intramuscular collagen, as the birds would have had a higher level of physical activity (Lewis *et al.*, 1005). It is not clear why the free range sample was so tender, we can only speculate that *ante mortem* and *post mortem* factors may have had an effect.

There is a moderately negative correlation between sustained juiciness and toughness ($r = 0.505$; $P = 0.094$). Typically, the drier the meat the tougher it is perceived to be (Davis *et al.*, 1979; Hawkins *et al.*, 1987). Toughness was also positively correlated to percentage drip loss ($r = 0.787$; $P = 0.002$). As the percentage drip loss increased, the sensory tenderness decreased.

A similar result was also found for juiciness. Again this confirms the link between tenderness and juiciness (Davis *et al.*, 1979; Hawkins *et al.*, 1987). It can be argued that the more water present in the piece of meat that the panel member analysed, the higher the dilution of the connective tissue per volume of the meat. Therefore the less juicy the meat the higher the content of the connective tissue per bite and the tougher the piece of meat is perceived to be.

CONCLUSIONS

The aim of this study was to perform an explorative descriptive sensory analysis in order to determine the sensory and physical quality characteristics of two commercial chicken samples marketed as conventional and free range to consumers in the South African market. Commercially, in South Africa, the same fast growing chicken strains used for intensive rearing are used for free range production. The results of this investigation indicate that although some attributes did not differ as expected; the free range samples were very tender and had a high juiciness score causing these two attributes to be the main driving force for this treatment to be different from the conventional samples. No information regarding the two rearing systems or their *ante* and *post mortem* handling were collected, but it can be assumed that other extrinsic and intrinsic factors may have had an effect on the greater tenderness and juiciness of the free range sample. This indicates that in further studies as many factors as possible need to be controlled or standardised.

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CHAPTER 3

LITERATURE REVIEW

INTRODUCTION

General background

The domestic chicken (*Gallus gallus domesticus*) is generally accepted to have originated from the Red Jungle Fowl (*Gallus gallus*). They were first domesticated by man about 2500 BC in Southeast-Asia and arrived in Sub-Saharan Africa sometime before 850 AD (Crawford, 1990; MacDonald, 1992; Mozdziak, 2004; Rose, 1997). Poultry was initially domesticated for religious, cultural and entertainment reasons and only later thought of as a food source.

More than a century of intense poultry breeding has resulted in a large diversity between the strains/genotypes of the poultry species. Crossing closely related poultry genotypes to produce hybrid offspring has the potential to increase the diversity of poultry even further (Rose, 1997).

Intensive broiler chicken production methods were first developed in the 1950`s. At that time poultry meat production was less than 10% of the world`s total meat output. Since then poultry meat output has taken a greater share of the expanding world meat market and it accounted for over 20% of total meat output by the mid 1980`s (Rose, 1997).

The commercial poultry industry of today is tremendously uniform in composition and appearance. Tightly managed breeding, incubation, rearing and nutritional systems have created a bird that have less phenotypic variation. This uniformity has allowed poultry processing plants to advance into highly automated facilities with an efficiency that is unmatched by other livestock processors (Owens *et al.*, 2010).

Chicken meat is a low fat protein source and provides essential vitamins and minerals such as niacin, vitamin A, vitamin E and magnesium. It also has a favourable ratio of polyunsaturated fatty acids to saturated fatty acids (PUFA:SFA) making it beneficial to consumers as a cholesterol lowering diet and thereby helping to reduce the risk of cardiovascular disease (Charlton *et al.*, 2008). Broiler meat is inexpensive when compared to other animal protein sources on the market (Fig. 3.1) with a producer selling price of R13.5/kg of carcass weight (Anon., 2012a). In addition, chicken meat is packed in convenient portions or sold as ready to eat products, making it easy to prepare in numerous dishes and ways thereby making it a very versatile product and a convenience for the lifestyle we live in. Chicken meat does not have any religious restriction against its consumption, making it a suitable product for different religions (Charlton *et al.*, 2008; Jaturasitha *et al.*, 2008). Consumers frequently consider chicken meat as the “healthy” option

when compared to other animal protein sources (Verbeke & Viane 1999; Charlton *et al.*, 2008 du Toit & Crafford, 2003).

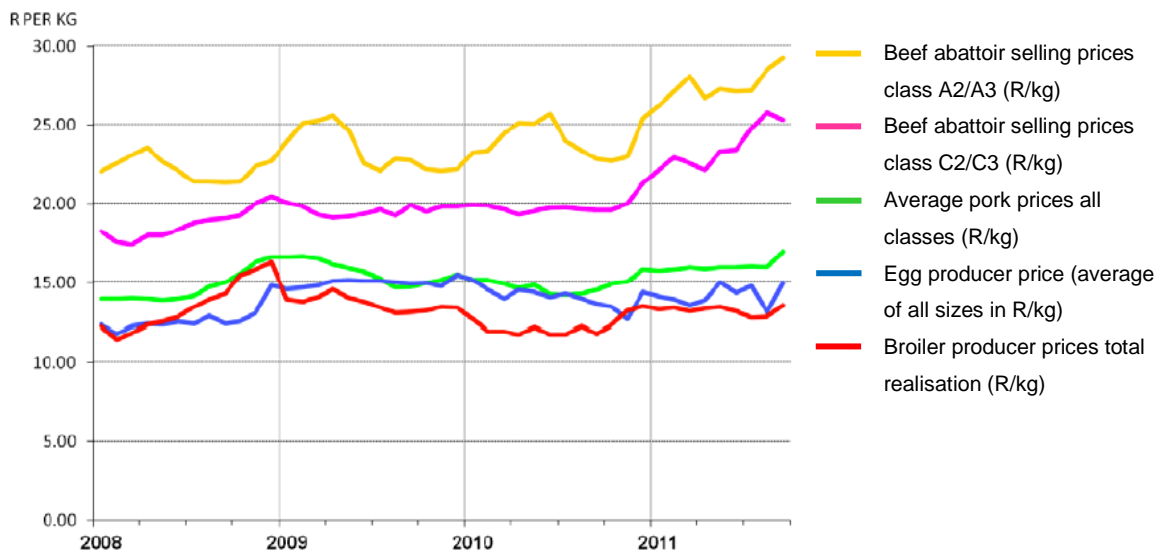


Figure 3.1 Animal protein selling prices (Modified from Anon., 2012a).

Modern consumers are more sensitive to animal welfare issues and are health conscious as pertaining to the food they consume. They want to be informed to make educated choices and would like to contribute to lowering their carbon footprint by looking after the environment (Grunert *et al.*, 2004; Grunert, 2006; Napolitano *et al.*, 2010). There is a higher demand by consumers for more “naturally” or extensive and humanely reared meat that has been produced with minimal use of additives and chemicals. Broilers, which are used for intensive production, are not suited for extensive production systems, as there is a higher incidence of mortality, lameness and leg disorders, but they do gain weight very fast and their meat is acceptable to the consumer (Branciaro *et al.*, 2009). Indigenous chickens, such as the Potchefstroom Koekoek, are adapted to the harsh conditions of extensive rearing; they can be produced without any supplementary feed and are extremely tolerant of diseases (Muchenje *et al.*, 2009). However, they tend to grow slowly and do not have as good a feed conversion ratio (FCR) as commercial broilers. Therefore, the South African industry requires a chicken line that can adapt to the harsh conditions of a free range system, is relatively fast growing, has a high meat yield per bird and produces meat which is acceptable to the consumer.

Background on South African poultry industry

The poultry industry comprises of three distinct, separate branches, namely, the broiler-, the egg- and the hatchery industries. The South African Poultry Association (SAPA) represents both commercial and non-commercial farmers within these three branches. Approximately 70% of the total broiler production in South Africa is supplied by roughly 13 large producers, while several

small production units and the informal sector are responsible for the remaining 30% (DAFF, 2011a).

In South Africa the poultry industry has developed into a major business over the past sixty years, with production still increasing each year (Anon, 2011a). The main factor that contributed to this growth was the higher demand for poultry meat by the health conscious consumer, as it has become the “healthier” choice of meat globally (Van Marle-Köster, 2001; Mozdziak, 2004). Another factor that may also have had an effect is the inexpensive price of chicken compared to other meats in the market. The poultry industry dominates the South African agricultural sector as the main supplier (23%) of animal protein for human consumption (Anon., 2012b). Over the past eleven years, the number of day old broiler chicks placed have increased by 44% (3.9% annually) while the number of broilers slaughtered have increased by 45.3% (3.66% annually) due to improved productivity (Anon., 2012b).

The gross farm income from poultry meat in 2010 was R22 940 billion and from eggs R6 658 billion, combined the gross farm income for 2010 was R29 598 billion for the poultry industry (DAFF, 2011a). In 2010 the poultry industry supplied South Africa with 1661 840 tonnes of meat.

There has been an increase of 4.1% in total broiler production from 2009 to 2010 with an average of 18.6 million broilers slaughtered each week (DAFF, 2011a). Even with this increase, South Africa is not self-sufficient. In 2010, broiler imports increased with 17% from 2009 (Anon., 2012b). During 2010, approximately 73% of poultry imports into South Africa originated from Brazil, 14% from Argentina and 7% from Canada. Despite the fact that the South African broiler industry is exposed to the global poultry meat industry, where it has to compete with frozen products imported from countries with relatively low production costs, growth still occurs (DAFF, 2011a). It was estimated that broiler production would increase by 1.04% in 2011 and an increase of 2.8% was forecasted for 2012 (Anon., 2012b).

Poultry consumption globally and in South Africa

Globally the average person consumes about 41.6 kg of meat a year, but in South Africa the average person consumes approximately 66 kg per annum (FAO, 2012; Anon., 2012b). In 2010 the average per capita consumption of poultry meat in South Africa was 32.96 kg per person compared to 17.77 kg beef, 8.48 kg eggs, 4.58 kg pork and 3.16 kg mutton and goat. There was an increase of 15% in the consumption of broiler meat from 2009 to 2010 (Anon., 2012b). Thus in South Africa, poultry consumption is more than all the other animal protein scores combined, and when all the animal protein in 2010 is accounted for, poultry was the highest making up 57% of the total consumption of meat (beef, mutton, pork and poultry) (DAFF, 2011a).

Local poultry production provided 84% of the total poultry consumed during 2010. For the same year an estimated 16% of local consumption of poultry meat consisted of imports and this resulted in a 1% increase from 2009 in total consumption (DAFF, 2011a; Anon., 2012b).

The growth of the free range chicken industry in South Africa will largely depend on consumer demand. In order to expand this demand and market share, the industry needs to market free range chicken meat through developing convenient, innovative, healthy and high quality products that appeal to the high income consumer. The modern consumer wants quality meat, as associated with the intensively reared broiler, but also demands products that are healthy, environmentally friendly, sustainable and comply with animal welfare guidelines as perceived by the consumer. These aspects create a great challenge for the industry. One of the alternatives is to look at hybrids between indigenous genotypes (hardy) such as the Potchefstroom Koekoek, with broilers (growth and quality).

CONSUMER PERCEPTION AND PREFERENCES

Consumers perceive meat quality as multidimensional with the main dimensions being sensory quality, 'healthiness', convenience, animal welfare and extensive production systems. At the point of purchase, these qualities are often unknown to the consumer, and are therefore contingent based on the information available (Grunert *et al.*, 2004). A consumer attitude study towards fresh meat (beef, pork and poultry) was conducted by Verbeke and Viane (1999). It was found that the top five attributes in a descending order towards meat were quality, taste, freshness, hormone absence and perceived 'healthiness'. Poultry scored the highest in these attributes and is inclined to be perceived more favourably than beef or pork. The only attribute that was scored lower than beef and pork in poultry was the perception on 'animal friendly' (Verbeke & Viane, 1999)

Grunert *et al.* (2004) tested whether perception plays a role in consumer decision making and evaluated further whether expectation was met by the actual experienced quality of extensively produced meat. From Fig. 3.2 it can be seen that perceived quality (including taste and tenderness) fell short of expectations after consumers consumed extensively produced pork meat. The study clearly showed that extensive products may be wrongly classified if certain qualitative characteristics, which are currently unfamiliar to consumers, are taken into account (Grunert *et al.*, 2004). Preferences are related to what consumers are familiar with and long term exposure to intensive broiler meat flavour may cause resistance in the perception of other flavours. This may be the reason why the taste attribute fell short of what the consumers were expecting (Castellini *et al.*, 2008). Castellini *et al.* (2008) also reported that an untrained consumer panel is unable to distinguish in preference, appearance, texture and flavour between extensively and intensively produced meat.



Figure 3.2 The difference between expected and experienced quality by consumers as pertaining to the meat derived free range pork. (Modified from Grunert *et al.*, 2004)

Diet / Health relationships

Over the past few decades consumers have become more health conscious and they prefer meat that is leaner and has less visible fat. Chicken is generally recognised as a low fat, protein rich meat source containing essential vitamins and minerals. The breast meat, in particular, is seen as being low in fat, with a favourable profile of PUFA:SFA (Chalton *et al.*, 2008). This is why consumers perceive chicken meat as a healthier option in comparison to other protein sources. Consumers also perceive free range and organic products to be healthier than intensive products and an investment in their health (Verbeke & Viane 1999, Grunert *et al.*, 2004). According to various health establishments, the ratio of omega 3 to omega 6 (n-6:n-3) in meat should be less than 4 and the PUFA:SFA should be greater than 0.45, to promote health and reduce the risk of cardiovascular diseases (Enser, 1999, Wood *et al.*, 2003, Warriss, 2010). Free range chicken meat is considered to have less saturated fat (SFA), higher polyunsaturated fat (PUFA) and a lower ratio of n-6:n-3 than intensive chicken meat making it a favourable health option (Castellini *et al.*, 2002a; Jahan & Paterson, 2007). However, the higher PUFA concentration makes the meat more prone to rancidity and causes off-flavours to develop, but free range meat is also known to have more vitamin E which helps maintain lipid stability (Valenzuela, 1995; Enser, 1999; Williams, 2000; Bou *et al.*, 2004).

It is possible to change the fatty acid and nutrient composition of chicken meat by manipulating the feed. For example, dietary supplements such as, omega 3 (n-3) fatty acids and dehydrated alfalfa have been used to change the fat and cholesterol content of poultry meat (Enser, 1999). The fatty acid profile of chicken can be changed by increasing the n-3 fatty acid content by feeding chickens either linseed, rapeseed, soybean, fish extract or algae oils (Enser, 1999; Farmer, 1999).

Animal welfare

In recent years consumers have become more concerned about the way animals are being managed during farming, especially intensive production systems. Consumers request that animal production farmers follow the animal welfare guidelines that contain Webster's five freedoms and state that they are willing to pay higher prices for certified humane products (Thompson, 1998; du Toit & Crafford, 2003; Napolitano *et al.*, 2010; Van Loo *et al.*, 2011; Janssen & Hamm, 2012). Producers are worried about the growing demand for animal friendly products, since these production systems increase production costs, and although consumers stated that they are willing to pay premium prices for these products, this is frequently not reflected in the purchasing figures (Sundrum, 2001; IGD, 2007, Van Loo *et al.*, 2011). The five freedoms to ensure adequate animal welfare as listed by the Farm Animal Welfare Council in 1993 are:

1. Freedom from thirst, hunger and malnutrition by ready access to fresh water and a diet to maintain full health and vigour.
2. Freedom from discomfort by providing a suitable environment, including shelter and a comfortable resting area.
3. Freedom from pain, injury, and disease by prevention or rapid diagnosis and treatment.
4. Freedom to express normal behaviour by providing sufficient space, proper facilities, and company of the animal's own kind.
5. Freedom from fear and distress by ensuring conditions that avoid mental suffering.

Of these five guidelines, it is especially the freedom to express natural behaviour and the freedom from pain, injury and disease that have been questioned by animal welfare groups when referring to intensive poultry production systems (Gade, 2002). Animal welfare groups argue that when birds are reared in a confined environment; lameness and leg disorders may occur, because the developing legs cannot support the increased body weight of the fast growing birds. The added weight also places stress on their heart and lungs and a disorder called ascites can develop (Gade, 2002; Branciaro *et al.*, 2009). Genetic selection for rapid growth rates and high productivity in conventional systems has led to the worsening of animal health (Van de Weerd *et al.*, 2009).

Meat quality

In intensive production systems, animals are being reared in total confinement and fed until they reach the desired slaughter weight. This kind of environment is perceived to be "unnatural" by consumers for animals cannot express natural behaviour. Therefore they do not associate intensive production systems with good meat quality (Gade, 2002; Fanatico *et al.*, 2007b; Van de Weerd *et al.*, 2009).

In both intensive and extensive production systems, there are welfare advantages and disadvantages that may affect the meat quality positively or negatively. In extensive production systems, animals may show more natural behaviour, but they may be more susceptible to stress during the catching method, which affect the meat quality negatively, since they are not used to

human handling. Although intensive production systems may restrict natural behaviour, it is easier to control the environment, feeding, diseases and treat individual animals. When natural behaviour is restricted, animals may become aggressive and show dominance disorders, causing the animals to fight which results in bruising and this may affect meat quality negatively. When intensive systems are managed correctly, they can actually be better, from a welfare point of view, than poorly managed extensive systems (Gade, 2002; Hoffman *et al.*, 2004; Van de Weerd *et al.*, 2009).

Environmental impact

Consumers are becoming more aware of their own environmental footprint and demand products that are more environmental friendly. Chicken meat is considered the “green” meat, because it uses the least energy of all the livestock production systems and has the lowest impact in terms of its potential contribution to global warming (Anon., 2006; Charlton *et al.*, 2008; Nunes, 2011). Agriculture generates 15.6% of the world’s total greenhouse gasses annually, with the main contributors being beef cattle, sheep and dairy cattle. Poultry contributes as little as 1% greenhouse gasses annually (Anon., 2006). The reasons why the broiler production systems contribute so little to global warming are: it has a short growing cycle, it is land usage efficient needing only 20 to 40 m² to produce 1 kg of meat and to produce this 1 kg of meat, less than 2 kg feed and 3.9 L of water is required (Nunes, 2011).

With regard to extensive production systems, where less energy is typically used for other food products, in the case of chickens the opposite is true. However, extensive chicken production systems still have a lower environmental impact than that of other livestock (Anon., 2006).

Food safety

Food safety is one of the key drivers when it comes to consumer preference towards free range or organic foods. A chain of food scares over the past years, such as chicken meat contaminated with *salmonella* and *campylobacter* and overuse of antibiotics in chicken increase concerns about the consumption of chicken (Yeung & Morris, 2001a; Bailey & Cosby, 2005). A survey by the Food Standards Agency (FSA) stated that 54% of all consumers are concerned about the hygiene status of intensively reared raw chicken meat (FSA, 2011). Three main types of food risks related to chicken have been identified, namely, microbiological risk, chemical risk and technological risk (Yeung & Morris, 2001a).

Microbial risk refers to risk caused by microorganisms such as *Salmonella* and *Campylobacter*, which cause food spoilage and food poisoning. Food borne illnesses may occur through inadequate waste management, because animal diseases spread rapidly through faecal contamination (Yeung & Morris, 2001b; Elamin, 2007). Chemical risk includes residues in food due to antibiotics fed to chickens as well as the leftovers of agricultural chemicals in the animal feed eaten. Continued use of antibiotics may result in the development of multidrug resistant strains of pathogenic bacteria. Technical risk refers to the possible negative consequences of

technological advancements in food products such as genetic modification of foods (Yeung & Morris, 2001b).

The Food and Agriculture Organisation (FAO) warned that in intensive production, where animals are reared in confined unsanitary conditions, and there is no adequate waste management system being applied, that this can cause a risk to meat safety. However, Gade (2002) states that microbial risks can be reduced with good management practices. During periods of food safety concern, consumer risk perception plays a key role as it greatly affects the purchase and consumption behaviour of the consumer (Yeung & Morris, 2001b; Grunert, 2005).

EXPERIMENTAL UNITS

Muscle types

Muscles can be classified as light and dark in colour. As food they are referred to as the white meat and the dark (red) meat (Parkhurst & Mountney, 1988). There are three types of muscle fibres (type I, type IIa and type IIb) and muscles contain all three, although in some cases one type can dominate (Parkhurst & Mountney, 1988; Mckee, 2003; Taylor, 2004). Table 3.1 shows the relationship between fibre type and meat quality.

Table 3.1 Relationship between fibre type and meat quality (adapted from Taylor, 2004)

Fibre type	Property	Role in meat quality
I	Red, oxidative, slow contracting, myosin type, more myoglobin, rich in mitochondria	High fat content, small fibre diameter, red colour, low glycolytic potential
IIa	Red, intermediate, fast contraction, anaerobic	Intermediate, faster into rigor than type I
IIb	White glycolytic, fast contraction, rich in glycogen, anaerobic, fewer mitochondria	Largest fibres so toughest, pale colour, changes size with exercise regimes and age, high glycolytic potential so low pH

Type I, slow oxidative or red fibres are used for activities such as maintaining posture, running and walking (Parkhurst & Mountney, 1988). They are rich in lipid, mitochondria, myoglobin, red in colour and small in size. These fibre types are associated with the sensory characteristics juiciness and flavour (Mckee, 2003; Taylor, 2004). Type II, fast glycolytic or white fibres are larger in size, white in colour, have less myoglobin, less mitochondria and higher glycogen content than type I (Mckee, 2003; Taylor, 2004). In a muscle, the fibre number is fixed at birth and with growth and development the size and type changes. Muscles have a characteristic fibre type profile that is species specific and related to the function of the muscle, other than exercise there are few factors that change fibre type. Therefore the differences in muscle function will determine the types of fibres present (Taylor, 2004).

Faster growing chicken lines were found to be more tender than slower growing chicken lines, because of smaller fibre diameter. The latter increases with age, but these fibres do not develop and become apparent as in those muscles with bigger fibres (Lawrie & Ledward, 2006; Fanatico *et al.*, 2005a). According to Taylor (2004), the differences in fibre type are usually greater within genotypes. Domestication of animals have resulted in more larger type IIb fibres, thereby increasing the meat toughness and also the colour, although some evidence shows that production system has no effect on tenderness (Taylor, 2004; Castellini *et al.*, 2008). When animals exercise more, type IIa fibres are formed, therefore free range animals will have more red meat than intensive reared animals (Fletcher, 1999; Taylor, 2004).

Breast

The breast portion consists of two muscles, the *M. supracoracoideus* and the *M. pectoralis* (Raj, 1999; Swatland, 2000). These two muscles are positioned in the front breast area of the carcass where the sternum provides a surface for these muscles to attach onto. The breast portion of chicken is usually sold with the muscle removed from the sternum as a deboned portion or as a whole breast with the sternum still intact. The *pectoralis* muscle extends from the clavicle and the coracoclavicular membrane to the pectoral crest of the humerus bone and is responsible for the depression or downwards stroke of the wings during flight. This muscle is the largest body muscle in the chicken, comprising about 8% of the total body weight. The *supracoracoideus muscle* originates from the keel bone, on the dorsal side of the humerus bone, and is responsible for the elevation or upwards stroke of the wings during flight (Raj, 1999; Swatland, 2000; Biewener, 2011). Chickens are capable of fast flapping flights in which a thrust is created during depression of the wings; therefore the *pectoralis muscle* is larger than the *supracoracoideus muscle* in chickens (Raj, 1999; Swatland, 2000). Both the *pectoralis* and *supracoracoideus* muscles consist of predominantly (> 90%) white, type IIb, fast glycolytic fibres and only a small amount of red, type IIa, fast oxidative glycolytic fibres (Ensminger, 1992; Chiang *et al.*, 1995; Taylor, 2004; Branciarri *et al.*, 2009). The breast, also known as the “white” meat of the chicken appears “white” in colour, because of less myoglobin and fewer capillaries supplying blood to the muscle, and has a very bland flavour and is not that juicy (McKee, 2003; Taylor, 2004).

The *pectoralis major* and *pectoralis minor* muscles are used during flight, therefore these muscles will theoretically be more active (more type IIa fibre types and darker in colour) in an extensive production system compared to animals in an intensive production system (Swatland, 2000).

Leg

The leg consists of two portions; the upper thigh and the lower drumstick and is often referred to as the “dark meat”. All of the muscles found in the pelvic limb of galliform birds are listed in Table 3.1 and illustrated in Figures 3.3 and 3.4. The leg muscles are locomotive muscles which are used

during activities such as walking, grazing and running, therefore these muscles will be more active in animals reared in an extensive production system compared to animals in an intensive production system (Castellini *et al.*, 2002a). These muscles consist of a combination of type I, type IIa and type IIb fibre types, depending on the muscle.

The thigh is the upper part of the leg containing the femur and comprises of the muscles *biceps femoris*, *tendofascia*, *semimembranosus* and *semitendinosus* (Koch, 1973; Owens *et al.*, 2010). This portion is separated from the drumstick at the knee joint and removed from the carcass at the hip joint (Swatland, 2000).

The drumstick is the lower part of the leg containing the tibia and fibula bones. This portion is separated from the thigh at the knee joint between the femur and the tibia (Swatland, 2000; Owens *et al.*, 2010). The two main muscles of the drumstick are the *peroneus longus* and *gastrocnemius* (Koch, 1973; Swatland, 2000; Owens, *et al.*, 2010).

Table 3.2 The muscles of the pelvic limb in galliform birds as shown in Figures 3.3 and 3.4.
(Hudson *et al.*, 1959)

Muscle name	Abbreviation (from Fig. 3.3 & 3.4)
Thigh	
<i>M. adductor longus et brevis</i>	Add. Long.
<i>M. ambiens</i>	Ambiens.
<i>M. biceps femoris</i>	Bis. fem.
<i>M. femoritibialisinternus</i>	Fem. tib. int.
<i>M. femoritibialismedius</i>	Fem. tib. med.
<i>M. glutaemusmedius et minimus</i>	Glut. med. et min.
<i>M. iliiothrochantericus anterior</i>	Il troc. ant.
<i>M. iliiothrochantericusmedius</i>	Il troc. med.
<i>M. iliiothrochantericus posterior</i>	Il troc. post.
<i>M. iliotibialis</i>	Il. tib.
<i>M. iliacus</i>	Iliacus
<i>M. ischiofemoralis</i>	Isch. fem.
<i>M. obturatorexternus</i>	Obt. ext.
<i>M. obturatorinternus</i>	Obt. Int.
<i>M. piriformis</i>	Pirif.
<i>M. sartorius</i>	Sar
<i>M. semimembranosus</i>	Semin.
<i>M. semitendinosus</i>	Semit.
Drumstick	
<i>M. extensor digitorumlongus</i>	Ext. dig. 1.
<i>M. flexor Digitorumlongus</i>	F. dig. 1.
<i>M. flexor hallucislongus</i>	F. hal. 1.
<i>M. flexor perforans et perforatusdigi II</i>	F. p et p. d. II
<i>M. flexor perforans et perforatusdigi III</i>	F. p et p. d. III
<i>M. flexor perforatusdigi II</i>	Flex. per. d II
<i>M. flexor perforatusdigi III</i>	Flex. per. d III
<i>M. flexor perforatusdigi IV</i>	Flex. per. d IV
<i>M. gastrocnemius</i>	Gas.
<i>M. peronaeusbrevis</i>	Per. brev.
<i>M. peronaeuslongus</i>	Per. long
<i>M. plantaris</i>	Plan.
<i>M. tibialis anterior</i>	Tib. ant.

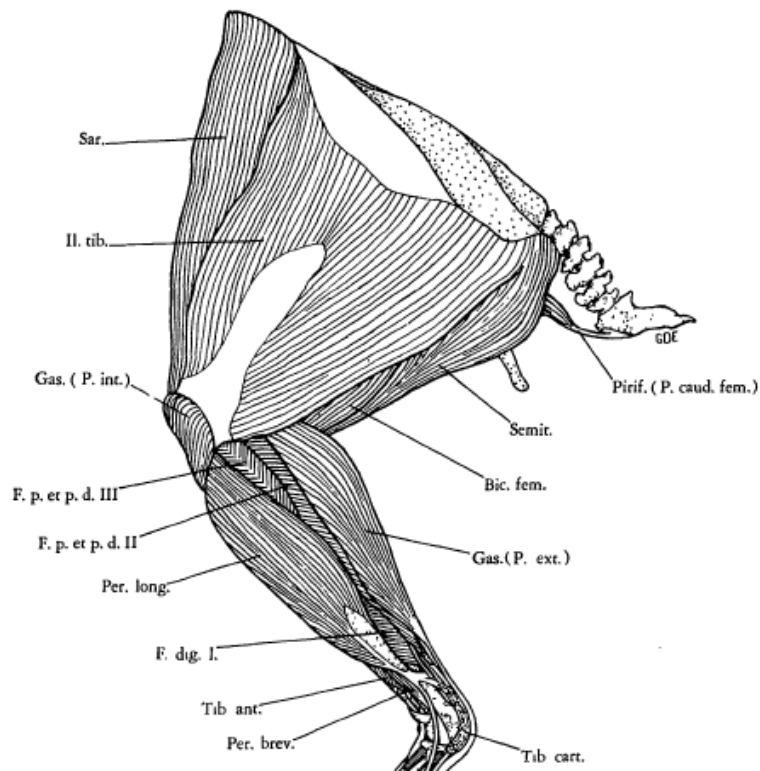


Figure 3.3 The superficial layer muscles of the pelvic limb in galliform birds, medial view. (Modified from Hudson *et al.* 1959, the full names of the muscles are depicted in Table 3.2)

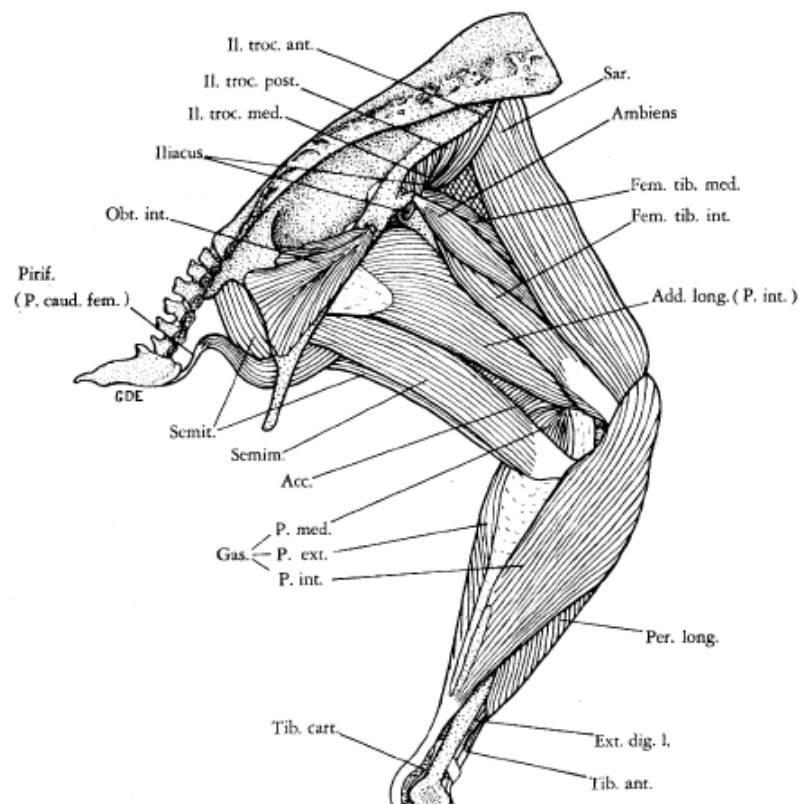


Figure 3.4 The superficial layer muscles of the pelvic limb in galliform birds, lateral view. (Modified from Hudson *et al.* 1959, the full names of the muscles are depicted in Table 3.2)

FACTORS EFFECTING MEAT QUALITY

The major factors that can influence chicken meat quality are the genotype of chicken used, type of production system in which it was reared, feed and season (Bianchi *et al.*, 2007; Fanatico *et al.*, 2007a; Ponte *et al.*, 2008),

Production system (Intensive, Free Range, Organic) and season

In South Africa there is no legislation with regard to free range and organic chicken farming, but according to the SAPA's code of practice (Anon., 2012c) and the European Regulation 2092/91, 1809/99 the minimum standards for intensive, free range and organic poultry production are listed in Table 3.3.

In an intensive production system animals are housed in a confined and controlled (light, temperature and ventilation) environment provided with water and a special formulated feed with limited physical activity. Antibiotics and growth promoters may be given to these chicks. All these practices still adhere to the code of practice for welfare of animals (Anon., 2012c). The implementation of an intensive production system benefits the farmer with efficiency, high productivity, high yields, high turn-over time, low production costs, high profit, low risk and minimal land required (Notter *et al.*, 1991). For intensive production systems, fast-growing chickens such as broilers are generally used (Castellini & Mourvaki, 2007).

Free range chicken meat is produced using similar management, housing and feeding practices as intensively produced meat chickens. The major differences are that free range chickens are allowed access to an outside forage area for a minimum of six hours each day after the brooding period and have a lower stocking density range. Free range production systems, limit or avoid the use of chemical feed additives and genetic modified organisms in feed ingredients. Antibiotics can be given to treat sick birds, but once treated; the meat from these birds cannot be sold as free range (Anon., 2012c). The meat quality of free-range birds varies greatly since producers use a wide range of slaughter ages, genotype types, feed ingredients and variation within a rearing system (Castellini *et al.*, 2008).

An organic production system, on the other hand, is where chickens are allowed to roam outside during the day without any boundaries. These chickens are also reared under strict farming standards adhered to for all stages of the animal's life, being fed a mainly organic diet and receiving no growth promoting chemicals or antibiotics. The minimum age at slaughtering is 81 days, since slower growing birds are normally used which take longer to reach slaughter weight (Anon., 2012c).

Table 3.3 Comparison of the minimum standards between the three rearing systems, intensive, free range and organic (Modified from Anon., 2012c)

Chicken meat sold as	Intensive	Free Range	Organic
Kept in cages	Yes/No	No	No
Housed in large barns	Yes	Yes	Yes
Access to outdoor forage area	No	Required after 21 days of age 6h per day	Required after 10 days of age (explicit requirement regarding access to green vegetation)
Stocking Density Maximum (inside the barns)	14-20 birds/m ² Depending on ventilation	8-16 birds/m ² Depending on ventilation	5 birds/m ²
Age of birds at slaughter	35 days	35 – 55 days	65 – 81 days
Given growth hormones	No	No	No
May be given antibiotics for prophylactic and therapeutic purposes	Yes	No	No
Feed consists mainly of grains	Yes	Yes	Yes
Feed may contain supplements such as vitamins and amino acids	Yes	Yes	Yes
Feed has to come from organic production (no chemical fertilizers, pesticides and herbicides used)	No	No	Yes
Use of GM products in feed	Yes, to a limit	Yes, to a limit	No
Model Code of Practice for the Welfare of Animals applies	Yes	Yes	Yes

Genetic Modified (GM)

Outdoor production systems have many factors such as temperature, photoperiod, and light intensity, which are season dependant and not controlled. These factors may have an effect on the performance of chickens grown extensively (Fanatico *et al.*, 2005b). Gordon and Charles (2002) reported that in colder temperatures and longer photoperiods, the feed intake of chickens increases, and in warm temperatures it decreases, affecting the growth performance of these birds. Consequently, differences in temperature and photoperiod can make reaching market weight more difficult and may cause variation in the carcass quality of outdoor birds (Fanatico *et al.*, 2005b).

There are still a number of misconceptions about “free range” and “organic” and these terms are often used loosely by all kinds of meat producers. These misconceptions are exacerbated in countries where there are no guidelines or regulations pertaining to these definitions.

Feed

The main difference between ruminants and chicken (monogastric) adipose tissue is chickens have a low capacity for fatty acid and triglycerides synthesis and an undeveloped lymphatic system. Therefore dietary lipids are directly incorporated into the tissue lipids, without any modification (Wood & Enser, 1997; Fébel *et al.*, 2008). Several experiments have been conducted on chickens with different feed formulations e.g. soybean, linseed, fish oil, fishmeal, rapeseed to only name a few. This is primarily done to change the nutritional (mostly fatty acid) composition of chicken meat as well as change the efficiency of their growth rate (Enser, 1999).

Excessive amounts of n-6 PUFA and a very high n-6:n-3 ratio is found in today's Western diets that potentially enhance the probability of getting sick with diseases such as cancer, inflammatory and autoimmune disease and various cardio vascular diseases (Simopoulos, 2002; Gebauer *et al.*, 2006). It is recommended that the ratio of n-6:n-3 in the human diet should be less than 4 (Enser, 1999; Simopoulos, 2002; Wood *et al.*, 2003). Western diets are therefore deficient in n-3 PUFA (Simopoulos, 2002; Gebauer *et al.*, 2006).

Numerous studies have shown that manipulating the dietary fatty acids of chicken feed increases the n-3 PUFA in poultry meat. Linoleic acid (C18:2n6) and α -linoleic acid (C 18:3n3) are two essential fatty acids needed for the synthesis of unsaturated eicosapentaenoic (EPA, 20:5n3) and docosahexaenoic acid (DHA, 22:6n3) and must be obtained from the feed (Nam *et al.*, 1997; Enser, 1999; Wood *et al.*, 2003). EPA and DHA can be directly incorporated into feed as fish oil or as fish meal to raise the n-3 PUFA concentrations (Enser, 1999). The latter can also be achieved by adding α -linolenic (n-3 PUFA), of which rapeseed, soybean and linseed are sources, to the feed and depending on the bird to synthesize and deposit the long chain fatty acids (Nam *et al.*, 1997; Enser, 1999). Adding α -linolenic acid to the feed can be advantageous since some of the α -linolenic is directly deposited into the tissues of the bird. This lowers the n-6:n-3 to a more favourable ratio in the human diet and consequently increases the EPA and DHA synthesis in humans. It has been shown that linseed or linseed oil is much more effective than other oils in raising the n-3 PUFA in broilers (Nam *et al.*, 1997; Enser, 1999; Williams, 2000; Wood *et al.*, 2003). While the supplementation of feed with α -linolenic may increase the EPA and DHA concentrations, the unsaturated fatty acids also increases the susceptibility of the lipid to oxidation, unless the feed is also enriched with Vitamin E for oxidative stability (Valenzuela, 1995; Nam *et al.*, 1997; Enser, 1999).

Feeding of fish oils or fish meal containing EPA and DHA however, results in a fishy taint in the meat and after some studies it is established that fishmeal or oil should not exceed 12% of the total feed formulation to avoid fishy taints. The difference in chicken flavour is dependent on which fatty acid (α -linolenic or linolenic) is more abundant, α -linolenic acid produces a strong flavour and linolenic acid produces a milder flavour (Enser, 1999; Wood *et al.*, 2003).

Fébel *et al.* (2008), Coetzee and Hoffman (2001) and Coetzee and Hoffman (2002) reported that chickens fed different diets reflected the same fatty acid pattern in the muscle tissues than in

the diets. The meat of birds fed sunflower and soybean oil in the diet, were enriched with PUFA of which the majority consisted of linoleic acid (C18:2n6), and a significant increase in C18:2 were observed in the meat. The birds fed linseed oil (n-3 fatty acid rich) showed a significant incorporation of EPA and DHA and reduction of arachidonic acid (C20:4) in the muscle tissue.

Genotype

In South Africa there are many different types of chicken genotypes, whether slow or fast growing. In this section only a few South African genotypes will be discussed.

The Potchefstroom Koekoek (Fig. 3.5b), a cross genotype between the Black Australorp male and the White Leghorn female, was bred in the 1950`s at the Potchefstroom Agricultural College of South-Africa by Mr. Chris Marais and was accepted as a South-African genotype by the SAPA in 1976 (Ramsey *et al.*, 2000). According to Fourie *et al.* (2006), the Koekoek was specifically developed to adapt to the harsh free-range conditions (heat and cold; wet and drought, sheltered in cages or unsheltered outside) of South-Africa. This was before modern commercial chicken lines were industrialised and the Koekoek functioned as a dual purpose bird to provide the industry with meat and eggs. The name Koekoek describes the black and white barred pattern of the bird, rather than the genotype. This colouring is gender linked making it very useful in breeding programs to tell males and females apart at a very young age (van Marle-Köster, 2001). The Koekoek has a high average body mass in comparison to other South African indigenous genotypes (Table 3.4) but it is slow growing. Birds only reach sexual maturity in 130 days and are slaughter ready in 140 days (20 weeks) (Fourie *et al.*, 2006).

Table 3.4 Average weights in grams of different indigenous South African chicken lines on 16 and 20 weeks (Adapted from van Marle-Köster & Webb, 2000)

Genotype	16 weeks		20 weeks	
	Male	Female	Male	Female
Koekoek	1839.0	1380.9	2381.1	1733.7
Ovambo	1742.4	1323.6	2167.3	1543.6
Venda	1569.6	1236.8	2015.2	1445.8
Naked neck	1521.7	1101.8	1950.0	1398.9

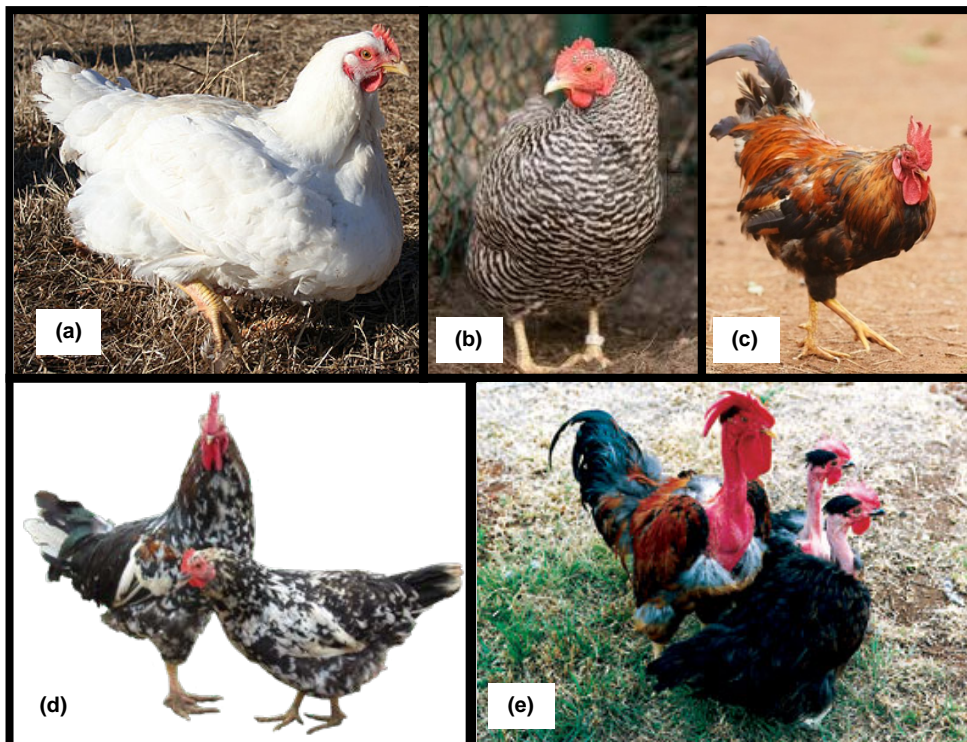


Figure 3.5 (a) a broiler (COBB500™) hen (b) a Potchefstroom Koekoek hen (c) an Ovambo rooster (adapted from Anon., 2010a) (d) Venda hen and rooster (adapted from Anon., 2010a) (e) Naked neck rooster and hens (adapted from ARC, 2010).

Broilers were first developed by the United States Department of Agriculture from a cross between the Cornish male and the Plymouth White Rock female in the late 1940's. A hybrid variety of the latter was produced and through selective breeding the modern broiler was developed by breeders (Rose, 1997; Mozdziak, 2004; Anon., 2010b). Broilers (Fig 3.5a) are chickens that are specifically bred for large scale efficient meat production. They are known for having very fast growth rates, reaching a slaughter weight of 2 kg in 6 to 7 weeks (32 days), a high feed conversion ratio, low levels of activity and good meat yield (Aviagen, 2007; Anon., 2011). These chickens are usually reared in total confinement, with environment and light conditions controlled by the producer. If extreme variations occur in the climatic conditions, it may reduce the growth performance of these chickens. The major market brand businesses in the South African industry are Ross, Cobb, Hybro, Hubbard and Arbor Acres (DAFF, 2011b).

The Ovambo (Fig 3.5c) originated in the northern rural part of Namibia and Ovambo land and the name refers to their geographical area. These chickens are predominantly dark coloured and smaller in size. The Ovambo reaches sexual maturity in 143 days (Anon., 2010a; ARC, 2010).

Venda chickens (Fig 3.5d) were first described by Dr. Naas Coetzee in 1979 in the Venda district in the Northern Cape Province of South Africa. These chickens are multi-coloured with white, black and red as predominant colours and green on their feather tips. They reach sexual maturity in 143 days (Anon., 2010a; ARC, 2010).

The South African Naked neck (Fig 3.5e) is thought to have originated in Malaysia, and was brought here by the European settlers. The naked neck is very colourful with red, white and black coloured feathers; they reach sexual maturity in 155 days. These chickens have 30% fewer feathers, and they can produce the same body weight with less feed (therefore a lower feed conversion ratio) than other indigenous genotypes, they are also more heat tolerant (Anon., 2010a; ARC, 2010).

Abdullah *et al.* (2010) investigated the carcass and meat quality characteristics of different crosses of broiler strains and found that the different strain of bird had a significant effect on the carcass weight, different portion weights, water holding capacity, tenderness, moisture content, protein content and crude fat content. No significant differences were obtained for dressing percentage and pH between the different broiler strains.

EFFECT OF GENOTYPE AND PRODUCTION SYSTEM

Morphology

Morphological properties refer to the carcass characteristics and the meat yield of a chicken carcass.

Growth, slaughter weight and carcass yield

Growth is defined as the increase in size (weight or dimensions) of an animal (Jones, 2004; Warris, 2010). Animal growth resembles a growth curve called the sigmoid curve and consists of three growth phases, slow, rapid and plateau (Jones, 2004; Lawrie & Ledward, 2006; Warris, 2010). Animal tissue follows a precise order of maturation: firstly the nervous tissue followed by bone then muscle and lastly fat (Warris, 2010). The growth rate of animals can be altered by various environmental and nutritional circumstances (Aberle *et al.*, 2001; Lawrie & Ledward, 2006).

Commercial or intensive production systems are associated with temperature, photoperiod and light intensity controlled conditions, high energy diets, high plane of nutrition and high feed efficiency rates which encourage rapid growth and the early onset of the fattening phase (Fanatico *et al.*, 2005b; Lawrie & Ledward, 2006). Extensive production systems, however, would be exposed to fluctuating temperatures and increased exercise on the forage area (Fanatico *et al.*, 2005b). Therefore it would be expected that the animals from the intensive production system would reach maturity at an earlier age and would produce heavier slaughter weight and carcasses with more fat if slaughtered at the same age as the free range animals (Fanatico *et al.*, 2005b). This coincides with results found by Castellini *et al.* (2002a) where lower growth rates and carcass weights of extensive birds compared to intensive birds were reported. However, Fanatico *et al.* (2005b) and Bogosavljević-Bosković *et al.* (2009) reported that the production system had no significant effect on the growth of the chickens and the carcass weight. On the other hand, Wang

et al. (2009) stated that the production system had an effect on the growth rate of the chickens, but no effect on carcass yield.

Different genotypes of animals have different carcass conformation, growth rates and curves (Warris, 2010). Therefore, slow growing chicken genotypes will take longer to attain the same degree of maturity or body weight as a fast growing chicken genotype. Broilers (fast growing) have been selected for rapid growth and reach market weight (2 kg) in 32 days, where medium and slow growing chicken genotypes usually take 63 to 81 days, depending on the diet fed (Gordon & Charles, 2002). Fanatico *et al.* (2005b) reported that the fast-, medium- and slow growing genotypes reached a similar market weight in 53, 67 and 81 days respectively and Bogosavljević-Bosković *et al.* (2009) found that the carcass yield of slower growing hybrids were lower than fast growing birds.

Muscle weight

Muscle weight is a function of the fibre type, amount, length and relative size of the fibre and increased muscle weight is mainly due to hypertrophy of fibres. The amount of muscle fibres are determined by genetic and environmental factors and remain constant at birth (Lefaucheur & Gerrard, 1998; Rehfeldt *et al.*, 2000). Skeletal muscle hypertrophy, which occurs during the growth phase of the animal, is affected by various factors such as hormones, nutrition, age and physical activity (Jones, 2004; Warris, 2010). During exercise, the glycolytic IIb muscle fibres increase in size (Taylor, 2004) and according to Lefaucheur and Gerrard (1998) glycolytic IIb muscle fibres have a higher relative volume than the other fibre types. Therefore an increase in fibre IIb proportion, during exercise, could lead to an increased muscle weight; typically found in extensively reared animals. Consequently, the degree of increase in muscle weight will be determined by the function of a specific muscle, period of exposure to exercise and the degree of exercise.

Husak *et al.* (2008) reported that chicken wing and leg quarter yields increased when they had access to an outdoor area, but the breast yield from intensive birds were higher than the extensive birds. In contrast Castellini *et al.* (2002a; 2008) found yields of breast, thigh and drumstick of outdoor birds to be higher than indoor birds. On the other hand, Fanatico *et al.* (2005b), Bogosavljević-Bosković *et al.* (2009) and Wang *et al.* (2009) found no effect of the production system on portion yield.

As mentioned, the amount of muscle fibres of an animal is genetically determined, therefore different genotypes of chicken may have different amounts of fibres present which will consequently affect the portion yield. According to Fanatico *et al.* (2005b), fast growing type birds have the largest breast yield, the lowest wing yield (%) and the lowest leg quarter yield in the same production system.

Physical

pH

At the time of slaughter, oxygen and nutrients that are supplied by the circulatory system are stopped. Glycogen is metabolised in an anaerobic environment to lactic acid. The lactic acid build-up causes a drop in pH and this helps in the conversion of muscle to meat. Normal *post mortem* muscle pH (pH_u) is approximately 5.5, but in chicken meat the pH_u values are usually higher, $pH_u \geq 6.0$ at 2 to 4 h *post mortem* (Honikel, 2004; Lawrie & Ledward, 2006; Nissen & Young, 2006; Warriss, 2010). The rate of pH decline will have a large effect on meat quality attributes such as colour, tenderness, water holding capacity (WHC), cooking loss, juiciness and microbial stability or shelf-life (Fletcher, 1999; Honikel, 2004). Muscle pH affects the water binding ability of proteins and therefore directly affects the physical structure of the meat and its light reflecting properties (Briskey, 1964). A rapid decline in *post mortem* pH increases the risk of pale, soft and exudative (PSE) meat and is associated with poor WHC and light meat (Fletcher, 1999; Castellini *et al.*, 2002a). A higher pH_u increases the risk of dark firm and dry (DFD) meat and is associated with darker colour meat and will be more susceptible to bacterial spoilage, thus poor shelf life (Monin, 2004; Lawrie & Ledward, 2006; Husak *et al.*, 2008). Generally speaking, a higher pH_u in meat is more effective for retaining desirable colour (more colour stable), moisture absorption properties and better flavour (Warriss, 2010; Lawrie & Ledward, 2006; Husak *et al.*, 2008). On the other hand, a higher pH_u value will also reduce the amount of *post mortem* proteolysis and result in tougher meat products (Warriss, 2010; Fletcher, 2002; Lawrie & Ledward, 2006). Chickens in general, have a very fast pH decline and are more prone to PSE meat (Fletcher, 2002; Lawrie & Ledward, 2006).

Studies on broilers showed that they are more likely to produce meat with a slower pH decline, resulting in a higher pH_u and better WHC, due to the selection for rapid growth and high breast meat yield (Le Bihan-Duval *et al.*, 1999; Berri *et al.*, 2001, 2007). However, some studies suggested that the selection for fast growth may have caused unfavourable effects on meat quality, like PSE, especially when chicks are submitted to stressful conditions (Sandercock *et al.*, 2001). pH decline in slower growing chicken lines such as the Koekoek occur more rapidly than in faster growing chicken lines such as the broiler resulting in a lower pH_u , this is due to the fact that slow growing chicken lines are frequently more susceptible to stress (Castellini *et al.*, 2002a; Debut *et al.*, 2003; Berri *et al.*, 2005; Debut *et al.* 2005).

Literature often notes that the meat of animals reared in extensive production systems, which provide better welfare conditions and lower stress conditions, is characterized by lower pH_u , due to more glycogen being present at point of slaughter (Enfalt *et al.*, 1997, Castellini *et al.*, 2002a; Fanatico *et al.*, 2007a; Wang *et al.*, 2009). However, recent studies by Ponte *et al.* (2008) and Połtowicz and Doktor (2011) showed pH results of extensive meat to be typical of normal meat and Husak *et al.* (2008) found no significant difference in pH between intensively produced and

free range broilers. The increased activity of animals during extensive rearing may result in more type I and IIa (red) muscle fibres with a higher content of glycogen. Therefore, there would be a higher anaerobic glycolytic potential in those muscles, especially in the thigh, during the anaerobic *post mortem* glycolysis, resulting in a lower pH_u *post mortem* (Lawrie & Ledward, 2006).

Colour

Colour is the main visual or appearance factor involved in the selection of a food when it comes to consumers and consumers regularly select or reject a product based merely on its appearance (Fletcher, 2002; Jahan *et al.*, 2005). Fletcher *et al.* (2000) showed that consumers generally prefer broiler meat colour ranging from pale tan to pink when raw and tan to grey when cooked. The three major contributing factors to poultry meat colour are myoglobin content, pH of the meat, and chemical state of the haem structure (Fletcher, 2002; Lawrie & Ledward, 2006). Muscle pH and meat colour are highly correlated and this also affects the water binding nature of the proteins and therefore directly affects the physical structure of the meat and its light reflecting properties as well as the biochemical state and chemical reactions of the myoglobin (Fletcher, 1999, 2002; Lawrie & Ledward, 2006). Lower muscle pH is associated with lighter meat, where the meat appears to be less red and more yellow, and higher muscle pH is associated with darker meat (Castellini *et al.*, 2002a; Fletcher, 2002; Lawrie & Ledward, 2006). Myoglobin content has been shown to be related to species, muscle, and age of the bird (Fletcher, 2002).

Meat colour is generally measured by a method recommended by the International Commission of Illumination (CIE); the so called CIEL*a*b* measurement coordinates (Honikel, 1998). The L* coordinate of the CIEL*a*b* measurement signifies the lightness or reflection of the sample (0 = black; 100 = white), the a* coordinate represents the red/green spectrum (positive = red; negative = green) and the b* yellow/blue (positive = yellow; negative = blue). From these values the hue-angle (°) and chroma value can be calculated.

It is evident from literature, that chickens from extensive production systems, produces meat with a lower L* value (darker) and higher a* value (more red) when compared to intensively raised chickens, which could be attributed to the higher myoglobin red type fibres content, due to increased physical activity of these outdoor birds (Bogosavljević-Bosković *et al.*, 2006; Husak *et al.*, 2008). The higher L* value of intensively reared chickens can also be ascribed to a higher lipid content in the muscles, due to the high energy diet fed to these birds. Lipids have high light reflection properties and the meat therefore appears lighter (Hedrick, 1983). However, when broilers were given access to an outdoor area, there were no effect on their carcass colour (Fanatico *et al.*, 2007a; Połtowicz & Doktor, 2011), but when slow growing birds had access to an outdoor area their meat became more yellow (higher b* value) (Fanatico *et al.*, 2007a). However, Husak *et al.* (2008) reported that breast and thigh meat of free range broiler chickens were less yellow (lower b* value) than intensively reared broilers. With regard to genotype, slow growing

birds had a higher a^* value (more red) than faster growing birds, due to a higher myoglobin concentration in the muscles of the older birds (Miller, 1994; Husak *et al.*, 2008).

Water holding capacity

Water holding capacity (WHC) is defined as the ability of the meat structure to hold water within its fibres (Offer & Trinick, 1983). Meat consists of approximately 73-75% water (bound, free and immobilized) (Lawrie & Ledward, 2006). The WHC of meat can be determined by calculating the percentage drip- and cooking loss of meat (Honikel, 1998).

When muscle pH drops below the isoelectric point (< 5.2) of the muscle proteins (actin and myosin myofibrills), these proteins lose their net charge and therefore their ability to bind water (Hamm, 1961; Warriss, 2010). When the muscle is then cut, excessive amounts of fluid oozes from the cut surface over time, this undesirable occurrence is known as drip loss (Warriss, 2010). Meat with a high drip loss, thus low WHC, have excessive amounts of moisture on the surface of the meat, thus increasing the meat's light scattering properties, causing it to appear lighter/pale (Briskey, 1964; Warriss, 2010). Water contains valuable nutritional components (vitamins, minerals, proteins and flavour components), and if water is lost during drip loss, the nutritional quality of the meat decreases (Hamm, 1961).

Cooking loss is the amount of moisture released by the meat during cooking when the muscle proteins denature, causing structural changes in the tissue of the meat (Honikel, 2004). Denaturation causes the sarcoplasmic and myofibrillar proteins to coagulate, thus shrinkage of the protein myofilaments occur and the water between these fibres are expelled (Honikel, 1998; Warriss, 2010). The amount of moisture lost during cooking is determined by the pH_u of the meat. Meat with a high pH_u will have a lower cooking loss compared to meat with a low pH_u (Honikel, 2004; Lawrie & Ledward, 2006) and the resulting meat products will be perceived as being dry (Warriss, 2010). The muscles of chickens exposed to extreme pre-slaughter stress have a low pH_u , consequently increasing the cooking loss of the meat (Castellini *et al.*, 2002a; Debut *et al.*, 2005; Lawrie & Ledward, 2006). Chatrin *et al.* (2006) found that breast muscles with higher lipid content will have an increased cooking loss. Drip loss is inversely correlated with the cooking loss of meat, therefore if the drip loss of a sample increases the cooking loss decreases (Thomas *et al.*, 2004).

Castellini *et al.* (2002a, b) found a higher cooking loss in extensively reared birds than in intensively reared, due to a lower muscle pH. A higher WHC and lower cooking loss was recorded in free range reared chicken breast meat by Fanatico *et al.* (2007b) and Husak *et al.* (2008) than in intensively reared chicken breast. These results are contradictory to the theory and to Castellini *et al.*'s (2002b) studies where lower muscle pH is most likely to result in reduced WHC. However, Husak *et al.* (2008) and Qiao *et al.* (2001) found that lower pH, nearer to the isoelectric point of protein from free range meat had a better WHC capacity; these results suggested that other factors such as protein and moisture content may have an external effect on the WHC of the meat. When

considering genotype, Lonergan *et al.* (2003) and Fanatico *et al.* (2005a) reported a higher cooking loss in slow growing birds than in fast growing birds, this was due to a higher lipid content in the muscle. If total moisture loss (drip- and cooking loss) is measured, then slow growing chicken genotypes have better WHC than fast growing chicken genotypes (Fanatico *et al.*, 2007a).

Instrumental tenderness

Tenderness is considered the most important palatability characteristic of meat and a primary factor of quality by consumers (Boleman *et al.*, 1997; Fletcher, 1999; Jahan *et al.*, 2005; Lawrie & Ledward, 2006; Destefanis, 2007). Tenderness can be evaluated by objective methods, instrumental or sensorial with trained panels, or by subjective methods, with a consumer panel (AMSA, 1995). Objective methods allow the comparison of different treatments as well as determining their effect on a specific characteristic, but do not provide information about product acceptability or preference of a specific sample (Destefanis, 2007). The most widely acknowledged method used for objectively evaluating the toughness of raw and cooked meat is the Warner Bratzler shear force test (Miller *et al.*, 1995; Boleman *et al.*, 1997). Meat is sheared vertical to the muscle fibre direction and a tougher meat sample will have a higher resistance to shearing. Destefanis (2007) noted that instrumental tenderness measurements are positively correlated with sensory tenderness. Toughness or tenderness of meat is affected by various factors of which marbling, connective tissue type and content, enzymatic ageing and muscle shortening are only a few (Miller *et al.*, 1995). Marbling or intramuscular fat (IMF) content of meat is associated with intensive production systems, and is positively correlated with meat tenderness (Castellini *et al.*, 2002a, 2002b, 2007; Zhao *et al.*, 2007; Chartrin *et al.*, 2006). Therefore muscles containing more type I and IIa red fibres with higher fat content will be more tender than muscles containing type IIb white fibres with less fat content (Lawrie & Ledward, 2006). The size and diameter of a fibre also affects the tenderness of meat. Type I red fibres have the smallest fibre size and type IIb white fibres the biggest, while Type IIa red fibres have an intermediate size (Maltin *et al.*, 1997; Mckee, 2003; Taylor, 2004). Maltin *et al.* (1997) stated that, prior to the onset of *post mortem* proteolysis; meat with larger muscle fibres tends to be less tender than meat with smaller fibre diameter. The tenderisation or ageing of meat is also endorsed by *post mortem* proteolysis, which is activated by proteolytic enzymes (calpains) and inhibited by the presences of proteolysis inhibitors (calpastatins) (Lawrie & Ledward, 2006). When adenosine triphosphate (APT) is depleted *ante mortem*, there is no *post mortem* pH drop and the sarcomeres in the muscle do not shorten, therefore resulting in tender meat (Warriss *et al.*, 1999). According to Warriss *et al.* (1999) poultry meat is considered to be tender.

Husak *et al.* (2008) reported that the breast meat of intensive chickens were more tender than those of free range chickens, but Castellini *et al.* (2002b) found extensive reared meat to be more tender and Fanatico *et al.* (2005a) found no difference in production system regarding tenderness. According to Smith and Carpender (1970) and Lewis *et al.* (2005), muscles with a

high level of physical activity will result in tougher meat due to increased intramuscular collagen content. Farmer *et al.* (1997) found, when comparing two different genotypes of chickens, that genotype and diet contributed the most to textural attributes.

Chemistry/Nutritional value

Chicken meat, also called white meat, is well known for its superiority in health features compared to red meat, mainly because of its low fat and cholesterol contents (Charlton *et al.*, 2008). Meat primarily consists of five chemical constituents: moisture (water), proteins, lipids (fats), carbohydrates and inorganic matter (ash or minerals) (Keeton & Eddy, 2004).

Moisture

Lean meat comprises approximately 72-75% water (Kauffman, 2001; Keeton & Eddy, 2004). The moisture content of meat contributes to numerous meat palatability traits such as juiciness, tenderness and flavour (Lawrie & Ledward, 2006). These three effects are considered to be the main factors that influence overall consumer acceptability and palatability of meat (Beilken *et al.*, 1990; Warriss, 2010). There is a contradiction in literature about the moisture content of animals reared in different production systems. Bogosavljević-Bosković *et al.* (2009) reported no significant difference in the moisture content of breast muscle for intensively and free range reared birds whilst Husak *et al.* (2008) and Fanatico *et al.* (2005a) found that the moisture content of free range reared birds was lower than the intensively reared birds. However according to literature, the moisture content of meat is inversely correlated with the fat content of the muscle (Pearson & Young, 1989), therefore in theory if a meat sample has a low fat content, it will have high moisture content. As previously mentioned, free range reared chickens generally have a lower fat content, and will consequently have higher moisture content than intensive birds.

With regards to genotype, Fanatico *et al.* (2005a) established that slow growing birds had a higher percentage moisture than fast growing birds. Fanatico *et al.* (2005a) also reported that the interaction between genotype and production system had no significant effect on the moisture content of the meat.

Crude protein

Lean chicken meat is a valuable source of protein (16-20%) which is rich in essential amino acids (lysine, leucine, isoleucine, sulphur containing amino acids) (Kauffman, 2001; Keeton & Eddy, 2004). It is known that the protein of meat decreases with an increased fat content (Keeton & Eddy, 2004). Therefore it would be expected that free range reared birds contain a higher percentage protein, due to their lower fat content, than intensively reared birds. This theory corresponds with the findings of Husak *et al.* (2008) and Bogosavljević-Bosković *et al.* (2009) where higher protein contents were reported in extensively reared birds' meat.

It would also be expected that the slow growing birds would contain a higher percentage protein in their meat than the fast growing birds, since they are late maturing and will contain less fat. Studies by Fanatico *et al.* (2007a) and Husak *et al.* (2008) confirm this where they reported higher protein contents in the slower growing birds.

Total lipid content and fatty acids

Animal muscle tissue is comprised of approximately 2.5 – 5% fat, containing phospholipids, neutral lipids (triglycerides) and cholesterol (Kauffman, 2001; Keeton & Eddy, 2004). Poultry meat is known for being low in fat (lean), with white meat (breast) having as low as 3% and red meat (thigh and drum) 7.3% fat (Parkhurst & Mountney, 1988; Mckee, 2003; Fanatico *et al.*, 2007a). Red muscles store intramuscular fat (IMF) within the muscle fibres, in the form of fat droplets and they normally have higher IMF contents compared to white muscles (Lawrie & Ledward, 2006). However the fat of poultry, unlike other meat animals, is mainly deposited in the abdomen or subcutaneously (under the skin) or between muscles rather than in the meat itself (IMF) and will therefore have corresponding lower lipid and higher moisture, protein and ash contents than other meat animals (Parkhurst & Mountney, 1988; Fanatico *et al.*, 2007a)

The composition of lipids in poultry is affected by several factors such as genotype, gender, age, weight, location of fat deposition in the carcass, environmental temperature and nutrition. Differences in the fat content between species and muscles are often a result of the differences in the muscle fibre types (Lawrie & Ledward, 2006). It is generally known that the red fibre muscles, like those in the thigh and drum stick, have a higher amount of triglycerides and phospholipids than white muscles and therefore contain a higher percentage of PUFA (Wood *et al.*, 2004).

The presence or absence of lipids plays a key role in the final meat quality, positively and/or negatively (Enser, 1999; Wood *et al.*, 2003). The IMF of meat is a good source of essential omega 3 (n-3) and omega 6 (n-6) fatty acids as well as fat-soluble vitamins (A, D, E and K) which are important for human nutrition and health (Keeton & Eddy, 2004; Charlton *et al.*, 2008). During mastication, the IMF of the meat stimulates the secretion of saliva, increasing the sustained juiciness of the meat as perceived by consumers (Lawrie & Ledward, 2006). The type of fatty acids present, together with the cooking process and Maillard reactions, produce volatile components and oxidation products that contribute to meat flavour and odour (Mottram, 1998; Wood *et al.*, 2003). Fatty acids also have different melting points and therefore the variation in fatty acid composition affects the firmness and elasticity of the fat present in the meat, whether it is intermuscular or intramuscular fat (Wood, *et al.*, 2003). The IMF content, fatty acid composition and unsaturated phospholipid fatty acids present in meat, therefore, directly affect the appearance, sensory properties, flavour and juiciness, and indirectly the tenderness of meat (Enser, 1999; Wood *et al.*, 2003). Consequently, meat with low IMF levels will be less flavoursome and dry. The health conscious consumers demand lean meat, but still want the same taste experience which high in fat products have to offer. This task makes it extremely difficult for the meat industry to

produce low fat meat products with good palatability traits. With regard to taste, fat in meat may be favourable in a gourmet market, but lean meat is advantageous in a health/diet driven market, therefore fat content in poultry need to be thoroughly analysed and marketed as a speciality product (Fanatico *et al.*, 2005a).

Extensively produced chicken meat has a lower percentage IMF than intensively produced chicken meat, this is due to increased physical activity and myogenesis being favoured over lipogenesis in the former (Castellini *et al.*, 2002a, 2002b, 2007, Fanatico *et al.*, 2007a; Husak *et al.*, 2008). However, Fanatico *et al.* (2005a) reported no significant difference in IMF for production system. With regard to genotype, some studies showed that slower growing birds contained less fat than fast growing birds (Fanatico *et al.* 2005a, 2007b). In general the meat from older birds will contain more fat with a higher SFA and lower PUFA than younger birds (Lawrie & Ledward, 2006; Fanatico *et al.*, 2005a) reported that the effect of production system and genotype had no significant effect on the meat quality in their studies.

As previously mentioned, lipids consist of storage triacylglycerols and phospholipids (structural lipids) (Enser, 1999). The latter tend to contain high concentrations of stearic (C18:0) and lower concentrations of oleic (C18:1) and palmitic (C16:0) acid than triacylglycerols, but is characterised by containing significant amounts of PUFA. Chicken meat has a very high percentage of phospholipids, due to its low IMF and therefore is very rich in PUFA (Lawrie & Ledward, 2006). Triacylglycerols contain one glycerol molecule and three long chain fatty acids (Keeton & Eddy, 2004) and are variable due to the manipulation of dietary fatty acids and are mainly made up of oleic (C18:1), palmitic (C16:0), linoleic (C18:2), stearic (C18:0) and palmitoleic (C16:1) acids and very few PUFA (Enser, 1999). The latter can be classified as saturated (no double bonds), monounsaturated (one double bond in the carbon chain) and polyunsaturated (two or more double bonds in the chain) (Keeton & Eddy, 2004). The IMF content and the main fatty acids present in bird fat are palmitic acid, palmitoleic acid, oleic acid, stearic acid and linoleic acid with oleic acid being the highest (Gunstone & Russell, 1954; Enser, 1999; Lawrie & Ledward, 2006).

The total fat content, PUFA:SFA and the n-6:n-3 ratios are the three main factors when considering the nutritional value and health consumption of meat (Enser *et al.*, 1998). Raes *et al.* (2004) suggest that a PUFA:SFA of > 0.7 and a n-6:n-3 ratio of < 0.5 contributes to the healthiness of meat products. As previously mentioned, various studies have been conducted to increase the PUFA concentration and lower the n-6:n-3 ratio in chicken meat by manipulating the fatty acid content of feeds using feedstuffs such as fish oils, fish meal, soybean, linseed and rapeseed. However, this operation must be thoroughly examined and controlled, since too high PUFA could have a negative effect on the meat quality and human health (Enser, 1999; Wood & Enser, 1997; Wood *et al.*, 2003).

Unsaturated fatty acids are more susceptible to oxidation, causing off-flavours in meat and shortening their shelf life, this phenomenon thus limits the production of meat with a much higher

PUFA:SFA ratio (Enser, 1999; Warriss, 2010; Wood *et al.*, 2003). However this tendency of PUFAs to oxidise is essential for flavour development during cooking (Wood *et al.*, 2003). Overall the PUFA:SFA ratio from the meat of monogastric animals is higher than in ruminants (Wood & Enser, 1997; Enser *et al.*, 1998). It is generally accepted that most of the SFAs increase low density lipoprotein (LDL) cholesterol and PUFAs somewhat lower LDL cholesterol levels (Raes *et al.*, 2004; Ruxton *et al.*, 2005). Chicken meat has a favourable fatty acid ratio, i.e. a high content of PUFA and a low content of SFA (Charlton *et al.*, 2008). This favourable ratio (< 0.7) lowers human blood cholesterol levels making chicken meat a very healthy product for consumption (Raes *et al.*, 2004).

It is general knowledge that chicken meat has a favourable fatty acid ratio and low cholesterol content and therefore is considered as a healthy product (Charlton *et al.*, 2008). However a few studies have shown that free range chicken meat have higher PUFA:SFA and lower n-6:n-3 ratios, making it an even more favourable product than intensively produced chicken meat (Castellini *et al.*, 2002a; Jahan & Paterson, 2007; Husak *et al.*, 2008). It is expected that free range chicken meat products would contain more n-3 PUFA, since the diet should include pasture, which is a good source of α -linolenic acid (18:3n3) (Ponte *et al.*, 2008; Jahan & Paterson, 2007).

Ash

Meat contains approximately 1-2% ash, which is the mineral constituent (iron, potassium, phosphorus, oxides, sulphates, silicates and chlorides) of meat; these are all essential for human nutrition (Keeton & Eddy, 2004; Lawrie & Ledward, 2006). Many authors have established that production systems have no significant effect on the ash content of meat (Castellini *et al.*, 2002a; Hoffman *et al.*, 2004; Fanatico *et al.*, 2005b, 2006; Kishowar *et al.*, 2005; Bogosavljević-Bosković *et al.*, 2006) whilst Fanatico *et al.* (2005a) found that the effect of production system and genotype had limited influence on the ash content. If a higher ash content in extensive production systems were detected, it could be ascribed to a higher meat binding capacity, improved capillarisation of muscles due to aerobic exercise and a higher haem pigment concentration (reviewed by Olsson & Pickova, 2005). This phenomenon can also be ascribed to higher IMF content of meat in intensive production systems as it is known that an increase in IMF content decreases the ash content of meat (Keeton & Eddy, 2004). From van Marle-Köster and Webb's (2000) results it can be seen that there was a significant difference between the ash content of the Koekoek and the Cobb broiler (Table 3.5), thus it can be argued that chicken genotypes do have an effect on the ash content.

Table 3.5 Proximate analysis of different South African indigenous chicken genotypes (Modified from Van Marle-Köster & Webb, 2000)

Genotype	Moisture (%)	Ash (%)	Crude Protein (%)	Crude Fat (%)
Koekoek	64.6 ^{ab}	3.9 ^{ab}	46.1 ^a	28.5 ^a
Naked-Neck	64.1 ^{ab}	3.9 ^{ab}	45.2 ^{ab}	34.9 ^b
Lebowa-Venda	68.6 ^a	4.7 ^b	49.6 ^d	28.8 ^a
Ovambo	61.5 ^b	2.7 ^c	44.8 ^{ab}	36.0 ^{bc}
Cobb	65.6 ^{ab}	2.4 ^c	39.9 ^c	40.6 ^c

^{ab}Means in columns with different superscripts are significantly different at $P \leq 0.05$

Sensory attributes

Sensory flavour and aroma

The eating quality of meat involves three main attributes, namely tenderness (texture), juiciness and flavour which are the major contributors to the consumers' acceptability of meat (Warris, 2010, Jahan *et al.*, 2005). The flavour of meat is a combination of the sensations perceived by the senses; taste and smell. Taste is perceived by the taste buds on the tongue and other parts of the mouth, and mainly includes the four taste sensations: sweet, sour, salt and bitter. The sense of smell or aroma is detected by the olfactory system when certain chemicals stimulate the receptors (Farmer, 1999; Lawrie & Ledward, 2006). Flavour and aroma are greatly affected by the fatty acid profile of the meat, as the thermal degradation of the lipids is one of the fundamental processes in producing the aroma volatiles (Mottram, 1998). Unsaturated fatty acids can sometimes cause off-flavours and -odours, because oxidation may occur and cause rancidity (Wood *et al.*, 2003). Extrinsic factors that affect meat flavour are feed, genotype, age and production system (Lawrie & Ledward, 2006)

Chickens are monogastric birds and the dietary lipids from the feed are directly incorporated into the tissue lipids without any modification (Wood & Enser, 1997). Accordingly the type of feed is a major determinant factor in flavour development in chickens.

According to Lawrie and Ledward (2006) and Elmore *et al.* (2006), extensive animals have more intense flavour, since they are usually older in age and more fat can be deposited for more flavour development. Animals reared in an extensive production system have higher n-3 polyunsaturated fatty acids (PUFA) in their meat, in particular long-chain EPA and DHA (Castellini *et al.*, 2002a; Jahan & Paterson, 2005). When n-3 lipids are heated, they will break down to give compounds that are more unsaturated and reactive than those of the n-6 fatty acids when broken down. These compounds then react with Maillard precursors and appear to catalyse the breakdown of more saturated fatty acids to affect, as well as contribute to, the meat flavour (Elmore *et al.*, 1999).

There is contradiction in the literature about the effect of production system and flavour development in chicken meat. Farmer (1999), Kishowar *et al.* (2005) and Husak *et al.* (2008) found that there was no significant difference in flavour between free range and intensively reared chicken meat when slaughtered at the same age. However, significant differences were found in flavour between free range and intensively reared chickens when they were not slaughtered at the same age (Fanatico *et al.*, 2006, 2007a).

Rural or indigenous chicken meat is firmer and more strongly flavoured than broiler meat and consumers sometimes find this flavour development more palatable than the bland taste of broiler meat (Jahan *et al.*, 2005; Grashorn & Serini, 2006). This phenomenon is due to the fact that rural or indigenous chickens are slow growing birds, thus being older in age than broilers, which are fast-growing birds, at slaughter (Fanatico *et al.*, 2005a, 2006, 2007a). Older animals have increased concentrations of nucleotides in muscle, which degrade to inosinic acid and hypoxanthine after death possibly contributing to the more developed flavour of older animals (Aberle *et al.*, 2001)

Sensory juiciness

Juiciness has two organoleptic components, initial and sustained juiciness. These two words are also used by sensory panels as descriptors in cooked meat (Lawrie & Ledward, 2006). Initial juiciness is defined as the amount of fluid released by the cut surface of meat during compression between the forefinger and thumb (AMSA, 1995). Initial juiciness of meat is positively correlated with the WHC of meat, which is influenced by the muscle's pH_u *post mortem* (Offer & Trinick, 1983). Chickens reared in an extensive production system are more prone to *ante mortem* stress than chickens reared intensively (Debut *et al.*, 2003; Berri *et al.*, 2005; Debut *et al.* 2005). This is due to the fact that extensive chickens are frequently not used to human handling during rearing and when being caught before slaughter experience higher levels of stress (Mulder, 1999). Pre-slaughter stress activates *ante mortem* muscle glycogen depletion and results in a high ultimate pH *post mortem* (Fletcher, 1999; Warriss, 2010; Lawrie & Ledward, 2006). Therefore, chickens reared extensively could have a higher pH_u with a higher WHC, resulting in a higher initial juiciness score compared to intensively reared chickens.

Sustained juiciness is defined as the perceived juiciness after a few seconds of chewing. Sustained juiciness is affected by the presence of fat as fat stimulates the secretion of saliva and thus improves juiciness (Lawrie & Ledward, 2006). An animal in an intensive production system has a higher average daily weight gain compared to an animal in an extensive production system and extensive production animals use energy to exercise (Castellini *et al.*, 2002a). Therefore, chickens in an intensive production system will have a higher carcass weight with more fat causing it to be juicier, than extensively reared chickens. However, no significant difference in juiciness was found by Kishowar *et al.* (2005) and Husak *et al.* (2008) between free range and intensively reared chickens. This could be because the chickens were slaughtered at the same age and not

the same level of physiological maturity. Sonayia *et al.* (1990) found that slow growing chicken lines were juicier compared to fast-growing chicken lines.

Sensory tenderness

As mentioned, tenderness is considered the most important palatability characteristic of meat and a primary factor of quality by consumers (Boleman *et al.*, 1997; Fletcher, 1999, 2002; Jahan *et al.*, 2005; Lawrie & Ledward, 2006; Destefanis, 2007). Tenderness refers to the force needed to shear, squeeze, cut and ground meat during chewing and consumption (Pearson, 1963). Miller *et al.* (1995) reported that consumers can easily distinguish between different meat tenderness levels and that they are willing to pay more for a certified tender meat cut.

Castellini *et al.* (2002b), Wattanachant *et al.* (2004) and Fanatico *et al.* (2005a) reported that faster growing chicken genotypes have more tender meat than slow growing chicken genotypes. This phenomenon can be ascribed to the formation of more stable collagen cross-linkages between muscle fibres from slow growing chickens; collagen cross linkages also increase with age (Fletcher, 1999; Castellini *et al.*, 2008). On the other hand, Farmer *et al.* (1997) obtained significantly higher scores for meat tenderness from slower growing birds. Then again, in a later study, Fanatico *et al.* (2006) found that that breast meat of medium growing birds were more tender than fast and slow growing genotypes, however all treatments were scored as “slightly to moderately tender”. Dransfield and Sosnicki (1999) suggested that reduced protein catabolism could be the main reason for abridged tenderization of meat in modern fast growing chicken lines. Calpains and cathepsins (proteins situated in the muscle fibres) are involved in the *post mortem* proteolysis process and weakening of the muscle fibres producing tender meat (Dransfield & Sosnicki 1999; Lawrie & Ledward, 2006). The higher degree of maturity of fast-growing birds at the same age and increased growth and muscle mass, leads to reduced protein catabolism (Dransfield & Sosnicki, 1999). This reduced protein catabolism leads to less activity of *post mortem* proteolysis and, therefore less tenderization of meat (Dransfield & Sosnicki, 1999).

CONCLUSIONS

The modern consumer wants quality meat, as associated with the intensive meat broiler, but also demands products that are healthy, environmentally friendly, promote sustainability and comply with animal welfare guidelines. Only medium and slow growing chicken genotypes can completely benefit from an extensive production system, since fast growing genotypes have the habit of being inactive, staying indoors and do not participate in any activity involving flying, foraging and running. To understand the full impact of rearing system and genotype on chicken meat quality under South African conditions, a complete study needs to be done on the meat characteristics of broiler (fast growing), a South African indigenous chicken (slow growing) and a hybrid (medium growing) genotype, to ensure consumer expectations are met and the quality is maintained.

Therefore the overall objective of this study is to investigate the impact of production system (free range and intensive) and chicken genotype (Broiler, Potchefstroom Koekoek, Ross X Koekoek hybrid) on the meat quality characteristics by using various physical, chemical, sensory and consumer analyses.

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CHAPTER 4

EFFECT OF REARING SYSTEM ON GENOTYPE ON THE GROWTH, CARCASS AND INDIVIDUAL PORTION YIELD OF CHICKEN

ABSTRACT

Consumer interest in free range poultry production as well as free range products is growing. In South Africa, little information is available on the effect of this system on the production indicators of chicken. This experiment was conducted to evaluate the effect of production system and genotype on the growth and production efficiency as well as carcass and individual portion yield of chicken. Fast growing (broiler), slow growing (Potchefstroom Koekoek) and Hybrid chickens were reared for 42, 56 and 91 days, respectively in either a commercial production system or under free range conditions. For each genotype the free range chickens produced heavier ($P \leq 0.05$) live weights than intensive reared chickens. The broilers had the best ($P \leq 0.05$) feed conversion ratio (FCR), highest average daily gain (ADG) and European production efficiency factor (EPEF), followed by the Hybrid and then the Potchefstroom Koekoek. The broilers had the highest ($P \leq 0.05$) breast yield (%) and the lowest ($P \leq 0.05$) thigh, drumstick and wing yield (%), whereas the Hybrid and Koekoek produced higher ($P \leq 0.05$) thigh, drumstick and wing yields. Production system also had an effect ($P \leq 0.05$) on the portions and free range rearing produced higher breast, thigh, drumstick and wing yields. Overall the growth and morphological attributes of the chickens were more strongly influenced by genotype than production system; therefore the latter should have no direct impact on the consumer acceptability of the meat. It would seem that the Hybrid could be a possible alternative for free range rearing.

Keywords: Broiler, Potchefstroom Koekoek, Ross x Koekoek hybrid, Morphological composition
Portion yield, Meat quality, Production system, Genotype

INTRODUCTION

The modern consumer is changing from products produced in intensive production systems to, what they perceive as, more sustainable and environmentally friendly produced products. The major reason for this shift is that consumers believe that the latter provide better, healthier and more nutritious products that taste better (Sundrum, 2001; Fanatico *et al.*, 2007; Branciaro *et al.*, 2009). In meat, the interest of the consumer has also grown towards quality aspects, rather than quantity; this mind shift has provided opportunities for market segmentation of more speciality products, such as free range and organic branded products.

Commercial poultry production, especially intensive broiler production, has shown a rapid increase and has dominated the South African agricultural sector over the past decade (Anon., 2012a; FAO, 2012). However, a new segment that is growing locally is the production and sale of free range chickens. In South Africa, the normal fast growing commercial broiler is currently used for both free range and intensive production systems. These chickens reach market weight as early as 32 days. However, this rapid growth has led to concerns about animal welfare, since more leg disorders and higher mortality rates occur. Castellini *et al.* (2002a) reported that only slow-growing chicken strains can completely benefit from an extensive rearing system. There is also the question on what the effect of a free range production system would be on the organoleptic quality of chickens? Dransfield and Sosnicki (1999) and Le Bihan-Duval *et al.* (1999) previously reported that selection for fast growth and high yield are likely to affect the sensory and functional qualities of the meat, therefore it is possible that differences in meat quality may exist between fast and slow growing broiler strains (Fanatico *et al.*, 2005). Lonergan *et al.* (2003) compared meat quality of chickens with different growth rates i.e. broilers, Leghorns and their crosses and reported high variation in composition and quality characteristics of breast meat.

Factors that determine the value of a chicken carcass include the carcass weight, the yield of meat and the quality of lean meat. Chickens are usually sold as portions, making it very versatile and convenient for the modern consumer (Kennedy *et al.*, 2004). Deboned portions and skinless chicken portions are also sold, making it even more convenient albeit more expensive. The importance of the carcass and muscle yield of the bird is therefore emphasized. A few studies have already evaluated the growth, carcass and portion yields from fast-, medium- and slow-growing birds, but there is large variation in the production systems and type of birds (genotype, strain and age) used (Castellini *et al.*, 2002a; Lonergan *et al.*, 2003; Quentin *et al.*, 2003; Fanatico *et al.*, 2005; Husak *et al.*, 2008). Such studies have never been done in a South African environment or on indigenous chickens cross bred with commercial broilers.

This study was undertaken to gain information on the production and morphological properties of three different chicken genotypes found in South Africa: Broiler (B) (Cobb 500), Ross 308 X Potchefstroom Koekoek hybrid and Potchefstroom Koekoek (K) reared in intensive and free range environments. The aim of this study was to investigate the effect of chicken genotype and production system (intensive (I) or free range (FR)) on the growth, production efficiency, carcass

and individual portion yield of chickens. This study did not include the quantification of the effect of gender (male or female) on the growth, production and carcass yield.

MATERIALS AND METHODS

Experimental birds, location, handling and slaughter procedure

Two hundred crossbred (Ross 308 roosters X Potchefstroom Koekoek hens) chicks were hatched at Mariendahl, (33° 51' 0 S; 18° 49' 60 E) Experimental Farm, Stellenbosch University, situated in the Western Cape, South Africa. Purebred one day old Potchefstroom Koekoek chicks (n = 200) were flown from the Agricultural Research Council – Animal Production Institute (ARC-API) (Pretoria, Gauteng, South Africa) and 200 one day old Cobb 500 (Broiler) chicks were purchased from Tydstroom hatchery near Hermon (Western Cape, South Africa) and brought to Mariendahl. Each chick was vaccinated against infectious bursal disease (IBD) at one day of age and Newcastle disease at one and 18 days of age. After individual weighing and tagging the one day old chicks were randomly assigned to two rearing systems; intensive (n = 100 per genotype) and extensive/free range (n = 100). Genotypes were maintained separately. All chickens were fed *ad libitum* the same complete commercial type diet consisting of a starter, grower and finisher feed (Table 4.1). Feed was allocated at the chicks at a volume of 900g starter, 1200g grower and finisher until slaughter.

Intensive production system

At day one of age, the BI, HI and KI chicks were placed into a bioassay unit (intensive system). The chicks were grouped according to genotype for each treatment. This unit comprises of a temperature controlled room equipped with wire cages (0.3 x 0.25 m; 53 birds/m²). Management practices described by ROSS International were followed (Aviagen, 2009). Artificial lighting was provided at a pattern of 16 h of light alternating with 8 h of darkness. Ventilation in the house was set to provide a minimum of six air changes per hour. At the age of 14 days, the chicks were moved to a chicken house equipped with wire cages (0.9 x 0.6 m; 14 birds/m²) (Fig. 4.1a), each containing a tube feeder and two nipple drinkers. Again the chicks were grouped according to genotype. The temperature in the room was controlled and decreased as they grew from 33°C to 15°C and ventilation in the house was set to provide a minimum of six air changes per hour. Artificial lighting was provided at a pattern of 16 h of light alternating with 8 h of darkness.

Table 4.1 Ingredient (%) and calculated nutrient composition of commercial diets fed to intensively and extensively reared chickens

Ingredients (%)	Starter	Grower	Finisher
Maize	61.59	65.76	59.66
Fish meal 65	9.79	10.00	-
Soybean full fat	16.85	18.84	36.13
Soybean 46	8.87	3.00	-
L-lysine HCL	0.27	-	0.20
DL methionine	0.27	0.21	0.31
L-Threonine	0.14	0.05	0.11
Vitamin + mineral premix	0.15	0.15	0.15
Limestone	0.80	1.01	1.58
Salt	-	0.05	0.25
Monocalcium phosphate	0.84	0.75	1.45
Sodium bicarbonate	0.43	0.17	0.17
Total	100.00	100.00	100.00
Calculated nutrient composition			
AMEn* chick	12.50	12.90	13.00
Crude protein %	22.54	20.73	18.97
Dry matter %	88.22	88.03	88.20
Lysine %	1.52	1.21	1.17
Methionine%	0.69	0.62	0.59
Crude fat %	6.57	7.03	8.95
Calcium %	0.90	0.96	0.92
Avail. Phosphorus %	0.50	0.48	0.45

*Nitrogen-corrected apparent metabolizable energy value (AMEn)

Extensive production system

The day old BFR, HFR and KFR chicks were placed in small pens (2.7 x 3.5 m) with deep wood shavings in an indoor chicken house facility. The chicks were grouped according to genotype for each treatment in the pens. The initial density of each pen was 10.5 birds/m². Artificial lighting was provided at a pattern of 16 h of light altering with 8 h of darkness and ventilation in the house was set to provide a minimum of six air changes per hour. At 21 days of age, the chicks were moved outside to a larger facility (Fig. 4.1b). This facility was naturally ventilated. The house was subdivided into three “indoor” pens that opened into three separate yards, which were surrounded by chicken wire. The “indoor” areas of each pen measured 1.5 x 3.0 m and contained fresh wood shavings and infrared light heaters that were used to maintain night temperatures above 15°C. Birds were allowed unlimited access to the “outdoor” area. The “outdoor” area consisted of a concrete floor area covered with shading (3.0 x 4.5 m) and an open air grassy area (3.0 m x 6.0 m). Each pen measured 3.0 x 12.0 m (2.8 birds/m²). The grassy area was completely covered

with natural growing vegetation (mainly kikuyu grass). The outdoor and indoor areas were provided with automatic drinkers as well as chicken feeders allowing for *ad libitum* access. Photoperiod was limited natural daylight (~15 h of daylight and 9 h of darkness). Management practices described by the SAPA code of practice 2012 under the section free range Broiler production were followed (Anon., 2012b).

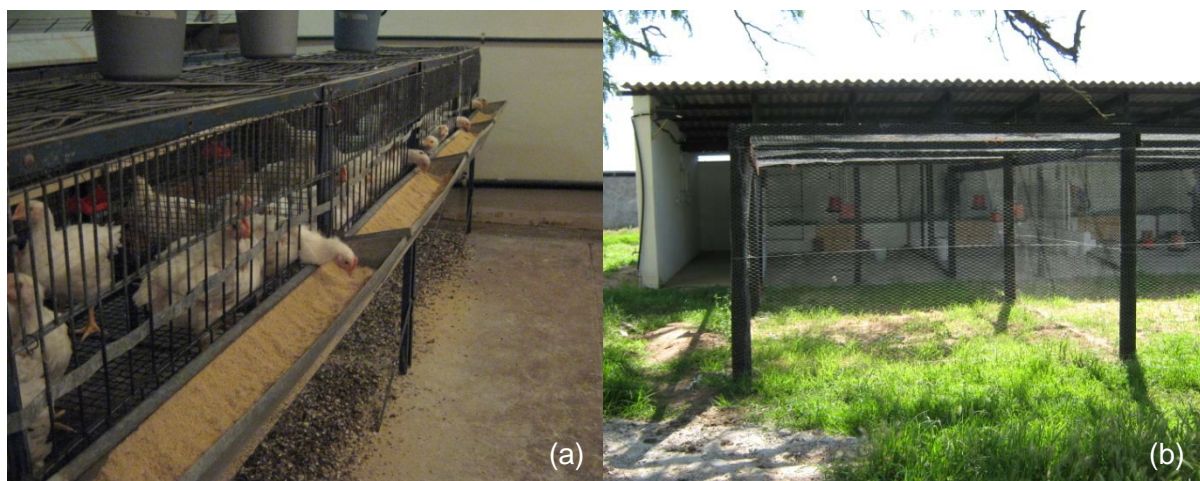


Figure 4.1 (a) Intensive production wire cages; (b) Extensive production housing pens.

Data collection

Body weights of all the chickens were determined at day old and weekly thereafter (intensive n = 8 groups; free range n = 1 group). Feed was supplied *ad libitum* and weekly intake was determined. Daily mortalities were recorded. Data were used for the calculation of feed conversion ratio (FCR), average daily gain (ADG), and the European production efficiency factor (EPEF) (Awad *et al.*, 2009). The FCR, ADG and EPEF were calculated as follows:

$$\text{Feed conversion ratio} = (\text{Cumulative feed intake per chick} / \text{Average live weight per chick})$$

$$\text{Average daily gain} = (\text{Average live weight per chick at slaughter day} - \text{Average live weight per chick at day 0}) / \text{Age (days)}$$

$$\text{European production efficiency factor} = ((\text{Liveability \%} \times \text{Live weight}) / (\text{Age (days)} \times \text{FCR})) \times 100$$

Slaughtering

At the age of 42, 56 and 91 days respectively, 100 broiler, 100 Ross X Koekoek hybrid chickens (n = 50 per genotype per production system) were selected within a target weight range of 2.0 to

* Liveability % (Percentage of birds alive at that given time/age).

2.3 kg, weighed and slaughtered, according to acceptable commercial standards through immobilization by electrical stunning (50-70 volts; 3-5 s), followed by exsanguination, defeathering and evisceration. The Potchefstroom Koekoek (n = 50 per genotype per production system) were slaughtered at 91 days of age with an average weight of 1.6 kg, as it would have taken them too long to reach an average weight of 2.0 kg. After evisceration the carcasses were chilled at 4°C for approximately 12 hr. After chilling the carcasses were transported to the meat science laboratory at Stellenbosch University. It should be noted that due to the sampling procedure, the live weights and therefore carcass weights of the birds slaughtered may differ from the mean live weights of the whole group.

Experimental units

At the meat science laboratory each carcass was weighed and the cold carcass weight recorded. Thereafter the carcass was divided into commercial cuts (breast, drumstick, thigh and wing) using a portioner. First the carcass was cut into half. Then the thighs and drumsticks were removed from the half carcasses by cutting above the thigh towards the acetabulum and behind the pubic bone. The thighs and drumsticks were then separated from each other by cutting perpendicular to the joint between the drumstick and thigh bones. The wings were removed by cutting the joint between the scapula and the coracoid. The separate portions were then weighed and the portion weights recorded. Thereafter all the portions, except for the wing was dissected into lean, skin and bone and weighed. The portions were then vacuum-packed and frozen at -18°C until further analysis. The experimental treatments included six meat units which consisted of either a broiler, a Hybrid or a Koekoek sample each reared intensively or free range. The following acronyms are used to describe the six different treatments:

BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range; KI – Potchefstroom Koekoek intensive; KFR – Potchefstroom Koekoek free range.

An experimental unit consisted of n = 50 chickens per treatment for the weights recorded. The dressing percentage (%) and portion yield (%) were calculated as follows:

$$\text{Dressing percentage (\%)} = (\text{Cold carcass weight} / \text{Live slaughter weight}) \times 100$$

$$\text{Portion yield (\%)} = (\text{Portion weight} / \text{Cold carcass weight}) \times 100$$

Statistical analysis of data

Experimentally, the study consisted of a randomised factorial block design with six treatments (3 Chicken lines x 2 rearing methods) and n = 50 replications for live slaughter-, carcass-, and portion weights, yields and percentages calculated. The weekly weights recorded (of all the birds) and FCR, ADG and EPEF calculated consisted of n = 8 replications for intensive and n = 1 replications

for free range, therefore these results were analysed by a completely randomised factorial design. Since there was only one replication for free range, no standard deviation could be calculated. The model for the experimental design is indicated by the following equation:

$$Y_{ijk} = \mu + \beta_j + b_i + g_k + (bg)_{ik} + \varepsilon_{ijk}$$

The terms within the model are defined as: the overall mean (μ), the effect of the block (β_j), the effect of genotype (b_i) the effect of rearing method (g_k), the effect of the interaction between chicken genotype and rearing method ($(bg)_{ik}$) and ε_{ijk} is the error associated with the effect of the block, chicken genotype, rearing method and interaction of the former and the latter. The sensory, physical and proximate data were subjected to an analysis of variance (ANOVA). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). All of the outliers were identified and removed before final ANOVA's. The Least Significant Differenced (LSD) was calculated at a 5% significance level to compare the treatment means. Results were defined as being not significant at $P > 0.05$ and significant at $P \leq 0.05$. SASTM statistical software (Statistical Analysis System, Version, 9.2, 2006, SAS Institute Inc., CARY, NC, USA) was used for the analyses of variance (ANOVA).

RESULTS

Growth parameters, live-, carcass weight and dressing percentage

Growth curves of the three genotypes reared under intensive and free range conditions from day 0 until day 56 are presented in Fig. 4.2. The mean scores and standard deviations (\pm SD) for ADG, FCR and EPEF of all the chickens as affected by genotype and production system are presented in Table 4.2. There was a clear genotype effect ($P \leq 0.05$) for ADG and EPEF where broiler scored higher than hybrid and hybrid higher than Koekoek (Table 4.2). For the FCR, broiler had a better ratio whilst Koekoek had a weaker ratio.

Production system had no effect on ADG and EPEF however; there was an effect on FCR. The KFR and HFR chickens had a poorer ($P \leq 0.05$) FCR than the KI and HI chickens respectively, but BI had a poorer ($P \leq 0.05$) FCR than the BFR, the latter having the best FCR.

In the intensive production system, the BI were significantly ($P \leq 0.05$) heavier (mean \pm s.e.) (2269.8 ± 30.67 g) than the HI (2021.4 ± 35.41 g) which also differed from the KI (1317.0 ± 30.67 g). For the free range birds, the BF had an average live weight of 2144.2 g compared to the HF's body weight of 1828.0 g whilst the KF were the lightest (935.6 g).

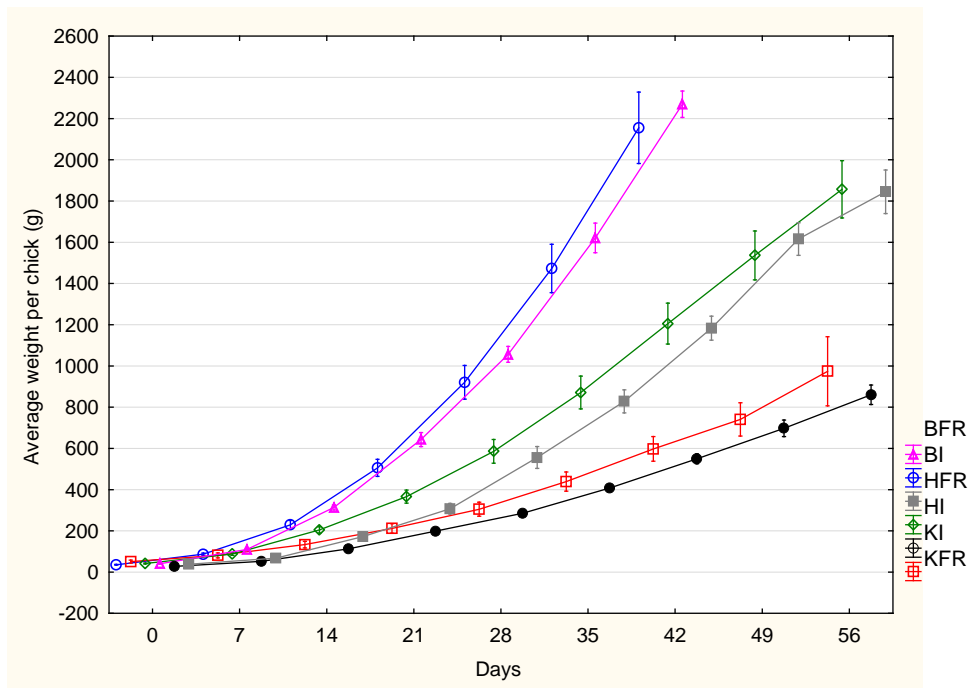


Figure 4.2 Growth curves of three chicken genotypes (broiler, Ross x Potchefstroom Koekoek and Potchefstroom Koekoek) reared under intensive and free range production systems from day 0 until slaughtered. (BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range; KI – Potchefstroom Koekoek intensive; KFR – Potchefstroom Koekoek free range)

The mean scores and standard deviations (\pm SD) for the weight at slaughter, carcass weight and dressing percentage of the sub-population of chickens selected to be slaughtered as affected by genotype and production system are presented in Table 4.3. From Table 4.3 and Fig. 4.2 the chickens from the free range production system within each genotype slaughtered were significantly larger (live slaughter weight) and had heavier carcasses ($P \leq 0.05$) than intensively reared chickens. Although the free range chickens of each genotype also produced heavier cold carcasses than intensively reared, this was not significant ($P > 0.05$). With regards to dressing percentage, the free range chickens of both the broiler and Hybrid genotypes produced significantly lower ($P \leq 0.05$) dressing percentages than the intensively reared chickens, although the KFR produced a higher ($P \leq 0.05$) dressing percentage than KI.

When considering the genotype difference as a whole for the attributes live slaughter weight, cold carcass weight and dressing percentage (Table 4.3); broiler scored significantly higher ($P \leq 0.05$) than hybrid, except for live weight where the differences in slaughter weight was not significant ($P > 0.05$). The latter scored significantly higher ($P \leq 0.05$) than Koekoek for the two different rearing systems.

Portion weight, deboned weight and portion yield

The means and standard deviations (\pm SD) for the live weight, carcass weight and dressing percentage of the selected chickens as affected by genotype and production system are presented in Table 4.4. The chickens were slaughtered at different weights due to sampling bias resulting in the varying portion weights. The portion weights and deboned weights could thus not be compared, but rather only percentage yield of the portions will be discussed from here on in.

With regards to the breast yield (%) the broiler was found to be higher ($P \leq 0.05$) than that of the Hybrid and Koekoek. The breasts yield (%) of the broiler and Koekoek reared under free range production system (BFR 26.0%) were higher ($P \leq 0.05$) than that reared in the intensive production system (BI 25.5%). The HI (23.2%) and KI (21.6%) was significantly higher ($P \leq 0.05$) than HFR (18.9%) and KI (17.1%), but still lower than BI and BFR and higher than KI and KFR for breast yield.

For thigh yield (%), HFR (14.9%) and KFR (14.6%) scored higher ($P \leq 0.05$) yields than HI (11.7%) and Ki (11.6%). The latter again scored heavier yields ($P \leq 0.05$) than BI (10.4%) and BFR (10.9%) of which, the former and the latter also differed ($P \leq 0.05$) from each other.

KFR (9.3%) had the heaviest ($P \leq 0.05$) drum yield compared to that produced from all the other treatments. Also HI (8.2%) and HFR (8.2%) differed ($P \leq 0.05$) from BI (7.1%) and BFR (7.0%) as pertaining to the drum yield.

The wing yield (%) of KFR (7.5%) had a higher ($P \leq 0.05$) yield than KI (6.7%), HFR (6.7%) and HI (5.7%) whilst BI (5.0%) and BFR (5.0%) had the lowest yield (Table 4.4).

Table 4.2 The mean scores (\pm SD) for production parameters of the six chicken treatments as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
FCR	1.78 ^d \pm 0.06	1.56 ^d	2.09 ^c \pm 0.17	2.43 ^b	2.69 ^b \pm 0.15	3.68 ^a	0.29
ADG	53.07 ^a \pm 1.82	50.08 ^a	32.27 ^b \pm 1.81	31.97 ^b	14.87 ^c \pm 1.00	16.22 ^c	3.50
EPEF	284.79 ^a \pm 32.94	311.00 ^a	161.78 ^b \pm 17.07	134.38 ^b	56.64 ^c \pm 6.43	43.88 ^c	49.53

Feed Conversion Ratio (FCR); Average Daily Gain (ADG); European Production Efficiency Factor (EPEF); Standard Deviation(SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Table 4.3 The mean scores (\pm SD) for the live weight, carcass weight and dressing percentage of the selected sub-population of the six chicken treatments (n = 50 per treatment) as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
Live slaughter weight (g)	2168.5 ^{bc} \pm 279.79	2331.6 ^a \pm 168.45	2101.0 ^c \pm 252.45	2250.5 ^{ab} \pm 274.56	1556.4 ^e \pm 276.90	1725.2 ^d \pm 274.16	101.77
Cold carcass weight (g)	1510.8 ^a \pm 213.96	1528.4 ^a \pm 128.97	1330.5 ^b \pm 182.73	1399.9 ^b \pm 181.03	935.2 ^d \pm 167.18	1056.1 ^c \pm 170.44	69.50
Dressing percentage (%)*	69.7 ^a \pm 2.47	65.5 ^b \pm 1.89	63.2 ^c \pm 2.12	62.17 ^d \pm 1.48	59.9 ^f \pm 2.05	61.2 ^e \pm 1.36	0.76

Standard Deviation (SD); Least Significant Difference (LSD)

*Dressing percentage expressed as the relationship between cold carcass weight and live slaughter weight.

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Table 4.4 The mean scores (\pm SD) for the portion weights, portion yields (%) and deboned weights of the six chicken treatments (n = 50 per treatment) as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
Breast (g)	385.4 ^a \pm 61.70	396.1 ^a \pm 37.42	308.2 ^b \pm 263.48	263.5 ^c \pm 43.24	227.6 ^d \pm 37.66	160.1 ^e \pm 30.76	17.18
Breast yield (%)*	25.5 ^b \pm 1.19	26.0 ^a \pm 1.36	23.2 ^c \pm 1.21	18.9 ^e \pm 1.35	21.6 ^d \pm 0.99	17.1 ^f \pm 0.71	0.46
Deboned breast weight (g)	183.8 ^b \pm 38.78	210.3 ^a \pm 30.06	132.8 ^c \pm 23.28	141.5 ^c \pm 23.26	94.4 ^d \pm 16.84	73.2 ^e \pm 16.00	10.19
Thigh (g)	158.3 ^{bc} \pm 25.41	166.5 ^b \pm 23.02	156.4 ^c \pm 27.93	208.1 ^a \pm 14.88	122.4 ^e \pm 20.97	136.5 ^d \pm 23.76	9.97
Thigh yield (%)*	10.4 ^d \pm 0.87	10.9 ^c \pm 0.88	11.7 ^b \pm 0.85	14.9 ^a \pm 0.83	11.6 ^b \pm 0.66	14.6 ^a \pm 0.86	0.33
Deboned thigh weight (g)	84.6 ^c \pm 21.61	101.5 ^a \pm 11.30	90.9 ^b \pm 14.72	90.5 ^b \pm 13.16	68.6 ^d \pm 13.43	56.2 ^e \pm 12.47	5.84
Drumstick (g)	107.3 ^b \pm 15.20	107.5 ^b \pm 12.97	108.6 ^{ab} \pm 17.91	114.3 ^a \pm 16.30	93.6 ^c \pm 18.02	87.6 ^c \pm 18.09	6.54
Drumstick yield (%)*	7.1 ^d \pm 0.67	7.0 ^d \pm 0.66	8.2 ^c \pm 0.68	8.2 ^c \pm 0.55	8.8 ^b \pm 0.63	9.3 ^a \pm 0.56	0.25
Deboned drumstick weight (g)	56.1 ^c \pm 15.57	64.0 ^b \pm 8.25	62.0 ^b \pm 9.17	70.1 ^a \pm 11.44	54.0 ^c \pm 11.49	49.0 ^d \pm 11.10	4.49
Wing (g)	76.2 ^b \pm 9.19	75.3 ^b \pm 7.98	75.5 ^b \pm 7.37	92.1 ^a \pm 10.94	70.0 ^c \pm 12.32	70.4 ^c \pm 11.68	4.01
Wing yield (%*)	5.0 ^d \pm 0.55	5.0 ^d \pm 0.49	5.7 ^c \pm 0.63	6.7 ^b \pm 0.69	6.7 ^b \pm 0.47	7.5 ^a \pm 0.52	0.22

Standard Deviation (SD); Least Significant Difference (LSD)

*yield expressed as a percentage of cold carcass weight

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

DISCUSSION

There are many factors such as production system, genotype, age, stocking density, lighting regime, temperature and diet that may have an effect on the overall production efficiency and yield of chickens. Therefore this experiment was designed in such a way as to limit the number of factors to production system and genotype. However, as it is well known that genotype and production systems affect growth rates, a sub-population of the chickens were thus slaughtered at different ages but at a fixed weight range to try and compensate for these effects. Growth ADG, FCR, EPEF, and live- and carcass weight percentage yield of muscle tissue are important parameters when determining the profitability and feasibility of any system within the chicken industry.

Effect of genotype

In conventional poultry production, the live weights of birds at slaughter are normally 2 to 2.5 kg, which results in a 1.3 to 1.6 kg carcass weight; this is also applicable to speciality poultry production (Fanatico *et al.*, 2005). Fast growing broilers reach this market weight in 32 days, while medium and slower growing birds typically take 63 to 81 days (Gordon & Charles, 2002; Aviagen, 2007). In this study the broiler chicks (in both production systems) reached this market weight in 42 days and the Hybrid in 56 days. The Koekoek never reached market weight and were slaughtered on 91 days, with lighter weights. According to Butcher and Nilipour (2009) an average FCR of 1.85, ADG of 50 g and EPEF of > 260 are required for normal broiler production – no data exists for free range systems. It is clear from Fig. 4.2 that the broiler was superior ($P \leq 0.05$) to the Hybrid and Koekoek in both production systems, a not so surprising result since this genotype has been selected for rapid growth over numerous generations. The live slaughter and carcass weights (Table 4.3) should be interpreted with caution as the data is biased; the BFR of the selected slaughter birds were heavier than that of the BI although the later had a heavier mean live weight when the live weights of all the birds were considered. Hybrid was superior ($P \leq 0.05$) to Koekoek, being the medium growing chicken and Koekoek the slower growing genotype. Therefore there was a clear genotype effect on the FCR, ADG and EPEF as expected (Warriss, 2010). Similar results were found by Van Marle-Köster and Webb (2000), Fanatico *et al.* (2005, 2008) and Bogosavljević-Bosković *et al.* (2009) where fast growing genotypes were reported to be superior to medium and slow growing genotypes with regards to growth and weight. Abdullah *et al.* (2010) also reported that genotype have an effect on body weight, FCR and ADG.

Although chick behaviour was not quantified, in this study the Koekoek and Hybrid (fast and medium growing) chicks were observed to be more active in activities like foraging (see Fig 4.3 where no more grass is left in the Koekoek and Hybrid pens (left and right pens) and where grass is growing high in broiler pens (middle pen), flying, running and venturing outdoors than the broilers

(slow growing). Broilers, however, did not forage but rather rested, and were frequently observed lying down or grouped around feeders and in the shaded area. The fact that the broilers were not active and did not venture onto the forage area warrants further research as this may have financial implications as it is commonly believed that chickens prefer foraging and it is then frequently recommended that free range systems have some foraging pastures available for welfare reasons. A few leg weaknesses and leg disorders were also observed in the broilers as well as a higher mortality (Liveability % - BI 95%; BFR 95%; HI 100%; HFR 100%; KI 96.7%; KFR 96.7%) during the experiment, compared to the Hybrid and Koekoek genotypes. Lewis *et al.* (1997), Gordon and Charles (2002), Nielsen *et al.* (2003), Fanatico *et al.* (2005) and Branciarri *et al.* (2009) also found that slower growing birds are more active and foraged more than faster growing birds. Therefore slower growing birds or more active birds are more suitable for an outdoor production system when pasture is important to the total meat quality. The latter pertains to the higher n-3 fatty acids that are present in free range meat, these fatty acids originate from the pasture which contain α -linolenic acid (18:3n3) (Jahan & Paterson, 2007; Ponte *et al.*, 2008). Higher activity of birds also has a negative effect on the feed efficiency, bringing into account the production costs in a system that already has higher costs (Fanatico *et al.*, 2005).



Figure 4.3 Image showing the forage (grass) in the Broiler pens (right) and no forage in Hybrid and Koekoek pens (middle and left).

With regard to the effect of genotype on the carcass composition and portion yield, the following general trend was observed: medium and slower growing (Hybrid and Koekoek) chickens produced higher ($P \leq 0.05$) yields in the thigh, drumstick and wing whereas faster growing chickens (broiler) produced higher ($P \leq 0.05$) breast yields. This phenomenon could once again be explained by the fact that the fast growing broiler genotype has been genetically selected for higher breast yield and thereby decreasing the relative yield of other parts in the body. Alternatively it could be due the slow and medium growing birds which were noted to have a higher activity, using their wings and legs more. Gordon and Charles (2002) noted that wing and leg usage is likely to

increase bone and supporting muscle mass. These results agree with that reported by Nielsen *et al.* (2003), Quentin *et al.* (2003) and Fanatico *et al.* (2005). Even though greater ($P \leq 0.05$) yields (%) were found for the Hybrid and Koekoek in the thigh, drumstick and wing compared to than the broiler, the differences were small and probably not of commercial value. In South Africa the consumers prefer dark meat (thigh and drumstick) over white meat (breast) (Mankiw & Swagel, 2005). Therefore the HFR would be a better genotype in this production system to meet this preference. However, Gordon and Charles (2002) reported that the whole (free range produced) bird may also be vital in the speciality market, since consumers may be looking for the whole bird cooking/roasting experience.

Although not quantified, it was observed that the Hybrid and Koekoek genotypes had longer legs than the broilers and as already mentioned the Hybrid thigh and drumstick yields and weights are heavier than those of the broiler. This aspect warrants further research as the equipment required to process medium and slow growing birds would need to be adjusted, since these birds have a larger frame and longer legs than broiler chicken which the equipment is usually set up for (Fanatico *et al.*, 2005).

Effect of production system

Production system had a significant effect ($P < 0.05$) on the live weight at slaughter (Fig. 4.2) of the different genotypes although from Table 4.2 it is interesting to note that the production system had no effect on ADG within genotype. It was expected that the intensive birds would perform better, since the free range chickens were more likely to forage and venture outdoors, also other factors such as temperature and light intensity, which are not controlled and liable to change, may have affected the growth performance and body weight. For the outdoor chickens to stay warm or maintain their body temperature they need more metabolise energy than indoor birds, in order to get more energy they need to consume more feed (increased feed intake). More exercise and active foraging behaviour are also known to increase feed intake (Fanatico *et al.*, 2008). Although this experiment was conducted in the summer months (October to January), the birds in the outdoor (free range) area, even though some did not venture outdoors, were exposed to more temperature fluctuations than the intensive reared birds. Also interesting to note from the growth curve (Fig. 4.2) is that KFR not only performed better in live weight gain weight, but also in growth performance than KI (Table 4.2). There is no explanation for this phenomenon, and further research is required. Production system also had an effect ($P \leq 0.05$) on the dressing percentage where the free range samples are characterised by lower percentages, except for the genotype Koekoek where the opposite is true (Table 4.3). A possible reason for the lower dressing percentage in the free range birds could be due to the intake of grass during foraging, since dressing percentage is highly correlated to diet (Cerrate *et al.*, 2006). The gastrointestinal tract of grass feeding chickens will be bigger, therefore resulting in a lower dressing percentage (Castellini *et al.*, 2002b). Similar results were found by Skomorucha *et al.* (2009) where indoor birds were

characterized by higher dressing percentages. There was also a significant effect of production system on the FCR, for chicken genotypes (Hybrid and Koekoek) with a higher ($P \leq 0.05$) FCR's when reared in a free range production system, decreasing the production efficacy of these birds. Interesting to note is that BFR had a better ($P \leq 0.05$) FCR and therefore more economical bird than BI, which was unexpected since intensive is theoretically production under more ideal conditions.

Production system also had a significant effect ($P \leq 0.05$) on some of the portion yields of the different genotypes. When broilers were placed in a free range environment their breast and thigh yield increased ($P \leq 0.05$) compared to an intensive environment. While Hybrids were reared in a free range production system compared to an intensive system the thigh, and wing weight and yield increased ($P \leq 0.05$) whereas breast weight yield decreased ($P \leq 0.05$). When Koekoek were raised in a free range environment breast yield decreased ($P \leq 0.05$) while thigh, drumstick and wing yield increased ($P \leq 0.05$). These results could be ascribed to the higher activity of the outdoor (free range) birds as previously mentioned. This higher activity favoured muscle mass development, increasing the weight of the muscle and bone (Lewis *et al.*, 1997; Castellini *et al.*, 2002a; Gordon & Charles 2002). The same results were found by Castellini *et al.* (2002a) and Husak *et al.* (2008) where muscle mass increased when birds were allowed access to an outdoor environment. The reason for the breast yield not increasing in the HFR chicken samples could be that the thigh and drumstick was used more in activities like running and grazing, increasing their weight. Also interesting to note is that the Koekoek also produced higher ($P \leq 0.05$) thigh, drumstick and wing yields and a lower breast yield than the Hybrid when reared in the intensive production system, but when reared in the free range production system the Hybrid scored higher yield ($P \leq 0.05$) for thigh, drumstick and wing and lower yield for breast ($P \leq 0.05$).

CONCLUSIONS

The aim of this study was to perform an explorative study to determine the growth, production efficiency, carcass and portion yield of the broiler, Hybrid and Potchefstroom Koekoek reared in intensive and free range production systems. In order to establish if the crossbreeding of broiler and Potchefstroom Koekoek would affect the morphological and growth properties of a chicken carcass and if there is any difference, between these treatments.

The results of this study indicate that genotype had a much larger effect than production system. The intensive broiler and Hybrid birds had a more efficient growth ($P \leq 0.05$) than the respective free range birds. From a cost of production view point it would seem that the broiler have a more efficient ($P \leq 0.05$) growth, feed efficiency and meat yield than the Hybrid and Koekoek genotypes. Despite the poorer growth performance and efficiency (FCR, ADG, and EPEF) of the medium growing Hybrid birds compared the broiler birds, the former had better liveability (less mortality), with fewer leg disorders. Further from a behavioural view point, these

medium growing birds may be more adapted to a free range production system since they forage more actively. Additional to these factors, the HFR had higher thigh, drumstick and wing yields than the broiler. This is beneficial to the industry, since South African consumers prefer dark meat over white meat. The question arises, whether the consumer is willing to pay a premium price for free range products to compensate for additional production costs?

It would seem that the Hybrid, when considered for free range rearing, could be a more suitable alternative than the broiler genotype when evaluated from a morphological yield view point. Another question that arises is whether the same production efficiency will be maintained if the study were performed in the winter months, however this still warrants more research?

Another aspect that warrants further research is whether these genotype and production systems differences, especially as pertaining to the portion yields will result in different meat quality (chemical composition and sensory quality)? Also, it is not clear what the average South African consumer would prefer: intensively produced or free range produced?

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CHAPTER 5**THE INFLUENCE OF REARING SYSTEM AND GENOTYPE ON THE PHYSICAL AND CHEMICAL CHARACTERISTICS OF CHICKEN MEAT****ABSTRACT**

Consumer interest in free range poultry production as well as free range produced poultry products is growing worldwide. In South Africa, little information is available about the effect of this system on the chemical and physical chicken meat quality. This experiment evaluated the effect of production system and genotype on the physical characteristics and chemical composition of chicken meat. Fast growing (Broiler), Slow growing (Potchefstroom Koekoek) and a hybrid between these two genotypes were reared for 42, 56 and 91 days, respectively before slaughter. Production system influenced ($P \leq 0.05$) the meat pH of the Hybrid and the Broiler. Lower L^* , a^* , b^* , chroma and higher hue ($P \leq 0.05$) values were found in the free range meat samples than the intensive. Production system caused the free range chickens of the Koekoek to have a higher ($P \leq 0.05$) fat content in the breast and drumstick than in the free range, but in the thigh the opposite was true. The ash content of the thigh and drumstick were higher ($P \leq 0.05$) in Hybrid intensive and Koekoek intensive than in Hybrid free range and Koekoek free range, respectively. Higher PUFA:SFA and n-6:n-3 ratios were found in all the free range samples. Koekoek had lower ($P \leq 0.05$) L^* values than Broiler and Hybrid. However, the Hybrid had a tendency to score lower ($P \leq 0.05$) for a^* and b^* values and higher ($P \leq 0.05$) for the hue angle than the Broiler and Koekoek genotypes. Genotype also had small influence on the chemical composition of the portions where Koekoek had a lower ($P \leq 0.05$) moisture content than broiler in the breast but a higher ($P \leq 0.05$) content than broiler and Hybrid in the thigh. Hybrid also had higher ($P \leq 0.05$) protein content than Broiler in the drumstick as well as a higher content ($P \leq 0.05$) than broiler and Koekoek in the breast. Overall, the physical and chemical attributes of the chickens were more strongly influenced by production system than by genotype, although the quality of the Hybrid meat was similar to that of the standard commercial Broilers

Keywords: Free range, Broiler, Potchefstroom Koekoek, Ross x Koekoek hybrid, Chemical composition, Meat quality, Production system, genotype

INTRODUCTION

Over the past decade poultry production has shown a rapid incline and dominates the South African agricultural sector (FAO, 2012; Anon., 2012a). The average South African person consumes approximately 32.96 kg poultry per annum (Anon., 2012a). This increase in poultry consumption can be ascribed to higher consumer demand for poultry products as they believe poultry are healthier and/or cheaper. Modern consumers are more aware of the nutritional value of the food they consume and wish to be informed of the nutrient composition of food (Sundrum, 2001). Most modern human diets are imbalanced as shown by the rising incidence of lifestyle and dietary-induced diseases such as depression, cardiocascular diseases, obesity, Type II diabetes and osteoporosis. A balanced intake of fatty acids (low intake of saturated fatty acids and a high intake of polyunsaturated and monounsaturated fatty acids) is essential for healthy cell membranes, normal human development, healthy infant nutrition, mental health in adults, bone health, healthy skin, strong immunity as well as the the prevention of cancer. Meat is seen as a major source of fat, especially saturated fatty acids. A high intake of saturated fatty acids and imbalanced n-6:n-3 ratio are risk factors for humans with coronary heart diseases and artherosclerosis (Simopoulos, 2002; Gebauer *et al.*, 2006). Poultry meat is a good source of protein, vitamins, and minerals, has a relatively low fat content and a favourable PUFA to SFA content which reduces the risk of cardiovascular diseases (Charlton *et al.*, 2008). It is well known that the chemical and fatty acid content of monogastric animals can be manipulated by the feed (Wood & Enser, 1997; Fébel *et al.*, 2008).

Consumers are not only more aware of their health and the nutritional value of the food consumed, but also care more about animal welfare and want more naturally produced products that support a more sustainable way of farming (Sundrum, 2001). Commercial broilers reared under controlled environments (often called factory farming) reach market weight in 32 days (2.0 kg). Not only does this rapid growth lead to welfare concerns, but it has been reported that selection for fast growth and high yield are likely to affect the sensory and functional properties of chicken meat (Dransfield & Sosnicki, 1999; Le Bihan-Duval *et al.*, 1999). It is possible that differences in meat quality frequently encountered in the market place may be caused by the difference in growth rate between fast and slow growing chicken strains/lines (Fanatico *et al.*, 2005).

Meat quality is to a large extent, influenced by the ultimate pH in the muscle. The pH is an important characteristic, since it influences amongst other factors the colour, water holding capacity, juiciness, flavour and microbial shelf life of meat. Chicken genotype and type of muscle also affects the colour and pH of the meat (Fletcher, 1999; Lawrie & Ledward, 2006). The nutritional or chemical composition of chicken meat is further influenced by the specific chicken portion i.e. breast, thigh or drumstick. Therefore, the chemical composition of the major primal cuts (breast, thigh and drumstick) is an important element in chicken meat quality.

A few studies have evaluated the physical characteristics and chemical composition of fast-, medium- and slow-growing birds, but there is great variation in the production systems, portion evaluated and type of birds (genotype, strain and age) used (Castellini *et al.*, 2002; Bogosavljević-Bosković *et al.*, 2006; Grashorn & Serini, 2006; Husak *et al.*, 2008; Ponte *et al.*, 2008; Wang, 2009; Poltowicz & Doktor, 2011; Fanatico *et al.*, 2005, 2007). Such studies have never been conducted in a South African environment or on indigenous cross bred (with commercial Broilers) chickens. Therefore research is needed to evaluate the sustainability of fast-, medium- and slow-growing genotypes for the South African free range production systems, with regard to performance, yield, nutritional composition and consumer acceptability. The objective of this study was to assess the impact of production system and genotype on meat quality and nutritional composition.

This study evaluated the chemical composition of three different chicken genotypes; Broiler, Ross X Potchefstroom Koekoek and Potchefstroom Koekoek reared in intensive and free range environments. The aim of this study was to investigate the effect of chicken genotype (Broiler, Ross X Koekoek hybrid and Potchefstroom Koekoek) and production system (intensive or free range) on the physical, chemical and fatty acid composition of the breast, thigh and drumstick. This study did not include the quantification of the effect of gender (male or female) on chicken meat quality.

MATERIALS AND METHODS

Experimental birds, location, handling and slaughter procedure

Refer to Chapter 4 for materials and methods on experimental birds, location, handling and slaughtering procedures of the different chicken treatments.

Experimental units

At the meat science laboratory the carcass was divided into commercial cuts (breast, drumstick, thigh and wing) with a portioner. First the carcass was cut into half. Then the thighs and drumsticks were removed from the half carcasses by cutting above the thigh towards the acetabulum and behind the pubic bone. The thighs and drumsticks were then separated from each other by cutting perpendicular to the joint between the drumstick and thigh bones. The wings were removed by cutting the joint between the scapula and the coracoid. Thereafter all the portions', except for the wings, skin were removed. The portions were then vacuum-packed and frozen at -18°C until further analysis. The experimental units included six meat treatments which consisted of a Broiler, Hybrid and Koekoek sample each reared intensive and free range. An experimental unit consisted of n = 20 per treatment for physical analysis and n = 10 per treatment for chemical analysis. The following acronyms are used to describe the six different treatments:

BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range; KI – Potchefstroom Koekoek intensive; KFR – Potchefstroom Koekoek free range.

Physical analysis

pH

The pH of the breast, thigh and drumstick were measured on the left side of each carcass 2 h post mortem. The pH was measured by means of a Crison pH 25 hand-held portable pH meter (Lasec (Pty) Ltd, South Africa) and calibrated before each set of readings with the standard buffers (pH 4.0 and pH 7.0) provided by the manufacturer.

Colour

Samples (n = 20 per treatment) for colour measurement were prepared as described by Honikel (1998). Each portion was deboned, skinned and bloomed (exposed to atmosphere) at 8°C for 1hr. The surface colour of the skinless chicken portion was measured at three randomly selected positions according to the CIELab colour system using a Colour-guide D65/10° (daylight illumination, aperture opening) 45°/0° colorimeter (Catalogue no. 6805, BYK-Gardner GmbH, Gerestried, Germany) with L* indicating the lightness, a* the red-green range and b* the blue-yellow range. The average of the three readings was used in the statistical analysis. The hue angle (°) and Chroma (C*) were calculated by the use of the individual a* and the b* values according to the following equations:

$$\text{Hue-angle (}^\circ\text{)} = \tan^{-1} (b^*/a^*)$$

$$\text{Chroma (C}^*\text{)} = (a^{*2} + b^{*2})^{-0.5}$$

After the colour readings had been taken, the meat (muscles) of the individual portions were vacuum packed and stored frozen (-18°C) until chemical analyses could proceed.

Chemical analysis

Sample preparation

The proximate analysis was performed on the uncooked breast, thigh and drumstick muscles of the chicken (n = 10 per treatment). After the deboned portions were thawed (4°C), homogenization followed. The samples were re-vacuum packed and frozen (-18°C) until the proximate analysis commenced when the samples were thawed (4°C) once more. All of the analysis was performed in duplicate, except for fatty acid analysis.

Proximate analysis

The proximate chemical analysis (%) consisted of total moisture, protein, lipid and ash content of chicken breast, thigh and drumstick muscles. The moisture content (%) (100°C, 24 h) was analysed by drying a 2.5 g homogenized meat sample according to the Association of Official Analytical Chemist's Standard Techniques (AOAC) method 934.01 (AOAC, 2002a). The ash content (%) (500°C, 6 h) of the moisture free sample was determined by the official AOAC method 942.05 (AOAC, 2002b). The total lipid (%) (intramuscular fat) content of a 5 g homogenised raw meat sample was determined by using the chloroform:methanol (1:2 v/v) extraction method of Lee *et al.* (1996). To determine the total crude protein content (%), a 0.15 g defatted, dried and finely grounded meat sample was analysed using a Leco Nitrogen/Protein Analyser (FP- 528, Leco Corporation). The Leco was calibrated with EDTA calibration samples (Leco corporation, 3000 Lakeview Avenue, St. Joseph, MI 49085-2396, USA, Part no. 502-092, Lot no. 1055) before each of the analysis sessions. The Dumas combustion method 992.15 (AOAC, 2002c) was used and the results were expressed in % nitrogen (N). The nitrogen (%) was multiplied with the conversion factor of 6.25 to determine the crude protein (%) present in the meat sample.

Fatty acid analysis

The fatty acid profile of the six meat samples of each treatment was determined by using the fatty acid methyl esters (FAME) extraction method as described by Folch *et al.* (1957). A 2 g sample was extracted by the use of a chloroform:methanol (2:1 v/v) solution. The extraction solvent contained 0.01% butylated hydroxytoluene (BHT) as an antioxidant. A polytron mixer (WiggenHauser Homogenizer, D-500 fitted with a standard shaft 1; speed setting D) was used to homogenise the meat sample with the extraction solvent. Heptadecanoic acid (C17:0) was used as an internal standard (catalogue number H3500, Sigma-Aldrich Inc., 3050 Spruce Street, St. Louis, MO 63103, USA) to quantify the individual fatty acids present within the meat sample. A 250 µL sub-sample of the extracted lipids was transmethylated for 2h at 70°C and a methanol/sulphuric acid (19:1; v/v) solution (2 ml) was used as the transmethylating agent. After the mixture was cooled to room temperature, extraction of the fatty acid methyl esters (FAME) with water and hexane followed. The top hexane phase was transferred to a spotting tube and dried under nitrogen. After drying 50 µL of Hexane were added to the FAME sample, and 1 µL of the sample was injected into the gas-chromograph (Termo-Electron S.p.A, Rodana, Milan, Italy) equipped with a 60 m BPX70 capillary column with an internal diameter of 0.25 mm and 0.25 µm film (SGE International, Ringwood, Victoria, Australia) and flame ionized detector. The gas flow rate of the carrier, hydrogen, was 30 mL/min. The temperature settings were as follows: initial temperature 60°C, injector 220°C, detector 260°C and the final temperature at 160°C. The injection volume was 1 µL with a run time of approximately 45 min. The FAME of the meat samples was compared to a standard FAME mixture (Supelco™ 37 Component FAME mix C4-

C24, CAT, no. 47885-U. Supelco, North Harrison Rd, Bellefonte, PA 16823-0048, USA) to identify the values. The results were recorded as percentage (%) of the total fatty acids.

Statistical analysis of data

Experimentally the study consisted of a randomized factorial block design with six treatments (3 chicken genotypes x 2 production methods) and $n = 20$ replications for physical measurements, $n = 10$ replications for proximate analysis (chosen randomly out of the 20 for physical analysis) and six replications (randomly chosen out of the 10 replications for proximate analysis) for fatty acid analysis for portions, breast, thigh and drumstick. The model for the experimental design is indicated by the following equation:

$$Y_{ij} = \mu + \beta_j + b_i + g_k + (bg)_{ik} + \varepsilon_{ijk}$$

The terms within the model are defined as; the overall mean (μ), the effect of the block (β_j), the effect of genotype (b_i) the effect of rearing method (g_k), the effect of the interaction between chicken genotype and rearing method ($(bg)_{ik}$) and ε_{ijk} is the error associated with the effect of the block, chicken genotype, rearing method and interaction of the former and the latter. The physical characteristics and proximate data were subjected to an analysis of variance (ANOVA). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). All of the outliers were identified and removed before final analysis of the ANOVA's. The Least Significant Difference (LSD) was calculated at a 5% significance level to compare the treatment means. Results were defined as being not significant at $P > 0.05$ and significant at $P \leq 0.05$. Correlations were calculated between the physical characteristics and proximate composition by means of the Pearson's correlation coefficient (Snedecor & Cochran, 1980). SAS™ statistical software (Statistical Analysis System, Version, 9.2, 2006, SAS Institute Inc., CARY, NC, USA) was used for the analyses of variance (ANOVA).

RESULTS

Physical analysis

pH

The means and standard deviations (\pm SD) for pH of the breast, thigh and drumstick for the three different genotypes reared in the two production systems are presented in Table 5.2. No effect for genotype ($P > 0.05$) within a production system was found. There were differences ($P \leq 0.05$) with regard to the effect of production system on the Hybrid for the breast, thigh and drumstick portions,

where lower ($P \leq 0.05$) pH readings were noted in the birds reared in a free range environment. For Broiler, the birds reared under free range (BFR) conditions, a higher ($P \leq 0.05$) pH reading for the portions thigh and drumstick were measured than for those reared under intensive (BI) conditions. Although the pH readings for some of the treatments differed statistically, they were of a smaller magnitude (< 0.2 pH units) indicating that the samples were very similar.

Table 5.2 The mean scores (\pm SD) for the pH of the breast, thigh and drumstick of chicken as affected by genotype and production system

pH	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free Range	Intensive	Free Range	Intensive	Free Range	
Breast	5.92 ^b \pm 5.94	5.93 ^{ab} \pm 0.21	6.08 ^a \pm 0.30	5.89 ^b \pm 0.27	5.92 ^b \pm 0.21	5.93 ^{ab} \pm 0.17	0.15
Thigh	6.16 ^b \pm 0.18	6.32 ^a \pm 0.12	6.28 ^a \pm 0.16	6.09 ^b \pm 0.16	6.30 ^a \pm 0.16	6.31 ^a \pm 0.10	0.10
Drumstick	6.27 ^{cd} \pm 0.20	6.41 ^{ab} \pm 0.11	6.47 ^a \pm 0.15	6.18 ^d \pm 0.19	6.34 ^{bc} \pm 0.16	6.31 ^{bc} \pm 0.12	0.10

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Colour

The means and standard deviations (\pm SD) for the colour coordinates (L^* , a^* and b^*), the calculated hue angle ($^\circ$) and Chroma (C^*) for the six different treatments as affected by genotype and production system are presented in Table 5.3.

According to Table 5.3 there was an effect of production system within a genotype on the L^* coordinate for all the portions where the BFR and KFR differed ($P \leq 0.05$) and was darker in colour (lower L^* value) than the respective intensive (BI and KI) breast samples. For the thigh and drumstick portions, KFR ($P \leq 0.05$) had a lower L^* value and was therefore darker in colour than KI and all the other samples. The HI and HFR did not differ ($P > 0.05$) from each other for all the portions as pertaining to the L^* value. There was a trend that the free range samples of each genotype showed a more green (lower a^* value) and blue (lower b^* value) colour, some of these differences were significant ($P \leq 0.05$) and some not ($P > 0.05$) in all the portions (Table 5.3). Hue angle ($^\circ$) and chroma (C^*) give a more comprehensive, three-dimensional view of the colour of meat. Production system also had an effect ($P \leq 0.05$) on the hue and chroma values within a genotype for the portions breast, thigh and drumstick. The free range sample of each genotype had lower ($P \leq 0.05$) chroma values than the intensive samples. Considering the hue angle, all the free range treatments had significantly higher ($P \leq 0.05$) values, except for Broiler breast, where free range had a lower hue ($P \leq 0.05$) value and Broiler drumstick, where no difference ($P > 0.05$) was detected.

For the effect of genotype within a production system, the Koekoek genotype had the lowest L^* (darker in colour) ($P \leq 0.05$) value L^* for portions thigh and drumstick than Hybrid and Broiler, the latter two however, did not differ ($P > 0.05$) from each other. There was also a tendency for the Hybrid and Koekoek to be a more green (lower a^* value) and blue (lower b^* value)

colour ($P \leq 0.05$) than Broiler. Regarding the hue value, it would seem that the hybrid within each respective production system had a higher value than Broiler and Koekoek genotypes. The hue angle of the former and the latter did not differ ($P \leq 0.05$) from each other in the breast, thigh and drumstick portions. For chroma, the broiler had higher values ($P \leq 0.05$) than the other genotypes within a specific production system for every portion. For the breast meat, the KI sample had a lower ($P \leq 0.05$) chroma value than the other genotypes for that same production system. It would seem that for colour the effect of production system was more pronounced than the effect of genotype.

Table 5.3 The mean scores (\pm SD) for the CIE L*a*b*, hue and chroma values of the breast, thigh and drumstick of chicken meat as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Extensive	Intensive	Extensive	
Breast							
CIE L*	56.8 ^a \pm 2.02	55.1 ^b \pm 1.74	57.0 ^a \pm 1.57	55.6 ^{ab} \pm 3.85	57.0 ^a \pm 1.98	51.0 ^c \pm 1.49	1.44
CIE a*	3.7 ^a \pm 0.85	3.2 ^a \pm 1.19	1.8 ^b \pm 1.01	-1.1 ^c \pm 1.59	2.1 ^b \pm 1.32	-0.6 ^c \pm 0.95	0.74
CIE b*	14.7 ^b \pm 2.15	11.2 ^{cd} \pm 2.25	12.2 ^{bc} \pm 1.74	9.4 ^e \pm 2.52	13.1 ^b \pm 2.65	9.9 ^{ed} \pm 2.00	1.41
Hue	75.4 ^d \pm 3.03	73.1 ^b \pm 6.03	80.9 ^c \pm 5.06	98.6 ^a \pm 11.16	79.7 ^c \pm 6.20	92.7 ^b \pm 5.36	4.22
Chroma	15.3 ^a \pm 1.98	11.4 ^c \pm 1.65	12.5 ^{bc} \pm 1.78	9.7 ^d \pm 2.44	13.4 ^b \pm 2.51	10.0 ^d \pm 2.03	1.32
Thigh							
CIE L*	56.0 ^a \pm 1.81	55.4 ^a \pm 1.46	55.4 ^a \pm 2.85	54.8 ^a \pm 2.52	53.2 ^b \pm 1.20	49.7 ^c \pm 1.67	2.21
CIE a*	5.5 ^a \pm 1.18	3.5 ^b \pm 1.03	4.0 ^b \pm 1.40	0.6 ^d \pm 2.31	5.3 ^a \pm 1.34	1.6 ^c \pm 1.10	1.03
CIE b*	14.4 ^a \pm 1.89	11.9 ^{bc} \pm 1.76	12.3 ^b \pm 1.67	10.0 ^d \pm 2.91	12.0 ^{bc} \pm 1.98	10.8 ^{cd} \pm 1.85	1.41
Hue	68.4 ^{de} \pm 5.11	73.4 ^c \pm 5.00	71.6 ^{cd} \pm 7.18	87.8 ^a \pm 12.23	64.8 ^e \pm 7.07	81.6 ^b \pm 5.92	1.98
Chroma	15.69 ^a \pm 1.77	12.5 ^b \pm 1.74	13.2 ^b \pm 1.42	10.4 ^c \pm 3.03	13.2 ^b \pm 1.42	11.1 ^c \pm 1.82	1.46
Drumstick							
CIE L*	56.9 ^a \pm 3.54	56.5 ^a \pm 2.24	57.4 ^a \pm 4.70	58.1 ^a \pm 4.44	54.4 ^b \pm 2.70	52.2 ^c \pm 2.66	1.33
CIE a*	5.3 ^{ab} \pm 1.53	5.1 ^{ab} \pm 1.15	4.5 ^b \pm 1.92	1.1 ^c \pm 2.20	5.8 ^a \pm 1.38	1.9 ^c \pm 1.40	1.98
CIE b*	13.6 ^a \pm 2.25	11.2 ^b \pm 1.92	10.3 ^{bc} \pm 2.91	9.8 ^c \pm 2.56	10.0 ^{bc} \pm 1.60	9.1 ^c \pm 1.83	1.98
Hue	66.8 ^c \pm 8.93	64.3 ^{cd} \pm 7.34	65.2 ^c \pm 9.72	83.9 ^a \pm 12.33	58.7 ^d \pm 6.50	77.5 ^b \pm 8.45	4.72
Chroma	15.6 ^a \pm 2.91	12.6 ^b \pm 1.69	11.7 ^b \pm 2.68	10.2 ^c \pm 2.77	9.6 ^b \pm 1.76	9.6 ^c \pm 1.77	1.98

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Proximate analysis

The proximate analysis results (means and standard deviations (\pm SD) expressed as g/100 g meat) of the raw breast, thigh and drumstick meat samples as affected by genotype and production system are depicted in Table 5.4. In all the portions, moisture was the highest, followed by protein, fat and then ash. In general the chemical composition of the three different portions and of the different treatments did not differ greatly.

Rearing system influenced some of the components of the chemical composition of the breast, thigh and drumstick portions ($P \leq 0.05$). Rearing chickens in a free range environment only influenced the protein content of the Broiler, where BFR (21.3 g/100 g) had significantly higher concentrations ($P \leq 0.05$) than BI (22.1 g/100 g) and the fat content of the Koekoek, where KFR (3.1 g/100 g) had lower ($P \leq 0.05$) concentrations than KI (3.6 g/100 g) in the breast sample. Rearing the Hybrid in a free range environment caused the breast meat to have a lower protein content than in an intensive ($P \leq 0.05$) environment (HFR: 22.5 g/100 g; HI 23.3g /100g). In the thigh meat, there was no production system effect on the Broiler samples ($P > 0.05$), however there were effects on the ash content of the Hybrid hybrid (HI 1.1 g/100 g; HFR 1.2g/100 g) and on the protein (KI 18.6 g/100 g; KFR 15.5 g/100 g) and fat (KI 8.3 g/100 g; KFR 12.1 g/100 g) contents of the Koekoek samples. Regarding the composition of the drumstick meat, production system had significant effects on the moisture and ash contents of the Koekoek and Hybrid hybrid samples respectively. Production system also had a significant effect on the fat content of the drumstick for genotypes Broiler and Koekoek, where intensive (BI 5.3 g/100g; KI 5.1 g/100g) had higher ($P \leq 0.05$) concentrations than free range (BFR 3.6 g/100 g; KFR 3.8 g/100g).

With regards to the effect of genotype, no differences were found for ash in the breast, although the ash content of the thigh and drumstick portions differed, however these were of small magnitude. Genotype had an effect on the breast and thigh portions where Koekoek had a lower ($P \leq 0.05$) moisture content than Broiler, but were similar to Hybrid ($P > 0.05$) in the breast, but in the thigh Broiler had a lower ($P \leq 0.05$) moisture content than Koekoek and Hybrid, the former and the latter did not differ from each other ($P > 0.05$). With regards to the fat content, genotype had an effect on the thigh and the breast meat samples where Koekoek had a higher ($P \leq 0.05$) content than Broiler in the breast although in the thigh the opposite were true. Hybrid did not differ ($P > 0.05$) from either Broiler or Koekoek for fat content. The Hybrid had a higher ($P \leq 0.05$) protein content than the Broiler and Koekoek genotypes, although the Broiler and Koekoek genotypes did not differ from each other ($P > 0.05$). For the drumstick meat, Hybrid and Koekoek, which did not differ ($P > 0.05$) from each other, had a higher ($P \leq 0.05$) protein content than Broiler. Genotype did not have any effect ($P > 0.05$) on protein content of the thigh meat. Although there were statistically significant differences in the effects of genotype and production system, all these values fall within the standard nutritional value of chicken meat.

Table 5.4 The mean scores (\pm SD) for the proximate composition (g/100 g as is) of raw chicken breast, thigh and drumstick as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
Breast							
Moisture	74.0 ^a \pm 0.78	73.4 ^a \pm 0.52	71.8 ^c \pm 0.31	72.0 ^c \pm 0.56	72.3 ^{bc} \pm 0.64	72.7 ^b \pm 0.77	0.55
Protein	22.1 ^{bc} \pm 0.63	21.3 ^d \pm 1.12	23.3 ^a \pm 0.65	22.5 ^b \pm 0.52	21.5 ^{cd} \pm 1.16	21.4 ^{cd} \pm 0.65	0.74
Fat	3.0 ^b \pm 0.29	2.8 ^b \pm 0.65	2.3 ^c \pm 0.48	2.7 ^{bc} \pm 0.62	3.6 ^a \pm 0.39	3.1 ^{bc} \pm 0.53	0.46
Ash	1.2 \pm 0.11	1.2 \pm 0.05	1.2 \pm 0.06	1.1 \pm 0.06	1.2 \pm 0.16	1.2 \pm 0.06	0.08
Thigh							
Moisture	68.5 ^c \pm 2.03	69.1b ^c \pm 1.48	69.1 ^{bc} \pm 2.2	70.1 ^{abc} \pm 1.6	71.7 ^a \pm 2.6	70.9 ^{ab} \pm 2.0	1.81
Protein	17.9 ^{ab} \pm 4.91	16.4 ^{abc} \pm 1.67	17.8 ^{ab} \pm 0.95	16.1 ^{bc} \pm 1.60	18.6 ^a \pm 2.06	15.5 ^c \pm 1.63	2.23
Fat	12.9 ^a \pm 4.55	12.9 ^a \pm 2.47	11.8 ^a \pm 2.48	12.4 ^a \pm 2.30	8.3 ^b \pm 1.44	12.1 ^a \pm 2.48	2.50
Ash	1.0 ^{bc} \pm 0.08	1.0 ^{bc} \pm 0.03	1.1 ^b \pm 0.09	1.2 ^a \pm 0.2	1.0 ^c \pm 0.04	1.1 ^{bc} \pm 0.06	0.09
Drumstick							
Moisture	75.3 ^a \pm 0.58	75.3 ^a \pm 0.58	74.8 ^a \pm 0.56	75.0 ^a \pm 0.46	74.0 ^b \pm 0.68	74.8 ^a \pm 0.56	0.58
Protein	16.6 ^c \pm 1.22	17.3 ^{bc} \pm 0.81	18.2 ^a \pm 0.72	17.5 ^{ab} \pm 0.46	17.6 ^{ab} \pm 0.56	18.2 ^a \pm 0.61	0.69
Fat	5.3 ^a \pm 0.47	3.6 ^d \pm 0.29	4.1 ^{bc} \pm 0.50	4.3 ^b \pm 0.47	5.1 ^a \pm 0.47	3.8 ^{dc} \pm 0.26	0.38
Ash	1.1 ^a \pm 0.5	1.1 ^a \pm 0.03	1.1 ^a \pm 0.06	1.0 ^b \pm 0.07	1.1 ^a \pm 0.11	1.1 ^a \pm 0.05	0.06

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Fatty acid analysis

The mean percentages and standard deviations (\pm SD) for the fatty acid composition of the raw breast, thigh and drumstick meat of the six different treatments are presented in Table 5.5, 5.6 and 5.7 respectively. All of the fatty acids present in the treatments were analysed and are presented in the table although only specific fatty acids will be discussed. In general the fatty acid composition of the three different portions and of the different treatments did not differ greatly. The concentration of total polyunsaturated fatty acid (PUFA) is the highest, followed by total saturated fatty acid (SFA) and then total monounsaturated fatty acid (MUFA) in all the chicken samples irrespective of genotype or portion (Table 5.5, 5.6 and 5.7).

When considering the overall SFA (Table 5.5) content of the breast meat, there is a production system effect in the Hybrid and Broiler samples, where the intensive production system (HI 33.3%; BI 35.9%) had a higher ($P \leq 0.05$) total SFA content than free range production system (HFR 28.8%; BFR 29.8%), although the SFA content of KI was higher than KFR, this was not significant ($P > 0.05$). As pertaining to production system, there was a difference ($P \leq 0.05$) between BI (24.0%), HI (21.7%), KI (21.0%) and BFR (18.1%), HFR (18.9%), KFR (18.6%) respectively for Palmitic acid (C16:0) where intensive had a higher ($P \leq 0.05$) percentage than free range. There were also differences ($P \leq 0.05$) between production systems within a genotype for Stearic acid (C18:0) where HI (9.9%) had higher values than HFR (8.3%). For the thigh meat

(Table 5.6), there was no production system effect ($P > 0.05$) with regards to the total SFA. As pertaining to the individual SFA of the thigh, Stearic acid differed ($P \leq 0.05$) for Broiler between BI (3.2%), with a higher content than BFR (2.4%). The total SFA content of the drumstick meat (Table 5.7) was also influenced by the production system where the free range samples had lower ($P \leq 0.05$) sums of SFA than the intensive samples, except HI and HFR whose sums did not differ ($P > 0.05$). Of the individual fatty acids, Palmitic acid and Stearic acid differed significantly between production systems for the Broiler and Koekoek genotypes, where the intensive had higher ($P \leq 0.05$) percentages than the free range.

The total MUFA content of the breast, thigh and drumstick meat differed between production systems for the Broiler and Koekoek genotypes, where the intensive reared genotypes had the higher ($P \leq 0.05$) MUFA. When considering the individual fatty acids, Palmitoleic acid (C16:1) and Oleic acid (C18:1n9c) were the major fatty acids that differed. In the breast meat, higher concentrations ($P \leq 0.05$) were found in the intensive samples BI and KI than in the free range samples BFR and KFR, respectively. The BI had higher ($P \leq 0.05$) levels of Palmitoleic and Oleic than BFR in the thigh meat. As pertaining to the drumstick meat, intensive reared broilers (BI) had higher ($P \leq 0.05$) concentrations of these two fatty acids than free range reared broilers (BFR).

In the total PUFA content of the breast, thigh and drumstick, there were a trend for the free range samples to have higher concentrations than the intensive. Linolenic acid (C18:2n6c) and L-Linolenic acid (C18:3n6) were the major PUFA present. In the breast meat, free range rearing had a significant effect and the BFR (36.3%; 4.6%), HFR (36.1%; 4.6%), KFR (38.6%; 4.5%) had higher ($P \leq 0.05$) Linolenic acid and L-Linolenic acid concentrations than the respective intensive samples, BI (23.1%; 2.6%), HI (31.5%; 3.4%) and KI (33.4%; 3.6%). In the thigh meat, the Broiler genotype had a higher ($P \leq 0.05$) Linolenic acid concentration when reared under free range conditions. With regards to the drumstick meat, BFR and KFR had higher Linolenic acid concentrations and HFR higher L-Linolenic acid concentrations than the respective intensive samples.

Considering the overall PUFA:SFA ratio, there seemed to be a trend for free range samples to have higher ratios than intensive, except for the Hybrid genotype in the drumstick meat, where HI had a higher ($P \leq 0.05$) ratio than HFR. The n-3:n-6 fatty acid ratio was lower ($P \leq 0.05$) in the intensive samples of the broiler (BI) genotype for breast, thigh and drumstick portions and also lower for the thigh and drumstick portions derived from KI. There were also significant ($P \leq 0.05$) differences in all the portions for the effect of production system within a specific genotype, for the remainder fatty acids, but these were very small, with differences $< 1.0\%$ and are therefore not discussed further.

It is clear from Tables 5.5, 5.6 and 5.7 that production system had a larger effect than genotype on the fatty acid profile of the different portions.

Table 5.5 The mean concentrations (\pm SD) of the fatty acid composition (% of total fatty acids) of raw chicken breast as affected by genotype and production system

Fatty acid	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free Range	Intensive	Free Range	Intensive	Free Range	
SFA							
C14:0	0.4 ^{ab} \pm 0.14	0.3 ^{bc} \pm 0.07	0.4 ^a \pm 0.43	0.3 ^c \pm 0.07	0.4 ^{ab} \pm 0.10	0.3 ^{bc} \pm 0.08	0.12
C15:0	0.1 ^b \pm 0.01	0.1 ^{ab} \pm 0.01	0.1 ^a \pm 0.02	0.1 ^{ab} \pm 0.02	0.1 ^a \pm 0.02	0.1 ^a \pm 0.02	0.02
C16:0	24.0 ^a \pm 2.70	18.1 ^d \pm 0.94	21.7 ^b \pm 0.81	18.9 ^{dc} \pm 2.63	21.0 ^{bc} \pm 2.08	18.6 ^d \pm 1.21	2.30
C18:0	10.0 ^a \pm 0.42	9.9 ^a \pm 1.46	9.9 ^a \pm 1.24	8.3 ^b \pm 0.65	9.9 ^a \pm 1.18	9.6 ^a \pm 0.67	1.26
C20:0	0.2 ^b \pm 0.09	0.3 ^a \pm 0.09	0.3 ^{ab} \pm 0.10	0.4 ^a \pm 0.09	0.3 ^b \pm 0.09	0.2 ^b \pm 0.03	0.10
C21:0	0.1 ^a \pm 0.01	0.1 ^b \pm 0.01	0.1 ^{ab} \pm 0.02	0.1 ^a \pm 0.01	0.1 ^{ab} \pm 0.02	0.00 ^{ab} \pm 0.01	0.02
C22:0	1.0 ^a \pm 0.14	1.0 ^a \pm 0.25	0.8 ^{ab} \pm 0.14	0.8 ^{bc} \pm 0.10	0.5 ^d \pm 0.08	0.6 ^{cd} \pm 0.10	0.19
C24:0	0.1 ^b \pm 0.02	0.1 ^a \pm 0.02	ND	ND	ND	ND	0.02
MUFA							
C14:1	0.0 ^a \pm 0.02	0.0 ^{ab} \pm 0.02	ND	ND	0.0 ^b \pm 0.02	ND	0.02
C16:1	3.1 ^a \pm 0.38	1.3 ^{dc} \pm 0.38	2.1 ^b \pm 0.63	1.4 ^{bc} \pm 0.78	1.5 ^{bc} \pm 0.43	0.8 ^d \pm 0.13	0.63
C18:1n9t	0.2 ^a \pm 0.03	0.1 ^c \pm 0.01	0.1 ^b \pm 0.01	0.1 ^{cd} \pm 0.03	0.1 ^c \pm 0.02	0.1 ^d \pm 0.00	0.02
C18:1n9c	27.8 ^a \pm 1.75	21.3 ^{bc} \pm 1.75	23.0 ^b \pm 2.15	22.2 ^{bc} \pm 1.76	23.1 ^b \pm 1.67	20.4 ^c \pm 0.57	1.98
C20:1	0.1 ^c \pm 0.01	0.1 ^{ab} \pm 0.01	0.1 ^b \pm 0.01	0.1 ^{ab} \pm 0.1	0.1 ^b \pm 0.01	0.1 ^a \pm 0.01	0.01
C22:1n9	0.1 ^b \pm 0.01	0.1 ^a \pm 0.02	0.1 ^b \pm 0.01	0.1 ^b \pm 0.02	0.0 ^c \pm 0.01	0.0 ^c \pm 0.01	0.02
C24:1	0.1 ^b \pm 0.03	0.1 ^{abc} \pm 0.03	0.1 ^{ab} \pm 0.03	0.1 ^{bc} \pm 0.02	0.1 ^{bc} \pm 0.02	0.1 ^c \pm 0.02	0.03
PUFA							
C18:2n6t	0.1 ^{ab} \pm 0.01	0.1 ^{ab} \pm 0.00	0.1 ^{ab} \pm 0.01	0.1 ^a \pm 0.00	0.1 ^{ab} \pm 0.02	0.1 ^b \pm 0.01	0.01
C18:2n6c	23.1 ^d \pm 1.71	36.3 ^{ab} \pm 2.45	31.5 ^c \pm 1.91	36.1 ^{ab} \pm 3.88	33.4 ^{bc} \pm 2.54	38.6 ^a \pm 2.27	3.31
C18:3n6	2.6 ^c \pm 0.29	4.6 ^a \pm 0.42	3.4 ^b \pm 0.38	4.6 ^a \pm 0.68	3.6 ^b \pm 0.43	4.5 ^a \pm 0.36	0.55
C18:3n3	0.5 ^a \pm 0.05	0.3 ^{bc} \pm 0.03	0.4 ^b \pm 0.05	0.3 ^b \pm 0.04	0.4 ^b \pm 0.04	0.3 ^c \pm 0.03	0.05
C20:2	0.4 ^b \pm 0.10	0.6 ^a \pm 0.15	0.4 ^b \pm 0.07	0.4 ^b \pm 0.08	0.3 ^c \pm 0.04	0.3 ^{bc} \pm 0.03	0.11
C20:3n6	2.1 ^b \pm 0.26	3.0 ^a \pm 0.97	3.1 ^a \pm 1.07	2.8 ^{ab} \pm 0.43	2.7 ^{ab} \pm 0.68	3.5 ^a \pm 0.69	0.92
C20:3n3	0.1 \pm 0.00	0.1 \pm 0.02	0.1 \pm 0.02	0.1 \pm 0.01	0.1 \pm 0.02	0.1 \pm 0.01	0.02
C20:4n6	0.1 ^a \pm 0.02	0.1 ^{ab} \pm 0.02	0.1 ^{ab} \pm 0.02	0.1 ^{ab} \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.02
C20:5n3	0.2 ^b \pm 0.04	0.3 ^a \pm 0.07	0.2 ^b \pm 0.03	0.2 ^{ab} \pm 0.03	0.2 ^b \pm 0.05	0.2 ^b \pm 0.02	0.06
C22:2	0.0 ^a \pm 0.01	0.1 ^a \pm 0.02	ND	ND	ND	ND	0.01
C22:5n3	0.5 ^a \pm 0.09	0.2 ^b \pm 0.05	0.2 ^b \pm 0.03	0.2 ^b \pm 0.02	0.1 ^c \pm 0.02	0.1 ^c \pm 0.01	0.05
C22:6n3	2.0 ^a \pm 0.42	1.0 ^{cd} \pm 0.34	1.5 ^b \pm 0.30	1.2 ^{bc} \pm 0.26	1.0 ^d \pm 0.24	1.4 ^{bc} \pm 0.30	0.38
SFA	35.9 ^a \pm 2.52	29.8 ^{cd} \pm 1.88	33.3 ^{ab} \pm 1.87	28.8 ^d \pm 3.00	32.2 ^{cb} \pm 3.10	29.5 ^{cd} \pm 1.86	2.99
MUFA	31.3 ^a \pm 1.40	23.4 ^{bc} \pm 2.43	25.7 ^b \pm 2.91	23.9 ^{bc} \pm 2.47	24.8 ^b \pm 2.03	21.4 ^c \pm 0.63	2.66
PUFA	32.2 ^c \pm 2.85	46.6 ^a \pm 62	40.8 ^b \pm 2.14	47.2 ^a \pm 4.97	42.5 ^b \pm 3.33	48.7 ^a \pm 1.96	4.03
PUFA:SFA	0.9 ^c \pm 0.13	1.6 ^{ab} \pm 0.16	1.2 ^c \pm 0.10	1.6 ^{ab} \pm 0.26	1.3 ^{bc} \pm 0.22	1.6 ^a \pm 0.17	0.24
n-6:n-3	9.5 ^c \pm 1.56	21.6 ^a \pm 4.44	16.7 ^b \pm 2.67	20.4 ^{ab} \pm 2.06	23.4 ^a \pm 4.16	23.5 ^a \pm 4.28	4.33

Standard Deviation (SD); Least Significant Difference (LSD); Not Detected (ND)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Table 5.6 The mean concentrations (\pm SD) of the fatty acid composition (% of total fatty acids) of raw chicken thigh as affected by genotype and production system

	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free Range	Intensive	Free Range	Intensive	Free Range	
SFA							
C14:0	0.2 ^a \pm 0.10	0.1 ^{dc} \pm 0.04	0.2 ^{ab} \pm 0.04	0.2 ^{abc} \pm 0.05	0.1 ^{bcd} \pm 0.03	0.1 ^d \pm 0.02	0.07
C15:0	0.1 ^a \pm 0.04	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.02	0.0 ^b \pm 0.01	0.02
C16:0	14.4 ^{ab} \pm 7.54	11.2 ^{ab} \pm 8.76	10.4 ^{ab} \pm 4.16	8.0 ^b \pm 1.76	15.8 ^a \pm 7.29	11.1 ^{ab} \pm 6.01	2.04
C18:0	3.2 ^a \pm 0.23	2.4 ^{bc} \pm 0.68	2.4 ^{bc} \pm 0.6	2.8 ^{ab} \pm 0.4	2.2 ^{bc} \pm 0.55	2.0 ^c \pm 0.45	0.68
C20:0	0.2 ^a \pm 0.10	0.1 ^{bc} \pm 0.05	0.2 ^{abc} \pm 0.09	0.2 ^{ab} \pm 0.09	0.1 ^{abc} \pm 0.11	0.1 ^c \pm 0.03	0.10
C21:0	0.1 \pm 0.02	ND	ND	ND	ND	ND	0.01
C22:0	0.5 ^a \pm 0.26	0.2 ^b \pm 0.04	0.1 ^b \pm 0.03	0.2 ^b \pm 0.04	0.1 ^b \pm 0.03	0.1 ^b \pm 0.02	0.13
C24:0	ND	ND	ND	ND	ND	ND	2.04
MUFA							
C14:1	0.1 ^a \pm 0.02	ND	ND	ND	ND	ND	0.01
C16:1	1.3 ^a \pm 0.07	0.6 ^{bc} \pm 0.15	1.3 ^a \pm 0.19	0.8 ^b \pm 0.19	0.7 ^{bc} \pm 0.20	0.5 ^c \pm 0.20	0.26
C18:1n9t	0.1 ^a \pm 0.03	0.0 ^{bc} \pm 0.01	0.0 ^b \pm 0.01	0.0 ^{bc} \pm 0.01	0.0 ^{bc} \pm 0.01	0.0 ^c \pm 0.01	0.02
C18:1n9c	31.6 ^a \pm 8.39	19.3 ^{bc} \pm 12.06	20.1 ^{bc} \pm 11.50	10.4 ^c \pm 1.81	25.0 ^{ab} \pm 8.15	18.3 ^{bc} \pm 9.03	2.04
C20:1	0.1 ^a \pm 0.03	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	ND	0.0 ^b \pm 0.01	0.02
C22:1n9	0.1 ^c \pm 0.02	0.0 ^c \pm 0.01	0.0 ^c \pm 0.01	0.0 ^c \pm 0.01	0.5 ^a \pm 0.18	0.3 ^b \pm 0.21	0.16
C24:1	0.1 \pm 0.02	ND	ND	ND	ND	ND	0.01
PUFA							
C18:2n6t	ND	ND	ND	ND	ND	ND	0.01
C18:2n6c	37.9 ^c \pm 13.21	63.2 ^{ab} \pm 12.58	60.2 ^{ab} \pm 15.48	73.2 ^a \pm 4.80	53.3 ^b \pm 13.00	65.1 ^{ab} \pm 13.75	2.04
C18:3n6	2.3 ^a \pm 0.98	1.8 ^{ab} \pm 0.31	1.7 ^{ab} \pm 0.45	2.3 ^a \pm 0.08	1.2 ^b \pm 0.38	1.7 ^b \pm 0.27	0.62
C18:3n3	0.3 ^a \pm 0.16	0.1 ^b \pm 0.02	0.2 ^b \pm 0.04	0.1 ^b \pm 0.03	0.1 ^b \pm 0.03	0.1 ^b \pm 0.02	0.09
C20:2	0.2 ^a \pm 0.13	0.1 ^b \pm 0.02	0.1 ^b \pm 0.03	0.1 ^b \pm 0.02	0.1 ^b \pm 0.02	0.1 ^b \pm 0.01	0.07
C20:3n6	1.5 ^a \pm 0.90	0.4 ^b \pm 0.14	0.4 ^b \pm 0.09	0.6 ^b \pm 0.12	0.4 ^b \pm 0.15	0.3 ^b \pm 0.15	0.47
C20:3n3	0.1 ^a \pm 0.01	ND	ND	ND	ND	ND	0.01
C20:4n6	ND	0.0 ^b \pm 0.1	0.0 ^{ab} \pm 0.01	ND	0.0 ^a \pm 0.01	ND	2.04
C20:5n3	0.2 ^a \pm 0.07	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.1 ^b \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.03
C22:2	ND	ND	ND	ND	ND	ND	2.04
C22:5n3	0.1 ^a \pm 0.01	0.0 ^b \pm 0.01	0.0 ^b \pm 0.02	0.1 ^b \pm 0.01	0.0 ^c \pm 0.01	0.0 ^c \pm 0.01	0.02
C22:6n3	0.8 ^a \pm 0.42	0.1 ^b \pm 0.05	0.2 ^b \pm 0.05	0.2 ^b \pm 0.04	0.1 ^b \pm 0.06	0.1 ^b \pm 0.04	0.20
SFA	21.7 ^a \pm 11.22	14.1 ^{ab} \pm 8.90	14.3 ^{ab} \pm 5.69	11.4 ^b \pm 2.20	18.4 ^{ab} \pm 6.64	13.4 ^{ab} \pm 5.50	2.04
MUFA	34.5 ^a \pm 7.85	20.1 ^{bc} \pm 11.91	21.9 ^{bc} \pm 11.63	11.6 ^c \pm 2.35	26.2 ^{ab} \pm 7.95	19.1 ^{bc} \pm 8.81	2.04
PUFA	43.6 ^c \pm 11.05	65.8 ^{ab} \pm 13.11	63.8 ^{bc} \pm 14.75	76.9 ^a \pm 4.52	55.4 ^{bc} \pm 13.60	67.5 ^{ab} \pm 14.10	2.04
PUFA:SFA	2.8 ^c \pm 1.89	6.3 ^{ab} \pm 3.24	5.1 ^{abc} \pm 2.26	7.0 ^a \pm 1.83	3.8 ^{bc} \pm 2.63	6.1 ^{ab} \pm 3.35	2.04
n-6:n-3	35.3 ^d \pm 25.73	216.8 ^{ab} \pm 20.66	162.3 ^c \pm 17.24	171.2 ^c \pm 39.83	186.0 ^{bc} \pm 29.68	242.4 ^a \pm 36.58	35.71

Standard Deviation (SD); Least Significant Difference (LSD); Not Detected (ND)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Table 5.7 The mean concentrations (\pm SD) of the fatty acid composition (% of total fatty acids) of raw chicken drumstick as affected by genotype and production system

Fatty acid	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free Range	Intensive	Free Range	Intensive	Free Range	
SFA							
C14:0	0.3 ^{ab} \pm 0.16	0.1 ^c \pm 0.04	0.4 ^a \pm 0.12	0.4 ^{ab} \pm 0.08	0.3 ^{ab} \pm 0.06	0.2 ^{bc} \pm 0.13	0.13
C15:0	0.1 ^{ab} \pm 0.04	0.0 ^c \pm 0.01	0.1 ^a \pm 0.03	0.1 ^a \pm 0.02	0.1 ^a \pm 0.02	0.1 ^{bc} \pm 0.03	0.03
C16:0	17.2 ^a \pm 7.00	7.0 ^b \pm 1.88	17.1 ^a \pm 5.01	18.1 ^a \pm 1.29	17.9 ^a \pm 1.67	8.0 ^b \pm 1.51	4.59
C18:0	5.3 ^b \pm 2.44	3.0 ^c \pm 0.88	7.7 ^a \pm 1.96	8.4 ^a \pm 0.48	8.5 ^a \pm 0.38	4.4 ^{bc} \pm 1.80	1.88
C20:0	0.2 ^b \pm 0.10	0.2 ^a \pm 0.08	0.3 ^b \pm .011	0.4 ^a \pm 0.04	0.3 ^a \pm 0.09	0.2 ^b \pm 0.07	0.1
C21:0	0.0 ^a \pm 0.02	0.0 ^b \pm 0.01	0.0 ^a \pm 0.02	0.1 ^a \pm 0.02	0.1 ^a \pm 0.02	0.0 ^b \pm 0.01	0.02
C22:0	0.5 ^b \pm 0.23	0.3 ^c \pm 0.09	0.5 ^b \pm 0.12	0.7 ^a \pm 0.08	0.7 ^a \pm 0.09	0.2 ^c \pm 0.12	0.16
C24:0	0.0 ^b \pm 0.02	0.0 ^c \pm 0.00	ND	ND	0.1 ^a \pm 0.1	ND	0.01
MUFA							
C14:1	0.1 ^a \pm 0.03	0.0 ^d \pm 0.01	0.1 ^{ab} \pm 0.02	0.0 ^{ab} \pm 0.01	0.0 ^{bc} \pm 0.01	0.0 ^{cd} \pm 0.01	0.02
C16:1	3.0 ^a \pm 1.23	0.8 ^c \pm 0.26	2.6 ^a \pm 0.98	2.1 ^{ab} \pm 0.63	2.0 ^{ab} \pm 0.83	1.4 ^{bc} \pm 0.76	1.00
C18:1n9t	0.1 ^a \pm 0.04	0.0 ^b \pm 0.01	0.1 ^a \pm 0.03	0.1 ^a \pm 0.02	0.1 ^a \pm 0.01	0.0 ^b \pm 0.01	0.03
C18:1n9c	36.4 ^a \pm 9.08	10.4 ^c \pm 3.01	21.9 ^b \pm 5.80	21.8 ^b \pm 1.77	21.4 ^b \pm 1.69	15.7 ^b \pm 6.93	6.66
C20:1	0.0 ^b \pm 0.02	0.0 ^b \pm 0.01	0.1 ^a \pm 0.02	0.1 ^a \pm 0.01	0.1 ^a \pm 0.01	0.1 ^b \pm 0.02	0.02
C22:1n9	0.0 ^b \pm 0.02	0.0 ^b \pm 0.01	0.0 ^b \pm 0.01	0.1 ^a \pm 0.01	0.1 ^a \pm 0.01	0.0 ^c \pm 0.00	0.01
C24:1	0.1 ^b \pm 0.02	0.0 ^c \pm 0.01	0.1 ^{ab} \pm 0.02	0.1 ^a \pm 0.01	0.1 ^a \pm 0.01	0.0 ^c \pm 0.02	0.02
PUFA							
C18:2n6t	0.0 ^c \pm 0.01	0.0 ^c \pm 0.00	0.1 ^b \pm 0.01	0.1 ^a \pm 0.01	0.1 ^a \pm 0.01	0.0 ^c \pm 0.01	0.01
C18:2n6c	32.3 ^b \pm 7.11	74.0 ^a \pm 6.17	34.1 ^b \pm 2.89	38.1 ^b \pm 3.45	38.4 ^b \pm 3.92	68.8 ^a \pm 5.64	6.44
C18:3n6	0.4 ^c \pm 1.17	2.4 ^c \pm 0.44	3.6 ^b \pm 0.84	4.7 ^a \pm 0.52	4.8 ^{ab} \pm 0.58	1.9 ^c \pm 0.45	0.89
C18:3n3	0.3 ^a \pm 0.15	0.1 ^b \pm 0.03	0.4 ^a \pm 0.09	0.3 ^a \pm 0.02	0.3 ^a \pm 0.03	0.2 ^b \pm 0.09	0.10
C20:2	0.2 ^c \pm 0.09	0.2 ^c \pm 0.04	0.3 ^b \pm 0.07	0.4 ^a \pm 0.05	0.4 ^a \pm 0.05	0.2 ^c \pm 0.07	0.08
C20:3n6	0.9 ^b \pm 0.52	0.8 ^b \pm 0.24	2.5 ^a \pm 0.28	2.8 ^a \pm 0.31	2.9 ^a \pm 0.35	1.0 ^b \pm 0.28	0.43
C20:3n3	0.0 ^c \pm 0.01	0.0 ^c \pm 0.01	0.1 ^b \pm 0.02	0.1 ^a \pm 0.01	0.1 ^{ab} \pm 0.00	0.0 ^c \pm 0.01	0.01
C20:4n6	0.0 ^a \pm 0.02	0.0 ^b \pm 0.01	0.1 ^a \pm 0.02	0.1 ^a \pm 0.01	0.1 ^a \pm 0.01	0.0 ^b \pm 0.00	0.02
C20:5n3	0.1 ^b \pm 0.05	0.1 ^b \pm 0.03	0.2 ^b \pm 0.05	0.2 ^a \pm 0.04	0.2 ^a \pm 0.04	0.1 ^b \pm 0.06	0.05
C22:2	0.0 ^b \pm 0.01	0.0 ^c \pm 0.00	ND	ND	0.0 ^a \pm 0.01	ND	0.01
C22:5n3	0.2 ^a \pm 0.10	0.1 ^c \pm 0.02	0.1 ^c \pm 0.03	0.2 ^b \pm 0.02	0.2 ^b \pm 0.02	0.1 ^c \pm 0.04	0.05
C22:6n3	0.6 ^a \pm 0.32	0.3 ^b \pm 0.06	0.8 ^a \pm 0.17	0.8 ^a \pm 0.07	0.8 ^a \pm 0.08	0.3 ^b \pm 0.19	0.21
SFA	26.5 ^a \pm 10.51	10.6 ^b \pm 2.86	26.8 ^a \pm 6.82	28.0 ^a \pm 1.65	27.9 ^a \pm 1.94	14.9 ^b \pm 6.63	7.31
MUFA	39.7 ^a \pm 8.01	11.3 ^d \pm 3.21	25.2 ^b \pm 7.16	24.2 ^b \pm 2.37	23.7 ^{bc} \pm 2.47	17.2 ^{cd} \pm 7.37	6.88
PUFA	33.0 ^d \pm 12.47	77.9 ^a \pm 5.54	42.4 ^{cd} \pm 3.45	47.6 ^c \pm 3.81	48.2 ^c \pm 4.21	67.6 ^b \pm 12.97	10.23
PUFA:SFA	1.7 ^c \pm 1.26	7.8 ^a \pm 2.02	2.2 ^c \pm 1.81	1.7 ^c \pm 0.23	1.7 ^c \pm 0.25	5.3 ^b \pm 2.06	1.82
n-6:n-3	26.8 ^b \pm 16.85	132.9 ^a \pm 28.97	34.9 ^b \pm 24.92	29.0 ^b \pm 3.40	30.0 ^b \pm 4.26	128.2 ^a \pm 27.40	25.1

Standard Deviation (SD); Least Significant Difference (LSD); Not Detected (ND)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Correlations

The correlation matrix showing the Pearson correlation coefficients (r) and the P-values of the data (excluding the fatty acid composition) for all the samples are depicted in Table 5.8. Where applicable, these will be used to illustrate specific points in the discussion.

Table 5.8 Correlation matrix showing the Pearson correlation coefficients (r) and the P-values for all the samples

Variables	1	2	3	4	5	6	7	8	9	10
1.%Moisture	1	0.0627	-0.7389	0.0506	0.1092	0.1865	0.1059	-0.1378	-0.0182	-0.0922
	0	0.0403	<0.0001	0.4998	0.1444	0.0122	0.1569	0.0651	0.0147	0.2184
2.%Ash	0.0627	1	-0.2626	0.3383	-0.2322	-0.1350	-0.2186	0.1199	0.2354	0.0574
	0.1030	0	0.0004	<0.0001	0.0017	0.0707	0.0032	0.1089	0.0015	0.4439
3.%Fat	-0.7389	-0.2626	1	-0.6490	0.2084	0.1724	0.1481	0.1331	-0.0714	0.1471
	<0.0001	0.0004	0	<0.0001	0.0050	0.0206	0.0473	0.0748	0.3407	0.0489
4.%Protein	0.0506	0.3383	-0.6490	1	-0.4835	0.0710	-0.2842	0.0429	0.2907	-0.0263
	0.4998	<0.0001	<0.0001	0	<0.0001	0.3433	<0.0001	0.5673	<0.0001	0.7265
5.%pH	0.1092	-0.2322	0.2084	-0.4835	1	-0.1369	0.3060	-0.0328	-0.3550	0.0396
	0.1444	0.0017	0.0050	<0.0001	0	0.0093	<0.0001	0.5348	<0.0001	0.4545
6.L*	0.1865	-0.1350	0.1724	0.0710	-0.1369	1	0.0190	0.1541	-0.0131	0.1328
	0.0122	0.0707	0.0206	0.3433	0.0093	0	0.7192	0.0034	0.8051	0.0117
7.a*	0.1059	-0.2186	0.1481	-0.2842	0.3060	0.0190	1	0.3286	-0.9334	0.5265
	0.1569	0.0032	0.0473	0.0001	<0.0001	0.7192	0	<0.0001	<0.0001	<0.0001
8.b*	-0.1378	0.1199	0.1331	0.0429	-0.0328	0.1541	0.3286	1	-0.1322	0.9632
	0.0651	0.1089	0.0748	0.5673	0.5348	0.0034	<0.0001	0	0.0120	<0.0001
9.Hue	-0.0182	0.2354	-0.0714	0.2907	-0.3550	-0.0131	-0.9334	-0.1322	1	0.9632
	0.0147	0.0015	0.3407	<0.0001	<0.0001	0.8051	<0.0001	0.0120	0	<0.0001
10.Chroma	-0.0922	0.0574	0.1471	-0.0263	0.0396	0.1328	0.5265	0.9632	0.9632	1
	0.2184	0.4439	0.0489	0.7265	0.4545	0.0117	<0.0001	<0.0001	<0.0001	0

The first row of each attribute shows the Pearson correlation coefficient (r) and the second row of each attribute shows the P-value. All the values in bold are significant at a level of $P \leq 0.05$.

DISCUSSION

Factors such as production system, genotype, age, stocking density, lighting regime, temperature and diet have an effect on the overall quality of chicken meat. Therefore the design of this experiment was such to try and limit the number of factors to production system and genotype. However, it is well known that genotype and production system effects growth rate and thus the chickens were slaughtered at different ages but as close as possible to a fixed weight to try and compensate for these effects. Even so, the Potchefstroom Koekoek still grew slower than the hybrids or broiler genotype and thus lighter and less fattened chickens were slaughtered (see Chapter 4). It is argued though that the difference in carcass weight would have a smaller effect than production system or genotype on the quality attributes.

As emphasised by many authors, it is well known that the chemical composition of the breast, thigh and drumstick muscles differs. Therefore only the effect of the genotype and production system would be discussed in more detail. It is also well known that feed has a critical effect on the chemical composition of chicken meat and in this investigation the same diet was fed to all the treatments (Chapter 4). The only difference was in the amount of grass/forage found in

the free range system. With the exception of the BFR, most of the grass for HFR and all of the grass for KFR had been consumed within 1 week (Chapter 4). Therefore it is argued that the effect of feed should be negligible in this investigation.

Effect of production system

Post mortem pH decline is one of the most important events in the conversion of muscle to meat, because of its effect on the meat texture, water holding capacity (WHC), cooking loss, juiciness, microbial stability and/or shelf-life and colour stability (Fletcher, 1999; Aberle *et al.*, 2001; Honikel, 2004). The rate of pH decline is dependent on the activity of glycolytic enzymes *post mortem* and the ultimate pH (pH_u) is determined by the initial glycogen reserves of the muscle at *mortem* (Lawrie & Ledward, 2006). A low pH is associated with poor meat quality and produces meat with lower WHC and functionality; a rapid decrease in pH *post mortem* can also cause similar negative quality attributes, this phenomenon is also known as PSE meat. A high pH_u produces DFD meat ($\text{pH} > 6$) with poor shelf life, making it a more favourable environment for bacterial spoilage (Aberle *et al.*, 2001; Honikel, 2004). In chicken meat the pH_u value is usually higher, ending at $\text{pH} \geq 6.0$ at 2-4h *post mortem*; chicken are known to enter *rigor mortis* rapidly (Honikel, 2004). The pH_u (Table 5.2) values for this study fall within the typical pH region for normal poultry meat ($\text{pH} \geq 6$). Castellini *et al.* (2002) also found pH values in the regions of 5.9 to 6.1 for breast meat and 6.1 to 6.3 for thigh and drumstick meat. Production system had an effect ($P \leq 0.05$) where free range reared birds either had a lower pH_u or a higher pH_u than the intensive reared birds. Extensive production systems are frequently characterized by a lower pH_u than intensive reared animals due to lower stress conditions and less consumption of glycogen reserves immediately prior to slaughter (Enfalt *et al.*, 1997, Castellini *et al.*, 2002, Fanatico *et al.*, 2007; Wang *et al.*, 2009). Another possible reason for the lower pH_u in the free range birds are that the increased activity of the birds during extensive rearing may result in more type IIa muscle fibres which are known to contain a higher content of glycogen and consequential a higher anaerobic glycolytic potential resulting in a lower pH_u (Lawrie & Ledward, 2006). The higher pH_u of the BFR can be ascribed to *ante mortem* stress. The free range chickens in this study were collected while they were running about, flapping their wings and the birds were therefore experiencing a certain amount of *ante mortem* stress; it was observed that during the growth phase the BFR were the least active group of birds. During these stress conditions there is a greater depletion of muscle glycogen *ante mortem* which will cause a higher pH_u . There was however no effect of production system for the genotype Koekoek and these results agrees with studies from Ponte *et al.* (2008), Husak *et al.* (2008) and Połtowicz & Doktor (2011) where production system played no significant role in muscle pH. From these results it could be concluded that some of the chickens may have experienced slight amounts of *ante mortem* stress during the capture and carrying and this had an effect on the ultimate muscle pH, also free range rearing of chickens may also result in lower, more favourable pH_u than intensive rearing.

Meat colour is the first meat quality characteristic observed by the consumer and is often the deciding point whether to purchase the specific product (Fletcher, 2002; Jahan *et al.*, 2005). Chicken meat is classified as a white meat which is low in redness (a^* value) and high in lightness (L^* value) when compared to red meat. The colour of meat is primarily affected by muscle fibre type, as well as genetics, myoglobin, *ante mortem* stress and pH (Fletcher, 1999; Fletcher, 2002).

Hue angle defines the colour of the meat and chroma defines colour intensity and saturation, therefore an increased hue angle will mean less red colour in the meat, while an increased chroma value will mean a more red colour in the meat. From this study free range chicken samples presented higher hue and lower chroma values ($P \leq 0.05$). Therefore these results indicate that the free range meat samples showed a less red colour than the intensive samples. This is also illustrated by the a^* value of this study where the free range samples was lower ($P \leq 0.05$) than the intensive samples. The free range birds in this study had a darker (lower L^*) and less yellow (lower b^*) ($P \leq 0.05$) value than the intensive birds. These results do not agree with Castellini *et al.* (2002); Nielsen *et al.* (2003); Jahan *et al.* (2004); Fanatico *et al.* (2005 ; 2007), Bogosavljević-Bosković *et al.* (2006) and Husak *et al.* (2008) where the a^* and b^* values of outdoor birds were found to be of a higher value, except in Husak *et al.* (2008) where lower b^* values were found. Fletcher (1999) and Taylor (2004) state that during exercise higher myoglobin red type I and IIa muscles form, causing the meat to have a more red (higher a^* and chroma value and lower hue angle) and darker (lower L^*) colour, therefore it was expected (but not found) that the free range birds would have a more red and darker colour than the intensive birds. In agreement with the results in this study, Castellini *et al.* (2002), Bogosavljević-Bosković *et al.* (2006) and Husak *et al.* (2008) also reported that the outdoor reared birds had less red and darker meat. A reason for the less red free range chicken meat could be due to the muscle pH, since, colour of meat and pH are highly correlated (Fletcher, 2002; Lawrie & Ledward, 2006). In Table 5.8 there is a strong positive correlation between pH and a^* value (red colour), as well as negative correlations between pH and the L^* value (lightness) and the Hue angle (less red colour), respectively. These correlations confirm that pH is partly responsible for the colour of chicken meat. Muscle pH_u is known to influence the myofibrils and consequently the water holding capacity and the colour of the meat. Lower muscle pH causes shrinkage of the contractile fibres, thereby reducing the WHC and altering the meat colour by increasing the light scattering (Warris, 2010). Furthermore, a lower pH_u reduces the importance of myoglobin in selectivity by absorbing green light, resulting in meat that appears less red (Castellini *et al.*, 2002). The HFR birds in this study had a lower pH_u than the HI birds, explaining the less red (lower a^*) colour of the meat. The thigh meat of the BFR was affected by production system as well as all the portions of the KFR with lower a^* values, this is unexpected since the free range samples had either the same pH_u value or higher (Table 5.2) than intensive reared samples and warrants further research. Another reason for the lower red colour could be due to the defeathering process, where chickens were dumped in hot water to remove the feathers; this hot water could have affected the colour readings as it was found that it was more

difficult to remove the feathers from the hybrid and Koekoek genotype causing these birds to be left in the water for a longer period. The darker colour (L^* value) of the free range birds can be ascribed to higher myoglobin concentration of the red type I and IIa fibres, due to more exercise. On the other hand, the lighter colour (L^* value) of intensive birds can be ascribed to a higher percentage fat content in the meat (Table 5.4) due to less activity of these birds. Lipids have high light reflection properties and cause the meat to appear lighter (Hedrick, 1983). The L^* value and fat were positively correlated (Table 5.8). The lower yellow colour of the free range meat in this study could be ascribed to less forage/pasture consumption than the mentioned studies where the free range meat was noted to be more yellow. The high carotenoid pigment content of the grass, in addition to the composition of the feed mixture, can cause an increase in the yellowness of chicken meat (Akiba *et al.*, 2001; Toyomizu *et al.*, 2001). All of the outdoor chickens of this study did have access to a forage area (21 days of age until slaughter) with green grass, but the BFR chickens did not consume a noticable amount of the grass and the HFR and KFR chickens consumed all of the grass within the first week (Refer to Figure 4.3 of Chapter 4). Consequently the grass should not have had an effect on the yellowness of the meat and no differences in the colour readings were noticed.

Since chickens are monogastric animals the effect of diet is usually reflected in the fatty acid profile and chemical composition. In this study the chickens were fed the same diet. This would explain why there were only a few differences found in the chemical composition as well as the fatty acid profile between genotypes and production system. The fat content of chicken meat differs between portions with breast meat containing approximately 3% fat, the drumstick between 3.5-5% and the thigh between 7-9%. The breast meat of chicken is generally considered low in fat (Parkhurst & Mountney, 1988; Mckee, 2003; Fanatico *et al.*, 2007). Similar results were found in this study (Table 5.4). It is expected that free range reared chicken meat would contain a lower fat content than intensive reared chicken meat, since higher activity would be likely in these birds. In this study there was an effect of production system on all the portions of the Koekoek genotype and the drumstick of the Broiler, where the intensive production system resulted in higher ($P \leq 0.05$) fat content than free range. These results confirm the findings of others where intensive birds had higher fat contents (Castellini *et al.*, 2002a, 2002b; Castellini *et al.*, 2006 Fanatico *et al.*, 2007; Bogosavljević-Bosković *et al.* 2009; Husak *et al.*, 2008). During growth, animal tissue follows a precise order of maturation of firstly the nervous tissue followed by bone then muscle and lastly fat (Warris, 2010). Referring back to chapter 4 (Fig. 4.2 and Tables 4.2 and 4.3), KFR showed better growth and higher body weight than KI. It could be possible that during the growth of the Koekoek, it favoured fat deposition in the breast and drumstick and lastly in the thigh. Since KI had a lower growth rate than KFR, and at the time of slaughter the KI did not deposit as much fat as the KFR in the thigh. Swatland (1994) stated that muscle growth and maturation in chickens follows a general trend of firstly occurring in the leg muscles, then the breast, and lastly the wing, but may differ in body proportions between genotypes.

Chicken meat is comprised of approximately 60-75% water (moisture); this also differs between portions (Kauffman, 2001; Keeton & Eddy, 2004). Similar results for moisture content were found in this study (Table 5.4). According to Pearson & Young (1989), the moisture content of meat is inversely correlated with the intramuscular fat (IMF) content. In this study a strong negative correlation (Table 5.8) was observed between IMF content and percentage moisture. There was also no effect ($P > 0.05$) of production system on the moisture content of the different meat portions (Table 5.4), except where KFR had higher levels than KI for the drumstick portion. This was expected since KFR had less ($P \leq 0.05$) fat in this portion than KI. The reason for the moisture content not differing could be ascribed to small or no differences in fat content between production systems. The same results were found by Bogosavljević-Bosković *et al.* (2009) where no difference between production systems was found for moisture content. There was no correlation (Table 5.8) between pH and moisture content.

Chicken meat is a valuable source of protein; 16-22% (Kauffman, 2001; Keeton, & Eddy, 2004). The protein content of the chicken samples in this study is similar to what is normally found (Table 5.4). It is known that the protein of meat decreases with an increase fat content (Keeton & Eddy, 2004), as illustrated further by the strong negative correlation (Table 5.8) between percentage fat and protein. Consequently it was expected that free range reared birds would contain more protein, due to their lower fat content, than intensive reared birds. From this study it is concluded that production system played a role in the protein content of the Koekoek thigh, most probably due to the lower fat content in the KI's thigh portion.

Meat contains approximately 1-2% ash, and the ash content of the chicken samples of this study, lies within this range (Table 5.4) (Keeton & Eddy, 2004; Lawrie & Ledward, 2006). There was a production system effect for the ash content ($P \leq 0.05$) for the Hybrid in the drumstick. A possible reason for this could be due to selected intake and digestion of small pieces of stones from the ground which were rich in minerals or due to higher haem pigmentation in the muscle caused by aerobic exercise of the drumstick (reviewed by Olsson & Pickova 2005). No other significant effect for ash content were detected and, these results agree with studies from Castellini *et al.*, (2002a), Fanatico *et al.*, (2005a, b), Kishowar *et al.*, (2005); Bogosavljević-Bosković *et al.*, (2006) and Fanatico *et al.*, (2006; 2007). Although there were statistically significant differences for the effect of production system in the nutritional value of meat, these differences were small and still fall within the standard nutritional value of chicken and it is questionable if the consumer would pick up these differences and whether it would have a significant effect on the diet and health of the consumer.

As previously mentioned; feed plays a very important role in determining the fatty acid composition of monogastric animals. Free range and intensive chickens were given the same feed (Table 5.1) which was mainly a maize based diet (~60%) with soybean full fat (~17%) for starter and grower diets with increased soybean (~36%) for the finisher diet. The main fatty acids present in chicken meat/fat are palmitic acid (C16:0), palmitoleic acid (C16:1), oleic acid (C18:1), stearic

acid (C18:0) and linoleic acid (C18:2) with oleic acid being the highest (Gunstone & Russell, 1954; Enser, 1999; Lawrie & Ledward, 2006). Similar results were found in this study and together palmitic acid, palmitoleic acid, oleic acid, stearic acid and linoleic acid comprised ~85% of the total fatty acids present in all the chicken meat samples (Table 5.5, 5.6 and 5.7). Fatty acid composition is described by two important ratios PUFA:SFA and n-6:n-3 (Enser *et al.*, 1998). Raes *et al.* (2004) suggest that a PUFA:SFA of >0.45 and a n-6:n-3 of <4 contributes to the healthiness of meat products. In this study there was an overall tendency for the intensive samples to score higher ($P \leq 0.05$) in SFA and MUFA and lower ($P \leq 0.05$) in PUFA than the free range samples. There was also a tendency for free range samples to score higher in the PUFA:SFA ratio. All the PUFA:SFA ratios in this study were > 0.45, however, all the free range samples have larger ratios than the intensive samples. Therefore the free range samples would be more favourable and healthier than the intensive samples as pertaining to the PUFA:SFA ratio. Similar results were also reported by Castellini *et al.* (2002), Jahan & Paterson (2007) and Husak *et al.* (2008).

A few studies have shown that free range chicken meat has a lower n-6:n-3 ratio, making it a more favourable product than intensive reared chicken meat (Castellini *et al.*, 2002; Jahan & Paterson, 2007; Husak *et al.*, 2008). It is expected that free range chicken meat products would contain more n-3 PUFA, since the major food source should be pasture/forage, which is a good source of α -linolenic acid (C18:3n-3) (Ponte *et al.*, 2008; Jahan & Paterson, 2007). In this study this was not the case; the n-6:n-3 ratio for all the meat samples was far above the recommended value (4); some of the free range samples even had higher ($P \leq 0.05$) n-6:n-3 ratios, especially the meat from the thigh and drumstick (Tables 5.5, 5.6 and 5.7), than the intensive samples. This despite the fact that pasture was available for the birds in the free range system, but as mentioned, this forage was consumed within the first week of outdoor access and only the KFR and HFR consumed the forage. The free range chickens thus had a very high n-6 and very low n-3 content. The linoleic acid (C18:2n6) (Tables 5.5, 5.6 and 5.7) is responsible for the high n-6 content in the chicken meat. This linoleic acid (C18:2n6c) originates from the maize component in the diet, which is high in linoleic acid (Storry & Rook 1965). Linoleic acid (C18:2n6) is the essential fatty acid needed for the synthesis of unsaturated eicosapentaenoic (EPA, 20:5n3) and docosahexaenoic acid (DHA, 22:6n3) (Enser, 1999). This study also showed low concentrations of EPA and DHA (Tables, 5.5, 5.6 and 5.7) in the chicken meat, indicating that few EPA and DHA were synthesised from the linoleic acid. Cook *et al.* (1993) reports that during stressful times, n-3 stimulates the body's physiological processes. Therefore it is speculated that the free range chickens were exposed to different and more extreme environmental factors compared to the intensive chickens and thus might have utilized n-3 as an essential nutrient in order to support their immune system against external stressful stimulations, rather than depositing it in the meat. The same results were also reported by Jahan *et al.* (2004) where extensive chicken meat contained lower n-3 fatty acids and higher contents of total PUFA, n-6 and n-6:n-3 ratios. Givens *et al.* (2011) also reported lower n-3 fatty acids, EPA and higher n-6:n-3 ratios in free range birds. It is also important to remember

that free range birds are usually given different diets than the normal conventional chickens, which are more suitable for free range rearing and might affect the fatty acid profile in different ways. For this study's purposes the feed given to the intensive and free range birds were of the same composition, to eliminate the effect of feed and to investigate only the effect of genotype and production system.

In this study there was also a trend for BI to contain higher ($P \leq 0.05$) oleic acid (C18:1n9c) and lower ($P \leq 0.05$) Linoleic acid (C18:2n6) than the BFR and all the other samples. This also caused the BI to contain higher ($P \leq 0.05$) MUFA and lower ($P \leq 0.05$) PUFA, as well as a lower n-6 content thereby lowering the n-6:n-3 ratio. As mentioned, the feed given to the chickens was mainly a maize based diet (~60%), and also contained lower levels of soybean (~17% and ~36%), which is high in oleic acid. Therefore the fatty acid content of the BI meat would have reflected this trend since the chickens were all fed the same diet and the diets' fatty acids are directly incorporated into the meat of monogastric animals (Tat *et al.*, 2007; Fébel *et al.*, 2008). This phenomenon was unexpected and would warrant further research.

Effect of genotype

The effect of genotype on the physical attributes and chemical composition was less substantial in comparison to that of production system. There was no effect of genotype ($P > 0.05$) detected in the muscle pH (Table 5.4) nor in the fatty acid composition (Tables 5.5, 5.6 and 5.7). However, it would seem that genotype had a slight effect on the colour, where Hybrid and Koekoek had a more green (lower a^*), more blue (lower b^*), and lower chroma than Broiler for all the portions, Hybrid also had higher hue values than Koekoek and Broiler genotypes. Koekoek genotype had a slightly darker (lower L^*) value than genotypes Broiler and Hybrid for portions thigh and drumstick (Table 5.5). The significant darker colour of the thigh and drumstick of the Koekoek could be related to *ante mortem* stress causing greater depletion of muscle glycogen, which causes a higher pH_u . However, the pH values (Table 5.4) did not differ ($P \leq 0.05$) in these two portions. Alternatively, the proportion of dark (red) and light (white) fibres types could also influence the colour – the Koekoek genotype is renowned for its ability to walk and maintain a high level of activity as it is actually a village chicken; this continuous activity would result in more dark (red) muscle fibres in the leg muscles. However, a less red (greener) colour was detected in the meat samples. A similar red colour (higher a^* value) was expected in the Hybrid and Koekoek genotypes (slower growing birds than broiler) due to higher myoglobin concentration in muscles of older birds (Miller, 1994; Husak *et al.*, 2008). Another possible reason of the difference in colour could be linked to the actual measurement of the colour. Bianchi and Fletcher (2002) and Sandusky and Heath (1996) found that meat sample thickness, position of the colour instrument on the meat as well as background colour can also radically affect instrumental colour readings. Although not quantified, Koekoek meat samples were overall thinner than the Boiler and Hybrid meat samples, which could have affected the instrumental colour. It is also important to keep in mind that these chickens were

dumped in hot water to remove feathers; this may have influenced the colour readings. Especially the Koekoek and Hybrid genotypes, where the temperature and time in the scalding water may have differed from broiler since their feathers did not remove as easily as the latter. Although there were differences in the colour readings between genotypes, these differences were so slight that it is doubtful that any consumer would have seen these differences with the naked eye.

It is clear that there was a genotype effect in the moisture content of the different portions. Broiler had higher ($P \leq 0.05$) moisture content than Koekoek in the breast portion, while the opposite was true in the thigh portion. Fanatico *et al.* (2005) established that slow growing birds had higher percentage moisture content than fast growing birds. The reason for the Koekoek to have a lower moisture content than the Broiler is due to the higher ($P \leq 0.05$) fat (Table 5.4) content in the breast; fat and moisture contents are negatively correlated to each other (Table 5.8). The differences in the fat content between species and muscles are often a result of the differences in the muscle fibre types. Slower growing birds (in this case the Koekoek) are older in age than the Broiler when they attain the targeted slaughter weight and therefore had more time to deposit fat in the breast muscle, also more red type IIa fibres could have formed in the breast meat of the Koekoek due to more frequent flapping of the wings (Swatland, 2000; Lawrie & Ledward, 2006). Although this behaviour was not quantified, it was observed and warrants further research. It is generally known that the red fibre muscles have a higher concentration of triglycerides and phospholipids than white muscles (Taylor, 2004; Wood *et al.*, 2003). However, the same trend was not observed in the Koekoek thigh meat, this could be due to the age of the bird and exercising of the muscle. As the Koekoek is late maturing, the birds were slaughtered before their growth inflection point (the age at which gain is at its maximum) at the stage where muscle development was favoured, due to the higher exercise level, before fat deposition occurred in the thigh (Gordon & Charles, 2002). Therefore it can be concluded that slower growing genotypes had higher moisture and lower fat content in the thigh, and faster growing genotypes score lower fat and higher moisture in the breast meat. Results by Fanatico *et al.* (2007) and Husak *et al.* (2008) confirmed that slower growing birds contained higher protein content, since they are late maturing and this increase is accompanied by a reduction in fat content.

CONCLUSIONS

The aim of this study was to perform an explorative study to determine the nutritional composition and physical attributes of the Broiler, Hybrid hybrid and Potchefstroom Koekoek reared in intensive and free range production systems.

The results of this study indicate that the effect of production system has a much larger influence on the physical and chemical composition of the meat than does genotype. Free range (outdoor access) resulted in lower muscle pH, darker (L^* value), less red (a^* value) and less yellow (b^* value) chicken meat. It also influenced the chemical composition in different carcass portions;

for example, a lower fat content in the thigh and higher protein in the breast of the Broiler. The Hybrid hybrid's chemical composition were not strongly influenced by the effect of production system. Rearing chickens in a free range environment increased the PUFA:SFA ratio, making it beneficial to human health. Genotype resulted in little difference other than affecting the lightness (L^* value) of the Koekoek and the a^* , b^* and hue values of the Hybrid hybrid, as well as the moisture, fat and protein content of the Broiler and moisture and fat content of the Koekoek. It would seem that Hybrid could possibly be a more suitable alternative for free range rearing than the Broiler genotype.

This study has shown that although there were significant differences between production systems and genotype, the differences were small, and thus the question arises whether a consumer would discern these differences when they consume the meat?

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CHAPTER 6

EFFECT OF REARING SYSTEM AND GENOTYPE ON THE SENSORY, PHYSICAL AND CHEMICAL QUALITY OF CHICKEN MEAT

ABSTRACT

Modern consumers are more health conscious and are shifting to more naturally produced products such as free range chicken. Commercial broilers strains are not suitable for free range rearing under local conditions and an alternative genotype is required, which will suite the South African market with the same meat quality as a broiler. The main objective of this study was to investigate the impact of genotype and production system on the sensory and chemical, including fatty acid, and instrumental meat quality characteristics of cooked chicken breasts (*pectolaris major* muscle). Three chicken genotypes, Broiler (fast growing bird), Hybrid (medium growing bird) and Potchefstroom Koekoek (slow growing bird) were reared in two production systems (intensive and free range) and fed the same formulated feed, *ad libitum*, and slaughtered at the age of 42, 56 and 91 days, respectively. Overall, the results of this study indicate that the differences were mainly genotype driven and not influenced by production system. Hybrid scored higher ($P \leq 0.05$) in chicken flavour and aroma than the Broiler and Koekoek. The Hybrid also had a higher percentage drip loss ($P \leq 0.05$) than Broiler and Koekoek. Broiler had a higher ($P \leq 0.05$) shear force value than Koekoek. With regard to production system, Broiler free range had a higher ($P \leq 0.05$) pH than Broiler intensive and higher ($P \leq 0.05$) n-6:n-3 ratios were found in the free range samples. Hybrid free range also had a higher ($P \leq 0.05$) fat content than Hybrid intensive. Although there were significant differences ($P \leq 0.05$) in sensory, chemical and physical attributes, the differences were so small that it could be argued that if these treatments were to be presented to the consumer, the latter would not notice any difference. None the less, it seems as if the Hybrid is the more suitable genotype for free range rearing in terms of aroma and flavour.

Keywords: Broiler, Potchefstroom koekoek, Hybrid hybrid, Meat quality, Production system, Genotype

INTRODUCTION

The modern consumer generally tends to be more aware of the health and nutritional value of the food consumed, is more animal welfare conscious, desires more naturally produced products and supports a more sustainable way of farming (Sundrum, 2001). Needless to say, together with these requirements, the consumer still expects a high standard regarding the taste of the food (Hoffman & Cawthorn, 2012). Similarly, as pertaining to the meat market, the interest of the consumer has grown towards quality aspects, rather than just quantity; this mind shift of the consumer has provided opportunities for market segmentation of speciality products, such as free range and organic. Although consumers expect a higher degree of welfare in free range chickens, this is only true if slow-growing chicken strains are used (Castellini *et al.*, 2008). Furthermore, consumers believe that the meat of free range chickens are healthier and tastier than birds reared in confinement and their overall perception is positive towards free range production systems (Fanatico *et al.*, 2007; Branciarri *et al.*, 2009).

In South Africa, the normal fast growing commercial broiler is currently used for both free range and intensive production. These chickens reach market weight as early as 28-32. As a result of the genetic selection, for fast growing animals, their behaviour has changed to reduced kinetic activity (Schütz & Jensen, 2001; Branciarri *et al.*, 2009). Therefore, broilers have a habit of staying indoors, being dormant and less active (Smith & Carpernter, 1970; Lewis *et al.*, 2005). This rapid growth has also led to concerns about animal welfare, since more leg disorders and a higher mortality rate occur. The latter, combined with the slower growth in extensive systems (i.e. older birds) resulting in higher costs for feed and less production cycles could result in higher production costs for the farmer. Also, Dransfield and Sosnicki (1999) reported that selection for fast growth and high yield may have a negative effect on the sensory and functional qualities of the meat; therefore it is possible that differences in meat quality may exist between fast and slow growing birds (Lonergan *et al.*, 2003).

The French *Label Rouge*, which requires outdoor access and a slow growing chicken genotype, has been very successful in the European sector, despite a higher retail price than intensive poultry products (Westgren, 1999). This high quality meat is more appropriate for a speciality gourmet market (Fanatico *et al.*, 2006). Farmers in South Africa utilize the same fast growing chicken lines, which has been bred specifically for intensive rearing for their extensive rearing methods. However, the suitability of these fast-growing broilers, for outdoor production and specialty markets, has not been extensively researched (Fanatico *et al.*, 2005). A few studies have evaluated the sensory quality of meat from fast, medium and slow growing birds, although the large variation in the production systems and type of birds (genotype, strain and age) used might skew the results (Touraille *et al.*, 1981; Castellini *et al.*, 2002b; Lonergan *et al.*, 2003; Fanatico *et al.*, 2006; Fanatico *et al.*, 2007). Such studies have never been done in a South African environment or on indigenous crossbred (with commercial broilers) chickens.

Castellini *et al.* (2008) reported that only slow-growing chicken strains can completely benefit from an extensive rearing system and that the fast growing strains are considered slow to adapt to change. Therefore, a slower growing chicken line is needed, that can adapt to the harsh conditions of the South African weather, can eat the forage in an extensive production system and still give the same meat quality as the broiler.

Tenderness, juiciness and flavour are the three important meat quality characteristics that determine consumer preference. It is important to evaluate the effects of genotype and production system on the sensory attributes and consumer preferences in order to assist producers in making informed choices regarding suitable production systems. The aim of this study was to investigate the effect of chicken genotype (Broiler, Ross x Potchefstroom Koekoek hybrid and Potchefstroom Koekoek) and production system (intensive or free range) on various meat sensory quality characteristics (flavour, aroma, initial juiciness, sustained juiciness, first bite and residue), physical measurements (pH, drip loss, cooking loss, WHC and Warner Bratzler instrumental tenderness) and chemical analysis (proximate and fatty acid composition) of chicken meat. This study excluded the quantification of the effect of gender (male or female) on the sensory quality characteristics and quality of the meat.

MATERIALS AND METHODS

Experimental birds, location, handling and slaughter procedure

Refer to Chapter 3 for materials and methods on experimental birds, location, handling and slaughtering procedure of the different chicken treatments.

Experimental units

At the meat science laboratory each carcass was skinned, the breast muscles removed by cutting from the *clavicale furcula* bone alongside the keel bone, the weight recorded and the meat vacuum-packed and frozen at -18°C until further analysis. The experimental units included six meat treatments which consisted of either a Broiler, a Hybrid or a Koekoek sample, each reared intensively or free range. The following acronyms are used to describe the six different treatments:

BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range; KI – Potchefstroom Koekoek intensive; KFR – Potchefstroom Koekoek free range.

Each experimental unit consisted of six replications (n = 6). The sensory analysis and physical measurements were performed on the cooked right breast, except for the pH which was measured

on the raw right breast, of the carcass while the proximate analyses were performed on the cooked left breast muscle of the carcass. Therefore, the analyses were performed on 36 birds.

Descriptive sensory analysis

Prior to conducting the sensory analyses, the breasts were removed from the freezer, maintained in their vacuum-packed bags, and defrosted for a 6 h period in a cold room (4°C). The sensory analysis consisted of six meat treatments with six consecutive replications of the sensory test, thus the experimental design is equal to 36 (6 treatments x 6 replications) treatment combinations. Before each of the sensory analysis sessions, the left and right breast muscles of the chicken were placed inside separately marked roasting oven bags (GLAD™, South Africa). The roasting bag with the meat samples was then placed on a stainless steel grid fitted onto an oven roasting pan. Thermocouple probes attached to a handheld digital temperature monitor (Hanna Instruments South Africa) were placed inside the centre of each of the meat samples, where after, the roasting bags were closed by the use of a metal tie (AMSA, 1995). The prepared samples were then placed inside two conventional ovens (Defy, Model 835) connected to a computerised monitoring system responsible for the regulation of the temperature (Viljoen *et al.*, 2001). The ovens were pre-heated to 160°C (AMSA, 1995). The meat samples were removed from the oven when an internal temperature of 75°C was attained (AMSA, 1995). After removal from the roasting bags the samples were allowed to equilibrate to ambient temperature (\pm 15 min) where after the right breasts were cut into 1 x 1 x 1 cm cubes, individually wrapped in aluminium foil squares and placed into glass ramekins with a randomized three digit code. Before the samples were served to the panellists for evaluation, the ramekins containing the meat samples were placed in a preheated oven (100°C) and reheated for 10 minutes where after they were immediately served to the panel.

Descriptive sensory analysis was performed on the six meat treatments. A panel of eight judges were selected based upon previous experience with the sensory analysis of meat. The panellists were trained according to the guidelines for sensory analysis of meat by the American Meat Science Association (AMSA, 1995) and the generic descriptive sensory analysis technique as described by Lawless and Heymann (2010). The panel undertook four training sessions and during each session the panellists received 1 x 1 x 1 cm cubes of meat from the six meat treatments using extra bird breasts from the same sample population. The panel decided on six sensory attributes: chicken aroma and flavour, as well as initial and sustained juiciness, tenderness (first bite) and residue. The definitions for each of the attributes are described in Table 6.1. The sensory attributes were analysed using an unstructured line scale with zero (low intensity) on the left hand side and 100 (high intensity) on the right hand side (AMSA, 1995).

The test re-test method was used for the sensory analysis and the six treatments were replicated six times. The panellists received the six meat treatments in a complete randomised order, while seated in individual tasting booths fitted with Compusense *five*® (Compusense, Guelph, Canada). The samples were analysed by completing the questionnaire assembled during

the training sessions. The sensory analysis sessions took place inside a temperature-controlled (21°C) and light-controlled (artificial daylight) room (AMSA, 1995). In order to cleanse and refresh their palates between evaluations the panellists received distilled water (21°C), half an apple and water biscuits (Carr, UK).

Table 6.1 Definition and scale of each attribute used for the descriptive sensory analysis of the chicken breasts

Sensory attribute	Description	Scale
Chicken Aroma	Aroma associated with chicken experienced as soon as the aluminium foil is removed	0 = Extremely bland 100 = Extremely intense
Chicken Flavour	Flavour associated with chicken prior to swallowing	0 = Extremely bland 100 = Extremely intense
Initial Juiciness	The amount of fluid exuded from the cut surface when pressed between the thumb and forefinger	0 = Extremely bland 100 = Extremely intense
Sustained Juiciness	The level of juiciness perceived after the first 5 chews using the molar teeth	0 = Extremely bland 100 = Extremely intense
First Bite	The impression of tenderness perceived after the first 5 chews using the molar teeth	0 = Extremely bland 100 = Extremely intense
Residue	The amount of residue left inside the mouth after the first 10 chews	0 = None 100 = Abundant

Physical measurements

pH

The pH of the six meat treatments, of each replication, was measured after thawing for 6 h. This measurement was done immediately after the meat was removed from the packaging and before the start of the cooking process. The pH was measured by means of a Crison pH 25 handheld portable pH meter (Lasec (Pty) Ltd, South Africa) that had been calibrated before each set of readings with the standard buffers (pH 4.0 and pH 7.0) provided by the manufacturer.

Drip loss

When the breast muscle was removed from the carcass, the weight (g) was documented before being vacuum-packed and frozen (-18°C) for approximately eight weeks. After the breast meat was defrosted in a fridge (4°C) for 6 h it was removed from the packaging and blotted dry with tissue paper and weighed again (g). The difference in the weight of each of the samples was calculated as the percentage drip (thaw) loss.

Cooking loss

The total weight loss during cooking (cooking loss) of the six treatments for the six replications was determined by using the method described by AMSA (1995). The breast muscle from each treatment was weighed (g) and documented before the cooking. After the cooking process, the

meat was removed from the cooking bag and allowed to cool down to ambient temperature, approximately 10-15 min. Before recording the final weight (g), the meat was blotted with tissue paper to remove excess moisture. The difference in the weight of each of the samples was calculated as the percentage cooking loss.

Water holding capacity

The water holding capacity test was performed according to Trout (1988). A cooked meat sample from each of the six treatments and six replications was used. The meat samples were cut into small pieces and 0.50 g thereof was placed on top of a filter paper (Laser, Paper Filter, grade 292, diameter 90 mm, part nr. FLAS3205090). The filter paper together with the meat sample was placed between two Perspex plates and a standard pressure of 588 N was enforced on the plates for 60 sec. A photograph was then taken of the filter paper showing the expelled liquid and meat areas. Image J Software (Version, 1.36b, NIH Image) were used to calculate the ratio between the liquid (outer) and meat (inner) purge area to indicate the water holding capacity of the meat sample.

Warner Bratzler Shear Force

The instrumental tenderness of the cooked meat samples was analysed by using the Warner Bratzler shear force (WBSF) test as described by Honikel (1998). Each of the six treatments (six replications) was used for the WBSF test. From the centre of the cooked meat sample, two adjacent 1 x 1 cm meat strips were cut parallel to the muscle fibre direction. Each of the meat strips were wrapped in aluminium foil and placed in the refrigerator (4°C) for 24 h. The meat strips were cut to produce a total of five rectangular cubes each with a length of two centimetres. An Instron Universal Testing Machine (Model 2519-107, Advanced Laboratory Solutions) fitted with a Warner-Bratzler (WB) blade was used to determine the force (Newton) necessary to shear a cooked rectangular meat cube perpendicular to the muscle fibre direction. The WB fitting was a 1 mm thick triangular (V-notch) blade with a semi-circular cutting edge (radius of 0.508 mm). The Instron Universal Testing Machine operated with a 2 kN compression load at a compression speed of 200 mm/min. The shear force value of each of the samples was recorded in Newton (N) and a higher value is indicative of a tougher sample.

Chemical analysis

Sample preparation

The cooked left breast muscle (sample) from each of the treatments were homogenised, vacuum sealed and placed in a -18°C freezer for one week until the chemical analysis were performed. The samples were thawed at 4°C for 6 h before each of the analysis. All of the analysis was performed in duplicate.

Proximate analysis

The proximate chemical analysis (%) consisted of total moisture, protein, lipid and ash content of the 36 chicken breast muscles. The moisture content (%) (100°C, 24 h) was analysed by drying a 2.5 g homogenized meat sample according to the Association of Official Analytical Chemists Standard Techniques (AOAC) method 934.01 (AOAC, 2002a). The ash content (%) (500°C, 6 h) of the moisture free sample was determined by the official AOAC method 942.05 (AOAC, 2002b). The total lipid (%) (intramuscular fat) content of a 5 g homogenised cooked meat sample was determined by using the chloroform:methanol (1:2 v/v) extraction method of Lee *et al.* (1996). To determine the total crude protein content (%), a 0.15 g defatted, dried and finely grounded meat sample was analysed using a Leco Nitrogen/Protein Analyser (FP- 528, Leco Corporation). The Leco was calibrated with EDTA calibration samples (Leco corporation, 3000 Lakeview Avenue, St. Joseph, MI 49085-2396, USA, Part no. 502-092, Lot no. 1055) before each of the analysis sessions. The Dumas combustion method 992.15 (AOAC, 2002c) was used and the results were expressed in % nitrogen (N). The nitrogen (%) was multiplied with the conversion factor of 6.25 to determine the crude protein (%) present in the meat sample.

Fatty acid analysis

The fatty acid profile of the six meat treatments of each replication was determined by using the fatty acid methyl esters (FAME) extraction method as described by Folch *et al.* (1957). A 2 g sample was extracted by the use of a chloroform:methanol (2:1 v/v) solution. The extraction solvent contained 0.01% butylated hydroxytoluene (BHT) as an antioxidant. A polytron mixer (WiggenHauser Homogenizer, D-500 fitted with a standard shaft 1; speed setting D) was used to homogenise the meat sample with the extraction solvent. Heptadecanoic acid (C17:0) was used as an internal standard (catalogue number H3500, Sigma-Aldrich Inc., 3050 Spruce Street, St. Louis, MO 63103, USA) to quantify the individual fatty acids present within the meat sample. A 250 µL sub-sample of the extracted lipids was transmethylated for 2h at 70°C and a methanol/sulphuric acid (19:1; v/v) solution (2 ml) was used as the transmethylating agent. After the mixture was cooled to room temperature, FAME with water and hexane followed. The top hexane phase was transferred to a spotting tube and dried under nitrogen. After drying 50 µL of Hexane were added to the FAME sample, and 1 µL of the sample was injected into the gas-chromograph (Termo-Electron S.p.A, Rodana, Milan, Italy) equipped with a 60 m BPX70 capillary column with an internal diameter of 0.25 mm and 0.25 µm film (SGE International, Ringwood, Victoria, Australia) and flame ionized detector. The gas flow rate of the carrier, hydrogen, was 30 mL/min. The temperature settings were as follows: initial temperature 60°C, injector 220°C, detector 260°C and the final temperature at 160°C. The injection volume was 1 µL with a run time of approximately 45 min. The FAME of the meat samples was compared to a standard FAME mixture (Supelco™ 37 Component FAME mix C4-C24, CAT, no. 47885-U. Supelco, North Harrison

Rd, Bellefonte, PA 16823-0048, USA) to identify the values. The results were recorded as percentage (%) of the total fatty acids.

Statistical analysis

Experimentally the study consisted of a randomised factorial block design with six treatments (3 Chicken lines x 2 rearing methods) and six replications. The trained panel consisted of eight judges and the six treatments were evaluated for the six sensory attributes established during the training sessions. The model for the experimental design is indicated by the following equation:

$$Y_{ij} = \mu + \beta_j + b_i + g_k + (bg)_{ik} + \varepsilon_{ijk}$$

The terms within the model are defined as; the overall mean (μ), the effect of the block (β_j), the effect of chicken genotype (b_i), the effect of rearing method (g_k), the effect of the interaction between chicken genotype and rearing method ($(bg)_{ik}$) and ε_{ijk} is the error associated with the effect of the block, chicken genotype, rearing method and interaction of the former and the latter. The sensory, physical and proximate data were subjected to an analysis of variance (ANOVA). The Shapiro-Wilk test was performed to test for normality (Shapiro & Wilk, 1965). All of the outliers were identified and removed before final analysis of the ANOVA's. The Least Significant Differences (LSD) was calculated at a 5% significance level to compare the treatment means. Results were defined as being not significant at $P > 0.05$ and significant at $P \leq 0.05$. Correlations were made between the sensory attributes, physical characteristics and proximate composition by means of the Pearson's correlation coefficient (Snedecor & Cochran, 1980). Principal Component Analysis (PCA) and Discriminant Analysis (DA) were performed to illustrate the relationships between the sensory, physical and proximate data (Rencher, 2002). SAS™ statistical software (Statistical Analysis System, Version, 9.2, 2006, SAS Institute Inc., CARY, NC, USA) was used for the ANOVA) while the multivariate statistical analysis was performed using XL STAT™ statistical software (Version 2011, Addinsoft, New York, USA).

RESULTS

Sensory attributes

The sensory means with standard deviations (\pm SD) of the six different treatments (t-tests) as affected by genotype and production system are presented in Table 6.2. Genotype within production system played a role ($P \leq 0.05$) on the attributes: chicken flavour, chicken aroma and residue. The HI sample scored the highest chicken flavour which differed ($P \leq 0.05$) from the BI and KI samples, which did not differ from each other. The HFR had a significantly ($P \leq 0.05$) higher chicken flavour than KFR. When considering the attribute chicken aroma, RKI scored higher

($P \leq 0.05$) than BI whilst the KI had the lowest score. With regard to residue, BI was significantly different ($P \leq 0.05$) from HI and KI, although KI and HI did not differ from each other. HFR had a lower ($P \leq 0.05$) residue score than BFR and KFR.

There were no differences between any of the genotypes or production systems as pertaining to initial juiciness. Although some of the treatments differed statistically when considering sustained juiciness and tenderness, they were still of similar magnitude, indicating that the samples were perceived to be very similar.

Table 6.2 The mean scores (\pm SD) for the sensory attributes of chicken breast as affected by genotype and production system

Attributes	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
Chicken flavour	54.2 ^{bc} \pm 10.44	56.0 ^{abc} \pm 9.04	58.0 ^a \pm 9.88	56.0 ^{ab} \pm 8.98	54.5 ^{bc} \pm 10.42	52.9 ^c \pm 10.48	3.62
Chicken aroma	51.9 ^{bc} \pm 5.35	53.4 ^b \pm 5.43	55.9 ^a \pm 5.63	53.4 ^{ab} \pm 6.29	51.0 ^c \pm 7.63	52.4 ^{bc} \pm 7.13	2.13
Initial juiciness	49.0 \pm 9.30	51.0 \pm 11.02	50.2 \pm 8.05	49.9 \pm 9.61	50.4 \pm 9.20	49.1 \pm 8.92	3.00
Sustained juiciness	47.6 ^b \pm 10.68	50.4 ^{ab} \pm 10.84	50.6 ^{ab} \pm 10.05	52.4 ^a \pm 6.86	51.7 ^{ab} \pm 9.55	49.8 ^{ab} \pm 10.50	4.04
Tenderness	64.9 \pm 14.73	63.7 \pm 10.43	64.0 \pm 11.05	65.0 \pm 10.08	62.0 \pm 11.45	60.6 \pm 14.23	4.04
Residue	14.1 ^a \pm 5.48	12.3 ^{ab} \pm 5.12	12.0 ^{bc} \pm 5.07	10.4 ^c \pm 5.47	12.5 ^b \pm 6.51	12.3 ^{ab} \pm 5.48	1.83

Standard Deviation (SD); LSD Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

* Means determined by an unstructured line scale (0 = low intensity, 100 = high intensity)

Physical attributes

The physical attributes measured included: pH, percentage drip loss, percentage cooking loss, water holding capacity and instrumental shear force of the meat samples. The t-tests with means and standard deviations (\pm SD) for the instrumental analysis of the different treatments as affected by genotype and production system are presented in Table 6.3. According to Table 6.3, the effect of production system only differed ($P \leq 0.05$) in the physical attribute pH within the broiler genotype; BFR measured significantly lower ($P \leq 0.05$) than BI.

With regard to the effect of genotype within production system, the attributes: % drip loss, % cooking loss, WHC and shearforce were affected. The HFR had significantly higher ($P \leq 0.05$) % drip loss than BFR and KFR. For % cooking loss and shear force, BI had higher values in both these attributes and differed significantly ($P \leq 0.05$) from KI. The KI had the highest WHC which differed ($P \leq 0.05$) from HI, although both these treatments did not differ ($P > 0.05$) from BI.

Table 6.3 The mean scores (\pm SD) for the physical characteristics of cooked chicken breast as affected by genotype and production system

Attributes	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
pH	5.8 ^b \pm 0.07	6.0 ^a \pm 0.11	6.0 ^a \pm 0.11	6.0 ^a \pm 0.07	5.9 ^{ab} \pm 0.05	5.9 ^{ab} \pm 0.07	0.10
% Drip loss	13.4 ^{ab} \pm 5.76	9.7 ^{bc} \pm 3.48	11.1 ^{ab} \pm 6.18	16.1 ^a \pm 10.51	6.8 ^{bc} \pm 2.46	6.2 ^c \pm 2.42	6.23
% Cooking loss	23.4 ^a \pm 5.77	25.9 ^a \pm 9.28	20.9 ^{ab} \pm 2.22	19.5 ^{ab} \pm 7.07	16.2 ^b \pm 1.29	21.4 ^{ab} \pm 5.56	6.95
WHC	3.3 ^{ab} \pm 0.47	3.4 ^{ab} \pm 0.37	3.1 ^b \pm 0.28	3.3 ^{ab} \pm 0.31	3.5 ^a \pm 0.12	3.1 ^{ab} \pm 0.31	0.40
Shear force (N)	24.0 ^a \pm 5.54	25.6 ^a \pm 7.32	20.3 ^{ab} \pm 3.29	20.9 ^{ab} \pm 4.40	17.9 ^b \pm 3.65	22.3 ^{ab} \pm 4.07	5.93

Standard Deviation (SD) ; Water holding capacity (WHC); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Proximate composition

The proximate analysis results of the cooked breast meat samples as affected by genotype and production system are indicated in Table 6.4. Neither genotype nor production system had any effect on the moisture and protein content of the cooked chicken breast muscle. With regard to the influence of production system within a genotype, there were no differences ($P > 0.05$) for any of the proximate components, except for intramuscular fat (%) content ($P \leq 0.05$) between HI (3.0 g/100g) and HFR (3.6 g/100 g).

Regarding the effect of genotype on the proximate components, only intramuscular fat (%) content and ash differed. The BI (3.9 g/100 g) with the higher intramuscular fat (%) content, differed ($P \leq 0.05$) from KI (3.1 g/100 g) and HI (3.0 g/100 g) although the latter two genotypes did not differ ($P > 0.05$) from each other (Table 6.4). BI, with the higher ash content, differed ($P \leq 0.05$) from KI, although neither of these two treatments differed from HI, which contained the highest ash content.

Table 6.4 The mean scores (\pm SD) for the proximate composition of cooked chicken breast as affected by genotype and production system

Attributes	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
Moisture	64.7 \pm 1.42	65.3 \pm 0.78	65.4 \pm 1.25	65.3 \pm 1.86	65.3 \pm 1.38	63.9 \pm 1.69	1.76
Protein	30.7 \pm 1.14	30.3 \pm 0.64	31.4 \pm 1.90	30.9 \pm 1.98	31.5 \pm 0.75	32.8 \pm 1.33	1.53
Fat	3.9 ^a \pm 0.65	3.9 ^a \pm 0.49	3.0 ^c \pm 0.36	3.6 ^{ab} \pm 0.47	3.1 ^{bc} \pm 0.46	3.2 ^{bc} \pm 0.36	0.56
Ash	1.3 ^a \pm 0.09	1.4 ^{ab} \pm 0.11	1.4 ^{ab} \pm 0.11	1.4 ^{ab} \pm 0.16	1.2 ^b \pm 0.09	1.3 ^b \pm 0.09	0.14

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Fatty acid composition

The mean percentages and standard deviations (\pm SD) for the fatty acid composition of the cooked meat of the six different treatments are presented in Table 6.5. All of the fatty acids present in the treatments were analysed and are presented in the table although only specific fatty acids will be discussed. In general the fatty acid composition of the different treatments did not differ significantly.

The concentration of polyunsaturated fatty acid (PUFA) was the highest, followed by saturated fatty acid (SFA) and then monounsaturated fatty acid (MUFA) in all the chicken samples. When considering the overall SFA content, there were no significant difference between the different chicken samples ($P > 0.05$). As pertaining to production system, there was a difference ($P \leq 0.05$) between KI and KFR for Stearic acid (C18:0). There were also differences ($P \leq 0.05$) between production systems within a genotype for the fatty acids Arachidic acid (C20:0) and Behenic acid (C22:0) between Hybrid and Broiler respectively, although there were significant differences, these are very small. There were minor, less than 1.0%, but significant differences ($P \leq 0.05$) for genotype within a production system for the individual SFAs Myristic acid (C14:0), Arachidic acid (C20:0), Heneicosanoic acid (C21:0) and Behenic acid (C22:0).

The effect of genotype within a production system on the overall MUFA content indicated that HI and KI differed significantly ($P \leq 0.05$) from BI. Oleic acid (C18:1n9c) was the major MUFA found with the highest concentration in all the chicken treatments with differences ($P \leq 0.05$) between genotypes within a production system. The BI with the highest percentage differed ($P \leq 0.05$) from HI and BFR differed ($P \leq 0.05$) from KFR. Although there were differences ($P \leq 0.05$) for the effect of genotype within a production system for the fatty acids Elaidic acid (C18:1n9t), Eicosenoic acid (C20:1n9) and Erucic acid (C22:1n9), the difference were very minor ($< 0.1\%$). There were also differences ($P \leq 0.05$) between production system within a genotype for the individual MUFA Eicosenoic acid (C20:1n9) and Erucic acid (C22:1n9), but these were also very minor ($< 0.1\%$ difference).

Regarding the total PUFA content; genotype and production system had an effect ($P \leq 0.05$). HFR, with a higher PUFA content differed ($P \leq 0.05$) from BFR whilst HFR also differed ($P \leq 0.05$) from HI (Table 6.5). For the individual PUFA's for production system within a genotype, Linoleic acid (C18:2n6c) differed ($P \leq 0.05$) between HFR, with the higher concentration, and HI. Other individual fatty acids that differed ($P \leq 0.05$) for production system within a genotype were L-Linolenic acid (C18:3n6), α -Linolenic acid (C18:3n3); Docosadienoic acid (C22:2), Eicosapentaenoic acid (EPA; C22:5n3) and Docosahexaenoic acid (DHA; C22:6n3), but again the differences were small ($< 1.0\%$). There were also small ($< 1.0\%$), but significant ($P \leq 0.05$) differences for the individual fatty acids L-Linolenic acid (C18:3n6), α -Linolenic acid (C18:3n3), Eicosatrienoic acid (C20:3n6), Docosadienoic acid (C22:2), C22:5n3 (Docosapentaenoic acid) and DHA (C22:6n3) for the effect of genotype within a production system.

The polyunsaturated to saturated fatty acid ratio (PUFA:SFA) did not differ ($P > 0.05$) for any of the treatments. The omega 3 to omega 6 ratio (n-6:n-3) did however differ ($P \leq 0.05$) for the effect of production system. For the effect of production system within a genotype, BFR had a higher $P \leq 0.05$ n-6:n-3 ratio than BI. HFR also had a higher ($P \leq 0.05$) ratio than HI.

Table 6.5 The mean scores (\pm SD) for the fatty acid composition (% of total fatty acids) of cooked chicken breast as affected by genotype and production system

Fatty acid	Broiler		Hybrid		Koekoek		LSD
	Intensive	Free range	Intensive	Free range	Intensive	Free range	
SFA							
C14:0	0.4 ^{ab} \pm 0.12	0.4 ^{ab} \pm 0.10	0.5 ^{ab} \pm 0.20	0.5 ^a \pm 0.13	0.5 ^{ab} \pm 0.25	0.3 ^b \pm 0.21	0.21
C15:0	0.1 \pm 0.2	0.1 \pm 0.03	0.13 \pm 0.04	0.1 \pm 0.02	0.1 \pm 0.03	0.1 \pm 0.03	0.04
C16:0	22.0 \pm 2.85	21.9 \pm 5.53	25.7 \pm 7.63	19.0 \pm 4.91	24.0 \pm 6.33	18.7 \pm 10.0	7.77
C18:0	9.8 ^b \pm 1.22	10.3 ^{ab} \pm 0.5	10.3 ^{ab} \pm 1.16	10.2 ^{ab} \pm 1.00	9.5 ^b \pm 1.04	11.3 ^a \pm 1.47	1.31
C20:0	0.3 ^{ab} \pm 0.03	0.4 ^a \pm 0.09	0.3 ^b \pm 0.08	0.4 ^a \pm 0.12	0.3 ^b \pm 0.07	0.2 ^b \pm 0.07	0.09
C21:0	0.1 ^b \pm 0.01	0.1 ^a \pm 0.01	0.1 ^b \pm 0.01	0.1 ^b \pm 0.01	0.1 ^b \pm 0.01	0.1 ^b \pm 0.01	0.01
C22:0	1.2 ^a \pm 0.23	1.1 ^{ab} \pm 0.25	1.13 ^{ab} \pm 0.18	0.9 ^{bc} \pm 0.22	0.9 ^c \pm 0.19	0.7 ^c \pm 0.23	0.27
C24:0	0.1 \pm 0.02	0.1 \pm 0.02	0.1 \pm 0.01	0.1 \pm 0.02	0.1 \pm 0.02	0.1 \pm 0.03	0.02
MUFA							
C14:1	0.1 \pm 0.02	0.0 \pm 0.01	0.1 \pm 0.02	0.0 \pm 0.02	0.1 \pm 0.02	0.0 \pm 0.02	0.03
C16:1n7	1.6 \pm 0.58	1.6 \pm 1.18	1.4 \pm 0.40	1.3 \pm 1.12	1.7 \pm 0.50	1.2 \pm 1.04	1.08
C18:1n9t	0.1 ^{ab} \pm 0.06	0.1 ^a \pm 0.02	0.1 ^{ab} \pm 0.06	0.1 ^b \pm 0.02	0.11 ^{ab} \pm 0.06	0.1 ^b \pm 0.03	0.07
C18:1n9c	24.6 ^a \pm 3.84	22.4 ^{ab} \pm 3.45	20.0 ^{bc} \pm 3.15	20.7 ^{abc} \pm 3.8	19.5 ^{bc} \pm 3.41	17.6 ^c \pm 5.34	4.60
C20:1n9	0.1 ^{abc} \pm 0.01	0.1 ^c \pm 0.01	0.1 ^c \pm 0.01	0.1 ^{ab} \pm 0.01	0.1 ^{bc} \pm 0.01	0.1 ^a \pm 0.01	0.01
C22:1n9	0.1 ^{bc} \pm 0.02	0.1 ^a \pm 0.02	0.1 ^{ab} \pm 0.02	0.1 ^{bc} \pm 0.02	0.1 ^b \pm 0.02	0.1 ^c \pm 0.02	0.02
C24:1n9	0.2 ^a \pm 0.02	0.1 ^{ab} \pm 0.02	0.1 ^{ab} \pm 0.03	0.1 ^b \pm 0.03	0.1 ^{ab} \pm 0.02	0.1 ^b \pm 0.03	0.03
PUFA							
C18:2n6t	0.0 \pm 0.01	0.0 \pm 0.01	0.0 \pm 0.01	0.0 \pm 0.01	0.0 \pm 0.01	0.0 \pm 0.01	0.01
C18:2n6c	28.2 ^b \pm 2.79	31.2 ^{ab} \pm 2.99	28.4 ^b \pm 5.62	34.9 ^a \pm 2.11	31.6 ^{ab} \pm 4.25	32.9 ^{ab} \pm 5.72	4.91
C18:3n6	3.2 ^{abc} \pm 0.50	3.8 ^{ab} \pm 0.63	3.0 ^{bc} \pm 0.83	4.0 ^a \pm 0.41	3.5 ^{abc} \pm 0.79	3.0 ^c \pm 0.63	0.78
C18:3n3	0.3 ^a \pm 0.05	0.3 ^b \pm 0.05	0.3 ^b \pm 0.06	0.3 ^b \pm 0.05	0.3 ^b \pm 0.04	0.3 ^b \pm 0.10	0.08
C20:2	0.5 ^a \pm 0.12	0.6 ^a \pm 0.06	0.5 ^{ab} \pm 0.08	0.5 ^{ab} \pm 0.16	0.4 ^{ab} \pm 0.10	0.4 ^b \pm 0.12	0.13
C20:3n6	3.3 ^{bc} \pm 0.75	2.9 ^c \pm 0.47	4.4 ^a \pm 0.77	4.2 ^{ab} \pm 0.96	4.3 ^{ab} \pm 0.88	3.9 ^{abc} \pm 1.39	1.08
C20:3n3	0.1 \pm 0.05	0.1 \pm 0.02	0.1 \pm 0.02	0.1 \pm 0.03	0.1 \pm 0.02	0.1 \pm 0.02	0.04
C20:4n6	0.1 \pm 0.02	0.1 \pm 0.01	0.1 \pm 0.02	0.1 \pm 0.01	0.1 \pm 0.01	0.1 \pm 0.02	0.02
C20:5n3	0.3 \pm 0.07	0.3 \pm 0.06	0.3 \pm 0.06	0.3 \pm 0.06	0.3 \pm 0.06	0.2 \pm 0.07	0.07
C22:2	0.1 ^b \pm 0.01	0.1 ^a \pm 0.02	0.1 ^b \pm 0.02	0.1 ^b \pm 0.01	0.1 ^b \pm 0.01	0.1 ^b \pm 0.02	0.02
C22:5n3	0.4 ^a \pm 0.10	0.3 ^{bc} \pm 0.05	0.3 ^b \pm 0.05	0.2 ^{bc} \pm 0.09	0.2 ^c \pm 0.06	0.2 ^c \pm 0.10	0.09
C22:6n3	1.9 ^{ab} \pm 0.30	1.0 ^d \pm 0.21	2.0 ^a \pm 0.47	1.5 ^{bc} \pm 0.43	1.7 ^{abc} \pm 0.32	1.4 ^d \pm 0.50	0.46
SFA	34.1 \pm 2.75	34.3 \pm 5.92	38.2 \pm 7.32	31.6 \pm 4.76	35.4 \pm 6.54	31.9 \pm 7.89	7.34
MUFA	27.1 ^a \pm 3.78	24.9 ^{ab} \pm 3.12	22.2 ^b \pm 1.91	22.3 ^b \pm 3.34	22.1 ^b \pm 2.82	21.6 ^b \pm 4.20	3.89
PUFA	38.7 ^b \pm 2.52	40.5 ^b \pm 3.70	39.4 ^b \pm 5.79	46.0 ^a \pm 2.65	42.4 ^{ab} \pm 4.16	43.7 ^{ab} \pm 6.64	5.30
PUFA:SFA	1.1 \pm 0.12	1.2 \pm 0.33	1.1 \pm 0.34	1.5 \pm 0.34	1.3 \pm 0.40	1.4 \pm 0.55	0.43
n-6:n-3	11.2 ^d \pm 3.54	20.1 ^a \pm 3.16	12.6 ^{dc} \pm 3.76	18.6 ^{ab} \pm 2.98	16.3 ^{abc} \pm 3.38	15.7 ^{bc} \pm 1.13	3.95

Saturated Fatty Acids (SFA); Monounsaturated Fatty Acids (MUFA); Polyunsaturated Fatty Acids (PUFA); Polyunsaturated to Saturated Fatty Acid Ratio (PUFA:SFA); Omega 6 to Omega 3 ratio (n6:n3); Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in rows with different superscripts are significantly different at $P \leq 0.05$

Correlations

The correlation matrix showing the Pearson correlation coefficients (r) and the P-values for all the samples are depicted in Table 6.6. A principal component analysis (PCA) bi-plot of the sensory,

physical and proximate data is illustrated in Fig. 6.1a and demonstrates the correlations between the different attributes. The combination of the two factors F1 and F2 explained 31.86% of the total variance of which F1 and F2 explained 18.75% and 13.10%, respectively. The PCA plot seems to indicate that there were no definite trends between any of the treatments, although there was a slight trend where BI and BFR are situated at the top half of the plot, and KI and KFR are situated at the bottom half of the plot.

The DA plot of the sensory, physical and proximate data is illustrated in Fig. 6.1b. The DA was used to visualize the observations and to analyse the differences between groups of data in order to see the relationship between groups. The combination of the two factors F1 and F2 explained 80.91% of the total variance of which F1 and F2 explained 52.30% and 28.61%, respectively. The DA plot indicates, and this corresponds with what is seen in the PCA, that the treatments are separated by genotype rather than production system, even though the genotypes are grouped and overlap with each other, with the exception of BFR. This overlapping again indicates that the treatments were very similar in terms of meat quality and barely distinguishable.

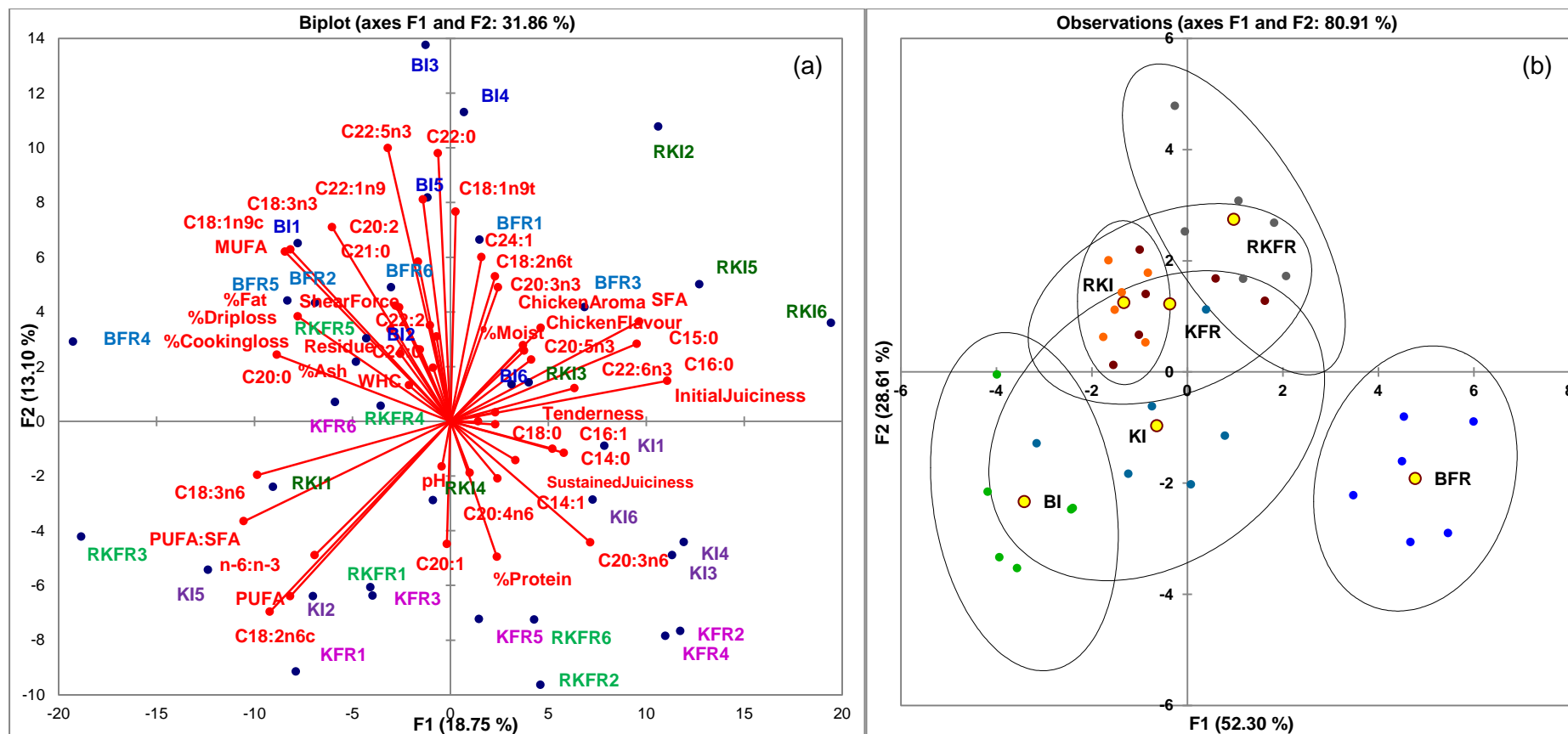


Figure 6.1 (a) Principal component analysis bi-plot of sensory attributes, physical characteristics, proximate analysis and fatty acid composition of cooked chicken breast as affected by genotype and production system; (b) Discriminant analysis plot of sensory attributes, physical characteristics, proximate analysis and fatty acid composition of cooked chicken breast as affected by genotype and production system. (BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range; KI – Potchefstroom Koekoek intensive; KFR – Potchefstroom Koekoek free range)

Table 6.6 Correlation matrix showing the Pearson correlation coefficients (r) and the P-values for all the samples

Variables	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1.Chicken A	1	0.043	0.504	0.254	0.361	-0.197	0.274	0.033	0.101	-0.166	-0.055	0.206	0.363	-0.157	-0.056	0.046	0.098
	0	0.804	0.002	0.135	0.031	0.250	0.106	0.850	0.558	0.333	0.749	0.227	0.030	0.361	0.746	0.791	0.568
2.Initial J	0.043	1	0.179	0.165	0.032	-0.169	0.063	0.113	0.191	-0.013	0.036	0.472	0.058	-0.421	-0.175	-0.332	0.175
	0.804	0	0.297	0.335	0.851	0.324	0.717	0.512	0.263	0.941	0.835	0.004	0.736	0.011	0.306	0.048	0.306
3.Chicken F	0.504	0.179	1	0.700	0.545	-0.536	0.232	-0.072	0.164	-0.310	-0.081	0.102	0.279	-0.166	0.088	-0.272	0.244
	0.002	0.297	0	< 0.0001	0.001	0.001	0.173	0.678	0.340	0.065	0.640	0.553	0.100	0.334	0.609	0.109	0.152
4.Sustained J	0.254	0.165	0.700	1	0.716	-0.659	0.162	-0.232	0.053	-0.045	-0.171	-0.003	0.084	-0.214	0.240	-0.284	0.360
	0.135	0.335	< 0.0001	0	< 0.0001	< 0.0001	0.345	0.173	0.760	0.796	0.320	0.988	0.628	0.210	0.159	0.093	0.031
5.Tenderness	0.361	0.032	0.545	0.716	1	-0.678	0.190	-0.112	0.054	0.162	-0.133	-0.040	0.204	-0.074	0.104	-0.225	0.136
	0.031	0.851	0.001	< 0.0001	0	< 0.0001	0.268	0.514	0.756	0.346	0.441	0.815	0.232	0.669	0.546	0.187	0.430
6.Residue	-0.197	-0.169	-0.536	-0.659	-0.678	1	-0.338	0.108	-0.080	0.105	0.006	0.069	-0.103	0.121	-0.216	0.298	-0.268
	0.250	0.324	0.001	< 0.0001	< 0.0001	0	0.044	0.529	0.644	0.542	0.971	0.690	0.550	0.483	0.206	0.078	0.113
7.pH	0.274	0.063	0.232	0.162	0.190	-0.338	1	-0.186	-0.161	-0.048	0.090	0.091	0.239	-0.072	-0.025	0.021	0.157
	0.106	0.717	0.173	0.345	0.268	0.044	0	0.278	0.349	0.779	0.603	0.596	0.161	0.678	0.886	0.901	0.362
8.%Driploss	0.033	0.113	-0.072	-0.232	-0.112	0.108	-0.186	1	-0.073	0.080	0.154	0.104	0.396	0.256	-0.270	0.176	-0.027
	0.850	0.512	0.678	0.173	0.514	0.529	0.278	0	0.671	0.644	0.370	0.545	0.017	0.131	0.111	0.304	0.878
9.%Cookingloss	0.101	0.191	0.164	0.053	0.054	-0.080	-0.161	-0.073	1	-0.218	0.338	-0.298	0.184	0.335	0.126	-0.146	0.001
	0.558	0.263	0.340	0.760	0.756	0.644	0.349	0.671	0	0.202	0.044	0.078	0.282	0.046	0.463	0.395	0.995
10.WHC	-0.166	-0.013	-0.310	-0.045	0.162	0.105	-0.048	0.080	-0.218	1	-0.018	0.315	0.072	0.145	-0.458	0.177	-0.008
	0.333	0.941	0.065	0.796	0.346	0.542	0.779	0.644	0.202	0	0.916	0.062	0.676	0.400	0.005	0.301	0.964
11.ShearForce	-0.055	0.036	-0.081	-0.171	-0.133	0.006	0.090	0.154	0.338	-0.018	1	0.085	0.023	0.247	-0.255	-0.015	-0.138
	0.749	0.835	0.640	0.320	0.441	0.971	0.603	0.370	0.044	0.916	0	0.621	0.894	0.146	0.133	0.929	0.421
12.%Moist	0.206	0.472	0.102	-0.003	-0.040	0.069	0.091	0.104	-0.298	0.315	0.085	1	-0.099	-0.366	-0.752	0.041	0.100
	0.227	0.004	0.553	0.988	0.815	0.690	0.596	0.545	0.078	0.062	0.621	0	0.565	0.028	< 0.0001	0.811	0.560
13.%Ash	0.363	0.058	0.279	0.084	0.204	-0.103	0.239	0.396	0.184	0.072	0.023	-0.099	1	0.259	-0.009	0.297	0.002
	0.030	0.736	0.100	0.628	0.232	0.550	0.161	0.017	0.282	0.676	0.894	0.565	0	0.127	0.959	0.079	0.991
14.%Fat	-0.157	-0.421	-0.166	-0.214	-0.074	0.121	-0.072	0.256	0.335	0.145	0.247	-0.366	0.259	1	-0.284	0.313	-0.216
	0.361	0.011	0.334	0.210	0.669	0.483	0.678	0.131	0.046	0.400	0.146	0.028	0.127	0	0.094	0.063	0.206
15.%Protein	-0.056	-0.175	0.088	0.240	0.104	-0.216	-0.025	-0.270	0.126	-0.458	-0.255	-0.752	-0.009	-0.284	1	-0.272	0.047
	0.746	0.306	0.609	0.159	0.546	0.206	0.886	0.111	0.463	0.005	0.133	< 0.0001	0.959	0.094	0	0.109	0.786
16.MUFA	0.046	-0.332	-0.272	-0.284	-0.225	0.298	0.021	0.176	-0.146	0.177	-0.015	0.041	0.297	0.313	-0.272	1	-0.399
	0.791	0.048	0.109	0.093	0.187	0.078	0.901	0.304	0.395	0.301	0.929	0.811	0.079	0.063	0.109	0	0.016
17.PUFA	0.098	0.175	0.244	0.360	0.136	-0.268	0.157	-0.027	0.001	-0.008	-0.138	0.100	0.002	-0.216	0.047	-0.399	1
	0.568	0.306	0.152	0.031	0.430	0.113	0.362	0.878	0.995	0.964	0.421	0.560	0.991	0.206	0.786	0.016	0

The numbers in the first row correlates with the numbers of the attributes in the first column. The letters following the attribute descriptors "A", "F", and "J" refers to aroma, flavour and juiciness respectively. The first row of each attribute shows the Pearson correlation coefficient (r) and the second row of each attribute shows the P-value. All the values in bold are significant at a level of $P \leq 0.05$.

DISCUSSION

There are many factors such as production system, genotype, age, stocking density, lighting, temperature and diet that may well have an effect on the overall quality of chicken breasts. Therefore this experiment was designed to limit the number of factors to production system and genotype. However, it is well known that genotype and production system effects growth rate and therefore the chickens were slaughtered at different ages but at more or less the same weight in order to compensate for these effects. Even so, the Potchefstroom Koekoek still grew slower than both the hybrids and broiler genotypes and as a result lighter chickens were slaughtered. It is argued though that the difference in carcass weight would have a smaller effect than production system or genotype on the quality attributes.

Effect of genotype

Tenderness is the ease of shearing, cutting or grounding meat during mastication and consumption (Gillespie, 1960; Forrest *et al.*, 1975). This attribute is considered to be the most important by consumers and the main driving force for the final approval of poultry meat (Fletcher, 2002; Boleman *et al.*, 1997). In this study, no correlation was found between sensory tenderness and instrumental tenderness (shear force) (Table 6.6). However, a strong negative correlation between sensory tenderness and residue (Table 6.6) (Fig. 6.1a) was found indicating that a tender meat sample resulted in less residue.

For genotype, there was no correlation between tenderness and shear force. However, there might be a trend for Broiler ($P = 0.0545$; Table 6.2) to measure higher for shear force than Koekoek and Hybrid resulting in BI and BFR being more closely associated with shear force (Fig. 6.1a). The panel also scored the Broiler less tender than Koekoek and Hybrid (Table 6.2). Tenderness is affected by the maturity of connective tissue, as well as the contractile state of the myofibrillar proteins (Fletcher, 2002). However, it was expected that the slower growing birds would be less tender than the fast growing birds, since the former were older in age and should have a higher concentration of mature collagen cross linkages at the time of slaughter (Fletcher, 2002). In addition, the Broilers had a higher intramuscular fat (%) content than the other two genotypes (Table 6.4) and previous studies on chicken and duck showed that a higher fat content is associated with higher meat tenderness (Zhao *et al.*, 2007; Chartrin *et al.*, 2006). This study's results do not agree with Castellini *et al.* (2002b), Wattanachant *et al.* (2004) and Fanatico *et al.* (2005) where the meat of faster growing chicken genotypes or young birds were more tender than that of slow growing or older chicken genotypes. However, results from Farmer *et al.* (1997), Kishowar *et al.* (2005); Fanatico *et al.* (2006, 2007) and Husak *et al.* (2008) showed that breast meat from slower growing birds were more tender than fast growing birds. This phenomenon could be due to muscle fibre size. It is generally known that the latter is associated with genotype and can influence the meat tenderness positively or negatively. Muscle fibres of fast growing birds

are more numerous and have a greater diameter than those found in slow growing birds. Broilers are selected for their fast growth, resulting in extreme hypertrophy of muscle fibres which is an indicator of poor meat quality and less tender meat (Fanatico *et al.*, 2007). Another reason for the difference in tenderness could be due to the reduced proteolytic activity of modern fast growing chicken lines to produce bigger muscle mass. This reduced proteolytic activity leads to less tenderization of the meat during *post mortem* proteolysis (Dransfield & Sosnicki, 1999).

In this study there was a positive correlation (Table 6.6) between shear force and cooking loss (%). Indicating that when a meat sample had an increased cooking loss (%), a decrease in tenderness could be expected, this could be the result of concentration of collagen fibres, etc. due to the moisture loss experienced in the meat. In this study, Broilers had a higher ($P \leq 0.05$) cooking loss (Table 6.3; Fig. 6.1a) than Hybrid and Koekoek genotypes. The amount of moisture present in meat causes a dilution effect of muscle fibres present in a specific area (Thomas *et al.*, 2004). It can be assumed that when a piece of chicken meat is less juicy or dry, the tougher the meat will be and the more residue the meat will have. This assumption is further substantiated by the strong positive correlation between sustained juiciness and tenderness (Table 6.6) and the strong negative correlation between sustained juiciness and residue (Table 6.6). This is also illustrated in the PCA bi-plot (Fig. 1a) where residue is situated on the opposite side of the plot to initial juiciness, sustained juiciness and tenderness.

Muscle pH is one of the most important meat quality characteristics, because of its effect on the meat texture, water holding capacity (WHC), cooking loss, juiciness, microbial stability and/or shelf-life and colour (Fletcher, 1999; Aberle *et al.*, 2001; Honikel, 2004). In this study genotype had no effect ($P > 0.05$) on the pH of the meat, therefore no genotype effect would be expected on the cooking loss, WHC, sustained- and initial juiciness.

Initial juiciness in meat is defined as the moisture released during mastication, whereas the stimulation of saliva secretion due to the presence of intramuscular fat is defined as sustained juiciness (Lawrie & Ledward, 2006). According to Offer and Trinick (1983) the initial juiciness and WHC of meat is positively correlated, consequently if the WHC is poor, the meat will lack juiciness. WHC gives an indication of the amount of water present in the meat following the cooking process. The latter causes moisture loss which results in a significant increase in the intramuscular fat (%) content of the cooked meat compared to the raw meat, typically meat with a higher cooking loss will have a higher intramuscular fat (%) content (Alfaia *et al.*, 2010). It is important to keep in mind that these chicken meat samples were not enhanced with added water, salt and phosphates to which consumers are familiar with, nor were the samples prepared with ingredients such as salt or any other seasoning that may stimulate saliva secretion and thus give an impression of juiciness.

There were no differences ($P > 0.05$) between sustained juiciness and initial juiciness (Table 6.2) for the effect of genotype within a production system for any of the chicken samples. It was expected that the faster growing birds (Broiler) would be more juicy, since they had

significantly higher ($P \leq 0.05$) intramuscular fat (%) content (Table 6.4), the latter normally contributes to the juiciness (Fanatico *et al.*, 2005). This would also explain why no correlation (Table 6.6) was found between sustained juiciness and high intramuscular fat (%) content (Fig 1a).

This study indicated that there was a genotype effect for percentage cooking loss; KI scored lower and significantly different ($P \leq 0.05$) from BI (Table 6.3). This result was unexpected, since there was no difference ($P > 0.05$) in the pH (Table 6.3) for these treatments. There is no explanation for this phenomenon, and further research is required. It was also expected that the slower growing Hybrid and Koekoek would have a higher cooking loss, since a low pH is caused by the higher activity and stress experienced by these birds (Castellini *et al.*, 2002a; Lonergan *et al.*, 2003; Fanatico *et al.*, 2005; Lawrie & Ledward, 2006). There was also a genotype difference ($P \leq 0.05$) between HFR and BFR for the % drip loss. This difference in drip loss could be explained by the size of the breast fillets of Hybrid which are smaller and thinner in dimension (Chapter 3) compared to Broiler, and therefore have relatively more surface area in relation to muscle mass and exposure to the air, which likely caused the higher drip loss (Fanatico *et al.*, 2005). The correlations between the attributes showed that there was a negative correlation between initial juiciness and intramuscular fat (%) (Table 6.6) and a positive correlation between cooking loss and intramuscular fat (%) (Table 6.6) and initial juiciness and percentage moisture (Table 6.6). This is further illustrated and confirmed in the PCA bi-plot (Fig. 1a) where percentage fat is situated on the opposite side of the plot to sustained and initial juiciness.

Flavour in meat is the third most important characteristic, after appearance and tenderness, perceived by the consumer (King *et al.*, 2009). The flavour of meat is a combination of taste and smell and is formed by chemical reactions during cooking (Mottram, 1998; Farmer, 1999). Meat flavour and aroma increases with animal age, therefore slower growing birds harvested at an older age are expected to have meat with a more intense flavour than conventional broilers (Aberle *et al.*, 2001; Elmore & Mottram, 2009). This increased flavour could be due to the fact that older birds contain higher concentrations of nucleotides in muscles, which degrade to inosinic acid and hypoxanthine after death; two chemical compounds known to be associated with meat flavour (Aberle *et al.*, 2001). The Hybrid chicken scored higher ($P \leq 0.05$) in flavour and aroma than the Broiler and Koekoek genotypes (Table 6.2). This is surprising, since a more intense flavour and aroma is generally associated with older birds, and therefore the Koekoek was expected to have the strongest flavour.

Flavour is also correlated to the intramuscular fat content of meat; therefore the presence of a higher fat content (%) will give a more flavoursome meat (Lawrie & Ledward, 2006). BI scored higher ($P \leq 0.05$) in intramuscular fat (%) content (Table 6.4) than HI, consequently the Broiler genotype were also expected to give a more flavoursome meat. Gordon and Charles (2002) reported that flavour precursors (flavour development) are only deposited in the muscle after the growth inflection point (the age at which gain is at its maximum). In this study it is possible that the Hybrid were at a more mature stage of development (as a function of their adult weight) than the

Koekoek chickens, which did not reach their inflection point before slaughter. It is also important to keep in mind that the breast meat was cooked with no salt added and the skin removed, as these would have enhanced the flavour. The findings of this study agree with those of Fanatico *et al.* (2007) and Touraille *et al.* (1981) where the meat of faster growing birds had more flavour than slower growing birds harvested at different ages.

According to Harkes and Begemann (1974), thermal oxidation of n-6 and n-3 fatty acids, especially arachidonic, linoleic and oleic acids, in meat are responsible for the characteristically cooked chicken flavour. These fatty acids break down during heating and give aldehyde compounds that are more unsaturated and reactive in further developments. These compounds then react with Maillard precursors and appear to catalyse the breakdown of more saturated fatty acids to affect, as well as contribute to, the meat flavour (Imafidon & Spanier, 1994, Elmore *et al.*, 1999). Enser (1999) reported that linoleic acid is responsible for the presence of a mild chicken flavour in meat. This fatty acid dominates over the other fatty acids in the fatty acid profile (Table 6.5). In this study, however, a negative correlation ($r = -0.08832$; $P \leq 0.05$) was found between chicken flavour and α -linoleic acid (C18:2n6c). A possible explanation for this phenomenon could be that during the trained panel sessions while defining the attribute chicken flavour, a strong chicken flavour was actually defined and not a mild chicken flavour, which α -linoleic acid represents. Chicken flavour did, however, correlated positively with total SFA (Table 6.6) and palmitic acid (C16:0) (Table 6.6). Therefore, it can be speculated that palmitic acid may be responsible for the stronger chicken flavour present in Hybrid. Chicken aroma also correlated positively with SFA (Table 6.6) and myristic (C14:0) (Table 6.6), pentadecylic (C15:0) (Table 6.6), palmitic (C16:0) (Table 6.6) acids. These correlations suggest that these fatty acids may be involved in the formation of the chicken flavour and aroma. Another possible explanation for the enhanced chicken flavour and aroma, especially for Hybrid, is that during cooking, the n-6 and n-3 fatty acids reacted with other flavour precursors or compounds forming aldehydes which could have contributed to the chicken flavour and aroma. This warrants further research to help clarify or explain the factors contributing to the stronger chicken flavour.

Feed composition plays a very important role in the fatty acid composition of monogastric animals. All the chickens in this study was given the same feed composition (Chapter 3; Table 6.1) which was predominately a maize diet (~60%) with soybean full fat (~17%) for starter and grower diets with an increased soybean (~36%) for the finisher diet and added fish meal (~10%). The IMF content and the main fatty acids present in bird fat are palmitic (C16:0), palmitoleic (C16:1), oleic (C18:1), stearic (C18:0) and linoleic (C18:2) acids with oleic (C18:1) acid being the highest in chicken meat (Gunstone & Russell, 1954; Enser, 1999; Lawrie & Ledward, 2006). Similar results were found in this study (Table 6.5). There was a trend in this study for the Broiler birds to contain higher ($P \leq 0.05$) oleic acid (C18:1n9c) than the Hybrid and Koekoek genotypes. This oleic originated from the soybean in the feed which is high in oleic acid (Tat *et al.*, 2007). It is possible

that the Broiler genotype utilises soybean better than the Hybrid and Koekoek genotypes to create oleic acid in the meat.

Fatty acid composition is described by two important ratios PUFA:SFA and n-6:n-3 (Enser *et al.*, 1998). Raes *et al.* (2004) suggest that a PUFA:SFA of > 0.45 and a n-6:n-3 ratio of < 4 contributes to the healthiness of meat products. In this study there was an overall trend for the Broiler to score higher ($P \leq 0.05$) in SFA and lower ($P \leq 0.05$) in PUFA than Hybrid and Koekoek. However this did not affect the overall PUFA:SFA ratio and this ratio, for all the chicken samples, falls within the recommended value to promote healthiness. The n-6:n-3 ratio was also not affected ($P < 0.05$) by genotype.

Effect of production system

The effect of production system on the sensory and physical attributes, as well as chemical and fatty acid composition was less substantial in comparison to that of genotype.

According to Tables 6.1 and 6.2, production system did not have any effect ($P > 0.05$) on the sensory tenderness and instrumental shear force of chicken meat. It was expected that the chickens who had access to an outdoor area or was exposed to free range rearing to have tougher meat, due to increased intramuscular collagen caused by the birds having a higher level of physical activity (Lewis *et al.*, 2005). Physical activity or exercise may cause strengthening of the connective tissue and alter the fibre type size, resulting in tougher meat (Aberle *et al.*, 2001). It has also been shown that birds reared outdoors have more firm meat than birds reared indoors (Castellini *et al.*, 2002a). This study's results agree with Fanatico *et al.* (2007) where production system had no effect on meat tenderness. In some previous studies, free range meat was even found to be more tender than indoor birds, although this was only noted for fast growing birds (Fanatico *et al.*, 2005). It is also important to remember that in this study only the breast meat of the three chicken genotypes was evaluated for tenderness. The breast muscle does not get as much exercise as the thigh or leg, which could also have led to less toughening of the breast meat in the free range reared birds.

Offer and Trinick (1983) concluded that the initial juiciness of meat is positively correlated with the WHC of meat, which is determined by the ultimate pH of the muscle. In this study there was a higher ($P \leq 0.05$) ultimate pH between BI and BFR (Table 6.3), although no difference ($P > 0.05$) was detected in the juiciness of these samples (Table 6.2). According to literature it was expected that the free range samples would be less juicy, since a lower pH was likely due to lower stress conditions and more consumption of glycogen before slaughter (Enfalt *et al.*, 1997; Castellini *et al.*, 2002a; Fanatico *et al.*, 2007; Wang *et al.*, 2009).

There was also a production system effect ($P \leq 0.05$) on the intramuscular fat (%) content of the HI and HFR. However, it did not have any effect on the juiciness content of these samples. These results agree with Kishowar *et al.* (2005) and Husak *et al.* (2008) where no difference in juiciness was found between intensive and free range reared birds. This study also indicates that

the correlation between WHC with initial juiciness and sustained juiciness is inconclusive (Table 6.6).

Production system within a genotype did not have an effect ($P > 0.05$) on chicken flavour and aroma (Table 6.2). Similar results were expected in this study to those of Touraille (1981) and Fanatico *et al.* (2006; 2007), where outdoor birds slaughtered at different ages had a stronger flavour due to more n-3 fatty acids being present in the meat. Chickens are monogastric animals, therefore the fatty acid composition of the feed will directly reflect in the meat muscle (Wood & Enser, 1997). These n-3 fatty acids originate from green forage and grass rich in α -Linolenic acid (C18:3n3) and will result in high levels of the latter being present in the muscle tissue of chickens that feed on grass (Enser *et al.* 1998, Pegg & Shahidi, 2004) In this study, the α -Linolenic acid content (Table 6.5) of the free range animals did not differ from the intensively reared animals. Forage did not play a role in the fatty acid composition of the outdoor birds as it was noted that the Hybrid hybrids and Koekoek chickens had consumed all the foliage within the first week of outdoor access. The chickens in this study were fed the same maize based diet (Chapter 4; Table 4.1). The latter is generally considered to be of a more saturated nature with higher palmitic acid (C16:1), oleic acid (C18:1) and linoleic acid (C18:2n6) content and lower PUFA compared to grass or forage based diets. Together, palmitic acid, oleic acid and linoleic acid comprised ~50% of the total fatty acids present in the cooked breasts of all the chicken samples (Table 6.5).

As mentioned the two important ratios to consider in the fatty acid analysis are the PUFA:SFA and the n-6:n-3 ratios. In this study there was no effect ($P < 0.05$) of production system on the PUFA:SFA ratio, but rearing Broiler and Hybrid in a free range environment caused the n-6:n-3 ratio to increase significantly ($P \leq 0.05$).

A few studies have shown that free range chicken meat has a lower n-6:n-3 ratio, making it a more favourable product than intensive chicken meat and aids to human health (Castellini *et al.*, 2002a; Jahan & Paterson, 2007; Husak *et al.*, 2008). As mentioned, it was expected that the free range chicken meat products would contain more n-3 PUFA, since the major food source should be pasture, which is a good source of α -linolenic acid (18:3n-3) (Ponte *et al.*, 2008; Jahan & Paterson, 2007). In this study this was not the case, resulting in the n-6:n-3 of all the meat samples being above the recommended value (4); in fact the BFR and HFR had even higher ($P \leq 0.05$) n-6:n-3 ratios (Table 6.5) than the BI and HI. The linoleic acid (C18:2n6c) is responsible for the high n-6 content in the meat and originated from the high maize diet (Storry & Rook, 1965). A possible reason for the higher n-6:n-3 ratio, could be that the free range birds used the EPA (20:5n3) and DHA (22:6n3), during stressful times as to support their immune system, rather than depositing it in the meat as described in Chapter 4 (Cook *et al.*, 1993). The same results were also found by Jahan *et al.* (2004) where extensive chicken meat contained higher n-6:n-3 ratios. It is important to remember that free range birds are usually given feed with a different composition than the normal conventional (intensive reared) chickens; these diets would be more suitable for free range rearing and might affect the fatty acid profile of the meat differently.

CONCLUSIONS

The aim of this study was to determine the sensory, physical, proximate and fatty acid quality characteristics of chicken breasts from three different genotypes (Broiler, Hybrid hybrid and Potchefstroom Koekoek) reared in intensive or free range production systems in order to establish if there are any differences in the meat quality.

The results indicate that the effect of production system within a specific genotype plays no significant role on the meat quality characteristics and that the differences in meat quality are mainly due to the genotype. Meat of the faster growing chicken genotypes or younger birds (Broiler) was less tender (higher shear force) than the meat of slow growing or older chicken genotypes (Hybrid and Koekoek). The Hybrid chicken genotype scored significantly higher ($P \leq 0.05$) in both flavour and aroma than the Broiler and Koekoek genotypes. This phenomenon could be ascribed to the n-6 and n-3 fatty acids and other flavour precursor's forming aldehydes during cooking or palmitic acid (C16:0) that could have contributed to the chicken flavour. This, however, would need further research since the chickens had all received the same diet and consequently the reasons for the differences in fatty acid composition is unknown. The Hybrid also had a higher percentage drip loss ($P \leq 0.05$) than Broiler. This could be explained by the smaller and thinner dimension of the Hybrid breast fillet compared to the Broiler fillet.

Although some attributes differed ($P \leq 0.05$) from each other, the question arises whether these minor differences are of such a magnitude that consumers could identify any differences between the different treatments. It also seems that the Hybrid genotype will be the more suitable for free range rearing than Broiler in terms of flavour and aroma. However, whether this hybrid would be the more economical choice, due to differences in feed conversion ratio, growth rate and yield, (Chapter 3) than the commercial genotype requires further research.

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CHAPTER 7

A SOUTH AFRICAN PERCEPTION OF CHICKEN MEAT

ABSTRACT

Modern consumers are health conscious and are shifting to more naturally produced products such as free range chicken. Commercial broilers strains are not suitable for free range rearing and an alternative genotype is needed that will suite the South African market without compromising on meat quality. The main objective of this study was to investigate the impact of genotype and production system on the consumer perception and degree of liking of cooked chicken breast (*pectolaris major*) meat. The consumers favoured Hybrid hybrid more than the normal Broiler genotype. Consumers prefer the overall flavour of intensive reared chicken when tested blind, but when information is given about the rearing system they lean towards free range reared chicken. The main drivers of chicken meat liking were found to be juiciness, tenderness, chicken aroma and chicken flavour. Consumer's perception and opinions are overall positive towards free range reared products and they believe it is better than intensive reared chicken. Three clusters of consumers were also identified: two groups of consumers whom will stay loyal to either free range or intensive reared chicken meat and the third that prefers both free range and intensive reared meat.

Keywords: Broiler, Hybrid hybrid, Consumer perception, Degree of liking.

INTRODUCTION

The modern consumer generally tends to be more aware of the health and nutritional value of the food consumed, is more conscious of animal welfare, desires more naturally produced products and supports a more sustainable way of farming (Sundrum, 2001). Needless to say, together with these requirements, the consumer still expects a high standard regarding the flavour of the food (Hoffman & Cawthorn, 2012). Studying the preferences and attitudes towards a specific type of product, as well as the information about consumers' age, gender, socio-demographics, and habits may be extremely relevant for product development, marketing endeavours and ultimately for increasing sales (Thybo *et al.*, 2004). Therefore producers need to understand consumer behaviour and perceptions that drive the consumers' attitude towards purchasing a product. The challenges the chicken farmers face are daunting and producers need to comply with the consumers' demand and at the same time generate a fair profit.

In the meat market, the interest of the consumer has grown towards quality aspects, rather than just quantity; this mind shift of the consumer has provided opportunities for market

segmentation of specialty products, such as free range and organic. Although consumers expect a higher degree of welfare in free range chickens, this is only true if slow-growing chicken strains are used (Castellini *et al.*, 2008; Van de Weerd *et al.*, 2009). In South Africa, the normal fast growing commercial broiler is currently used for both free range and intensive production. These chickens reach market weight as early as 28 - 32 days under the optimal intensive production system. As a result of genetic selection, for fast growing animals, their behavior has changed to reduced kinetic activity (Schütz & Jensen, 2001; Branciarri *et al.*, 2009). Therefore, broilers have a habit of staying indoors, being dormant and less active (Smith & Carpernter, 1970; Lewis *et al.*, 2005). This rapid growth has also led to concerns about animal welfare, since more leg disorders and a higher mortality rate occur. On the other hand, extensive production practices leads to higher production costs and lower turn over, causing the products to be more expensive than intensive production products. The question arises whether the consumer is willing to pay for a quality product? According to Thompson (1998), Bennett *et al.* (2002), Du Toit and Crafford (2003), Napolitano *et al.* (2010), Van Loo *et al.* (2011) and Janssen & Hamm (2012), consumers are frequently willing to pay a higher price for certified products. The consumer, who can afford free range and organic products, is generally a more wealthy, well-educated and traveled person who places value on the quality aspects of the meat (Martelli, 2009).

As already mentioned, the farmers in South Africa utilize the same fast growing chicken lines, which has been bred specifically for intensive rearing for their extensive rearing methods. However, the suitability of these fast-growing broilers, for outdoor production and specialty markets, has not been extensively researched (Fanatico *et al.*, 2005).

Castellini *et al.* (2008) reported that only slow-growing chicken strains can completely benefit from an extensive rearing system and that the fast growing strains are considered slow to adapt to change. Therefore, a slower growing chicken line is needed, that can adapt to the harsh conditions of the South African weather, can eat the forage in an extensive production system and still give the same meat quality as the broiler.

A few studies have been done on consumer perception and attitude towards chicken meat, as well as their perception on different rearing systems and consumers believe that the meat of free range chickens are healthier and tastier than birds reared in confinement and their overall perception is positive towards free range production systems (Verbeke & Viane 1999; Yeung & Morris, 2001; Harper & Makatouni 2002; Grunert *et al.*, 2004; Greene *et al.*, 2005 as cited by Fanatico *et al.*, 2005; Fanatico *et al.*, 2007; Castellini *et al.*, 2008; Branciarri *et al.*, 2009). In a consumer study where commercial broilers were compared with organic free range broilers in a blind tasting, it was reported that although consumers found no differences in breast fillet juiciness, tenderness, or flavour, consumers did prefer the commercial broiler meat over the organic free-range broiler meat (Greene *et al.*, 2005 as cited by Fanatico *et al.*, 2005). Such studies have never been done in a South African environment or on indigenous chickens cross bred with commercial broilers.

In view of the above, this study was undertaken to gain information on the consumers' degree of liking of two different chicken genotypes: Broiler (Cobb 500) and Ross 308 X Potchefstroom Koekoek reared in intensive and free range environments. The consumers were also tested for perceptions on the rearing method i.e. intensive or free range of chickens *per se*. Correlations between the sensory and consumer data were made in order to determine the drivers of liking, as well as understanding consumer expectations.

MATERIALS AND METHODS

Experimental birds, location, handling and slaughter procedure

†Two hundred crossbred (Ross 308 roosters X Potchefstroom Koekoek hens) chicks were hatched at Mariendahl, (33° 51' 0 S; 18° 49' 6 0 E) Experimental Farm, Stellenbosch University, situated in the Western Cape, South Africa. Two hundred one day old Cobb 500 (Broiler) chicks were purchased from Tydstroom hatchery near Hermon (Western Cape, South Africa) and brought to Mariendahl. Each chick was vaccinated against infectious bursal disease (IBD) at one day of age and Newcastle disease at one and 18 days of age. After individual weighing and tagging the one day old chicks were randomly assigned to two rearing systems; intensive (n = 100 per genotype) and extensive/free range (n = 100). Genotypes were maintained separately. All chickens were fed *ad libitum* the same complete commercial type diet consisting of a starter, grower and finisher feed (Table 7.1). Feed was allocated to the chicks at a volume of 900 g starter, 1200 g grower and finisher until slaughter.

Intensive production system

At day one of age, the BI, HI and KI chicks were placed into a bioassay unit (intensive system). The chicks were grouped according to genotype for each treatment. This unit comprises of a temperature controlled room equipped with wire cages (0.3 x 0.25 m; 53 birds/m²). Management practices described by ROSS International were followed (Aviagen, 2009). Artificial lighting was provided at a pattern of 16 h of light alternating with 8 h of darkness. Ventilation in the house was set to provide a minimum of six air changes per hour. At the age of 14 days, the chicks were moved to a chicken house equipped with wire cages (0.9 x 0.6 m; 14 birds/m²) (Fig. 4.1a), each containing a tube feeder and two nipple drinkers. Again the chicks were grouped according to genotype. The temperature in the room was controlled and decreased as they grew from 33°C to 15°C and ventilation in the house was set to provide a minimum of six air changes per hour. Artificial lighting was provided at a pattern of 16 h of light alternating with 8 h of darkness.

†Note that in this chapter the Koekoek genotype was not evaluated as in the previous chapters, thus the description of the experimental birds is described again.

Table 7.1 Ingredient (%) and calculated nutrient composition of commercial diets fed to intensively and extensively reared chickens

Ingredients (%)	Starter	Grower	Finisher
Maize	61.59	65.76	59.66
Fish meal 65	9.79	10.00	-
Soybean full fat	16.85	18.84	36.13
Soybean 46	8.87	3.00	-
L-lysine HCL	0.27	-	0.20
DL methionine	0.27	0.21	0.31
L-Threonine	0.14	0.05	0.11
Vitamin + mineral premix	0.15	0.15	0.15
Limestone	0.80	1.01	1.58
Salt	-	0.05	0.25
Monocalcium phosphate	0.84	0.75	1.45
Sodium bicarbonate	0.43	0.17	0.17
Total	100.00	100.00	100.00
Calculated nutrient composition			
AMEn* chick	12.50	12.90	13.00
Crude protein %	22.54	20.73	18.97
Dry matter %	88.22	88.03	88.20
Lysine %	1.52	1.21	1.17
Methionine%	0.69	0.62	0.59
Crude fat %	6.57	7.03	8.95
Calcium %	0.90	0.96	0.92
Avail. Phosphorus %	0.50	0.48	0.45

*Nitrogen-corrected apparent metabolizable energy value (AMEn)

Extensive production system

The day old BFR, HFR and KFR chicks were placed in small pens (2.7 x 3.5 m) with deep wood shavings in an indoor chicken house facility. The chicks were grouped according to genotype for each treatment in the pens. The initial density of each pen was 10.5 birds/m². Artificial lighting was provided at a pattern of 16 h of light altering with 8 h of darkness and ventilation in the house was set to provide a minimum of six air changes per hour. At 21 days of age, the chicks were moved outside to a larger facility (Fig. 7.1b). This facility was naturally ventilated. The house was subdivided into two “indoor” pens that opened into two separate yards, which were surrounded by chicken wire. The “indoor” areas of each pen measured 1.5 x 3.0 m and contained fresh wood shavings and infrared light heaters that were used to maintain night temperatures above 15°C. Birds were allowed unlimited access to the “outdoor” area. The “outdoor” area consisted of a concrete floor area covered with shading (3.0 x 4.5 m) and an open air grassy area (3.0 m x 6.0 m). Each pen measured 3.0 x 12.0 m (2.8 birds/m²). The grassy area was completely covered

with natural growing vegetation (mainly kikuyu grass). The outdoor and indoor areas were provided with automatic drinkers as well as chicken feeders allowing for *ad libitum* access. Photoperiod was limited natural daylight (~15 h of daylight and 9 h of darkness). Management practices described by the SAPA code of practice 2012 under the section free range broiler production were followed (Anon., 2012b).



Figure 7.1 (a) Intensive production wire cages; (b) Extensive production housing pens.

Slaughtering

At the age of 42 and 56 days respectively, 100 Broiler and Hybrid hybrid chickens with a target weight range between 2.0 to 2.3 kg were randomly selected and slaughtered, according to acceptable commercial standards through immobilization by electrical stunning (50-70 volts; 3-5 s), followed by exsanguination and de-feathering and dressing. After evisceration, the carcasses were chilled at 4 °C for approximately 12 h. Thereafter the carcasses were transported to the meat science laboratory at Stellenbosch University. After skinning, the breast muscles were removed by cutting from the *clavicale furcula* bone alongside the keel bone, the weight recorded and the meat vacuum-packed and frozen at -18 °C until analysed further.

Experimental units

The experimental units included four meat treatments which consisted of a Broiler and Hybrid sample each reared in intensive and free range production systems (n = 4). The consumer analysis was performed on the cooked right and left breasts of the carcass with three consumers per breast (Fig. 7.2). The analyses were thus performed on 68 birds. The following acronyms are used to describe the four different treatments: BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range.

Sample preparation

The consumer test was conducted at the sensory research facility of the Food Science Department, University of Stellenbosch inside a temperature-controlled (21°C) and light-controlled (artificial daylight) room (AMSA, 1995). The frozen breast samples from each treatment, were removed from the freezer (-18°C) and defrosted in a refrigerator at 4°C for 12 h prior to the consumer analysis session. The defrosted samples were removed from the packaging and placed inside separate marked oven roasting bags (GLAD™). Meat was not salted or seasoned. The roasting bags with the meat samples were then placed on a stainless steel grid and fitted onto an oven roasting pan. The samples were placed in an industrial forced convection oven (Hobart), preheated to 160°C (AMSA, 1995). The meat samples were roasted for 20 min and removed from the oven. After removal from the roasting bags the samples for each consumer for sample set 1 (served with no information) and sample set 2 (served with information) were cut into 2 x 2 x 2 cm cubes as illustrated in Fig. 7.2. Consumers were given samples from the same chicken breast for sample set 1 and sample set 2 to lessen variation within breasts. The samples were then individually placed into corresponding marked glass ramekins. Before the samples were served to the consumers for analysis, the ramekins containing the meat samples were placed in a preheated oven (100°C) and reheated for 10 min where after they were immediately served to the panel.

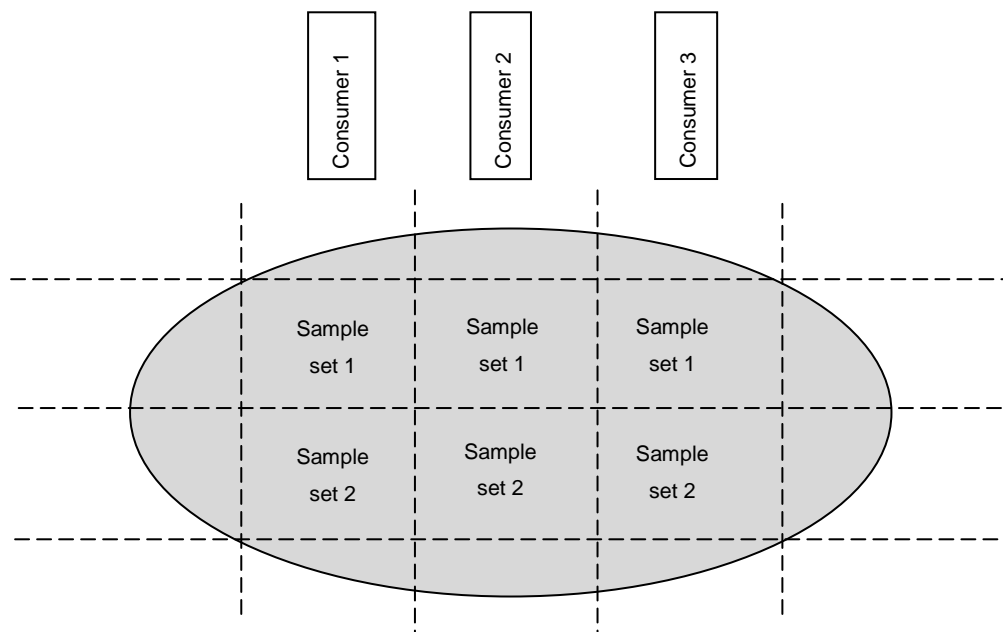


Figure 7.2 Diagram showing the division of a single chicken breast sample into test samples for consumers in sample set 1 (no information) and sample set 2 (with information).

Consumer sensory analysis

As a consumer panel can only analyse a limited number of samples, the genotypes broiler and Hybrid hybrid were chosen for this study. Hundred consumers ($n = 100$) who regularly consume chicken meat, between the ages of 18 and 60 were sourced in the Western Cape area, South

Africa. The group of consumers were asked to complete a questionnaire (Addendum A) determining the overall degree of liking of the eating quality, as well as the texture of the chicken samples using the 9-nine point hedonic scale (Addendum A). Internationally, the nine point hedonic scale has been studied widely and has been found to be extremely useful in the hedonic assessment of various foods and beverages on the market. In this test, the consumer is asked to indicate which term best describes his/her attitude towards the products being tasted using the scale with the following nine categories (Lawless & Heymann, 2010): 9 = *Like extremely*; 8 = *Like very much*; 7 = *Like moderately*; 6 = *Like slightly*; 5 = *Neither like nor dislike*; 4 = *Dislike slightly*; 3 = *Dislike moderately*; 2 = *Dislike very much* and 1 = *Dislike extremely*. Consumers were asked to cleanse their palates with distilled water and water biscuits (Carr, UK) so as to prevent a carry-over effect between samples.

The questionnaire consisted of a sample set 1 where consumers were not given any information about the chicken genotype or rearing environment; this test purely tested consumer preference and degree of liking and eliminated any bias and it was envisaged that it would prevent any preconceived ideas of the product influencing their answers. In this sample set the samples were presented in a completely randomised order. In sample set 2, however, consumers were given information about the rearing system, as well as genotype of the chicken to gain information about perception and prejudice over a specific product. The purpose of this test was to identify which products the consumers viewed as acceptable or unacceptable. It is also important to note that no consumers were asked to explain their choice (Lawless & Heymann, 2010).

Questions relating to socio-demographics of the consumers were also incorporated in the questionnaire and included: gender, age, race, income, education, current employment and frequency of consuming chicken products.

Along with the questionnaire about preference of the four chicken meat samples, consumers were asked to complete a questionnaire where they would indicate their opinion about free range products and normal conventional or intensive reared chicken by answering "Yes", "No", or "I am not sure". This test indicates consumer perception or opinion of free range products. A question was posed to ascertain whether the consumers were aware of the true meaning of the terms "free range" and "intensive production systems". Finally the consumers were probed on factors that might affect their purchasing intent. A nine-point scale ranging from 1 = *Not important* to 9 = *Extremely important* was used to indicate whether specific factors such as price, place of purchase and rearing method of chickens play would influence the purchasing decision.

Statistical analysis

For the consumer analysis, a randomised complete block design was used, with each consumer (n = 100) testing the four chicken samples (2 genotypes x 2 rearing methods) in random order without any information regarding the samples. In the second session, the testing of the samples was repeated, however, the information pertaining to genotypes and rearing methods was

supplied. The model for the consumer experimental design including the consumer effect and the two factor interactions is indicated by the following equation:

$$Y_{ijk} = \mu + \text{Cons}_n + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + (\alpha^*\text{Cons})_{in} + (\beta^*\text{Cons})_{jn} + (\gamma^*\text{Cons})_{kn} + (\alpha\beta^*\text{Cons})_{ijn} + (\alpha\gamma^*\text{Cons})_{ikn} + (\beta\gamma^*\text{Cons})_{jkn} + \varepsilon_{ijkn}$$

Where μ is the overall mean, α , β and γ are the main effects for the corresponding design factors (genotype, rearing method and information, respectively), Cons is the consumer effect and ε_{ijkn} is the random error.

The segmentation model including additional consumer demographic information is:

$$Y_{ijk} = \mu + \Phi_l + \text{Cons}(\Phi)_{ln} + \alpha_i + \beta_j + \gamma_k + \alpha\beta_{ij} + \alpha\gamma_{ik} + \beta\gamma_{jk} + \Phi^*\alpha_{il} + \Phi^*\beta_{jl} + \Phi^*\gamma_{kl} + \Phi^*\alpha\beta_{ijl} + \Phi^*\alpha\gamma_{ikl} + \Phi^*\beta\gamma_{jkl} + (\alpha^*\text{Cons}(\Phi))_{inl} + (\beta^*\text{Cons}(\Phi))_{jnl} + (\gamma^*\text{Cons}(\Phi))_{knl} + (\alpha\beta^*\text{Cons}(\Phi))_{ijnl} + (\alpha\gamma^*\text{Cons}(\Phi))_{iknl} + (\beta\gamma^*\text{Cons}(\Phi))_{jknl} + \varepsilon_{ijknl}$$

where Φ_l represents the demographic effect and $\text{Cons}(\Phi)_{nl}$ represents the consumer effect within the demographic effect (Næs *et al.*, 2010).

Analyses of variance (ANOVA) was performed using SASTM statistical software (Statistical Analysis System, Version, 9.2, 2006, SAS Institute Inc., CARY, NC, USA), while the multivariate statistical analysis was performed using XL STATTM statistical software (Version 2011, Addinsoft, New York, USA). Student's t-least significant differences were calculated at the 5% level to compare preference means for samples, overall and for different demographic groups. A probability level of 5% was considered significant for all significance tests. Principal component analysis (PCA) was conducted to investigate the association of preference patterns for the samples with demographic groupings.

RESULTS AND DISCUSSION

Consumer preference testing of chicken

Relating consumer liking and sensory data

The purpose of this study was to determine the degree of liking of the four chicken variants by consumers from the Western Cape area, South Africa. The samples were firstly tested blind for degree of liking (no additional information supplied), thereafter the same four samples were tested again, this time with added information on the genotype as well as rearing system. Table 7.2 indicates the mean scores of degree of liking of the texture and flavour of the four different chicken samples within informed and non-informed scenarios, respectively. Table 7.3 indicates the overall

mean scores of degree of liking of the texture and flavour of the four different samples. From Table 7.2 it is clear that HFR from the informed scenario scored the highest degree ($P \leq 0.05$) of liking for both texture and flavour. Also interesting to note from Table 7.2, for the informed scenario, consumers scored an overall higher degree of liking for the free range samples (BFR and HFR) than the intensive samples (BI and HI). From Table 7.3 it can be concluded that the consumers preferred ($P \leq 0.05$) the texture and flavour of the Hybrid hybrid more than the Broiler for both production systems. It would seem that genotype had a higher impact on consumer liking than production system'. These results are in agreement with that of Fanatico *et al.* (2007) where genotype also had a stronger influence than production system in a consumer analysis.

Associations between sensory, physical and chemical attributes as defined in Chapter 5 of the chicken meat and the consumer data from this chapter were investigated using PCA (Fig. 7.3a, b). Fig. 7.3a indicates the association of consumer's degree of liking of the texture of the meat for both sample sets (with information and no information) and Fig. 7.3b the degree of liking of the flavour of the meat for both the sample sets (with information and no information). Factor 1 and 2 (F1 and F2) of Fig. 7.3a explained 80.35% of the total variance. F1 and F2 of Fig. 7.3b explained 81.67% of the total variance. These PCA bi-plots seem to indicate that there was a trend between the different treatments, where PC1 divided genotype, with Hybrid hybrid situated on the right hand side of the plot and Broiler on the left hand side of the plot. On the other hand, PC2 divides production system with intensive situated on the bottom half of the plot and free range on the top half of the plot.

From Fig. 7.3a and b it is clear that the consumers preferred the flavour and texture of HI and HFR more than they would BI and BFR. Sensory descriptors that correlated positively with the degree of liking were chicken aroma, chicken flavour, tenderness and juiciness. From this it is clear that the consumers prefer chicken meat that is juicy, tender and has a chicken flavour and aroma. These findings compare well to work reported by Aaslyng (2009). From Fig. 7.3 it is also clear that this group of consumers responded less positively to the attributes shear force and residue.

The results in Fig. 7.3a and 7.3b also showed that the consumers' preference for a specific chicken sample differed when tested within non-informed and informed scenarios. In the non-informed scenario (i.e. tasting the sample blind), consumers preferred the Hybrid intensive sample and for the informed scenario they preferred the Hybrid free range sample. Guinard *et al.* (2001) also found a difference in degree of liking when consumers tasted beer samples informed versus blind. Our results indicate that consumer perception plays an immense role when it comes to consumer decision making and is therefore the main reason for change in decision. Consumers make decisions based on how they perceive free range and intensive products. In our study, consumers perceived and believe that free range products have a better value (whether it is healthier – as linked to its chemical composition, especially fatty acids, tastier, leaner or juicier) than intensive products and therefore scored it a higher.

Table 7.2 The mean scores of degree of liking (\pm SD) of texture and flavour of the four different chicken samples for when no information was supplied (blind) and when information was supplied

Sample*	Texture	Flavour
BI_Info	5.7 ^e \pm 1.68	5.8 ^{cd} \pm 1.65
BI_No	5.9 ^{cde} \pm 1.86	6.0 ^{bcd} \pm 1.79
BFR_Info	6.2 ^{bc} \pm 1.78	6.1 ^{bc} \pm 1.86
BFR_No	5.8 ^{de} \pm 1.65	5.7 ^d \pm 1.67
HI_Info	6.3 ^{ab} \pm 1.78	6.1 ^{bcd} \pm 1.71
HI_No	6.1 ^{bcd} \pm 1.41	6.2 ^{ab} \pm 1.70
HFR_Info	6.6 ^a \pm 1.50	6.6 ^a \pm 1.61
HFR_No	6.1 ^{bcd} \pm 1.78	6.3 ^{ab} \pm 1.66
LSD	0.39	0.38

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in columns with different superscripts are significantly different at $P \leq 0.05$

*BI_Info – Broiler intensive with information; BI_No – Broiler intensive with no information; BFR_Info – Broiler free range with information; BFR_No – Broiler free range with no information; HI_Info – Ross X Potchefstroom Koekoek hybrid intensive with information; HI_No – Ross X Potchefstroom Koekoek hybrid intensive with no information; HFR_Info – Ross X Potchefstroom Koekoek hybrid free range with information; HFR_No – Ross X Potchefstroom Koekoek hybrid free range with no information

Table 7.3 The overall mean scores of degree of liking (\pm SD) of texture and flavour of the four different chicken samples

Sample*	Texture	Flavour
BI	5.9 ^c \pm 1.72	5.9 ^b \pm 1.77
BFR	5.8 ^{bc} \pm 1.76	5.9 ^b \pm 1.72
HI	6.3 ^a \pm 1.6	6.4 ^{ab} \pm 1.64
HFR	6.2 ^{ab} \pm 1.61	6.2 ^a \pm 1.70
LSD	1.96	0.31

Standard Deviation (SD); Least Significant Difference (LSD)

^{ab}Means in columns with different superscripts are significantly different at $P \leq 0.05$

*BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range

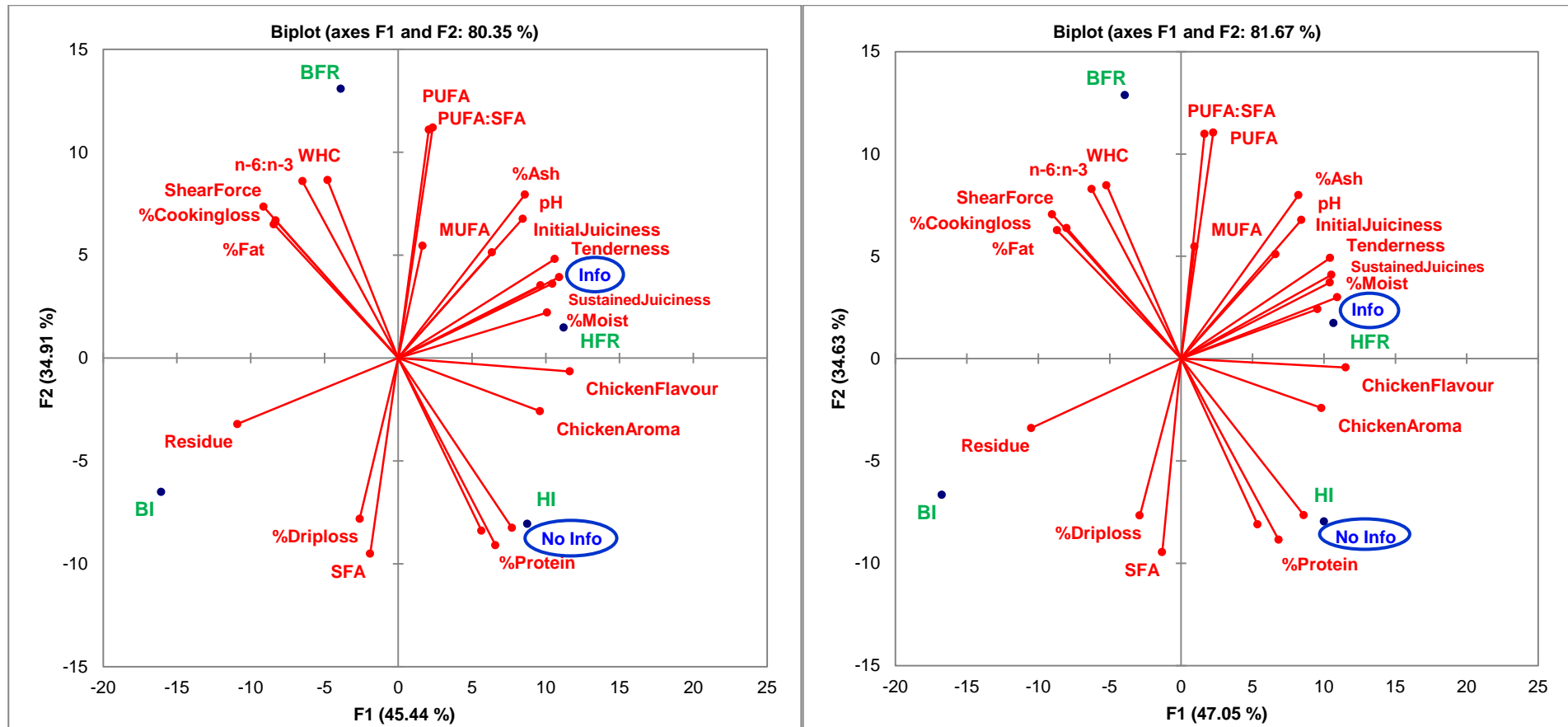


Figure 7.3 (a) Principal component analysis (PCA) bi-plot indicating the position of the sensory attributes (indicated in red), in relation to the four chicken meat samples (indicated in capital letters and green) and the degree of liking of the information and no information tests (indicated in blue and circled) of the texture of the chicken samples. (b) Principal component analysis (PCA) bi-plot indicating the position of the sensory attributes (indicated in red), in relation to the four chicken meat samples (indicated in capital letters and black) and the degree of liking of the information and no information tests (indicated in blue and circled) of the flavour of the chicken samples. (BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range)

Socio-demographic information and correlation with preference

In any consumer study, socio-demographic data sourced from the consumer can be studied and correlated with specific variables, thus enabling the clustering of consumers into different categories or groups according to their different profiles (Geel *et al.*, 2005). In this study gender, age, race, income, current employment, education and consumption frequency of chicken meat were obtained from each consumer. In the ANOVA table (Table 7.4) the significant interactions are indicated in bold. There was a significant interaction ($P \leq 0.05$) for Education*Genotype*Treatment for both texture and flavour which was then further investigated in the PCA plots (Fig. 7.4a and b). This section will not be discussed here, but rather in the “further analysis with segmentation” section - where the specific demographic factor(s) that had an effect will be discussed.

Fig. 7.4a and b indicate that the consumers with an academic degree preferred the Hybrid intensive and free range chicken samples more and that the consumers without a degree and only with a Gr.12 diploma or less were more inclined to prefer the Hybrid intensive and Broiler free range samples.

It was expected that the consumers with a degree would prefer Hybrid free range reared products more, since they would have more knowledge of rearing systems and the type of bird used in the production system. They would know that free range rearing could be more harmful to broilers than intensive for which they are specifically genetically selected for and that a more tough bird i.e. Hybrid would be more suitable for free range rearing. The opposite was expected from the consumers without a degree, since it was assumed that they would not have the knowledge of rearing systems and type of chicken used.

Table 7.4 ANOVA table of the overall linking for texture and flavour

	DF	Texture	Flavour
Education	1	0.1257	0.5382
Consumer	98	<.0001	<.0001
Genotype*Treatment	3	0.0039	0.0073
Information	1	0.0078	0.2263
Genotype*Treatment*Information	3	0.0507	0.068
Education*Genotype*Treatment	3	0.0152	0.0008
Education*Information	1	0.2902	0.2246
Consumer*Genotype*Treatment (Education)	294	<.0001	<.0001
Consumer*Info (Education)	98	0.0636	0.0076

Degrees of freedom (DF)

Significant interactions are indicated in bold.

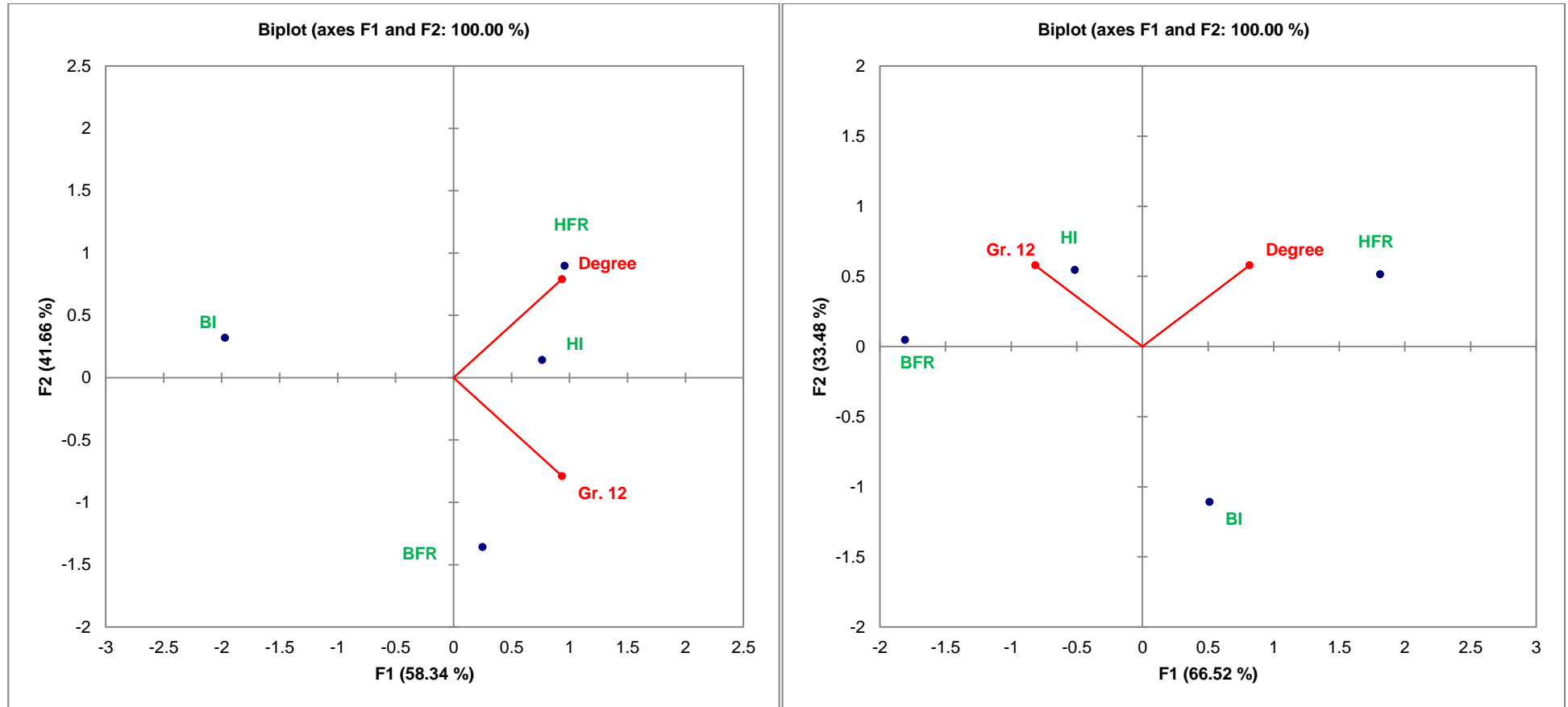


Figure 7.4 Principal component analysis (PCA) bi-plot for the four chicken samples with regard to degree of liking of (a) texture and (b) flavour. Samples are indicated as the scores in green and education as loadings in red. The PCA bi-plots explain 100.00% and 100.00% of the variance respectively. (Degree – Consumers with a degree; Gr. 12 – Consumers with a Gr. 12 diploma; BI – Broiler intensive; BFR – Broiler free range; HI – Ross X Potchefstroom Koekoek hybrid intensive; HFR – Ross X Potchefstroom Koekoek hybrid free range)

Cluster analysis of consumer liking data

The *degree of liking* results for the total consumers have already been discussed earlier (Fig. 7.3), however, market researchers are usually interested to explore sub-segments of consumers within a larger group of consumers (Parpinello *et al.*, 2009). To determine whether the consumers' *degree of liking* scores of this study would result in different clusters, a clustering technique was performed on the full data set of the *degree of liking* scores. This technique identified three clusters for this study, namely:

- Cluster 1: Consumers inclined to *strongly favour free range reared chicken meat*
- Cluster 2: Consumers inclined to *strongly favour intensive reared chicken meat*
- Cluster 3: Consumers inclined to *equally favour free range and intensive reared chicken meat*

A PCA was done using the above-mentioned cluster data to see how the respective clusters of consumers associate with the four different samples tested in a blind scenario (non-informed) and informed scenario. According to Fig. 7.5(a) Cluster 1, representing 37% of the total group of consumers, associate with all the free range meat samples, whether it was with information or no information given, i.e. BFR and HFR. Cluster 2, representing 31% of the total group of consumers, associate with all the intensive meat samples (BI and HI) and Cluster 3, representing 32% of the total group of consumers, lies within the two identified groups indicating that consumers equally preferred free range and intensive reared meat. These clusters indicate that there is a group of consumers who will buy free range products, a group who will buy intensive reared products and a group who would buy either free range or intensive reared products; usually another factor like price or convenience would determine these consumers' final decision making.

Further PCA analysis with the clusters and sensory attributes in Fig. 7.5(b) revealed once again that all the consumers from Cluster 1, 2 and 3 are more inclined to favour meat that is more juicy, tender and has a good chicken flavour and aroma.

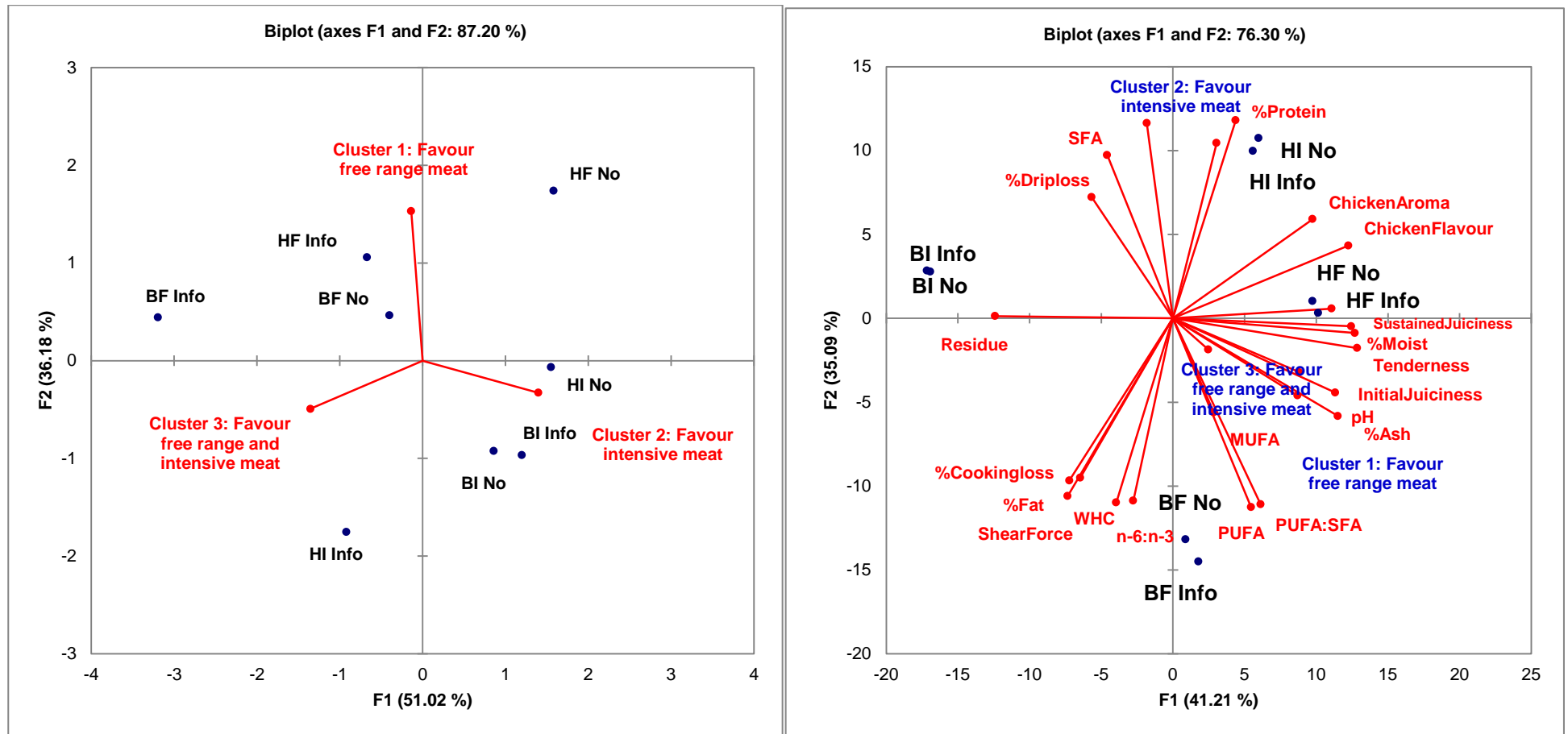


Figure 7.5 (a) PCA bi-plot of the association of liking scores of the four chicken samples and three clusters of consumers. The PCA bi-plot explains 87.20% of the variance. (b) Association between sensory attributers and consumer liking for all identified clusters. The PCA bi-plot explains 76.30% of the variance.

(BI Info – Broiler intensive with information; BI No – Broiler intensive with no information; BFR Info – Broiler free range with information; BFR No – Broiler free range with no information; HI Info – Ross X Potchefstroom Koekoek hybrid intensive with information; HI No – Ross X Potchefstroom Koekoek hybrid intensive with no information; HFR Info – Ross X Potchefstroom Koekoek hybrid free range with information; HFR No – Ross X Potchefstroom Koekoek hybrid free range with no information)

Consumer options and perception on chicken in general

In research where *sensory attributes* and *degree of liking* of a selection of chicken meat are tested, general opinions on the products and related aspects regarding the products are usually also investigated (Mueller & Szolnoki, 2010). In this study the group of consumers were also surveyed on their *general opinions* or *perceptions* on the consumption and purchasing of chicken, as well as the factors that drive these opinions (Table 7.5). These associated factors were tested on a 9-point hedonic category scale and opinions on a three point scale i.e. “yes”, “no” and “not sure” as indicated in Table 7.5 (Green & Srinivasan, 1978). The group of 100 consumers, all residents of the Western Cape, were sourced to include male and female consumers. ANOVA were firstly performed on the options of the total group of consumers.

Table 7.5 Range of general opinions influencing the purchase and consumption of chicken

Opinions and associated factors tested		Scale used	Short title
Importance of price		1 = Not important 9 = Extremely important	Price
Appropriate outlets for the purchasing of chicken	Supermarket Fresh produce market Directly from farmer	1 = Not appropriate 9 = Extremely appropriate	Places purchased
Importance of intensive production		1 = Not appropriate 9 = Extremely appropriate	Intensive
Importance of free range production		1 = Not appropriate 9 = Extremely appropriate	Free range
Free range taste better than intensive		Yes No I am not sure	Taste
Free range is leaner than intensive		Yes No I am not sure	Leaner
Free range is healthier than intensive		Yes No I am not sure	Healthier
Free range is juicier than intensive		Yes No I am not sure	Juicier
Free range is more tender than intensive		Yes No I am not sure	More tender

Opinions and perception of the total group of consumers on chicken purchasing and consumption

It is well known that there are product-specific aspects that drive the consumer's purchasing or deciding process (Grunert, 2007). From the ANOVA results in Table 7.6 it is clear that price ($P \leq 0.05$) is a very important purchasing factor for consumers when considering chicken as menu item. Also important is the place of purchase. This group of consumers indicated that they prefer the supermarket ($P \leq 0.05$) as a more favourite place of purchasing, and more so than a fresh

produce market or directly from the farmer. These results clearly indicate the convenience factor of the supermarket above that of the fresh produce market or the farmer. From Table 7.6 it can also be seen that consumer perception of free range reared meat plays an important role in purchasing, more so than intensive ($P \leq 0.05$) reared meat.

The results of the consumers' opinions and perceptions on the positives of free range chicken meat are depicted in Fig. 7.7. According to Fig. 7.7 it is clear that consumers are positive towards free range meat. More than 50% of the consumers think that free range reared chicken meat is healthier than intensive reared chicken meat and more than 40% the consumers think that free range reared chicken meat tastes better and is leaner than intensive reared chicken meat. On the question whether free range chicken meat is more juicy and tender, the consumers perceived it to be either "yes" or "no" or "not sure" in similar proportions (Fig. 7.7). The same results were also found by other researchers (Verbeke & Viane 1999; Yeung & Morris, 2001; Harper & Makatouni 2002; Grunert *et al.*, 2004; Greene *et al.*, 2005 as cited by Fanatico *et al.*, 2005; Fanatico *et al.*, 2007; Castellini *et al.*, 2008; Branciaro *et al.*, 2009).

In a PLS (partial least squares) regression (Fig. 7.8) the opinion of the consumers (X) were regressed on the cluster liking scores (Y). This revealed that the consumers from cluster 1 (who prefer free range meat) strongly inclined to believe that free range is leaner, more juicy, healthy and tender than intensively reared meat. They were, however, unsure if free range reared chicken meat had a better flavour than intensively reared meat. These consumers also knew the answer to the definition of free range and intensively reared chicken meat. In contrast to cluster 1, the consumers from cluster 2 think that intensively reared chicken meat tastes better, is more juicy, healthy and tender than free range reared chicken meat. These consumers were also unsure if intensive reared chicken meat is leaner, healthier or more tender than free range reared chicken meat. The consumers from cluster 3 said either "yes", "no" or "are not sure" to the different opinions. This places them in a position where that they would prefer either free range reared or intensively reared chicken meat. The consumers from clusters 3 were also the people who did not know the difference between free range and intensive reared chicken meat.

These opinions or perceptions of the consumer play a very important role in the final decision making process of the consumer and would sometimes influence a consumer to buy a specific type or "brand" of chicken meat.

Table 7.6 ANOVA table indicating purchasing factor importance

Question for purchasing factor	Mean ± SD
Price	6.9 ^a ± 1.69
Places purchased	Supermarket 6.3 ^b ± 2.14
	Fresh produce market 5.5 ^c ± 2.12
	Directly from farmer 4.5 ^d ± 2.67
Intensive	4.1 ^d ± 2.23
Free range	6.1 ^{bc} ± 2.41
LSD	0.60

^{ab}Means in column with different superscripts are significantly different at P ≤ 0.05

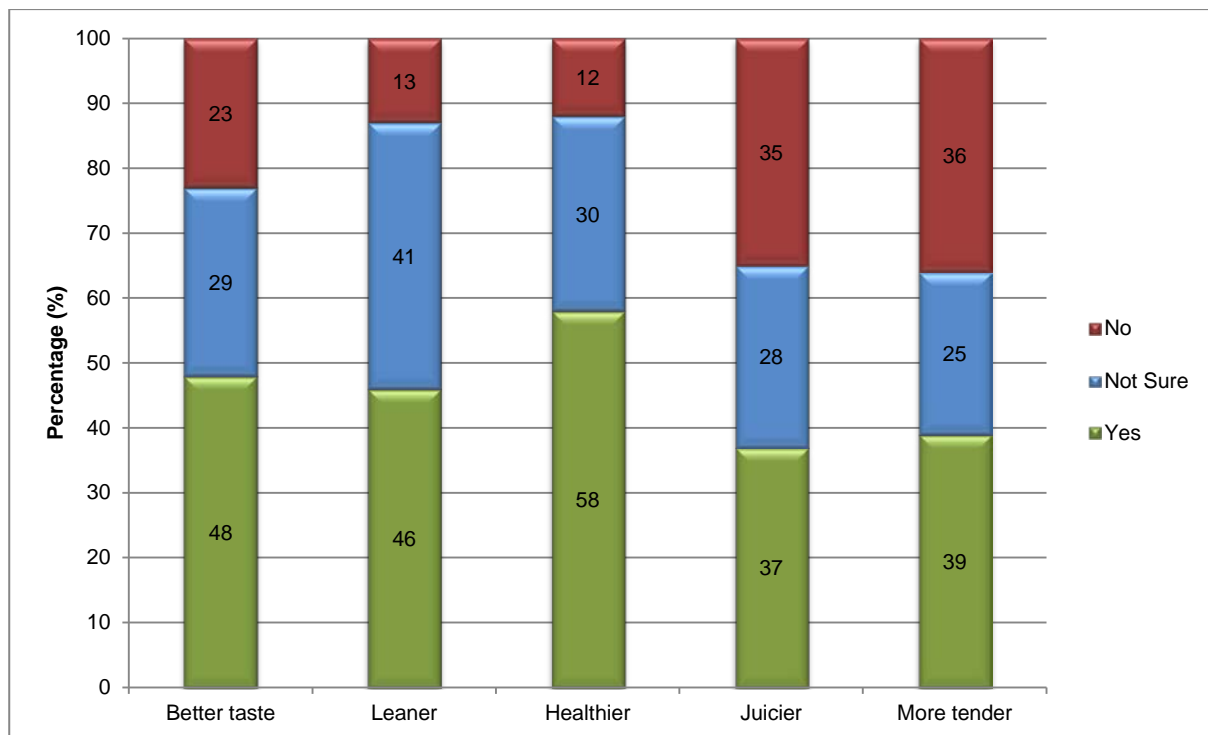


Figure 7.7 Consumers' opinion or perception on free range reared chicken meat.

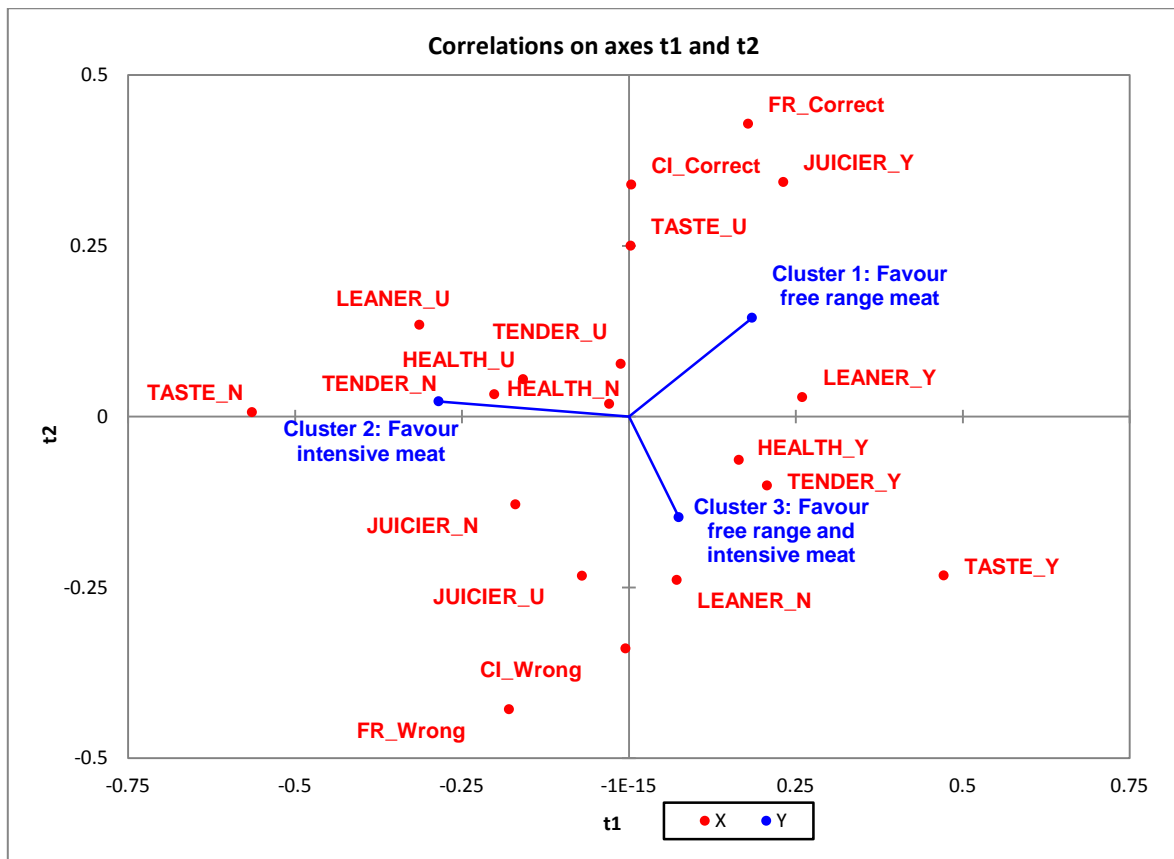


Figure 7.8 PLS plot indicating the driving forces for consumer decision making in their specific clusters. The map was obtained using partial least square regression, where the opinions or perceptions (X-space) were regressed onto the cluster data (Y-space). (Taste_Y – consumers who perceive that free range taste better than intensive; Taste_U - consumers who are unsure if free range taste better than intensive; Taste_N – consumers who believe that free range do not taste better than intensive; Leaner_Y - consumers who perceive that free range is leaner than intensive; Learner_U - consumers who are unsure if free range is leaner than intensive; Learner_N – consumers who believe that free range is not leaner than intensive; Health_Y - consumers who perceive that free range is healthier than intensive; Health_U - consumers who are unsure if free range is healthier than intensive; Health_N – consumers who believe that free range is not healthier than intensive; Juicier_Y - consumers who perceive that free range is juicier than intensive; Health_U - consumers who are unsure if free range is juicier than intensive; Health_N – consumers who believe that free range is not juicier than intensive; Tender_Y - consumers who perceive that free range is more tender than intensive; Tender _U - consumers who are unsure if free range is more tender than intensive; Tender _N – consumers who believe that free range is not more tender than intensive; FR_Wrong – Consumers who got the definition of free range wrong; FR_Right – Consumers who got the definition of free range right; CI_Wrong – Consumers who got the definition of intensive wrong; CI_Right – Consumers who got the definition of intensive right.)

CONCLUSIONS

The aim of this study was to gain information on consumers' degree of liking towards the two different genotypes i.e. Broiler and Hybrid hybrid reared intensively or in a free range system. Consumers' perception and opinions on free range and intensive reared products were also tested.

Overall, genotype had a greater impact on the consumers' degree of liking than production system, but when information was given on the production system of a chicken product, the consumers tend to lean more towards a free range reared product than an intensively reared product. Correlation with the sensory results indicated that juiciness, tenderness, chicken aroma and chicken flavour are the main drivers of liking. Furthermore, three different clusters of consumers were identified, when investigating the degree of liking of the consumers. The clusters were described as:

- Cluster 1: Consumers that prefer *free range reared chicken meat*
- Cluster 2: Consumers that prefer *intensive reared chicken meat*
- Cluster 3: Consumers that prefer both *free range and intensive reared chicken meat*

These clusters clearly indicate that there are two extreme groups, i.e. a group of consumers who is loyal to free range reared chicken meat and then also a group who will definitely buy intensive reared chicken meat when given the option. The third cluster is a group of consumers who are not loyal to a specific "brand" and neither prefer free range nor intensive reared chicken meat, regardless of the information given. This group will most probably be influenced by other factors, such as price, place of purchase or general convenience.

From this study it would seem that Hybrid would be the better alternative for free range rearing and the success of this type of chicken would be ascribed to successful marketing and education endorsing this type of chicken and rearing environment to the consumers.

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CHAPTER 8

GENERAL CONCLUSIONS AND RECOMMENDATIONS

The modern consumer tends to be conscious of animal welfare and general health, requests products that are environmentally friendly, promote sustainability, have nutritional value, as well as excellent meat quality traits. Therefore the meat industry is constantly facing new challenges, not only driven by the consumers' preferences and concerns, but also economic factors and environmental changes. One such consumer preference that is growing is that for free range produced poultry meat and products. Free range poultry producers need to understand the expectations and potential willingness of target consumers to pay a premium price for this product so as to assess whether it is possible to offset the higher cost of production associated with these chickens. The costs are higher as some of the production parameters associated with a free range system differ from that linked to an intensive production system; one of these factors is that the free range system requires slower growing genotypes resulting in an older bird being slaughtered. In this investigation, the effect of slower growing indigenous Koekoek (and their hybrid) compared to commercial Broilers reared in either an intensive or free range system were evaluated in terms their meat quality parameters.

The results of this study indicate that genotype had a much larger effect than production system on the morphological and growth properties of chicken meat, as well as on the sensory characteristics. As expected, the broiler genotype, which is specifically bred for efficient growth, feed efficiency and meat yield, thrived in these aspects compared to the Hybrid and Koekoek genotypes, but despite the poorer growth performance and efficiency of the medium growing Hybrid birds, they had a lower mortality and fewer leg disorders than the broiler. Additional to these factors, the hybrid free range reared chickens had higher thigh, drumstick and wing yields than the broiler, which is beneficial to the industry, since South African consumers prefer dark meat over white meat. The Hybrid chicken scored significantly higher in both flavour and aroma than the Broiler and Koekoek genotypes.

With regard to the physical characteristics and chemical composition of the meat, it would seem that the effect of production system was more pronounced than the effect of genotype. Although production system differences were found in the pH values, CIE a*, CIE b* CIE L* colour values, fat and protein content in selected portions; the most significant of these were the pH and CIE*a values. The free range chicken meat was found to be less red in colour and this could be due to the lower muscle pH caused by minor *ante mortem* stress during the capture and carrying of the birds. Meat colour is an indicator of freshness and quality and one of the most important factors that influence consumer decision making at the point of purchase. Although chicken is classified as a "white" meat, with a low CIE a* value, consumers might be influenced by the pale white colour of the free range chicken meat. Rearing chickens in a free range environment

increased the total polyunsaturated fatty acids (PUFA) and polyunsaturated to saturated fatty acid ratio (PUFA:SFA), and can be considered more favourable to the human health than the intensively reared chicken meat.

Consumers' perceptions, attitudes and beliefs are very important features that must be considered by the agricultural sector, since this is a very strong driving force for the industry and determinethe sustainability and feasibility of a product in the market. From a South African perspective of chicken meat, it was found that genotype had a greater impact on the consumers' degree of liking than production system. However, when information was given on the production system of the chicken product, the consumers tend to lean more towards a free range reared product than an intensively reared product. Three different clusters of consumers were identified after tasting chicken meat in a "blind" analysis:

- Cluster 1: Consumers that prefer *free range reared chicken meat*
- Cluster 2: Consumers that prefer *intensively reared chicken meat*
- Cluster 3: Consumers that prefer both *free range and intensive reared chicken meat*

These clusters clearly indicate that there are groups of consumers who will stay loyal to a specific "brand" and a group who won't, and usually, factor(s) such as price, place of purchase or convenience would influence their final decision for purchasing. The main sensory drivers for consumer's preference towards chicken meat are juiciness, tenderness, chicken aroma and chicken flavour.

The results seem to indicate that the Hybrid hybrid would be a good alternative genotype for free range rearing in South Africa.

From this study the following recommendation can be made to the South African poultry meat industry: for the poultry industry to compete in a free range or health-driven market, a hybrid or medium growing bird should be used for free range rearing to achieve optimum profit. Excellent marketing practices should be in place to promote free range chicken products; for example, an educational program could be initiated to inform consumers about the differences, positive and negative aspects of free range production systems. However, to improve on this study and to thoroughly understand the full impact of a production system and genotype on the sensory, chemical, nutritional and instrumental quality characteristics and consumer preference of chicken meat, it is recommended that season (summer, winter, spring and autumn) and the effect of gender (male and female) should be quantified. Another aspect that would prove interesting is the analysis of different crosses, to find the optimum hybrid for free range production, or even the development of a dual purpose genotype, combining both egg and meat production, which could potentially fulfil free range production if demands on production are not as high as for intensive production. A more in-depth study on muscle fibre type and its effect on the muscle chemical composition and quality will also provide interesting information in understanding the role of muscle fibre types in meat quality as it was postulated that the fibre types may change as the free range birds have more exercise. Larger and more representative consumer panels that include race and

culture as main effects can also be explored to gain more insight into the perceptions and preferences of the entire population of Southern Africa.

ADDENDUM A

CONSUMER TESTING OF CHICKEN

Please <u>circle</u> the applicable answer		Judge no. ____
<u>GENDER:</u> Male / Female	<u>AGE:</u> 18-23 / 24-29 / 30-39 / 40 – 49 / 50+	
<u>RACE GROUP:</u> Black / Coloured / White / Indian / Other: _____	<u>EDUCATION:</u> Grade 11 or less / Grade 12 (Matric) / Diploma or Degree	
WHAT IS YOUR <u>CURRENT EMPLOYMENT:</u> Student / Assistant/ Administrative / Professional / Retired / Unemployed Other: _____	<u>INCOME GROUP:</u> Please give an indication of your MONTHLY or YEARLY income Monthly: <5,000 / 5,001 - 10,000 / 10,001 - 30,000 / >30,000 Yearly: <60,000 / 60,001 - 120,000 / 120,001 - 360,000 / >360,000	
HOW OFTEN DO YOU PURCHASE <u>BUY CHICKEN:</u> More than 3x per week / 1-2x per week / 2x per month / Approx 4x per year / NEVER	HOW OFTEN DO YOU <u>CONSUME CHICKEN:</u> More than 3x per week / 1-2x per week / 2x per month / Approx 4x per year / NEVER	

WHICH OF THE FOLLOWING STATEMENTS BEST DESCRIBE THE 2x METHODS OF CHICKEN PRODUCTION CURRENTLY USED IN SA?

Please CIRCLE the corresponding number next to the preferred answer:

HIGHLY COMMERCIALIZED, INTENSIVE PRODUCTION SYSTEM

1. Method of farming where pesticides or artificial chemicals are used and animals cannot roam freely.
2. Method of farming where no pesticides or artificial chemicals are used and animals can roam freely
3. Method of farming where pesticides or artificial chemicals are used and animals can roam freely

FREE RANGE PRODUCTION SYSTEM

1. Method of farming where pesticides or artificial chemicals are used and animals cannot roam freely.
2. Method of farming where no pesticides or artificial chemicals are used and animals can roam freely.
3. Method of farming where pesticides or artificial chemicals are used and animals can roam freely

Please turn to page 2

SET 1

DEGREE OF LIKING of 4x chicken samples

INSTRUCTIONS:

Rinse your mouth with water between samples. Take a **GENEROUS BITE** from each sample. Rank the samples for **DEGREE OF LIKING & CIRCLE** the number next to the preferred answer

<p>How do you like the</p> <p><u>TEXTURE</u></p> <p>of the chicken?</p>	CODE		CODE		CODE		CODE	
	9	Like extremely	9	Like extremely	9	Like extremely	9	Like extremely
	8	Like very much	8	Like very much	8	Like very much	8	Like very much
	7	Like moderately	7	Like moderately	7	Like moderately	7	Like moderately
	6	Like slightly	6	Like slightly	6	Like slightly	6	Like slightly
	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike
	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly
	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately
	2	Dislike very much	2	Dislike very much	2	Dislike very much	2	Dislike very much
1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	

<p>How do you like the</p> <p><u>TASTE</u></p> <p>of the chicken?</p>	CODE		CODE		CODE		CODE	
	9	Like extremely	9	Like extremely	9	Like extremely	9	Like extremely
	8	Like very much	8	Like very much	8	Like very much	8	Like very much
	7	Like moderately	7	Like moderately	7	Like moderately	7	Like moderately
	6	Like slightly	6	Like slightly	6	Like slightly	6	Like slightly
	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike
	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly
	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately
	2	Dislike very much	2	Dislike very much	2	Dislike very much	2	Dislike very much
1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	

Refresh your mouth with water & Turn to page 3 for more samples

SET 2

DEGREE OF LIKING of 2x Intensive + 2x Free Range chicken samples

INSTRUCTIONS:

Rinse your mouth with water between samples. Take a **GENEROUS BITE** from each sample. Rank the samples for **DEGREE OF LIKING**, **CIRCLE** the number next to the preferred answer.

		Sample A		Sample B		Sample C		Sample D	
		Existing genotype + Intensively reared		Existing genotype + Free Range		New indigenous genotype + Intensively reared		New indigenous genotype + Free Range	
Indicate how you like the <u>TEXTURE</u> of the chicken	9	Like extremely	9	Like extremely	9	Like extremely	9	Like extremely	
	8	Like very much	8	Like very much	8	Like very much	8	Like very much	
	7	Like moderately	7	Like moderately	7	Like moderately	7	Like moderately	
	6	Like slightly	6	Like slightly	6	Like slightly	6	Like slightly	
	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	
	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	
	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	
	2	Dislike very much	2	Dislike very much	2	Dislike very much	2	Dislike very much	
	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	

		Sample A		Sample B		Sample C		Sample D	
Indicate how you like the <u>TASTE</u> of the chicken	9	Like extremely	9	Like extremely	9	Like extremely	9	Like extremely	
	8	Like very much	8	Like very much	8	Like very much	8	Like very much	
	7	Like moderately	7	Like moderately	7	Like moderately	7	Like moderately	
	6	Like slightly	6	Like slightly	6	Like slightly	6	Like slightly	
	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	5	Neither like nor dislike	
	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	4	Dislike slightly	
	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	3	Dislike moderately	
	2	Dislike very much	2	Dislike very much	2	Dislike very much	2	Dislike very much	
	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	1	Dislike extremely	

Please turn to page 4

