NUTRITIVE VALUE OF MANITOBA-GROWN CORN (*Zea mays* L.) CULTIVARS FOR SWINE

By

Florence O. Opapeju

A Thesis

Submitted to the Faculty of Graduate Studies

In Partial Fulfilment of the Requirement

For the Degree of

MASTER OF SCIENCE

Department of Animal Science

University of Manitoba

Winnipeg, Manitoba

Canada. R3T 2N2

March 2005

THE UNIVERSITY OF MANITOBA

FACULTY OF GRADUATE STUDIES
*****
COPYRIGHT PERMISSION

NUTRITIVE VALUE OF MANITOBA-GROWN CORN (*Zea mays* L.) CULTIVARS FOR SWINE

BY

Florence O. Opapeju

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of Manitoba in partial fulfillment of the requirement of the degree

Master Of Science

ABSTRACT

Three experiments were conducted to evaluate the nutritional value of Manitoba-grown corn cultivars for swine.

In Experiment 1, the effect of corn heat units (CHU) rating of corn cultivars and field location on the chemical and nutrient composition of thirty-six corn cultivars replicated in two locations (St. Pierre and Reinland) in Manitoba was determined. Cultivars from each location were further subdivided into low CHU rated cultivars (less than 2300 CHU) and high CHU rated cultivars (2300 or more CHU). Samples were analyzed for dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), fat (hexane extract), ash and total and phytate phosphorus. Data on yield, bushel weight and moisture content at harvest were also collected as agronomic parameters. As expected, there was a significant effect ($P < 0.05$) of location on DM, CP, ADF, ash, phytate and total phosphorus contents and on yield. Corn heat units rating had an effect ($P < 0.05$) on CP, bushel weight and yield with the low CHU rated cultivars having higher CP and bushel weight but lower yield than the high CHU rated cultivars.

In Experiment 2, the digestible energy, CP and amino acids (AA) contents of the two most widely grown corn cultivars in Manitoba obtained from three locations were determined using six ileal cannulated barrows with an average initial body weight (BW) of 21.5 ± 0.9 kg (mean ± SD) according to a 6 × 6 Latin square design. There was an effect ($P \leq 0.05$) of location on apparent ileal digestible CP and AA and on digestible energy (DE). Location significantly affected ($P < 0.05$) the digestible contents of all AA except lysine, threonine, alanine, glycine, proline and serine. Cultivar had an effect on apparent ileal digestible CP and AA and on DE. Cultivar significantly affected ($P < 0.05$)

the digestible contents of all AA except lysine, phenylalanine, valine and cysteine. Overall, the digestible energy, protein and AA in the two corn cultivars averaged 3662 kcal kg^{-1}, 5.95% and 0.40%, respectively.

Based on the results of Experiment 2, Experiment 3 was conducted to determine the performance and carcass characteristics of growing-finishing pigs fed diets based on the two corn cultivars. Twenty-four Cotswold pigs with an average initial BW of 41.4 ± 1.4 kg (mean ± SD) were blocked by BW and sex and randomly allotted to one of three dietary treatments based on; 1) barley (control), 2) corn cultivar 1 and 3) corn cultivar 2 on a three-phase feeding program for the 20-50 kg, 50-80 kg and 80-110 kg BW range. The diets were formulated to contain 3,500 kcal kg^{-1} DE and 0.95%, 0.75% and 0.64% total lysine for phases I, II and III, respectively. There were no effects ($P > 0.05$) of dietary treatments on average daily gain (ADG), average daily feed intake (ADFI) and gain:feed ratio (G:F) in all the three phases. The overall ADG, ADFI and G:F averaged 0.87 kg, 2.43 kg and 0.36, respectively. Carcass length, dressing percentage, loin eye area, loin depth, midline backfat thickness, 10th rib backfat thickness, belly firmness fat color and the amount of saturated fatty acids, monounsaturated fatty acids and total unsaturated fatty acids in belly fat and backfat were similar ($P > 0.05$) across dietary treatments. Pigs fed diet based on corn cultivar 2 contained a higher ($P < 0.05$) amount of polyunsaturated fatty acids in their backfat compared with those fed barley-based diet.

The results from the three experiments show that the nutritional composition of corn varies with field location and CHU rating and that digestible energy, protein and AA contents of corn vary with location and cultivar. Furthermore, growth performance and carcass characteristics of pigs fed diets based on Manitoba-grown corn cultivars were similar to those fed barley-based diets.

DEDICATION

This thesis is dedicated to my parents, Dn. and Mrs J. O. Amole. You believe in me and my potentials. Thanks Dad and Mum.

ACKNOWLEDGEMENTS

I wish to sincerely appreciate my advisors, Dr. C. M. Nyachoti and Dr. J. D. House, for their guidance, valuable suggestions and constructive criticism throughout the course of my Master's program. Dr. Nyachoti's special contribution in improving my writing skill and research potential is greatly appreciated. I would also like to appreciate other members of my project committee, Dr. L. Onischuk and Dr. D. Flaten. I am also grateful to Dr. G. Crow and Dr. L. Onischuk for their immense contributions to the statistical analysis of the data.

I would like to thank Manitoba Corn Growers Association, Manitoba Pork Council and University of Manitoba through University of Manitoba Graduate Fellowship for funding this research project.

Appreciation also goes to Dr. Hodges, Heather Simpson, Dr. Yu Lan, Amy Hawkins, Sanjiv Bhandari, Tamara Wilson, Hongtao Guan, Bai Xu, Akbar Nikkah, Tyra Dickson, Ehsan Khafipoor, Obioha Durunna, Roger, Megan Bédard, Zhenbin Zhang, Terri Fahrenschon, R. Stuski and R. Lavallee for assisting with animal surgeries and animal cares.

Special thanks to all the administrative and technical staff of the department of Animal Science, Margaret Ann Baker, Ilse Frank, Claire Hutchinson, Cathy Plouffe, Karen Carrette, Thomas Davie, Ricky Araneda, Prakash Sharma, Jason Neufeld, Janice Haines and Harry Muc.

I can not but appreciate Dr. H. Weiler (Human Nutrition) for allowing me to use her laboratory and for her immense contribution to the fatty acid laboratory analysis procedures. It was fun brain storming with you! Shirley Fitzpatrick-Wong and Dennis Labossiere are also appreciated for providing technical assistance while working at Human Nutrition department.

Dr. H. D. Sapirstein (Food Sciences) is appreciated for giving me free access to his laboratory and so also is W. J. Johnson for providing technical assistance.

I appreciate my friends and family for being there when I need them most. Seyi, Tope and Yemi, you're the best siblings! Finally, my sincere appreciation goes to my dear husband for loving me for who I am, thanks Onitemi.

All the glory, honour and power belong to the almighty God for ever and ever!

FOREWORD

This thesis was written in a manuscript format and it is composed of three manuscripts. Manuscript I was partly published in Manitoba Corn School proceeding (February 20, 2004), Farmers Independent Weekly (August 12, 2004) and Council Research News (December, 2004). Manuscripts I and II were presented at the Canadian Society of Animal Science Annual Meeting (July, 2004). Manuscript II and III were presented at the Manitoba Corn School (February 18, 2005). Manuscript III will be presented at the ASAS-ADSA-CSAS joint meeting in July, 2005. All manuscripts were written according to the guideline for Canadian Society of Animal Science manuscript preparation. Authors to the manuscripts I and II are F.O. Opapeju, C. M. Nyachoti and J. D. House. Authors to manuscript III are all above mentioned authors and H. D. Sapirstein.

TABLE OF CONTENTS

Page

ABSTRACT..i

DEDICATION..iv

ACKNOWLEDGEMENT...v

FOREWORD...vii

TABLE OF CONTENTS...viii

LIST OF TABLES..xii

LIST OF FIGURES...xv

LIST OF ABBREVATIONS...xvi

1.0 GENERAL INTRODUCTION...1

2.0 LITERATURE REVIEW..6

2.1 Introduction...6

2.2 Corn as a feedstuff for swine...9

2.2.1 Chemical and nutrient composition of corn.................................9

2.2.1.1 Corn carbohydrates..11

2.2.1.2 Corn protein..12

2.3 Indicators of corn quality...13

2.4 Factors affecting corn quality..13

2.4.1 Soil texture, organic matter and moisture content........................14

2.4.2 Fertilizer type and amount..15

2.4.3 Row spacing and plant density...17

2.4.4 Genetics...17

2.4.5 Processing techniques....18

2.5 Corn heat units and corn production....19

2.6 Dietary supply of nutrients....21

2.6.1 Digestibility coefficients....22

2.7 Techniques for estimating nutrient digestibility....23

2.8 Growth performance and carcass and pork characteristics as a measure of feeding value....24

2.9 Conclusions....27

3.0 MANUSCRIPT I: CHEMICAL COMPOSITION AND AGRONOMIC PARAMETERS OF MANITOBA GROWN CORN CULTIVARS AS AFFECTED BY CORN HEAT UNITS AND FIELD LOCATION....29

3.1 Abstract....29

3.2 Introduction....30

3.3 Objectives....32

3.4 Materials and Methods....32

3.4.1 General experimental protocol....32

3.4.2 Sample preparation and chemical analysis....33

3.4.3 Statistical analysis....35

3.5 Results and Discussion....35

3.6 Conclusions....44

4.0 MANUSCRIPT II: DIGESTIBLE ENERGY, PROTEIN AND AMINO ACID CONTENT IN SELECTED MANITOBA-GROWN CORN CULTIVARS FED TO GROWING PIGS....45
4.1 Abstract....45
4.2 Introduction....46
4.3 Materials and Methods....47
4.3.1 General....47
4.3.2 Animals and housing....48
4.3.3 Experimental diets....48
4.3.4 Experimental design and procedures....50
4.3.5 Sample preparation and chemical analysis....50
4.3.6 Digestibility calculation and statistical analysis....52
4.4 Results and Discussion....53
4.5 Conclusions....71
5.0 MANUSCRIPT III: GROWTH PERFORMANCE AND CARCASS CHARACTERISTICS OF PIGS FED MANITOBA GROWN CORN CULTIVARS....72
5.1 Abstract....72
5.2 Introduction....73
5.3 Materials and Methods....74
5.3.1 Animals and diets....74
5.3.2 Carcass evaluation....78
5.3.3 Fatty acid analysis....81

5.3.4 Statistical analysis..82

5.4 Results and Discussion..83

5.4.1 Growth performance..85

5.4.2 Carcass characteristics..87

5.4.3 Fatty acid profiles of backfat and belly fat..90

5.5 Conclusions..97

6.0 GENERAL DISCUSSION..100

7.0 CONCLUSIONS..105

8.0 REFERENCES..108

9.0 APPENDIX..126

LIST OF TABLES

Page

2.0 LITERATURE REVIEW

Table 2.1. Grain corn production, capital expenses and cash receipts in Manitoba between 1999 and 2002..8

Table 2.2. Chemical and nutrient composition of grain corn (DM basis)..................10

3.0 MANUSCRIPT I

Table 3.1. Corn heat units and location effects on agronomical parameters and nutritional composition of Manitoba-grown corn cultivars......................36

4.0 MANUSCRIPT II

Table 4.1. Ingredient composition of the experimental diets.................................49

Table 4.2. Analyzed composition of corn corn cultivars (39M27 and 39W54) grown in different locations in Manitoba (St. Pierre, Reinland and Carman)..54

Table 4.3. Proportion of amino acids relative to protein content in the corn cultivars (39M27 and 39W54) grown in different locations in Manitoba (St. Pierre, Reinland and Carman)......................................55

Table 4.4. Analyzed composition of the experimental diets (%), as fed basis..............57

Table 4.5. Apparent ileal and total tract digestibilities (%) of dry matter, crude protein and energy in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location..58

Table 4.6. Apparent ileal digestibility of amino acids (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location.................61

Table 4.7. Standardized ileal digestibilities of crude protein and amino acids (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location 64

Table 4.8. Apparent digestible energy (kcal/kg) and ileal digestible crude protein and amino acids (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location (DM basis) 66

Table 4.9. Standardized ileal digestible crude protein and amino acids contents (%)in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location (DM basis)....68

5.0. MANUSCRIPT III

Table 5.1. Ingredient composition and calculated nutrient composition of the experimental diets....76

Table 5.2. Fatty acids profiles of barley and the corn cultivars used in the experimental diets....84

Table 5.3. Effects of diet and gender on growth performance of growing-finishing pigs....86

Table 5.4. Effects of diet and gender on carcass characteristics of growing-finishing pigs....88

Table 5.5. Effect of diet and gender on backfat fatty acid profiles in finishing pigs....91

Table 5.6. Effect of diet and gender on belly fat fatty acid profiles in finishing pigs....94

Table 5.7. Comparison of the amount of different fatty acids in the backfat and belly fat of pigs fed diets based on barley and two corn cultivars........98

LIST OF FIGURES

Page

2.0 LITERATURE REVIEW

Figure 2.1 Nitrogen cycle....................16

3.0 MANUSCRIPT I

Figure 3.1 Cumulative frequencies of crude protein and crude fat contents of the corn samples from Reinland and St. Pierre....................39

Figure 3.2. Cumulative frequencies of neutral detergent fiber and acid detergent fiber contents of the corn samples from Reinland and St. Pierre....................41

4.0 MANUSCRIPT II

Figure 4.1. Interaction between location and cultivar on apparent ileal digestibility of methionine....................62

5.0 MANUSCRIPT III

Figure 5.1. Lateral and vertical belly flex measurement....................80

LIST OF ABBREVIATIONS

AA	Amino acid
ADF	Acid detergent fiber
ADFI	Average daily feed intake
ADG	Average daily gain
AID	Apparent ileal digestibility
ATTD	Apparent total tract digestibility
BW	Body weight
CHU	Corn heat units
CP	Crude protein
DE	Digestible energy
DM	Dry matter
DMI	Dry matter intake
DON	Deoxynivalenol
G:F	Gain:feed ratio
LEA	Loin eye area
LP	Lipid deposition
L	Location
MUFA	Monounsaturated fatty acids
NDF	Neutral detergent fibre
OM	Organic matter
PD	Protein deposition
PUFA	Polyunsaturated fatty acids

SID	Standardized ileal digestibility
SFA	Saturated fatty acids
UFA	Total unsaturated fatty acids

1.0 GENERAL INTRODUCTION

Corn (*Zea mays* L.), tropical in origin, has since been adapted to areas with short growing seasons like Manitoba. Recently, there was a dramatic increase in the quantity of corn produced in Manitoba. For instance, Manitoba Agriculture, Food and Rural Initiatives (MAFRI) (2003) reported a 46.5% increase in the amount of corn produced in 2002 compared to 2001. Also, Manitoba is the leading producer of grain corn in western Canada (MAFRI 2003). Although wheat and barley are the main sources of energy in western Canadian swine feeds, with the present growth rate in corn production, there is interest in increasing the use of corn as an energy source.

Temperatures in most parts of Canada are usually too low for corn production. This has triggered the use of cumulative temperatures such as corn heat units (CHU) in place of calendar days for measuring the temperatures required for the growth and development of corn. According to MAFRI (undated), "corn heat units are a measure of useful heat required for growth and development of corn". Corn heat units are estimated based on the daily minimum and maximum temperatures. Therefore, the amount of CHU varies with location and as a result, cultivars and geographical locations are rated based on CHU and these ratings are used to determine the appropriate cultivar for a particular field location. Grain corn cultivars grown in Manitoba require a minimum amount of 2200 CHU to reach maturity and based on CHU requirement, a larger part (about 95%) of Manitoba's agricultural land is capable of supporting the production of grain corn.

The use of nutritional book values, such as those published by the National Research Council (NRC), to formulate feed for pigs poses a big challenge to the swine industry because the feeding value of feedstuffs changes with location. It has been well documented that chemical and nutrient composition of corn, like other feedstuffs, changes from region to region even within the same cultivar (Singh et al. 2000; Kuo et al. 2001; Schmidt et al. 2002). This is basically due to variability in factors such as growing conditions, cultivars and management practices that affect grain quality. Therefore, swine producers that use book values to formulate diets for pigs are faced with a possibility of over- or under-supplying dietary nutrients relative to the animals' requirements. In order to efficiently incorporate Manitoba grown corn cultivars into swine diets, it is important to quantify the amount and bioavailability of nutrients in the cultivars grown locally. This is because knowledge of the feeding value of locally available feedstuffs will allow for accurate and cost-effective formulation of swine diets. Furthermore, manipulation of dietary supply of nutrients to minimize excretion of nutrient requires precise knowledge of the feeding value of locally available feedstuffs. The feeding value of Manitoba-grown corn cultivars for swine is yet to be determined.

Various indicators have been used to determine the nutritive value of feedstuffs and these include chemical and nutrient composition, nutrient bioavailability, animal performance and product quality. Chemical and nutrient composition of feedstuffs are determined through proximate (which is a chemical determination of moisture, crude protein (CP), crude fiber, ash, ether extract and nitrogen-free extract components of feedstuffs) and other laboratory analyses used to determine nutrients such as amino acids (AA) and phosphorus (Crampton and Harris 1969). However, chemical and nutrient composition of feedstuffs estimated through proximate and other laboratory analyses only serve as an indicator of the potential nutritive value of the feedstuff and it has been suggested that these measurements are not adequate indicators of the feeding value of feedstuffs (D'Alfonso 2002).

Nutrient bioavailability is "the proportion of the nutrient that is digested, absorbed and metabolized through normal pathways" (Srinivasan 2001). Nutrient digestibility (the difference between the nutrient intake and output) is often used as an indicator of available nutrients. In fact, for some nutrients such as CP and AA, determination of their digestibility values in feedstuffs are preferred as a routine evaluation of the feeding value of feedstuffs for feed formulation purposes because availability measurements are expensive and time-consuming (Gabert et al. 2001). Apparent digestibility of nutrient, a measure of the difference between the nutrient intake and output, does not distinguish dietary nutrient from the endogenous nutrient losses in the gut of an animal. For CP and AA, standardized and true ileal digestibilities are preferred to apparent ileal digestibility (AID) because basal and specific endogenous CP and AA losses are accounted for, respectively, and they are more additive in a mixture of feedstuffs (Nyachoti et al. 1997, 2002; Rademacher 2001; Moter and Stein 2004). Basal endogenous CP and AA losses are products of regular metabolic activities of the animal while specific endogenous CP and AA losses are secreted as a result of nutritional factors such as type and source of fiber, anti nutritional factors and level and quality of protein (Butts et al. 1993; Hess and Sève 1999; Rademacher et al. 2000; Moter and Stein 2004). Although true ileal digestibility of CP and AA account for specific endogenous CP and AA losses related to that particular feedstuff, it is expensive to employ as a routine assay for measuring CP and AA digestibility of every feedstuff in a practical feed formulation because it requires animal experiments. Standardized ileal CP and AA digestibility on the other hand can be calculated from the previously determined book values of endogenous CP and AA losses making it less expensive and more suitable as a routine estimate of CP and AA digestibility.

Digestibility of nutrients has been estimated using different approaches such as direct, difference and regression methods (Fan and Sauer 1995; Gabert et al. 2001). The decision as to which approach to use depends on the chemical and nutrient composition of the feedstuff and its palatability (Gabert et al. 2001). While feedstuffs that are high in protein content can be evaluated using any of the three approaches, the difference and regression approaches are more suitable for feedstuffs that are low in protein content (Fan and Sauer 1995).

For profitable swine production, it is important to bring pigs to market at the earliest possible time and to produce good quality products. Therefore, animal performance and carcass and pork quality characteristics such as back fat thickness, loin depth, and fat color (National Pork Producers Council (NPPC) 1998; Burson 2001) are critical to profitability. Lean meat and firm, white fat are preferred (Lampe et al. 2004; Carr et al. 2005) as these are closely associated with human health, pork product processing and local and international market demands. Colored fat could increase the processing cost of lard especially the cost associated with bleaching (a process of removing coloring materials from fats). Furthermore, it has been well established that pig performance and pork quality are affected by the composition of diets (Berg 2001; Averette Gatlin et al. 2003) and therefore, feeding diets high in unsaturated fats could reduce the concentration of saturated fatty acids in pork fat. Although meat with a low concentration of saturated fatty acids could reduce the risk of cardiovascular diseases in humans, feeding a diet containing high amount of unsaturated fat results in soft bellies, which are difficult to slice and often yield lower quality bacon (St. John et al. 1987; Shackelford et al. 1990; Carroll et al. 1999).

Thus, a complete evaluation of the feeding value of an ingredient should be done in light of nutrient digestibility, animal performance and end product quality.

It was hypothesized that:

1. Chemical and nutrient composition of corn varies with CHU rating of corn cultivar and with field location.

2. Digestible energy, CP and AA contents of corn vary with cultivar and field location.

3. Feeding corn-based diet to growing finishing pigs will produce similar growth performance and carcass characteristics as barley-based diet.

The overall objectives of these studies were:

1. To evaluate the chemical composition and nutritive value of Manitoba-grown corn cultivars fed to growing pigs.
2. To determine growth performance and carcass characteristics of pigs fed diets based on Manitoba-grown corn.

2.0 LITERATURE REVIEW

2.1 INTRODUCTION

The swine industry is a very important component of the agricultural sector in Canada and other parts of North America. Sustainability of this sector depends partly on the proper management of dietary nutrient supply. This is because feed, energy being the major component, represents more than half of the total cost of production (Noblet and Perez 1993). Production of barley and wheat, traditionally the main sources of energy in swine diets in western Canada, was recently challenged by drought conditions in the Prairies and also by mycotoxin infection (Loyns 2002; Clowes and Zijlstra 2003). Corn, which is an excellent energy source, has been reported to be more resistant to fusarium head blight compared to barley and wheat (Loyns 2002). Likewise, Campbell et al. (2002) and Scott (1997) observed that compared with barley and wheat, corn has a higher incidence but lower content of deoxynivalenol (DON) (a mycotoxin that induces anorexia in pigs) contamination. The relationship between the incidence and concentration of DON in corn was attributed to the presence of husk cover for corn kernels. However, there is only limited information on the relative susceptibility of various cereal grains to mycotoxin infections and this needs to be investigated.

Production of corn (*Zea mays* L.) became commercially significant in Manitoba in the late 1970s (MAFRI 2003). The increased production was a result of the extensive work by plant breeders to adapt corn to areas with short growing seasons. In Manitoba, grain corn production has experienced a tremendous growth in the last four years. The number of farms where grain corn is cultivated increased by 29%, the seeded area increased by 41% and the harvested area increased by 55% in 2002 compared with 2001 (Table 2.1). Grain corn production in Manitoba has not only increased in terms of tonnage, but also in terms of amount of dollars generated. For example, in 1999, 2000, 2001 and 2002, the cash receipts were 19, 21, 22 and 35 million dollars, respectively (Table 2.1). In addition to increased production, Manitoba grown corn is attracting a lot of interest as a swine feedstuff because it is locally grown and therefore offers opportunities to effectively manage dietary nutrients and maintain sustainability. Until now, the amount of Manitoba grain corn used in the swine industry has been small partly due to availability and lack of data on the feeding value of the available cultivars.

The use of locally-grown corn cultivars would be beneficial to corn growers and pig producers. Environmental conservation, reduced cost of transportation and handling and addition of value to feedstuffs are part of the reasons why the use of locally grown feedstuffs should be encouraged (House et al. 2002). As environmental conservation has become an important issue in livestock production, the use of locally available ingredients has potential to reduce net accumulation of nutrients that results from importation of feedstuff and thereby enhance nutrient recycling within an ecosystem. This review will explore the feeding value of grain corn for swine in terms of chemical composition, nutrient digestibility, animal performance and product quality.

Table 2.1. Grain corn production, capital expenses and cash receipts in Manitoba between 1999 and 2002.

	Year				
Item	1999	2000	2001	2002	'02 as a % of '01
Estimated number of farms	540.0	600.0	542.0	700.0	129.2
Crop production					
Seeded area ('000 acres)	110.0	145.0	110.0	155.0	140.9
Harvested area ('000 acres)	100.0	130.0	100.0	155.0	155.0
Yield/acre (bushels)	94.0	80.0	98.5	93.5	94.9
Production (million bushels)	9.4	10.4	9.9	14.5	146.5
Average price ($ bu^{-1})	2.6	2.7	3.0	3.6	120.0
Value of production ($ million)	24.1	28.3	29.5	52.7	178.6
Estimated total expenses ($ ac^{-1})	268.8	263.6	279.0	267.8	96.0
Cash receipts ($ million)	19.2	21.4	22.1	35.1	158.8

Adapted from MAFRI (2003)

2.2 CORN AS A FEEDSTUFF FOR SWINE

Corn is the most commonly used cereal grain in animal feed in North America and it is widely accepted as an excellent source of energy in swine diets. Also, because corn is used in relatively large amounts in most swine diets, it makes a significant contribution to the dietary amount of other nutrients like CP and AA. It has been shown that when fed to pigs, corn has superior or equal feeding value as barley (ZiRong et al. 2002; Lampe et al. 2004), which along with wheat are traditionally the main sources of energy in swine diets in western Canada. Although the feeding value of corn for swine has been evaluated extensively, its variability in chemical and nutrient composition from location to location (D'Alfonso 2002) warrants evaluation of the feeding value of locally available cultivars in order to optimize their use as a feedstuff.

2.2.1 Chemical and nutrient composition of corn

The chemical and nutrient composition of corn varies with location because it depends on factors such as genetics, climatic conditions, management practices, handling and processing (Pomeranz and Bechtel 1978; D'Alfonso 2002). Table 2.2 shows the published chemical and nutrient composition of corn.

Corn is a one-seeded fruit whose structure consists of pericarp (about 6%), endosperm (83%) and germ (11%) (Pomeranz and Bechtel 1978). All the three parts of the corn kernel vary in nutrient composition. The pericarp contains 73% insoluble non-starch carbohydrates, 16% fiber, 7% protein and 2% oil; the endosperm contains 85% starch and 12% protein while germ contains mostly oil (81-85%) and limited amounts of protein and carbohydrate (Pomeranz and Bechtel 1978). The kernel, generally high in

Table 2.2. Chemical and nutrient composition of grain corn (DM basis)

	References[z]			
Item	1	2	3	4
Dry matter, %	91	89	-	-
Crude Protein, %	6.8-8.2	9.3	11	9.8
Ether Extract, %	-	4.4	4.2	-
Ash, %	-	-	1.3	-
Nitrogen-free extractives, %	-	-	7.2	-
ADF, %	2.8	3.1	-	-
NDF, %	9.6	10.8	-	-
Gross Energy, Mcal/kg	4.10-4.15	-	4.16	-
Essential amino acids, %				
Arginine	0.39	0.42	0.49	0.42
Histidine	0.22	0.26	0.31	0.33
Isoleucine	0.30	0.31	0.38	0.36
Leucine	0.96	1.11	1.45	1.34
Lysine	0.27	0.29	0.28	0.27
Methionine	0.16	0.19	0.28	0.22
Phenyalanine	0.40	0.44	0.53	0.54
Threonine	0.28	0.33	0.35	0.38
Tryptophan	0.06	0.07	-	0.06
Valine	0.39	0.44	0.57	0.50

[z]1, Moeser et al. (2002); 2, NRC (1998); 3, Sproule et al. (1988); 4, Ortega et al. (1986).

carbohydrates (mostly starch) and low in protein, contains a small amount of fat, fiber, ash and important minerals and vitamins such as calcium, phosphorus, niacin and carotene (Pomeranz and Bechtel 1978; NRC 1998; Prasanna et al. 2001). Although corn is a poor source of two indispensable AA namely lysine and tryptophan (Qi et al. undated; Prasanna et al. 2001), it is especially valued for its high energy content which is the most expensive component of a swine diet. Corn has higher digestible energy (DE) content (3525 kcal kg^{-1}) compared with barley and wheat, (3050 and 3365 kcal kg^{-1}, respectively) (NRC 1998). Characterization of corn cultivars from different locations offers an opportunity to manage the dietary supply of nutrients in swine diets to closely match the animals' requirements. This will not only minimize the cost of production by preventing excessive supply of dietary nutrients but will also minimize the amount of nutrients (e.g. nitrogen and phosphorus) excreted into the environment and the associated pollution problems.

2.2.1.1 Corn carbohydrates

Corn carbohydrates, like other grain cereals, are made up of starch, pentosans and sugar (Pomeranz and Bechtel 1978). The high amount of starch (about 71% of the corn kernel) in corn makes it a concentrated source of dietary energy (Johnson et al. 1999; Prasanna et al. 2001). Corn starch is a polymer of glucose linked together as alpha 1-4 or 1-6 linkages (Johnson et al. 1999). Alpha 1-4 linkage forms a linear chain molecule called amylose and alpha 1-6 forms a branch chain molecule called amylopectin (Johnson et al. 1999). Regular corn starch contains about 27% amylose, which is responsible for the gel formation property of starch and about 73% amylopectin, which is responsible for the viscous property of starch (Johnson et al. 1999). In fact, alteration of the ratio of amylose to amylopectin in corn starch changes the starch property. For example, waxy corn, contains 100% amylopectin, has a viscous starch (Rooney and Pflugfelder 1986). However, waxy corn has been reported to have equal or superior feeding value compared with regular corn when fed to growing and finishing pigs (Johnston and Anderson 1996; Swantek et al. 1996; Camp et al. 2003). Superior feeding value of waxy corn relative to regular corn has been related to higher availability of branched chain amylopectin compared with the straight chain amylose (Rooney and Pflugfelder 1986; Granfeldt et al. 1993). However, due to the viscous property of amylopectin, nutrients in waxy corn might not be well utilized by young pigs because their digestive systems have not been developed fully. The nutritional value of waxy corn for young pigs requires further investigation.

2.2.1.2 Corn protein

Corn contains four types of protein, which include water-soluble proteins (albumins), salt-soluble proteins (globulins), alcohol-soluble proteins (prolamins) and acid- and alkali-soluble proteins (glutelins) (Pomeranz and Bechtel 1978). Prolamins which are otherwise called zeins are the predominant protein in corn and are found only in the endosperm (Prasanna et al. 2001). Zeins constitute about 60% of the endosperm and are rich in glutamine, leucine and proline but contain no lysine and tryptophan (Prasanna et al. 2001). Although, albumins, globulins and glutelins are balanced in AA contents, the corn kernel as a whole is deficient in lysine and tryptophan due to the effect of zeins (Prasanna et al. 2001).

2.3 INDICATORS OF CORN QUALITY

Corn growers evaluate corn quality based on agronomic parameters (yield and bushel weight) while livestock producers are interested in the chemical and nutrient profile of corn. Zijlstra et al. (2003) reported that bushel weight, which has been used traditionally as a measure of grain quality, is not a good indicator of the nutritive value of cereal grains, including corn. Of interest to livestock producers are oil and protein contents of grain corn (Roozeboom and Herrman 2001). High oil content in corn has an advantage of increasing the energy concentration of diet and at the same time reducing the amount of dust in feed. Increased protein content in grain corn can drastically reduce feed cost by reducing the amount of expensive protein supplements required. In fact, additional 1% increase in protein and oil contents of corn can reduce the cost of feed by $5 and $2, respectively, for every ton of corn depending on the amount of soybean and grease oil replaced in the diet (Roozeboom and Herrman 2001).

2.4 FACTORS AFFECTING CORN QUALITY

It has been well documented that grain corn quality, both agronomical and nutritional, varies. Corn quality varies with cultivar (Moss et al. 2001; Schneider et al. 2004) and location (D'Alfonso 2002; Schmidt et al. 2002) as a result of variability in factors such as fertilizer type and quantity, precipitation, processing and storage and genetics that affect corn quality. Although the effects of these factors on agronomic quality indicators such as yield have been widely studied, there is limited information on their effects on the chemical composition and nutrient bioavailability in corn. Thus, there is need for research to characterize the effects of factors that affect growth and development of corn (and other feedstuffs) on the chemical composition and nutrient bioavailability in order to efficiently manage dietary nutrient supply in livestock diets.

2.4.1 Soil texture, organic matter and moisture content

Corn prefers well drained soils especially sandy-loam or silty-clay-loam textured soils compared with poorly drained (clay) or rapidly drained (sandy) soils (MAFRI undated). Furthermore, soil differs in organic matter (OM) content and high OM usually translates to greater N mineralization and availability and hence, greater yields (Mahmoudjafari et al. 1997; Schmidt et al. 2002). Rainfall and grain corn yield are positively correlated (Carreker et al. 1972; Garlipp 1976; Drury and Tan 1995). In a study by Schmidt et al. (2002), variation in nitrogen availability to corn plants among different locations in a field was partly attributed to soil water content.

Availability of nutrients, through soil water, to plant is closely associated with soil texture. For example, excess soil water, which can result from a poorly drained soil, is detrimental to corn growth and yield and it increases the rate of susceptibility to diseases (Carter et al. 1990; MAFRI undated). According to Durst and Beegle (1999), when soil is saturated or under anaerobic conditions as a result of excessive rainfall or poor drainage, soil bacteria use up nitrate oxygen and convert nitrate nitrogen to nitrogen gas, a form that is unavailable to plant and that is readily lost to the atmosphere. Furthermore, excessive rainfall in a rapidly drained soil leads to leaching of soil nitrate before plants get any chance to absorb it (Figure 2.1). Likewise, inadequate supply of water or low water input limits potential grain yield, retards growth, and in severe cases may lead to development of nutrient deficiency symptoms (MAFRI undated; Liang et al. 1991). Since soil water plays an important role in nutrient uptake by plants, any factor that reduces efficiency of nutrient uptake through soil water could affect grain nutrient concentration. However, the relationship between soil texture and soil moisture content in relation to nutritional quality of grain corn has not been fully explored.

2.4.2 Fertilizer type and amount

Soil fertility is important to corn yield and nutrient content. Yield and protein content of grain corn increase with nitrogen fertilization (Cherney and Cox 1992; Moss et al. 2001; MAFRI undated). Furthermore, fertilizer type and amount may affect corn yield, nutrient content and nutrient digestibility. For instance, in a study by Moss et al. (2001), corn fertilized with a low (4.5 Mg ha^{-1}) amount of broiler litter had lower N-uptake and whole plant yield compared to corn fertilized with a medium (9 Mg ha^{-1}) amount of broiler litter or ammonium nitrate commercial fertilizer (202 kg ha^{-1}). Although yield and nutrient content of corn fertilized with appropriate rate of broiler litter was comparable to that of ammonium nitrate fertilizer, in vitro dry matter (DM) digestibility was lower (Moss et al. 2001). Nutrient deficiency generally retards plant growth and consequently reduces yield (MAFRI undated). However, the effects of type and amount of fertilizer on nutrient digestibility, an important quality indicator for swine producers, of grain corn in animal studies are yet to be fully addressed.

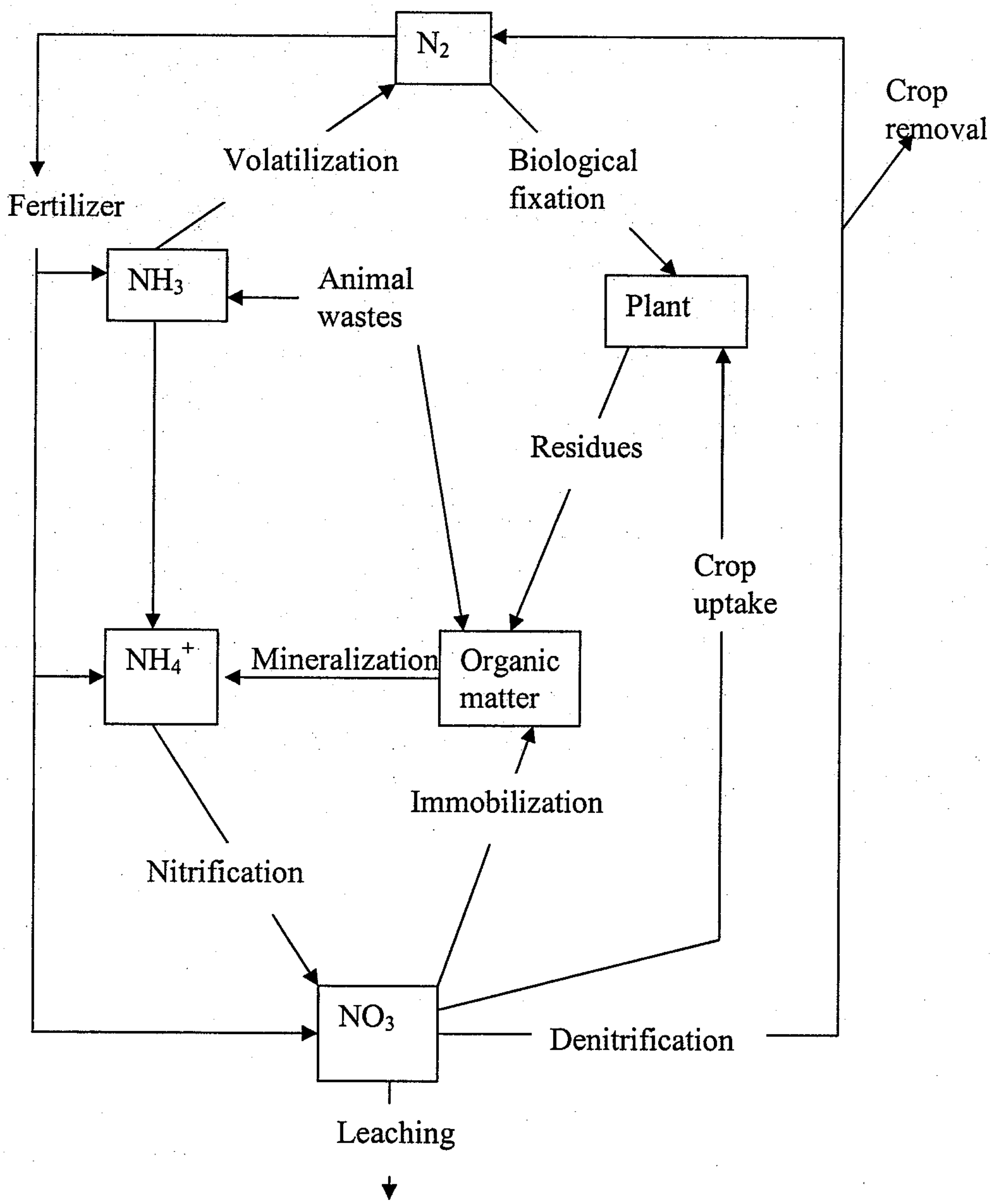


Figure 2.1. Nitrogen cycle

Source: Durst and Beegle (1999)

2.4.3 Row spacing and plant density

Optimization of planting space, through increased plant density, to reduce cost and increase yield is of economic importance to corn growers (Farnham 2001). Fulton (1970) and Norwood (2001) reported a higher yield for plants grown at high density. Likewise, high grain yield has been associated with corn grown in narrow row spacing (Lutz et al. 1971; Fulton 1970; Porter et al. 1997). Row spacing had no effect on grain moisture content (Porter et al. 1997; Farnham 2001) but the effects of row spacing and plant density on chemical composition and feeding value of corn have not been evaluated.

2.4.4 Genetics

The role of genetics in developing corn cultivars with better agronomic and nutritive potential can not be over emphasized. Over the years, plant breeders have targeted specific, desirable traits, such as yield (Duvick 1992, 1997; Tollenaar and Lee 2002), days to maturity and foliage characteristics (Modarres et al. 1998; Begna et al. 1999; Dijak et al. 1999), protein, lysine and oil contents (O'Quinn et al. 2000), and herbicide tolerance (Ridley et al. 2002; Herman et al. 2004). Tollenaar and Lee (2002) reported that 60% of the improvement made to yield of grain corn can be attributed to genetics and 40% to improved agronomic practices. A significant interaction between genetics and agronomic management was reported for production of desirable yield (Duvick 1997; Tollenaar and Lee 2002). The genetic-environment interaction suggests that the agronomic and nutritional quality potential of a plant might not be fully expressed under unfavorable growing conditions. A good understanding of the suitable growing conditions for different corn cultivars will enhance expression of their full genetic potential and will be of great benefit in producing quality grain corn for livestock feed. Furthermore, corn cultivars that can be grown successfully in areas with short growing season have been developed by plant breeders. However, it is unknown whether the nutritional quality of these cultivars was altered while they were being developed.

2.4.6 Processing Techniques

Processing of grains for storage and at feed mills can have a significant effect on their nutritional value. Prolonged post-harvest drying of corn at high temperature could result in heat damage and hence reduce its nutritional value for pigs and poultry (MAFRI undated; Jensen et al. 1960; Emerick et al. 1961). The observed relationship between heat damage and feeding value of grains might be due to starch degradation and unavailability of limiting amino acids (Milner and Woodforde 1965).

Whole grains are usually subjected to various forms of processing such as grinding and pelleting before they are fed to pigs and poultry. It has been shown that for grinding, the type of mill (hammer mill vs roller mill) used has no consistent effects on nutrient digestibility and animal performance. For example, Reece et al. (1985) reported an increase in the efficiency of gain when broiler chicks were fed corn milled in a roller mill compared with a hammermill. However, Ohh et al. (1983) failed to find such effects of mill type (hammermill vs roller mill) on nutritional value of corn and sorghum fed to nursery pigs. Wondra et al. (1995a) also reported inconsistent results of the effects of mill type on animal performance and nutrient digestibility. In that study, coarsely ground (800 μm) roller mill processed corn had higher nutrient digestibility compared with hammer milled corn. However, finely ground (400 μm) roller mill processed corn had higher nutrient digestibility in one experiment and lower nutrient digestibility in another. This inconsistency in the effect of mill type on nutrient digestibility in relation to particle size warrants further research.

Generally, the particle size of grain used to formulate diets has been shown to affect digestibility of nutrients and feed efficiency. For example, feed efficiency and nutrient digestibility of finishing pigs were improved when corn particle size was reduced from 1,000 to 400 μm (Wondra et al. 1995b). Compared with mash diets, pelleted diets have been shown in most studies to increase feed efficiency and nutrient digestibility in pigs (Skoch et al. 1983; Wondra et al. 1995b). The improvement in nutrient digestibility might be due to inactivation of anti-nutritional factors as a result of the heat treatment involved in pelleting (Mavromichalis and Baker 2000). With the current environmental concerns related to intensive livestock production, grain processing techniques that offer opportunities to increase digestibility and reduce fecal excretion of nutrients will be of great benefit to the swine industry.

2.5 CORN HEAT UNITS AND CORN PRODUCTION

Corn heat units (CHU) are cumulative temperatures that have been adopted as a means of measuring growth and development of corn in areas like Manitoba with low temperatures. Plett (1992) reported that CHU is the most consistent thermal index for measuring growth and development of corn. For efficient corn production, both the cultivar and field location are rated based on CHU. In other words, selection of a corn cultivar that can be grown successfully in a particular area is based on its CHU rating and on the CHU accumulation at the field location during the planting season (MAFRI undated). Daily CHU accumulation is calculated as follows (MAFRI undated):

$$CHU = \left[\frac{1.8(T_{min} - 4.4) + 3.3(T_{max} - 10) - .084(T_{max} - 10)}{2} \right]$$

where T_{min} = daily minimum temperature (°C) and T_{max} = daily maximum temperature (°C).

It is expected that the CHU accumulation in an area will vary within and between years as daily maximum and minimum temperatures are important determinants of CHU. Indeed, this has been shown to be the case by Major et al. (1978) who reported that there was a substantial year to year variability in the amount of CHU accumulated in an area. Corn heat units accumulation at field location has been shown to influence chemical composition and yield of grain corn. Liang et al. (1993) reported a reduction in the N concentration of grain corn as CHU accumulation at the field location exceeded 3000 irrespective of plant population, fertilizer rate and precipitation. The authors attributed the reduced N concentration of grain to reduced N uptake at very low or very high CHU levels. Likewise, Liang et al. (1991) found a curvilinear relationship, at conventional population density, between grain corn yield and the increasing amount of CHU accumulation at the field location; yield increased as the amount of CHU accumulated increased from 2836 to 3013 and thereafter dropped. Furthermore, Dwyer et al. (1991) reported an increase in yield as the amount of CHU accumulated at the field location increased from 2832 CHU to 3232 CHU. There is, however, lack of information on the effects of CHU rating of corn on the chemical composition and nutrient concentration of grain corn. Detailed knowledge of the effect of CHU rating of corn cultivar on the feeding value of corn (e.g. nutrient digestibility) will help in selecting cultivars to grow for use in animal diets.

2.6 DIETARY SUPPLY OF NUTRIENTS

One of the indicators of the feeding value of a feedstuff is the digestibility of its nutrients, which is a measure of the disappearance of nutrients from the gastrointestinal tract. Insufficient supply of dietary nutrients will prevent the full manifestation of the genetic production potential of livestock. On the other hand, excessive dietary supply of nutrients could escalate the cost of production that could otherwise be avoided and this could impair profitability and sustainability of the livestock industry. Moreover, excessive dietary supply of nutrients could lead to high amounts being excreted in feces and a high concentration of nutrients in manure, especially nitrogen and phosphorus, has been associated with environmental pollution (Kornegay, 1996). Generally, manipulation of dietary supply of nutrients has been suggested as an effective tool in improving nutrient utilization by animals and thereby reducing environmental concerns related to livestock production (Miner 1999; Knowlton et al. 2004; Powers 2004). Therefore, in order to optimize nutrient utilization by livestock, an accurate estimation of nutrient digestibility coefficients of feedstuff is important. Digestibility coefficients of nutrients are measured typically at the ileal or fecal level.

2.6.1 Digestibility coefficients

Ileal digestibility coefficients are measured by estimating the difference between dietary nutrient content and the digesta nutrient content at the terminal ileum while total tract digestibility coefficients are estimates of the difference between the amount of nutrient fed to the animals and the amount excreted in feces. Measurement of digestibility coefficient, whether ileal or total tract, can be apparent, standardized or true. Apparent digestibility of a nutrient is a direct measurement of nutrient digestibility without accounting for endogenous nutrient losses in digesta or feces. For CP and AA standardized and true ileal digestibilities provide better estimates of digestibility than AID because they are more additive in a mixture of feedstuffs (Nyachoti et al. 1997, 2002; Rademacher 2001). True ileal CP and AA digestibility coefficients are apparent ileal digestibility coefficients corrected for specific endogenous CP and AA losses related to the feed ingested. Standardized ileal CP and AA digestibility coefficients are apparent ileal digestibility coefficients corrected for non-specific (basal) endogenous CP and AA losses (Rademacher et al. 2000). The non-specific endogenous CP and AA losses are based on the average values derived from a number of animal studies, and therefore standardized CP and AA digestibility is more suitable as a routine measure of CP and AA digestibility in practical feed formulation.

The appropriateness of ileal or total tract digestibility for a particular nutrient depends basically on the nutrient of interest. For example, true ileal and true total tract digestibility of phosphorus were not different (Fan et al. 2001; Ajakaiye et al. 2003) but the digestible energy (DE) content of feedstuffs is measured at fecal level because DE measured at the fecal level provides a better estimate of the energy available for pig use. However, ileal rather than total tract digestibility measurements are preferred for AA because total tract AA digestibility coefficients do not account for modifications that occur to AA metabolism due to the activities of hind gut miroflora (Zebrowska 1973; Li and Sauer 1994). Hind gut microflora are capable of utilizing dietary protein and synthesizing AA. Total tract AA digestibility can therefore be underestimated or overestimated as a result of AA degradation or de novo synthesis of AA, respectively (Sauer and Ozimek 1986; Darragh and Hodgkinson 2000). Also, the efficiency of utilization for the nitrogen absorbed at the hind gut for body metabolism is negligible (Just et al. 1981).

2.7 TECHNIQUES FOR ESTIMATING NUTRIENT DIGESTIBILITY

Three major approaches, direct, difference and regression, are used to evaluate ileal and total tract digestibilities of a nutrient. The direct approach involves feeding the test ingredient as the sole source of the desired nutrient (Lin et al. 1987). In a case where the feedstuff can not be fed solely for a long time or where the amount available is limited, the test feed ingredient can be fed along with another feedstuff that supplies the nutrient of interest (Fan and Sauer 1995; Adeola 2001). This approach is called the indirect method and is based on the assumption that there is no interaction between the desired nutrient digestibility in the test feedstuff and the other feedstuff (Furuya and Kaji 1991; Fan et al. 1993). Another widely used approach is the regression method, and like the difference method, it involves the use of basal and test diets and it is based on the assumption that there is no interaction between digestibilities of the desired nutrient in the basal and test feedstuffs (Fan and Sauer 1995). In this approach, a series of test diets are formulated using graded levels of the desired nutrient and these levels are accomplished through mixture of various of amounts of basal and test feedstuffs. Detailed estimation of apparent nutrient digestibility, including mathematical equations, using the three approaches has been fully reviewed by Fan and Sauer (1995).

The choice of the approach to use for determining nutrient digestibility coefficients depends on palatability and the nutrient content of the test feedstuff. Adeola and Bajjalieh (1997) reported similar DE values for corn cultivars evaluated with the direct and difference methods. With respect to CP and AA, feedstuffs with high levels can be evaluated using any of the three approaches; the difference and regression approaches are suitable for feedstuffs with low protein content (Fan and Sauer 1995; Gabert et al. 2001); and the regression method is more appropriate for less palatable feedstuffs (Fan and Sauer 1995). Although nutrient digestibility is a good indicator of feedstuff quality, a complete evaluation of the feeding value of a feedstuff has to be done in light of its effects on animal performance and end product quality.

2.8 GROWTH PERFORMANCE AND CARCASS AND PORK CHARACTERISTICS AS A MEASURE OF FEEDING VALUE

In order to maximize profit in the swine industry, producers aim at bringing pigs to market at the earliest possible time and at the lowest possible cost without compromising product quality. In this light, pigs have been genetically developed over the years for high growth rates, low feed conversion ratio and high lean meat percentage (Holck et al. 1998; Karlsson et al. 1999). Expression of these genetic potentials is closely related to environmental conditions (Holck et al. 1998; Frank et al. 1998) and nutrition (Ellis and Mckeith 1999). From a nutritional point of view, growth performance, carcass characteristics and fat quality are important indicators of the feeding value of a feedstuff. Measures of growth performance include average daily gain (ADG), average daily feed intake (ADFI) and feed:gain ratio. A feedstuff that produces high ADG at the lowest amount of feed intake has the potential for reducing the costs of production by reducing the amount of time required to raise the pig to market and thereby cutting down on associated costs of production such as housing and labor cost. For example, according to Dial et al. (2001), a pig between 20 and 110 kg body weight is expected to have an ADG of 0.75 kg, ADFI of 2.21 kg and gain:feed ratio of 0.34. A feedstuff will be of good feeding value if it can support animal performance equal to or more than that standard. Beside growth performance, which is particularly of interest to swine producers, effect of feedstuff on carcass and fat qualities are important in order to meet the competitive local and international market demands (Lampe et al. 2004). Lean meat and firm, white fat are preferred (Carroll et al. 1999; Averette Galtin et al. 2003; Carr et al. 2005). Feeding diets high in carotenoids (naturally occurring fat soluble pigments found in plants) to pigs might result in production of yellow fat and thereby cause a reduction in the market value of the pork products.

Furthermore, nutrition has been reported to be an effective tool in altering the fatty acids profile of pork and fat tissue. Berg (2001) and Ellis and McKeith (1999) reported that apart from the de novo synthesis of fat, pork fatty acid profile is a product of dietary fatty acid profile. Feeding diets high in unsaturated fats to pigs has been associated with a lower concentration of saturated fatty acids in pork and consumption of unsaturated fat has a potential of reducing the risk of coronary heart diseases in humans by reducing low density lipoprotein-cholesterol (Rentfrow et al. 2003). However, a high amount of unsaturated fats in pork can pose serious processing problems. Difficulty in belly slicing, reduced visual attractiveness of sausage and susceptibility to rapid oxidative rancidity are among the problems associated with high amounts of unsaturated fats in pork (Carroll et al. 1999; Averette Gatlin et al. 2003; Carr et al. 2005). For bacon processing, it is recommended that the amount of linoleic acid (18:2) and poly unsaturated fatty acid (PUFA), the major contributors to soft belly, should not exceed 14 and 15%, respectively, in the belly fat (NPPC 2000). Likewise, less then 23% of PUFA in the backfat of pigs is recommended for salami making (Warnants et al. 1998). A feedstuff with good feeding value should support the fat deposition in the belly fat and backfat of pigs in a way that will not impair end product processing.

As discussed, it is well established that nutrition affects animal performance and carcass and fat qualities. Utilization of dietary energy for either protein deposition (PD) or lipid deposition (LD) can affect carcass quality. An appropriate ratio of AA to energy must be supplied in the diet in order to optimize protein utilization for PD. In a study by Bikker et al. (1994), PD remained constant with increased lysine intake beyond the amount required for optimal PD but with increased energy intake, PD, LD and LD:PD ratio increased in gilts with high genetic potential for lean gain. Generally, at the appropriate dietary AA to energy ratio, a feedstuff with good feeding value will maximize animal performance and support production of lean meat and white, firm fat.

2.9 CONCLUSION

The recent increase in corn production in Manitoba has generated interest in increasing its inclusion in swine diets. However, chemical and nutrient composition of grain corn varies with cultivar and field location. The variability in chemical composition of corn due to field location is partly due to the differences in growing conditions because factors such as precipitation and soil texture that influence corn quality vary with geographical location. Although the effects of these factors on the agronomical indicators of grain corn quality (e.g. yield) have been widely studied, only limited information is available on their effects on the feeding value of corn. Therefore, the variability in chemical and nutritional composition of corn warrants evaluation of the nutritive value of locally available cultivars.

In addition to the effects of field location and cultivar on the nutritive value of corn, CHU accumulated at the field location which influences kernel development might also have an impact on the chemical and nutrient composition and the feeding value of corn. Both the field location and corn cultivars are rated based on CHU and this information is used in selecting appropriate corn cultivars for a particular field location. Corn heat units accumulation at field location affect yield and nitrogen concentration of grain corn but the effect of CHU rating of corn cultivars on their feeding value has not been investigated.

Chemical composition of a feedstuff shows only its potential nutritive value; it provides no clue as to the bioavailability of the nutrients to the animal and the associated effects on the end product. A complete evaluation of a feedstuff should be done in the light of chemical and nutrient composition, nutrients digestibility, animal performance and product quality.

In this project, Manitoba grown corn cultivars will be evaluated for their chemical composition and feeding value through a series of experiments. The results from this project will be beneficial to the corn growers in selecting appropriate corn cultivars for various field locations in Manitoba. Furthermore, the data from this project will enhance the sustainability of the Manitoba swine industry by providing much needed data on the feeding value of Manitoba-grown corn cultivars. The use of locally grown corn cultivars will not only reduce the cost of feed but will reduce fecal excretion of nutrients as a result of improved precision in diet formulation for swine.

3.0 MANUSCRIPT I

Chemical composition and agronomic parameters of Manitoba grown corn cultivars as affected by corn heat units and field location.

3.1 ABSTRACT

Factors such as location are known to influence the nutritive value of feedstuffs. For corn, the amount of corn heat units (CHU) which influences kernel development may also have an impact on its nutritive value as a feedstuff. Therefore, a study was conducted to evaluate the nutrient profile of Manitoba-grown corn cultivars as affected by location and the CHU rating of corn. Samples of thirty-six corn cultivars from each of two locations (St. Pierre and Reinland) were further subdivided into low CHU rated cultivars (less than 2300 CHU) and high CHU rated cultivars (2300 or more CHU). Samples were analyzed for dry matter (DM), crude protein (CP), fiber (ADF and NDF), fat (hexane extract), ash and total and phytate phosphorus. Data on yield, bushel weight and moisture content at harvest were also collected. Data were analyzed as a completely randomized design with a 2 x 2 factorial arrangement of treatment. As expected, there was a significant effect ($P < 0.05$) of location on DM, CP, ADF, ash, phytate and total phosphorus contents and yield. Corn cultivars from St. Pierre had higher ($P < 0.05$) CP (10.4 vs. 9.5%), ash (1.3 vs. 1.2%), ADF (3.0 vs. 2.7%), phytate phosphorus (0.22 vs. 0.19%) and total phosphorus (0.40 vs. 0.35%) contents and yield (165 vs. 129 bu/ac) but lower DM (88.4 vs. 89.8%) content compared with those from Reinland. Corn heat units rating of corn had an effect ($P < 0.05$) on CP, bushel weight and yield. Low CHU rated

cultivars had higher ($P < 0.05$) CP (10.12 vs. 9.76%) and bushel weight (62.0 vs. 59.9 lb bu^{-1}) but lower ($P = 0.0003$) yield (140 vs. 154 bu ac^{-1}) compared with high CHU rated cultivars. However, there was no interaction effect of location and CHU rating on any of the parameters measured. The results show that field location and amount of CHU have significant effects on the nutritional composition and agronomic parameters of corn cultivars.

3.2 INTRODUCTION

There has been a considerable increase in corn (Zea mays L.) production in Manitoba over the last 4 years. Although corn is originally from the tropics, it has since been adapted to areas with low temperatures and short growing seasons like Manitoba (MAFRI undated). In 2001, Manitoba produced almost the entire Western Canadian grain corn crop. Also, seeded area increased from 110,000 acres in 2001 to 155,000 acres in 2002 (MAFRI 2003). This increase in corn production has stimulated the interest in using locally grown corn cultivars in swine diets. Furthermore, recent drought conditions and high incidences of mycotoxins in the Prairies have threatened the production and utilization, respectively, of barley and wheat that are the traditional energy sources in swine diets in western Canada (Loyns 2002; Clowes and Zijlstra 2003).

In areas with low temperatures such as Manitoba, cumulative temperatures such as corn heat units (CHU) have been employed as a means of measuring growth and development of corn (Plett 1992). Corn heat units are a measure of useful heat required for growth and development of corn (MAFRI undated). Corn heat units accumulation vary with geographical location and serves as a determinant of grain corn cultivar that can be grown successfully in each location. Grain corn cultivars in Manitoba require 2200 to 2400 CHU to reach maturity and based on this amount of CHU, about 95% of Manitoba agricultural land can support the production of grain corn (MAFRI undated). Generally, both the cultivar and the field location are rated based on CHU in determining the appropriate cultivar for a particular field location.

As with other feed ingredients, chemical and nutrient composition of corn varies with location (Singh et al. 2000; Kuo et al. 2001; D'Alfonso 2002; Schmidt et al. 2002). The reported differences in nutrient composition of grain corn due to location were attributed to variability of factors such as temperature, precipitation and soil fertility that influence the nutrient profile of corn. Manitoba-grown corn cultivars are yet to be characterized in terms of chemical and nutrient composition, which is an important grain quality indicator for swine producers. Therefore, characterization of the nutrient composition of the locally available corn cultivars is important in order to efficiently incorporate them into swine diets. Furthermore, characterization of the locally available corn cultivars would provide a cheaper feedstuff for the Manitoba swine industry compared to imported corn considering the cost of transportation (Loyns 2002). Utilizing locally available corn cultivars would also offer opportunities to reduce net accumulation of nutrients in the soil resulting from importation of feedstuffs (House et al. 2002) and thus, enhances environmental conservation and nutrient recycling within an ecosystem. Although the effects of location on nutrient composition of corn have been widely studied, the impact of the CHU rating of corn on nutrient profile of corn cultivars is yet to be addressed.

3.4 OBJECTIVES

1. To evaluate the chemical composition of Manitoba grown corn cultivars.
2. To determine the effects of corn heat units rating of corn and field location on nutrient profile and some agronomic parameters of corn.

3.4 MATERIALS AND METHODS

3.4.1 General experimental protocol

Thirty-six cultivars of corn were evaluated in this study. These cultivars were replicated in two experimental stations of Manitoba Agriculture, Food, and Rural Initiatives (MAFRI), St. Pierre and Reinland during 2003 planting season (May to October). Based on the average annual accumulation of CHU in Manitoba, St. Pierre represents an area with low amount of CHU with an average annual accumulation of 2400 CHU while Reinland represents an area with high amount of CHU having an average annual accumulation of 2700 CHU. However, the year 2003 was an unusually warm year and the amounts of CHU accumulated at St. Pierre and Reinland from May 1 to October 31 were approximately 2950 and 3007, respectively. The soil textures in St. Pierre and Reinland are loamy and sandy soil, respectively. Cultivars within location were further divided into low CHU rated cultivars (2100 – 2299 CHU) and high CHU rated cultivars (2300 – 2700 CHU).

St. Pierre and Reinland field locations were seeded on the 5th and 6th May, 2003. The plot at St. Pierre was fertilized before planting with injected liquid manure, followed by incorporation of 20 lbs N and 15 lbs K_2O into the soil. Field location at Reinland was fertilized pre-seeding with 40 lbs N, 45 lbs P_2O_5, 15 lbs K_2O and 15 lbs S and banded at seeding with 55 lbs N, 10 lbs P_2O_5, 10 lbs K_2O and 3 lbs S. At both locations, weeds were controlled with a combination of Accent and Banvel II.

3.4.2 Sample Preparation and Chemical Analyses

A sub-sample (approximately 500g) of each cultivar was ground in a Wiley mill through a 1-mm sieve and thoroughly mixed prior to analyses. Samples were analyzed for DM, CP, fat (hexane extract), ash, fiber (acid detergent fiber (ADF) and neutral detergent fiber (NDF)) and phytate and total phosphorus.

Dry matter was determined by drying a 5 g sample in a pre-weighed silica dish in vacuum oven to a constant weight at 100°C overnight. The sample was cooled in a desiccator and weighed. Nitrogen was determined using a LECO CNS-2000 Elemental Analyzer (LECO Corp., St. Joseph, MI) and CP was calculated using the formula N x 6.25. Ash was analyzed according to Association of Official Analytical Chemists (AOAC) (1990) procedures by ashing a 1 g sample in a pre-weighed 45 mL silica crucible for 12 h in a muffle furnace at 600°C.

Fat content was determined according to AOAC (1990) procedures using SER 148 solvent extraction apparatus with Viton seals (VELP® Scientifica, Usmate, Italy). A 5 g sample was weighed into an extraction thimble and connected to the extraction unit with thimble connector. Hexane (75 mL) was dispensed into a pre-weighed extraction beaker, placed right below the thimble in the extraction unit and the unit was closed. The thimble was lowered into the hexane, extracted for 60 minutes, washed for 60 minutes and hexane was recovered for 18 minutes.

Neutral detergent fiber content was determined using a refluxing apparatus, ANKOM^{200} (ANKOM Technology Corporation, Fairport, NY), according to a procedure outlined by Van Soest and Wine (1967) and modified by Robertson and Van Soest (1977) with the addition of α-amylase enzyme (Termamyl; Novo Nordisk A/S, Bagsvaerd, Denmark). Briefly, samples were treated with boiling neutral detergent to dissolve protein, enzyme, carbohydrate and ash. Amylase was added to digest the starch and the samples were later washed with acetone to remove fat and pigments. Acid detergent fiber was determined following a similar procedure except that acid detergent buffer solution was used in place of neutral detergent buffer and no amylase was added.

Total phosphorus was determined according to AOAC (1990) procedures. Briefly, 1 g sample was weighed into a 50 mL borosilicate tube and ashed for 12 h in a muffle furnace at 600°C. To each sample, 10 mL of a solution containing 5 N HCl and HNO_3 (1% v/v) was added and the mixture heated in a sonicator water bath at 65°C for 1 h, after which caps were removed and the tubes allowed to settle overnight. Standards with phosphorus concentration range of 0 to 15 μg/mL were prepared. The absorbance of samples was read against that of the standard solutions at 400 nm using Pharmacia Ultrospec 2000 spectrophotometer (Pharmacia Biotech, Cambridge, England). Phytate content was determined according to the method of Haug and Lantzsch (1983). Briefly, 10 mL of 0.2 N HCl was added to 100 mg of sample, shaken at room temperature for 3 h and then filtered. After filteration, 2 mL of ferric solution was added to 1 mL of the filtrate in the hydrolysis tube and boiled for 30 min. The mixture was cooled for 15 min each on ice and room temperature and centrifuged (Centra GP8, International Equipment Co., Needham Heights) at 3000 rpm for 30 min. To 1 mL of the supernatant, 1.5 mL of bipyridine solution was added and the absorbance was read after 10 minutes against distilled water at 519 nm using Pharmacia Ultrospec 2000 spectrophotometer.

Data on yield, moisture content at harvest and bushel weight were collected as agronomic parameters.

3.4.4 Statistical Analysis

Data were analyzed as a completely randomized design with 2 × 2 factorial arrangement of treatment using GLM procedures of SAS (SAS Inst., Inc., Cary, NC). When a significant F-value ($P < 0.05$) was indicated by the ANOVA, the Bonferroni test was used to separate and compare treatment means. The model used was $y_{ijk} = \mu + b_i + d_j + bd_{ij} + e_{ijk}$. Where y_{ijk} = nutrient content of corn; μ = population mean; b_i = the main effect of i'th CHU; d_j = the main effect of j'th location; bd_{ij} = the interaction of the two main effects and e_{ijk} is the residual deviation of k'th corn cultivar in the ij'th treatment.

3.5 RESULTS AND DISCUSSION

Chemical composition and agronomic parameters of Manitoba grown corn cultivars as affected by field location and CHU rating of corn are shown in Table 3.1. There was no interaction of CHU rating of corn and location on any of the parameters measured ($P > 0.10$) and therefore, only main effects are presented.

Table 3.1. Corn heat units rating of corn cultivars and location effects on agronomical parameters and nutritional composition of Manitoba-grown corn cultivars[z]

	Reinland		St. Pierre			*P* value	
Item	Low	High	Low	High	SEM[y]	CHU[x]	L[w]
Nutritional composition (%)[v]							
Dry matter	89.87	89.71	88.36	88.49	0.11	0.9218	<0.0001
Crude protein	9.71	9.34	10.54	10.18	0.13	0.0067	<0.0001
Fat (Hexane extract)	4.45	4.19	4.49	4.44	0.10	0.1265	0.1327
ADF	2.66	2.74	2.92	3.00	0.09	0.3663	0.0049
NDF	9.11	9.23	8.96	8.92	0.16	0.8155	0.1653
Ash	1.24	1.22	1.36	1.34	0.03	0.4289	0.0002
Phosphorus	0.35	0.34	0.41	0.40	0.01	0.0695	<0.0001
Phytate	0.19	0.17	0.23	0.22	0.01	0.2184	<0.0001
Agronomic data							
Moisture (%)	16.87	17.93	17.51	17.88	0.43	0.1020	0.5010
Bushel weight (lb bu^{-1})	61.30	58.85	62.71	57.27	1.59	0.0162	0.9578
Yield (bu ac^{-1})	121.84	136.05	158.70	171.26	3.44	0.0003	<0.0001

[z]Values are least square means

[y]Pooled standard error of the means

[x]Corn heat units rating of corn cultivars

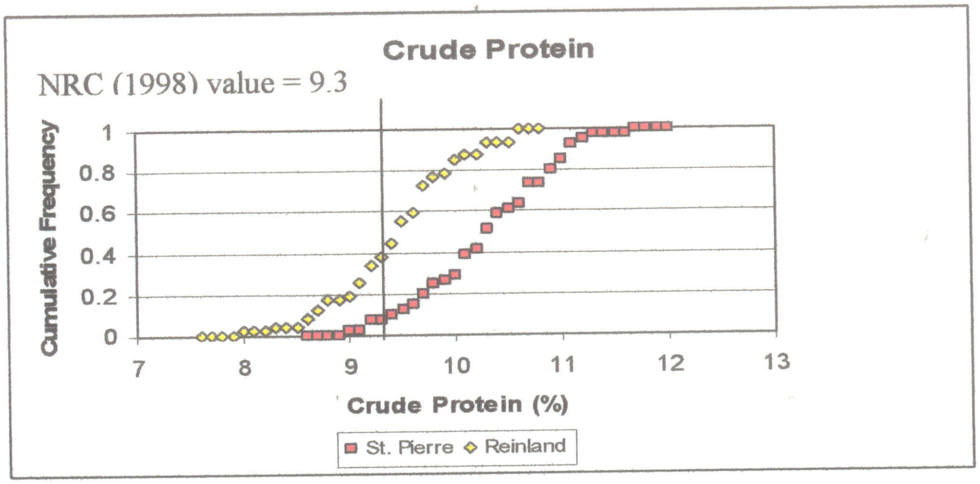
[w]Location

[v]Expressed on DM basis

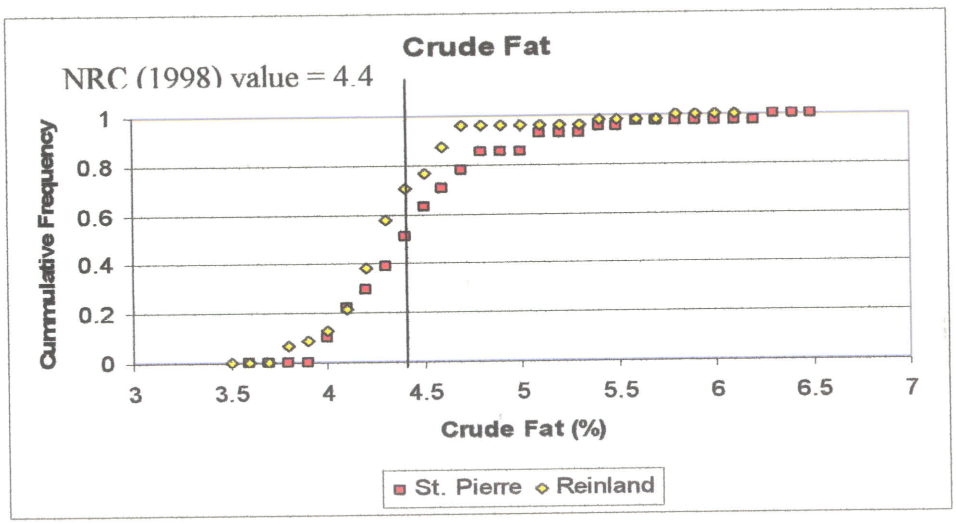
There was no difference ($P = 0.9218$) in DM content of low CHU rated and high CHU rated cultivars and it averaged 89.1% in both groups. However, location had an effect ($P < 0.05$) on DM content. Despite the fact that the year the study was conducted was abnormally warm (more than 2900 CHU accumulation at the field locations), corn cultivars from Reinland had higher ($P < 0.0001$) DM content compared with those from St. Pierre (89.8 vs. 88.4%). In general, DM content of all the corn cultivars evaluated ranged from 87.1 to 90.6% and these are within the range of values that have been reported in previous studies (NRC 1998; Adeola and Bajjalieh 1997; Moeser et al. 2002). The difference in DM content observed between the two locations might be due to differences in grain maturity. Moss et al. (2001) attributed an increase in whole plant DM to greater grain maturity. Since Reinland had higher amount of accumulated CHU, DM deposition might be favored.

Corn heat units rating and field location had an effect ($P < 0.05$) on CP content of the corn cultivars. Crude protein content of low CHU rated cultivars (10.1%) was higher ($P = 0.0067$) compared with that of high CHU rated cultivars (9.8%). This suggests that as plant breeders selected for high CHU rated cultivars, CP content of grain was reduced. Furthermore, the fact that low CHU rated cultivars had higher CP content though similar DM content compared with high CHU rated cultivars means that low CHU favors accumulation of CP in corn kernel. Cultivars from St. Pierre had higher ($P < 0.0001$) CP content (10.4 vs. 9.5%) compared with cultivars from Reinland. This is in agreement with the findings of Wiersma et al. (1993) who reported decreased whole plant protein content with increased maturity of corn. It also agrees with Liang et al. (1993) who reported a sharp reduction in the N uptake and grain N concentration as the amount of CHU of field location increased irrespective of fertilizer rate and water input. Crude protein was expected to increase with increased DM but the opposite was the case in the current study. The higher CP content of the corn cultivars in St. Pierre compared with those from Reinland could be due to differences in soil texture among other confounding environmental and climatic factors. Under adequate soil N and moisture contents, corn, like other plants, has capacity to increase N uptake which would result in high CP:DM ratio in the grain (Sattell et al. 1999). St. Pierre is characterized by a well drained loamy soil that can hold moisture better than the rapidly drained sandy soils in Reinland. Crude protein content of all the analyzed corn cultivars ranged from 8.0 to 11.7% and these are equal to or higher than values reported previously (Ortega et al. 1986; Sproule et al. 1988; Adeola and Bajjalieh 1997; Moeser et al. 2002). About 60 and 90% of corn cultivars in Reinland and St. Pierre, respectively, had higher CP content compared to the NRC (1998) value (Figure 3.1a). The difference observed in CP content in the current study and others could be due to differences in genetic composition of the cultivars and growing conditions (Singh et al. 2000; D'Alfonso 2002; Schmdit et al. 2002).

There was no effect of CHU rating ($P = 0.1265$) or field location ($P = 0.1327$) on the fat content of the corn cultivars evaluated. Fat content averaged 4.5 and 4.3% in low and high CHU rated cultivars, respectively, and 4.3 and 4.5% in Reinland and St. Pierre, respectively. However, about 30 and 50% of cultivars in Reinland and St. Pierre had higher fat content compared to the NRC (1998) value (Figure 3.1b). In all the cultivars evaluated, fat (hexane extract) contents ranged from 3.7 to 6.2%, a range which compares with the values reported in previous studies (Burgoon et al. 1992; Adeola and Bajjalieh 2000; Yin et al. 2002).



a



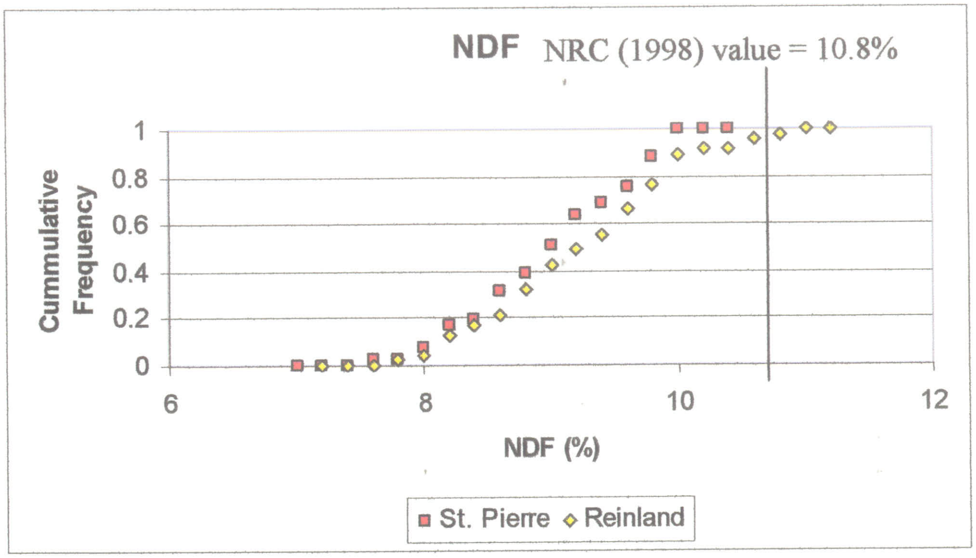
b

Figure 3.1. Cumulative frequencies of crude protein (a) and crude fat (b) contents of the corn samples from Reinland and St. Pierre

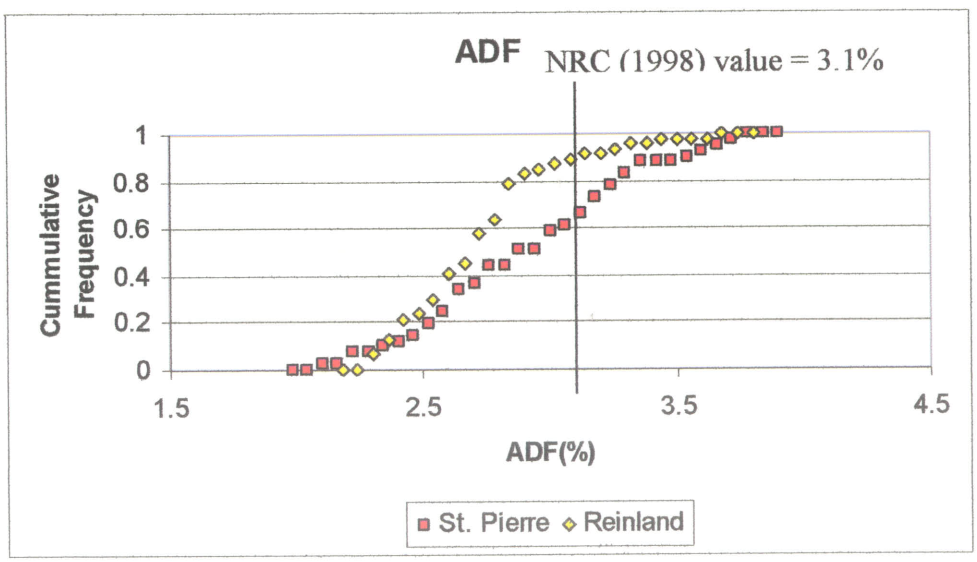
Corn heat units rating had no effect ($P = 0.4289$) on the ash content of the corn cultivars, and it averaged 1.3% for all cultivars regardless of CHU rating. However, there was an effect of location on the ash content. The ash content of the cultivars from St. Pierre was higher ($P = 0.0002$) compared with the content of those from Reinland (1.3 vs. 1.2 %). The higher ash content in St. Pierre corn could be attributed to differences in growing condition such as the soil texture of the area. Since plants obtained their nutrients mainly through soil water, nutrient uptake in St. Pierre might be improved due to its good water holding capacity hence the higher ash content. In all the cultivars evaluated, ash content ranged from 1.0 to 1.8% and these values are consistent with those reported by Burgoon et al. (1992) and Adeola and Bajjalieh (1997).

Corn heat units rating ($P = 0.8155$) and field location ($P = 0.1653$) had no effect on NDF content. It averaged 9.0 and 9.1% in low CHU and high CHU rated cultivars, respectively, and 9.2 and 8.9% in Reinland and St. Pierre, respectively. In the current study, NDF content of the cultivars ranged from 7.5 to 10.8%. Compared to NRC (1998), about 96 and 100% of cultivars in Reinland and St. Pierre, respectively, had lower NDF content (Figure 3.2a). Low CHU and high CHU rated cultivars were similar ($P = 0.3663$) in ADF content (2.8 vs. 2.9%) but cultivars from Reinland had lower ($P = 0.0049$) ADF content compared with those from St. Pierre (2.7 vs. 3.0%). Acid detergent fiber content ranged from 2.1 to 3.8%. In comparison to NRC (1998), about 91 and 73% of the cultivars in Reinland and St. Pierre, respectively, had lower ADF value (Figure 3.2b).

Low CHU rated cultivars tended to have higher ($P = 0.0695$) total phosphorus content than high CHU rated cultivars (0.38 vs. 0.37%). There was an effect of location



(a)



(b)

Figure 3.2. Cumulative frequencies of Neutral detergent fiber (a) and acid detergent fiber (b) contents of the corn samples from Reinland and St. Pierre

on total phosphorus content. Total phosphorus content was higher ($P < 0.0001$) in cultivars from St. Pierre (0.40%) than in those from Reinland (0.35%). In all the analyzed samples, total phosphorus content ranged from 0.26 to 0.41%. In general, about 40% and 97% of cultivars in Reinland and St. Pierre, respectively, had higher total phosphorus content compared with NRC (1998) value. Low CHU and high CHU rated cultivars had similar ($P = 0.2184$) phytate phosphorus content (0.21 vs. 0.20%). The cultivars from Reinland had lower ($P < 0.0001$) phytate phosphorus content than those from St. Pierre (0.19 vs. 0.22%). In all the analyzed cultivars, phytate phosphorus ranged from 0.12 to 0.24%. As expected, the effect of location on phytate and total phosphorus followed the same trend as with the ash content. The ratio of phytate phosphorus to total phosphorus ranged between 0.44 and 0.65. Although phytate phosphorus content in these cultivars were comparable to the values reported by Spencer et al. (2000) and Veum et al. (2001), the ratios of phytate phosphorus to total phosphorus were smaller compared to the ratio of 0.8 reported by these authors. Pigs have inadequate phytase enzyme required to hydrolyze phytate phosphorus molecule and as result the majority of phytate phosphorus passes through the gastro-intestinal tract undigested (Omogbenigun et al. 2003). Therefore, from nutritional point of view, low value of the ratio of phytate phosphorus to total phosphorus observed in this study shows that Manitoba-grown corn cultivars have higher amount of available phosphorus compared with values reported by Spencer et al. (2000) and Veum et al. (2001), and utilization of phosphorus in these cultivars by pigs will likely be enhanced.

Corn heat units rating and field location had an effect ($P < 0.05$) on yield of the corn cultivars. Low CHU rated cultivars had lower ($P = 0.0003$) yield compared with high CHU rated cultivars (140 vs. 154 bu ac^{-1}). This agrees with the findings of Dwyer et al. (1991) where high CHU rated cultivars had higher ($P \leq 0.05$) yield than low CHU rated cultivars (9.8 and 6.9 Mg ha^{-1}). Corn cultivars from St. Pierre had higher ($P <$ 0.0001) yield compared with those from Reinland (165 vs. 129 bu ac^{-1}). The difference in yield observed between the two locations is in accordance with findings of other researchers (Schmidt et al. 2002; Singh et al. 2000) showing that field location has an effect on the yield of grain corn. However, this result is contrary to the findings of Dwyer et al. (1991) who reported higher yield ($P \leq 0.05$) in an area with high CHU (3232 CHU) compared to an area with low CHU (2832 CHU) (9.5 vs. 8.3 Mg ha^{-1}). The reason for this difference could be due to differences in growing conditions; factors such as soil texture, precipitation and drainage affect growth and development of corn and subsequently yield varies with geographical location. The yield of the corn cultivars evaluated in the current study ranged from 100 to 200 bu ac^{-1}.

There was an effect of CHU rating but not of location on bushel weight. In the current study, bushel weight ranged from 53.4 to 66.2 lb bu^{-1} and these values are within commercially acceptable range (Lilburn and Dale 1989). Low CHU rated cultivars (62 lb bu^{-1}) had higher (P = 0.0162) bushel weight compared with high CHU rated ones (58 lb bu^{-1}). Although the effect of CHU on bushel weight has not been reported, the observed difference in the current study could be attributed to differences in genetic composition of the cultivars which is one of the major factors affecting bushel weight (Lilburn and Dale 1989). This result suggests that low CHU rated cultivars have heavier kernels compared with high CHU rated cultivars. It would be expected that high CHU rated cultivars will have higher bushel weight due to higher yield observed in high CHU rated cultivars.

However, according to Sunde et al. (1976), shape and size of kernel affect bushel weight of corn. Larger kernels may have lower bushel weight compared with smaller kernels even if they have the same density because larger kernels may pack loosely. Furthermore, presence of air pockets in corn kernel affects bushel weight (Sunde et al. 1976). Bushel weight of the corn cultivars in Reinland (60.1 lb bu^{-1}) and St. Pierre (60.0 lb bu^{-1}) were similar (P = 0.9578).

In the current study, moisture content at harvest ranged from 13.4 to 22.1%. Neither CHU nor location had any effect on the moisture content at harvest. Low CHU rated cultivars and high CHU rated cultivars were similar (P = 0.1020) in moisture content at harvest (17.2 vs 17.9%). There was no difference (P = 0.5010) in the moisture content of the cultivars from St. Pierre and Reinland (17.4 and 17.7%, respectively). This observation is contrary to the report of Dwyer et al. (1991) that areas with low amount of CHU had higher ($P \leq 0.05$) grain moisture content at harvest.

3.6 CONCLUSIONS

The chemical composition and agronomic parameters of corn cultivars vary with field location and CHU rating of corn cultivars. Low CHU rated cultivars had higher amount of CP compared with high CHU rated cultivars. Corn heat units rating of the seed and the field location should be considered by corn producers in order to produce corn of high agronomical and nutritional quality. Clearly, from the chemical composition, Manitoba-grown corn cultivars have an excellent nutritional profile which encourages their inclusion in swine diets.

4.0 MANUSCRIPT II

Digestible energy, protein and amino acid content in selected Manitoba-grown corn cultivars fed to growing pigs.

4.1 ABSTRACT

The objective of this study was to determine digestible energy (DE) and ileal digestible crude protein (CP) and amino acids (AA) contents in two corn cultivars commonly grown in Manitoba. Samples of the cultivars 39W54 and 39M27 obtained from St. Pierre, Reinland and Carman were used in the study. Six Cotswold barrows with an initial BW of 21.5 ± 0.9 kg (mean ± SD) and equipped with a T-cannula at the distal ileum were fed six diets according to a 6 × 6 Latin square design. Diets contained 97% corn as the only source of energy and protein and 0.3% chromic oxide as a digestibility marker. After a 4-d acclimation period to experimental diets, fecal samples were collected for 12 h each on two consecutive days followed by ileal digesta collection for 12 h on each of the next two days for each experimental period. Apparent total tract digestibilities of energy and CP and apparent and standardized ileal digestibilities of CP and AA were calculated. There was an effect ($P \leq 0.05$) of location on ileal digestible CP and AA and on DE. Standardized ileal digestible CP content of cultivars from Carman and Reinland (7.3%) was higher ($P < 0.05$) than for those from St. Pierre (6.8%). Cultivars from Reinland had highest ($P < 0.05$) contents of standardized ileal digestible aspartic acid, methionine, histidine and arginine (0.64, 0.23, 0.22 and 0.37 %, respectively) compared with those from Carman and St. Pierre. Cultivars from Carman had highest ($P < 0.05$) contents of standardized ileal digestible phenylalanine and

cysteine (0.50 and 0.27, respectively) compared with those from Reinland and St. Pierre. Digestible energy content of cultivars from Carman was higher ($P < 0.05$) than the value for those from St. Pierre (3673 vs. 3644 kcal kg^{-1}) but similar to the value for those from Reinland (3669 kcal kg^{-1}). Cultivar 39W54 had higher ($P < 0.05$) contents of standardized ileal digestible CP, histidine, aspartic acid, threonine, serine, glutamic acid, proline, glycine, alanine and arginine (7.70, 0.21, 0.59, 0.24, 0.61, 1.62, 0.57, 0.18, 0.69 and 0.36 %, respectively) than cultivar 39M27. Cultivar 39M27 had higher ($P < 0.05$) contents of standardized ileal digestible methionine, isoleucine and tyrosine (0.22, 0.31 and 0.29%, respectively) compared with cultivar 39W54. The DE content of cultivar 39M27 was higher ($P < 0.05$) compared with that of 39W54 (3674 vs. 3651 kcal kg^{-1}). The current data indicate that digestible energy, CP and AA contents of corn vary with location and cultivar and this should be considered when formulating diets for pigs.

4.2 INTRODUCTION

Corn is an excellent source of energy in swine diets and because it is included at high amount, it makes a significant contribution to other nutrients such as CP and AA. Recent increase in corn production in Manitoba (MAFRI 2003) has generated interest in increasing its use as an energy source in swine diets. Thus far, only a limited amount of locally grown corn has been routinely included in swine diets partly due to availability and lack of data on its feeding value.

The chemical and nutrient profile of corn has been shown to vary widely depending on such factors as cultivar and field location (Sproule et al. 1988; NRC 1998;

Singh et al. 2000; Moeser et al. 2002; Schmdit et al. 2002). For instance, the CP and starch contents in corn from different countries were shown to vary from 7.4 to 8.8% and 64.5% to 69.6% (as is basis), respectively (D'Alfonso 2002). In another study, CP content in two corn cultivars varied from 8.8 to 10.6% (DM basis) (Yin et al. 2002).The energy content in corn has been reported to vary from 4.10 to 4.44 Mcal kg^{-1} (DM basis) (Sproule et al. 1988; Adeola and Bajjalieh 1997; Moeser et al. 2002). Clearly, grain corn varies in energy and nutrient composition and therefore, characterizing the nutritive value of locally available corn cultivars is critical to accurate and cost-effective diet formulation. To date, energy and nutrient digestibilities in Manitoba-grown corn cultivars are yet to be determined.

The objective of this study was to determine the digestible energy and CP and AA contents in representative Manitoba grown corn cultivars fed to growing pigs.

4.3 MATERIALS AND METHODS

4.3.1 General

Two cultivars of corn, 39W54 and 39M27, were obtained from three locations, St. Pierre, Reinland and Carman, in Manitoba in 2003. The CHU rating of 39W54 and 39M27 were 2100 and 2150, respectively and the CHU accumulations at St. Pierre, Reinland and Carman in 2003 growing season were 2950, 2942 and 3007, respectively. The use of pigs and experimental procedures were reviewed and approved by the Animal Care Committee of the University of Manitoba, and animals were cared for according to the standard guidelines of the Canadian Council on Animal Care (CCAC 1993).

4.3.2 Animals and Housing

Six Cotswold barrows, obtained from the University of Manitoba's Glenlea Swine Research Farm, with an average initial BW of 21.5 ± 0.9 kg (mean ± SD) were used in this study. Pigs were individually housed in adjustable metabolism crates [70''(length) × 24''(breadth) × 32''(height)] with smooth transparent plastic sides and plastic-covered expanded metal sheet flooring in a temperature-controlled room (22 ± 2°C). Pigs were allowed 8-d to adjust to the metabolism crates after which they were surgically fitted with a simple T-cannula at the distal ileum as described by Sauer et al. (1983). Immediately after surgery, pigs were returned to their metabolism crates and allowed a 10-d post-surgery recovery period during which they were fed twice daily increasing amounts of a commercial grower diet. Pigs had unlimited access to drinking water from low pressure drinking nipples. Each pig received excenel (Upjohn company, Orangeville, Ontario, Canada) intramuscularly (1 mL/17 kg BW) a day before and three days after surgery. Throughout the experimental period, pigs were washed twice daily with hibitane (Wyeth-Ayerst Canada Inc.) and zincoderm (Rhone Merieux Canada Inc.) was applied to the cannula site to minimize skin irritation.

4.3.3 Experimental Diets

Six diets were formulated to contain 97% corn (Table 4.1) as the sole source of energy and protein. Diets 1, 2 and 3 contained 39M27 from St. Pierre, Reinland and Carman, respectively, while diets 4, 5 and 6 contained 39W54 from St. Pierre, Reinland and Carman, respectively. Prior to diet mixing, the corn samples were ground in a hammer mill through a 3 mm screen. Vitamins and minerals were supplemented to meet

Table 4.1. Ingredient composition of the experimental diets

Item	St. Pierre		Reinland		Carman	
	39M27	39W54	39M27	39W54	39M27	39W54
Ingredient (%)						
Corn	97	97	97	97	97	97
Dicalcium Phosphate	0.4	0.4	0.4	0.4	0.4	0.4
Limestone	1.5	1.5	1.5	1.5	1.5	1.5
Vitamin-Mineral Premix[z]	0.8	0.8	0.8	0.8	0.8	0.8
Chromic Oxide	0.3	0.3	0.3	0.3	0.3	0.3
Calculated nutrient composition[y]						
Digestible energy (kcal kg^{-1})	3419	3419	3419	3419	3419	3419
Crude protein (%)	8.3	8.3	8.3	8.3	8.3	8.3

[z]Vitamin-mineral premix supplied the following per kilogram of complete diet: vitamin A, 7560 IU; vitamin D3, 1260 IU; vitamin E, 15.2 IU; vitamin K, 1.3 mg; choline chloride, 210 mg; niacin, 24.7 mg; calcium pantothenate, 23.1 mg; riboflavin, 7.9 mg; Thiamine, 0.84 mg; pyridoxine, 0.84 mg; vitamin B12, 21 μg; biotin, 42 μg; folic acid, 0.42 mg; Ca, 0.48 %; P, 0.22 %; NaCl, 0.29 %; Na, 0.12 %; Mg, 0.01 %; Mn, 23.1 mg; Fe, 96.6 mg; Zn, 88.2 mg; Cu, 105 mg; I, 0.5 mg.

[y]Based on NRC (1998) feed composition data.

or exceed NRC (1998) recommendations. Chromic oxide (0.3%) was used as a digestibility marker for determining energy and nutrient digestibilities. Diets were provided to the animals in a mash form.

4.3.4 Experimental design and procedures

The six experimental diets were fed to the six pigs in a 6 x 6 Latin square design at 2.6 times maintenance energy requirements (Agricultural Research Council 1981) based on their BW at the beginning of each experimental period. Daily feed allowance was divided into two equal portions and fed at 0800 and 1600. Feed refusal and spillage were recorded and used to determine actual dry matter intake. Each experimental period lasted 8-d with a 4-d acclimation period to experimental diets. Feces and ileal digesta were collected over a 12 h period (0800 to 2000) on days 5 and 6 and days 7 and 8, respectively. Ileal digesta were collected into soft transparent bags containing 10 mL of formic acid (v/v) solution to minimize microbial activities. All samples were frozen immediately after collection at -20°C.

4.3.5 Sample Preparation and Chemical Analyses

Ileal digesta samples were pooled per pig per period by homogenizing the samples in a heavy duty blender (Waring Commercial®, Torrington, Conneticut) and about 200 g digesta was sub-sampled for chemical analyses. Fecal and ileal samples were freeze dried, and along with diet samples, they were finely ground in a CBG5 Smart Grind™ coffee grinder (Applica Consumer Products, Inc., Shelton) and thoroughly mixed before analyses. Diet, fecal and digesta samples were analyzed for energy, DM, N (for CP) and chromic oxide. Digesta and diet samples were further analyzed for AA.

Dry matter and N contents were determined as described in manuscript 1. Diet and digesta samples were analyzed for AA according to AOAC (1990) procedures using an ion exchange column in LKB 4151 Alpha plus AA analyzer (LKB Biochrom, Cambridge, UK) equipped with an LKB 4029 programmer and a 3393A Hewlett-Packard Integrator (Hewlett-Packard Co., Avondale, USA), which uses a cation exchange column. Briefly, a 100 mg sample was weighed into a side-arm hydrolysis tube. Following addition of 2 drops of 2-Octanol, the sample was hydrolyzed with 4 mL of 6 N HCl. A lid was placed on the tube and then the tube evacuated for 30 s before the lid was tightly secured. The sample was then digested in a pre-heated block at 110°C for 24 h. The sample was cooled to room temperature and neutralized with 4 mL of 25% w/v NaOH and then made up to 50 mL with a sodium citrate solution (pH 2.2). The sample was thoroughly mixed and filtered through a Whatman # 40 filter paper and a 0.22 μm nylon syringe filter. Cysteine and methionine were determined by oxidizing a mixture of 100 mg sample and 2 drops of 2-Octanol with 2 mL performic acid (88% formic acid and 35% H_2O_2 mixed in a 9:1 ratio) in the fridge for 20 h. At the end of the 20 h, 0.4 g of sodium metabisulphate was added to the sample, allowed to stand for 6 h in the fumehood and oxidized with 2 mL concentrated HCl. The sample was then digested in a pre-heated block for 16 h at 110°C, cooled to room temperature and then neutralized with 25% w/v NaOH. The rest of the procedure was the same as for the regular AA analysis method. Tryptophan was not determined.

Diet, fecal and digesta samples were analyzed for energy using an adabiatic bomb calorimeter (Parr Instrument Company Inc. Moline, Illinois, USA). Chromic oxide concentration in diet, fecal and digesta samples was determined following the procedure described by Williams et al. (1962).

4.3.6 Digestibility Calculation and Statistical Analysis

Apparent digestibilities of energy and nutrient were calculated using the following equation (Nyachoti et al. 1997):

Digestibility, % = $[1-(N_f/Cr_d) \times (N_d/Cr_f)] \times 100$

where N_f is energy or nutrient concentration in feces or digesta (%); N_d is energy or nutrient concentration in diet (%); Cr_d is chromic oxide concentration in diet and Cr_f is chromic oxide concentration in feces or digesta.

Standardized ileal digestibilities (SID) of protein and AA were determined by correcting the apparent ileal digestibilities (AID) for non-specific endogenous protein and AA losses according to the following equation (Rademacher et al. 2000):

SID, % = AID + $(N_{EL}/N_{Diet}) \times 100$

where AID= apparent ileal digestibility of CP or AA (decimal percent); N_{Diet} = CP or AA concentration in the diet (mg kg^{-1} DM); and N_{EL} = non-specific endogenous CP or AA loss (mg kg^{-1} DMI).

Data were subjected to analysis of variance as a Latin square design with a 2 × 3 arrangement of treatment using GLM procedures of SAS (SAS Inst., Inc., Cary, NC). The effects of pig (n=6), period (n=6) and diet (n=6) were included in the model as sources of variation. The individual pig was considered as the experimental unit. When a significant

F-value (P<0.05) was indicated by the ANOVA, dietary treatment means were separated and compared by Tukey's test.

4.4 RESULTS AND DISCUSSION

The analyzed nutrient composition of the corn samples used in this study is shown in Table 4.2. In all the locations, DM, CP, ADF and NDF contents were higher while hexane extract (fat) content was lower in 39W54 compared with 39M27. Variability in the chemical composition of corn types has been well documented. Yin et al. (2002) reported a CP content (DM basis) of 8.8 and 10.6% and a crude fat content (DM basis) of 3.1 and 3.6% in the two cultivars of corn evaluated. Similarly, Moeser et al. (2002) observed differences in the GE (4.15 vs. 4.10 Mcal kg^{-1}, DM basis) and CP (6.8 vs. 8.2%, DM basis) contents in the two cultivars of grain corn evaluated. The difference in the chemical composition of corn cultivars from the same location might be due to differences in genetic composition of the cultivars (Yin et al. 2002). In the current study, when AA content was expressed as a proportion of CP, the levels of AA in the two cultivars evaluated were comparable irrespective of location (Table 4.3). When AA content of the corn samples evaluated in this study was expressed as a proportion of CP content, leucine and glutamic acid were present in the highest levels among the indispensable and dispensable AA, respectively, an observation that is similar to the report of Snow et al. (2004). The nutrient contents of all the samples evaluated in this study were within the range that has been reported in previous studies (Adeola and Bajjalieh 1997; NRC 1998; Snow et al. 2004).

Table 4.2. Analyzed composition of corn cultivars (39M27 and 39W54) grown in different locations in Manitoba (St. Pierre, Reinland and Carman) (as is basis)

	St. Pierre		Reinland		Carman	
Item (%)	39M27	39W54	39M27	39W54	39M27	39W54
Dry matter	88.87	90.45	88.61	89.05	88.65	90.23
Crude protein	8.57	9.63	8.74	9.48	8.30	9.52
Hexane extract	4.08	3.82	3.98	3.60	3.95	3.89
ADF	2.32	2.72	2.62	2.78	2.55	2.86
NDF	7.07	9.25	7.69	8.98	7.69	8.34
Amino Acids						
Indispensable						
Arginine	0.30	0.32	0.30	0.32	0.33	0.35
Histidine	0.22	0.25	0.19	0.24	0.23	0.24
Isoluecine	0.31	0.35	0.31	0.31	0.29	0.34
Leucine	1.13	1.28	1.07	1.33	1.06	1.23
Lysine	0.24	0.26	0.24	0.26	0.26	0.24
Methionine	0.22	0.23	0.31	0.21	0.21	0.21
Phenylalanine	0.46	0.45	0.37	0.46	0.42	0.48
Threonine	0.30	0.33	0.29	0.34	0.26	0.31
Valine	0.44	0.50	0.39	0.43	0.43	0.47
Dispensable						
Alanine	0.66	0.77	0.70	0.74	0.67	0.74
Aspartic acid	0.65	0.73	0.66	0.70	0.65	0.75
Cystine	0.19	0.20	0.19	0.20	0.19	0.21
Glutamic acid	1.32	1.51	1.29	1.40	1.26	1.51
Glycine	0.33	0.38	0.31	0.33	0.32	0.36
Proline	0.71	0.87	0.76	0.87	0.67	0.89
Serine	0.66	0.72	0.66	0.71	0.65	0.73
Tyrosine	0.33	0.36	0.29	0.34	0.29	0.36

Table 4.3. Proportion of amino acids relative to protein content in the corn cultivars (39M27 and 39W54) grown in different locations in Manitoba (St. Pierre, Reinland and Carman)

	St. Pierre		Reinland		Carman	
Amino acids (%)	39M27	39W54	39M27	39W54	39M27	39W54
Indispensable						
Arginine	3.50	3.32	3.43	3.38	3.98	3.68
Histidine	2.57	2.60	2.17	2.53	2.77	2.52
Isoluecine	3.62	3.63	3.55	3.27	3.49	3.57
Leucine	13.19	13.29	12.24	14.03	12.77	12.92
Lysine	2.80	2.70	2.75	2.74	3.13	2.52
Methionine	2.57	2.39	3.55	2.22	2.53	2.21
Phenylalanine	5.37	4.67	4.23	4.85	5.06	5.04
Threonine	3.50	3.43	3.32	3.59	3.13	3.26
Valine	5.13	5.19	4.46	4.54	5.18	4.94
Dispensable						
Alanine	7.70	8.00	8.01	7.81	8.07	7.77
Aspartic acid	7.58	7.58	7.55	7.38	7.83	7.88
Cystine	2.22	2.08	2.17	2.11	2.29	2.21
Glutamic acid	15.40	15.68	14.76	14.77	15.18	15.86
Glycine	3.85	3.95	3.55	3.48	3.86	3.78
Proline	8.28	9.03	8.70	9.18	8.07	9.35
Serine	7.70	7.48	7.55	7.49	7.83	7.67
Tyrosine	3.85	3.74	3.32	3.59	3.49	3.78

Analyzed CP content of the experimental diets (Table 4.4) is comparable to the calculated values (Table 4.1) for 39M27 but not for 39W54. This observation could be explained by the variability in genetic composition of corn cultivars as in previous studies (Singh et al. 2000; Yin et al. 2002).

There was no interaction effect ($P > 0.10$) of location and cultivar on the AID of DM, CP and energy, therefore only main effects are presented (Table 4.5). Apparent ileal digestibility of DM was higher ($P < 0.05$) in the corn cultivars from Reinland compared with those from St. Pierre and Carman. Apparent ileal digestibility of energy in cultivars from Reinland was higher ($P = 0.0018$) than in those from St. Pierre but was not different from the cultivars from Carman ($P > 0.10$). Apparent ileal digestibility of CP was similar across all the locations and averaged 60, 61, and 57% in Carman, Reinland and St. Pierre, respectively. The higher CP protein content in cultivar 39W54 compared with cultivar 39M27 (Table 4.2) was reflected in the AID of CP in the two cultivars with cultivar 39W54 having a higher ($P < 0.05$) digestibility compared with cultivar 39M27 (Table 4.5). The observed differences in the AID of energy, CP and AA with respect to cultivar and field location are in agreement with previous research (Yin et al. 2002; Snow et al. 2004). However, the values obtained for the AID of DM, CP and energy in the current study were lower than the values obtained by Yin et al. (2002) where average values of 78, 77 and 78%, were reported for AID of DM, CP and energy, respectively. This observation could be explained by the differences in cultivar and source (includes factors such as field location, growing conditions and management practices) of the corn samples evaluated.

Table 4.4. Analyzed composition of the experimental diets (%), as fed basis

	St. Pierre		Reinland		Carman	
Item	39M27	39W54	39M27	39W54	39M27	39W54
DM	89.8	92.2	88.5	90.3	89.0	89.3
CP	8.4	9.6	8.4	9.4	8.4	9.6
NDF	7.0	7.6	7.2	8.4	7.0	8.5
ADF	2.1	2.6	2.5	2.4	2.5	2.3
Amino Acids						
Indispensable						
Arginine	0.25	0.34	0.36	0.38	0.31	0.36
Histidine	0.21	0.23	0.21	0.23	0.18	0.20
Isoluecine	0.28	0.27	0.30	0.30	0.35	0.30
Leucine	1.12	1.32	1.14	1.18	1.27	1.31
Lysine	0.25	0.27	0.25	0.25	0.24	0.23
Methionine	0.23	0.19	0.28	0.22	0.18	0.23
Phenylalanine	0.44	0.41	0.40	0.36	0.45	0.51
Threonine	0.28	0.34	0.29	0.28	0.27	0.32
Valine	0.45	0.49	0.47	0.49	0.45	0.42
Dispensable						
Alanine	0.69	0.77	0.68	0.74	0.70	0.78
Aspartic acid	0.58	0.70	0.67	0.77	0.62	0.63
Cystine	0.28	0.29	0.27	0.27	0.29	0.28
Glutamic acid	1.30	1.45	1.27	1.42	1.21	1.54
Glycine	0.32	0.36	0.32	0.36	0.36	0.36
Proline	0.74	0.82	0.74	0.74	0.75	0.84
Serine	0.65	0.75	0.60	0.66	0.59	0.74
Tyrosine	0.31	0.35	0.29	0.27	0.44	0.35

Table 4.5. Apparent ileal and total tract digestibilities (%) of dry matter, crude protein and energy in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location[z]

	St. Pierre[y]		Reinland		Carman			P value	
Item	39M27	39W54	39M27	39W54	39M27	39W54	SEM[x]	Location	Cultivar
Ileal digestibility									
Dry matter	69.7	70.0	73.2	73.1	70.6	71.4	0.85	0.0021	0.7396
Crude protein	56.0	58.8	58.9	63.0	56.7	63.8	1.75	0.1184	0.0038
Energy	69.3	69.0	73.0	72.4	70.2	71.2	0.89	0.0026	0.9741
Total tract digestibility									
Dry matter	85.8	85.4	85.9	85.9	85.6	85.0	0.20	0.0166	0.0456
Crude protein	75.6	77.3	75.7	79.0	75.8	79.3	0.88	0.4117	0.0007
Energy	84.4	83.8	84.5	84.4	84.3	83.8	0.28	0.3173	0.0781

[z]Values are least square means

[y]Corn samples were grown at St. Pierre, Reinland and Carman.

[x]Pooled standard error of the least square means

The effect of interaction between location and cultivar on ATTD of DM, CP and energy was not significant ($P > 0.10$) and therefore, only the effects of location and cultivars are presented (Table 4.5). Corn cultivars from Reinland had higher ($P = 0.0127$) ATTD of DM compared with those from Carman but ATTD of DM of cultivars from St. Pierre were comparable ($P > 0.10$) with those from both locations. There was no effect ($P > 0.10$) of location on the ATTD of CP and energy. Cultivar had an effect ($P < 0.05$) on ATTD of DM and CP. Cultivar 39W54 had a higher ($P < 0.05$) ATTD of CP just as observed for AID of CP but a lower ATTD of DM compared with 39M27. The effect of cultivar on the ATTD of energy tended to be higher ($P = 0.0781$) in 39M27 compared with 39W54, a trend that is completely different from AID of energy (Table 4.5). The difference observed in the pattern of nutrient digestibility, as affected by location and cultivar, at the ileal level and fecal level might be due to microbial intervention on nutrient digestibility at the hindgut. For example, hind gut bacteria are capable of utilizing dietary protein and synthesizing AA (Li and Sauer 1994). In the current study, the values obtained for the ATTD of DM, energy and CP were higher than the values obtained for AID (Table 4.5) which is in agreement with previous research (Moeser et al. 2002; Yin et al. 2002). The ATTD of DM, CP and energy of the corn samples evaluated in the current study were comparable to the values reported by Adeola and Bajjalieh (1997) and Snow et al. (2004) but lower than the values reported by Moeser et al. (2002) and Yin et al. (2002). Again the variability in the ATTD of DM, CP and energy further confirms the variability in nutrient digestibility value of grain corn with respect to field location and cultivar.

Location had no effect ($P > 0.05$) on the AID of AA except for methionine and phenylalanine among the indispensable AA, and for aspartic acid, cysteine and tyrosine among the dispensable AA (Table 4.6). Compared with cultivars from Reinland, those from Carman had higher ($P < 0.05$) AID for phenylalanine and tyrosine but lower values for methionine and aspartic acid. Except for phenylalanine and cysteine, where cultivars from St. Pierre had lower ($P < 0.05$) values, AID of AA in cultivars from St. Pierre and Carman were similar ($P > 0.05$). Apparent ileal digestibilities of aspartic acid and cysteine were lower ($P < 0.05$) in cultivars from St. Pierre compared with those from Reinland. Apparent ileal digestibility of arginine tended to be higher ($P = 0.0554$) in cultivars from Reinland compared with those from St. Pierre. Cultivars from Carman tended to have higher ($P = 0.0693$) AID of leucine compared with those from St. Pierre. Cultivar had an effect ($P < 0.05$) on the AID of arginine and methionine. Cultivar 39W54 had higher ($P = 0.0496$) AID for arginine compared with 39M27. The higher AID digestibility of arginine in 39W54 compared with 39M27 is similar to the trend observed in AID and ATTD of CP (Table 4.5) but the reverse was the case for the AID of methionine with 39W54 having lower value compared with 39M27. This observation shows that the digestibility of individual AA is unique and does not necessarily follow the same pattern as CP digestibility. There was an interaction effect ($P < 0.05$) of location and cultivar on the AID of methionine, cysteine and glycine. This implies that the pattern of AID of methionine, cysteine and glycine in 39M27 and 39W54 varies with location. For example, 39W54 and 39M27 had similar AID for methionine in Carman and Reinland but in St. Pierre, 39M 27 had higher digestibility (Figure 4.1). Apparent ileal digestibility of most AA in this study were comparable to the values reported by

Table 4.6. Apparent ileal digestibility of amino acids (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location[z]

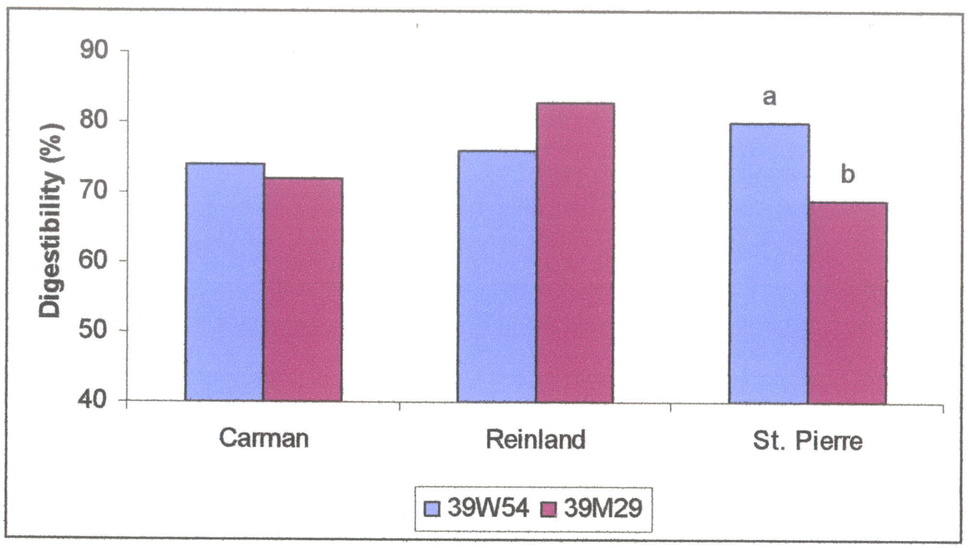
	St. Pierre[y]		Reinland		Carman			P value		
Amino acids	39M27	39W54	39M27	39W54	39M27	39W54	SEM[x]	Location	Cultivar	L*C[w]
Indispensable										
Arginine	61.9	69.3	72.8	73.2	66.1	73.0	2.84	0.0554	0.0496	0.3825
Histidine	71.8	70.8	76.3	75.7	70.1	73.2	2.65	0.1625	0.8102	0.6969
Isoluecine	69.6	67.3	65.3	66.3	73.9	66.7	2.58	0.2387	0.1869	0.2952
Leucine	81.3	80.6	82.2	82.2	85.6	83.2	1.42	0.0693	0.3891	0.6768
Lysine	44.7	51.8	46.7	46.8	44.5	46.8	4.14	0.8282	0.3624	0.6917
Methionine	79.7	69.4	82.9	76.0	71.5	74.0	2.15	0.0159	0.0118	0.0211
Phenylalanine	74.0	72.5	75.5	71.0	76.9	80.5	2.36	0.0493	0.6745	0.2473
Threonine	51.8	57.6	55.4	51.5	50.5	54.7	2.73	0.7382	0.3789	0.1919
Valine	68.8	67.2	67.3	68.6	69.5	64.8	1.92	0.8888	0.2908	0.3146
Dispensable										
Alanine	74.2	75.6	76.1	75.9	71.1	73.6	1.55	0.4165	0.9100	0.8382
Aspartic acid	59.6	64.3	67.2	70.0	64.3	60.9	2.12	0.0093	0.4334	0.1649
Cysteine	72.0	69.2	73.1	77.9	80.6	75.6	1.30	<0.0001	0.3524	0.0032
Glutamic acid	79.2	70.4	81.4	80.9	78.7	81.6	3.45	0.1660	0.4615	0.2360
Glycine	19.7	34.9	20.4	32.6	29.5	20.6	4.17	0.8579	0.0851	0.0181
Proline	30.5	57.3	31.6	41.1	30.4	37.4	10.00	0.5883	0.0920	0.5673
Serine	67.6	66.1	68.9	71.5	67.1	70.4	1.78	0.2068	0.3186	0.3600
Tyrosine	69.2	73.9	68.9	67.0	80.9	77.1	3.31	0.0101	0.9059	0.4179

[z]Values are least square means

[y]Corn samples were grown at St. Pierre, Reinland and Carman.

[x]Pooled standard error of the least square means

[w]Interraction between location and cultivar



a,b Bars bearing different letters differ ($P < 0.05$)

Figure 4.1. Interaction between location and cultivar on apparent ileal digestibility of methionine in corn cultivars fed to growing pigs.

Stein et al. (1999) and Snow et al. (2004) but were lower than the values reported by Burgoon et al. (1992), NRC (1998) and Yin et al. (2002).

Standardized ileal digestibilities of CP and AA are shown in Table 4.7. Except for methionine, the observed effects ($P > 0.05$) of location and cultivar on AID of indispensable AA were completely eliminated for SID. Location had an effect ($P < 0.05$) only on the SID of aspartic acid and cysteine for dispensable AA. As observed for the AID of AA, cultivars from Reinland had higher ($P < 0.05$) SID of methionine compared with cultivars from Carman, and of aspartic acid compared with cultivars from Carman and St. Pierre. Standardized ileal digestibility of cysteine was lower ($P < 0.05$) in cultivars from St. Pierre compared with those from Reinland. There was an effect ($P < 0.05$) of cultivar on the SID of crude protein and methionine. Similar to the trend observed for AID of CP and methionine, 39W54 had higher ($P = 0.0287$) SID of CP but lower ($P = 0.0193$) value for methionine compared with 39M27. There was no effect ($P > 0.05$) of interaction between location and cultivar on the SID of any of indispensable AA. However, the interaction between location and cultivar tended to be significant ($P = 0.0633$) for methionine. For dispensable AA, the interaction between location and cultivar was only significant ($P < 0.05$) for SID of cysteine and glycine. The values observed for SID of CP and AA in the current study were lower than the value obtained by Yin et al. (2002), and this could be due to differences in the source and type of cultivars used.

The DE and apparent and standardized ileal digestible CP and AA contents of the corn samples evaluated are presented in Table 4.8 and 4.9. The effect of location on

Table 4.7 Standardized ileal digestibilities of crude protein and amino acids (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location[z]

	St. Pierre[y]		Reinland		Carman			P value		
Item	39M27	39W54	39M27	39W54	39M27	39W54	SEM[x]	Location	Cultivar	L*H[w]
Crude protein	68.7	70.2	71.4	74.3	69.2	74.8	1.75	0.1455	0.0287	0.5061
Amino Acids										
Indispensable										
Arginine	87.5	88.8	90.7	90.1	86.7	90.8	2.83	0.7228	0.4944	0.7068
Histidine	85.5	83.9	89.5	88.3	85.9	87.3	2.65	0.3042	0.8227	0.8161
Isoluecine	85.9	84.1	80.0	81.4	85.1	81.7	2.58	0.2580	0.5469	0.6354
Leucine	89.4	87.6	90.0	89.9	92.7	90.1	1.42	0.1586	0.2157	0.6668
Lysine	59.0	65.4	61.2	61.3	59.1	62.5	4.14	0.9374	0.3402	0.7508
Methionine	83.9	74.8	86.4	80.6	76.8	78.4	2.15	0.0359	0.0193	0.0633
Phenylalanine	90.1	87.9	91.9	89.6	91.5	93.5	2.36	0.3447	0.6636	0.5897
Threonine	67.8	71.1	70.7	67.8	66.8	68.7	2.73	0.7926	0.7307	0.5034
Valine	83.7	81.3	81.2	82.1	83.6	80.6	1.92	0.9140	0.3503	0.5669
Dispensable										
Alanine	81.7	82.5	83.6	82.9	81.5	80.3	1.55	0.3236	0.7355	0.8326
Aspartic acid	72.8	75.5	78.5	80.0	75.9	73.0	2.12	0.0470	0.8047	0.3922
Cysteine	78.8	75.8	80.1	84.8	86.9	82.8	1.30	<0.0001	0.3873	0.0044
Glutamic acid	104.2	93.3	106.5	103.8	105.1	102.5	3.44	0.1701	0.0689	0.4025
Glycine	36.4	49.2	36.5	47.4	44.2	35.2	4.17	0.7033	0.1480	0.0277
Proline	51.0	76.3	51.8	61.7	50.3	55.4	10.00	0.5598	0.1153	0.5836
Serine	76.5	74.0	78.3	80.2	76.8	78.1	1.78	0.1073	0.8740	0.4179

[z]Values are least square means

[y]Corn samples were grown at St. Pierre, Reinland and Carman.

[x]Pooled standard error of the least square means

[w]Interraction between location and cultivar

Table 4.8 Apparent digestible energy (kcal kg^{-1}) and ileal digestible crude protein and amino acids (%) contents in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location (DM basis)[z]

	St. Pierre[y]		Reinland		Carman			P value		
Item	39M27	39W54	39M27	39W54	39M27	39W54	SEM[z]	Location	Cultivar	L*C[y]
Energy	3664	3625	3678	3660	3680	3667	12.14	0.0541	0.0292	0.5567
Crude protein	5.2	6.1	5.6	6.6	5.4	6.8	0.17	0.0295	<.0001	0.2116
Amino acids										
Indispensable										
Arginine	0.17	0.25	0.30	0.31	0.23	0.29	0.01	<.0001	<.0001	0.0063
Histidine	0.17	0.17	0.19	0.19	0.14	0.17	0.01	0.0001	0.0302	0.2769
Isoluecine	0.21	0.20	0.22	0.22	0.33	0.22	0.01	<.0001	<.0001	<.0001
Leucine	1.01	1.16	1.06	1.08	1.22	1.22	0.02	<.0001	0.0027	0.0029
Lysine	0.12	0.15	0.13	0.13	0.12	0.12	0.01	0.3308	0.3529	0.2899
Methionine	0.21	0.14	0.26	0.18	0.15	0.19	0.00	<.0001	<.0001	<.0001
Phenylalanine	0.34	0.35	0.34	0.28	0.39	0.45	0.01	<.0001	0.5831	<.0001
Threonine	0.16	0.21	0.18	0.16	0.16	0.19	0.01	0.1052	0.0109	0.0010
Valine	0.34	0.35	0.36	0.38	0.37	0.30	0.01	0.0202	0.2040	0.0012
Dispensable										
Alanine	0.58	0.63	0.59	0.62	0.59	0.64	0.01	0.6938	<.0001	0.6696
Aspartic acid	0.39	0.49	0.50	0.60	0.47	0.43	0.02	<.0001	0.0005	0.0002
Cystine	0.22	0.22	0.22	0.24	0.27	0.23	0.00	<.0001	0.2050	<.0001
Glutamic acid	1.14	1.11	1.16	1.28	1.07	1.41	0.05	0.0196	0.0055	0.0080
Glycine	0.07	0.14	0.08	0.13	0.12	0.08	0.02	0.9949	0.0566	0.0107
Proline	0.25	0.51	0.27	0.34	0.26	0.35	0.08	0.5631	0.0522	0.4869
Serine	0.49	0.54	0.47	0.53	0.44	0.59	0.01	0.3586	<.0001	0.0034
Tyrosine	0.24	0.28	0.23	0.20	0.40	0.30	0.01	<.0001	0.0131	<.0001

[z]Values are least square means

[y]Corn samples were grown at St. Pierre, Reinland and Carman.

[x]Pooled standard error of the least square means

[w]Interraction between location and cultivar

Table 4.9. Standardized ileal digestible crude protein and amino acids contents (%) in corn cultivars 39M27 and 39W54 fed to growing pigs as influenced by location (DM basis)[z]

	St. Pierre[y]		Reinland		Carman			P value		
Item	39M27	39W54	39M27	39W54	39M27	39W54	SEM[y]	Location	Cultivar	L*C[x]
Crude Protein	6.4	7.3	6.8	7.8	6.5	8.0	0.17	0.0286	<.0001	0.2157
Amino Acids										
Indispensable										
Arginine	0.25	0.33	0.37	0.38	0.30	0.37	0.01	<.0001	<.0001	0.0041
Histidine	0.20	0.20	0.22	0.23	0.17	0.20	0.01	<.0001	0.0154	0.1970
Isoluecine	0.26	0.25	0.27	0.27	0.38	0.27	0.01	<.0001	<.0001	<.0001
Leucine	1.11	1.26	1.16	1.18	1.32	1.32	0.02	<.0001	0.0027	0.0029
Lysine	0.16	0.19	0.17	0.17	0.16	0.16	0.01	0.3308	0.3529	0.2899
Methionine	0.22	0.15	0.27	0.19	0.16	0.20	0.01	<.0001	<.0001	<.0001
Phenylalanine	0.41	0.42	0.41	0.36	0.46	0.53	0.01	<.0001	0.4578	<.0001
Threonine	0.21	0.26	0.23	0.21	0.21	0.24	0.01	0.1052	0.0109	0.0010
Valine	0.42	0.43	0.43	0.45	0.44	0.38	0.01	0.0144	0.1014	0.0006
Dispensable										
Alanine	0.63	0.69	0.65	0.68	0.64	0.70	0.01	0.7373	<0.0001	0.5317
Aspartic acid	0.47	0.57	0.59	0.68	0.56	0.51	0.02	<.0001	0.0008	0.0002
Cystine	0.24	0.24	0.24	0.26	0.29	0.25	0.00	<.0001	0.1376	<.0001
Glutamic acid	1.50	1.47	1.53	1.64	1.43	1.77	0.05	0.0916	0.0055	0.0080
Glycine	0.13	0.20	0.13	0.19	0.18	0.14	0.02	0.9776	0.0387	0.0115
Proline	0.42	0.68	0.43	0.51	0.43	0.52	0.08	0.5641	0.0509	0.4776
Serine	0.55	0.60	0.53	0.59	0.51	0.65	0.01	0.3359	<.0001	0.0033

[z]Values are least square means

[y]Corn samples were grown at St. Pierre, Reinland and Carman.

[x]Pooled standard error of the least square means

[w]Interraction between location and cultivar

apparent and standardized ileal digestible AA was significant ($P < 0.05$) for indispensable AA except for lysine and threonine, and for dispensable AA except for alanine, glycine, proline and serine (Table 4.8 and 4.9). Compared with cultivars from Carman, cultivars from Reinland had higher ($P < 0.05$) standardized ileal digestible aspartic acid, valine and methionine contents but lower ($P < 0.05$) cysteine and leucine contents. Cultivars from St. Pierre had lower ($P < 0.05$) standardized ileal digestible aspartic acid and methionine contents compared with cultivars from Reinland, and lower ($P < 0.05$) values for cysteine and isoleucine compared with cultivars from Carman. Cultivars from Carman, Reinland and St. Pierre were all significantly different ($P < 0.05$) in standardized ileal digestible tyrosine, phenylalanine, histidine and arginine contents. Standardized ileal digestible CP content of cultivars from Carman and Reinland was higher ($P < 0.0001$) compared with that of cultivars from St. Pierre. Digestible energy content of cultivars from Carman tended to be higher ($P = 0.0541$) compared with that of cultivars from St. Pierre but DE content of cultivars from Reinland was comparable to that of cultivars from Carman and St. Pierre (Tables 4.8).

Cultivar had an effect ($P < 0.05$) on the apparent and standardized ileal digestible CP and AA and on DE (Tables 4.8 and 4.9). Cultivar 39W54 had higher ($P < 0.05$) standardized ileal digestible histidine, aspartic acid, threonine, serine, glutamic acid, proline, glycine, alanine and arginine contents but lower ($P < 0.05$) methionine, isoleucine and tyrosine contents compared with 39M27. Cultivar 39M 27 had higher ($P <$ 0.0292) DE content compared with 39W54. There was a significant ($P < 0.05$) effect of interaction between location and cultivar on apparent and standardized ileal digestible AA except for histidine, lysine, alanine and proline. Digestible energy, CP and AA contents in the corn samples evaluated in the current study were comparable to the values reported by Yin et al. 2002.

4.5 CONCLUSIONS

Digestibility of energy, CP and AA in the corn samples evaluated in the current study varied with location and cultivar. Similarly, digestible energy, CP and AA contents were considerably variable between cultivar and location, thus emphasizing the need for nutritional characterization of locally available corn cultivars before incorporating them into swine diets. The data indicate that the digestible energy, CP and AA contents of the Manitoba-grown corn cultivars are similar to published values.

5.0 MANUSCRIPT III

Growth performance and carcass characteristics of pigs fed Manitoba grown corn cultivars.

5.1 ABSTRACT

An experiment was conducted to determine growth performance, carcass characteristics and fat quality of growing-finishing pigs fed diets based on two widely grown corn cultivars in Manitoba. Twenty-four Cotswold growing pigs (41.4 ± 1.4 kg (mean ± SD) initial BW) individually housed in floor pens were blocked by BW and sex and randomly allotted from within block to one of three diets to give eight replicate pigs per diet. Experimental diets consisted of a control based on barley and two corn based diets containing corn 39M27 or corn 39W54 as the main energy sources. A three-phase feeding program for 20-50 kg (phase I), 50-80 kg (phase II) and 80-110 kg (phase III) BW range was used. Diets for each phase contained 3.5 Mcal kg^{-1} DE, but total lysine was 0.95%, 0.75% and 0.64% in phase I, II and III diets, respectively. Average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio (G:F) were monitored weekly during each phase. Pigs were slaughtered after reaching a minimum BW of 100 kg. There were no effects ($P > 0.05$) of diet on ADG (lsmean ± SE) (0.87 ± 0.04, 0.85 ± 0.05 and 0.90 ± 0.05 kg for phase I, II and III, respectively), ADFI (lsmean ± SE) (1.96 ± 0.07, 2.46 ± 0.08 and 2.86 ± 0.09 kg for phase I, II and III, respectively) and G:F (lsmean ± SE) (0.45 ± 0.02, 0.34 ± 0.02 and 0.31 ± 0.02 for phase I, II and III, respectively). Carcass length, dressing percentage, loin eye area, loin depth, backfat thickness, belly firmness and L*, b* and a* fat color were similar ($P > 0.05$) across dietary treatments.

Pigs fed the diet based on corn 39W54 had a higher ($P < 0.05$) concentration of polyunsaturated fatty acids in their backfat compared with those fed the barley-based diet but the amount of saturated, monounsaturated and total unsaturated fatty acids in the belly fat and backfat were similar ($P > 0.05$) across dietary treatments. The results suggest that growth performance, carcass characteristics and fat quality of pigs fed diets based on Manitoba-grown corn cultivars and those fed the barley-based diet were comparable.

5.2 INTRODUCTION

It is often speculated that pigs fed corn-based diets will produce inferior quality products compared with pigs fed barley- or wheat based diets in terms of meat and fat color and fat firmness (Lampe et al. 2004; Carr et al. 2005). This argument is based on the fact that yellow corn contains higher amount of carotenoids and unsaturated fatty acids compared with barley and wheat (NRC 1998). Carotenoids are naturally occurring fat soluble pigments often found in plants (Priolo et al. 2002; Prache et al. 2003) and feeding diets containing feedstuff with high amount of carotenoids to pigs might result in production of colored fat as opposed to white fat that is in high demand in international markets. Another product quality concerns related to feeding corn-based diets to pigs is production of soft fats due to the high content of unsaturated fatty acids in corn. Berg (2001) and Ellis and McKeith (1999) reported that apart from the de novo synthesis of fat, pork fatty acid profile is a product of dietary fatty acids profile. In other words, high amount of dietary unsaturated fatty acids will result in pork products with high amount of unsaturated fatty acids. Although, dietary unsaturated fat can have some health benefits such as reducing the risk of cardiovascular diseases in humans, a high amount of unsaturated fats in pork has been associated with some serious product processing and quality problems such as difficulty in belly slicing, visually unattractive sausage and susceptibility to rapid oxidative rancidity. According to Carr et al. (2005), pigs fed corn-based diet were more efficient than those fed a barley-based diet. Furthermore, the authors failed to find any beneficial effect of barley compared with corn on all the carcass and fat quality characteristics evaluated, which contradicts results of others (Robertson et al. 1999). Clearly, the effects of feeding corn to swine relative to barley on growth performance and carcass characteristics have not been conclusively determined. Furthermore, the effects of specific corn cultivars on these parameters have not been well researched. Therefore, the objective of this study was to evaluate the effects of representative Manitoba-grown corn cultivars on growth performance and carcass and fat characteristics of growing-finishing pigs. A sample of locally grown barley was also evaluated as the control.

5.3 MATERIALS AND METHODS

5.3.1 Animals and Diets

Twenty-four Cotswold pigs (12 barrows and 12 gilts), obtained from the University of Manitoba's Glenlea Swine Research Farm, with an average initial BW of 41.4 ± 1.4 kg (mean ± SD), were used in this study. Pigs were blocked on the basis of

BW and sex into eight blocks each with three pigs. Pigs from each block were randomly allotted to one of the three treatment groups resulting in a total of eight pigs per treatment.

Each treatment group was assigned to one of the three dietary treatments consisting of a barley-based diet (control) and two diets each containing one of the two most cultivated corn cultivars in Manitoba, 39M27 and 39W54. The CHU rating of 39M27 and 39W54 were 2150 and 2100, respectively. The barley sample was obtained from University of Manitoba Glenlea Research Farm and the corn samples were obtained from Carman. All grain samples were from the 2003 planting season harvest. Pigs were fed on a three-phase dietary program for BW 20-50 kg (phase I), 50-80 kg (phase II) and 80-110 kg (phase III) as is usually done in the industry. The diets were formulated to meet the NRC (1998) recommendations for each phase (Table 5.1). The dietary level of CP, lysine and DE were comparable across dietary treatments within each phase.

Pigs were housed individually in floor pens [72'' (length) × 48'' (breadth) × 36'' (height)] with plastic-covered expended metal sheet flooring in a temperature controlled room (19°C to 21°C). Each pen was equipped with a feeder and a nipple drinker to allow unrestricted access to feed and water at all times. Diets were provided to the animals as a mash. Individual pig weight and feed disappearance were measured weekly during each phase to determine average daily gain (ADG), average daily feed intake (ADFI) and gain to feed ratio. The use of pigs and the experimental procedures were reviewed and approved by the Animal Care Committee of the University of Manitoba, and animals were cared for according to the standard guidelines of the Canadian Council on Animal Care (CCAC, 1993).

Table 5.1. Ingredient composition and calculated nutrient composition of the experimental diets

	Phase I			Phase II			Phase III		
Item	Barley	39M27	39W54	Barley	39M27	39W54	Barley	39M27	39W54
Ingredient (%)									
Corn	-	72.00	72.00	-	77.17	77.17	-	79.75	79.75
Barley	78.26	-	-	83.85	-	-	89.71	-	-
Soybean Meal	11.20	15.30	15.3	4.98	7.90	7.90	3.89	5.00	5.00
Canola Meal	7.73	9.91	9.91	8.70	12.53	12.53	4.00	13.00	13.00
Dicalcium phosphate	0.06	0.12	0.12	0.02	0.06	0.06	0.01	0.01	0.01
$CaCO_3$	1.18	1.17	1.17	0.98	0.94	0.94	0.93	0.88	0.88
Mineral Premix[x]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Vitamin Premix[w]	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
Lysine-HCl	0.17	0.10	0.10	0.12	0.05	0.05	0.11	0.01	0.01
Salt	0.40	0.40	0.40	0.35	0.35	0.35	0.35	0.35	0.35
Calculated Composition[v]									
CP (%)	17.55	17.49	17.79	15.62	15.39	15.70	14.14	14.42	14.74
Lysine (%)	0.95	0.95	0.95	0.75	0.75	0.75	0.63	0.64	0.64
Ca (%)	0.59	0.60	0.60	0.50	0.50	0.50	0.45	0.46	0.46
P (%)	0.49	0.50	0.50	0.45	0.45	0.45	0.40	0.41	0.41
Ca:P	1.20	1.20	1.20	1.11	1.11	1.11	1.12	1.12	1.12
DE (Mcal kg^{-1})	3.50	3.50	3.50	3.50	3.50	3.50	3.40	3.50	3.50

[z] Represents 39M27.

[y]Represents 39W54.

[x]Supplied the following kg^{-1} of complete diet: copper, 15 mg; iodine, 0.21 mg; iron, 100 mg; manganese, 40 mg; selenium, 0.30 mg; zinc, 150 mg for phase 1 diets; and copper, 15 mg; iodine, 0.21 mg; iron, 100 mg; manganese, 20 mg; selenium, 0.15 mg; zinc, 100 mg for phase 2 and 3 diets.

[w]Supplied the following kg^{-1} of complete diet: vitamin A, 8250 IU; vitamin D3, 825 IU; vitamin E, 40 IU; vitamin K3, 4 mg; riboflavin, 5 mg; niacin, 35 mg; vitamin B12, 25 μg; biotin, 200 μg for phase 1, 2 and 3 diets.

[v]Calculated based on NRC (1998) feed composition data except CP that was based on analyzed values.

5.3.2 Carcass Evaluation

One pig was removed during the experiment due to poor growth performance. After reaching a minimum live BW of 100 kg, all pigs were slaughtered at the Meat Science Laboratory of Animal Science Department, University of Manitoba after 18 h of feed deprivation. Prior to slaughter, pigs were weighed and then given an intramuscular injection of acepromazine maleate (0.3 mg kg^{-1} BW, Atravet 10 mg Injectable) (Wyeth Animal Health, ON, Canada) mixed in a single syringe with 15 mg kg^{-1} BW ketamine hydrochloride Ketalea (Bimeda-MTC Animal Health Inc., ON, Canada) as a pre-anesthetic tranquilizer. Once tranquilized sufficiently, approximately 20 mg kg^{-1} BW of sodium pentobarbital (Bimeda-MTC Animal Health Inc., ON, Canada) was administered intravenously through the lateral ear vein to provide for a plane of surgical anaesthesia but not enough to cause respiratory arrest. Pigs were then exsanguinated and the viscera were removed. The dressing percentage was determined as the ratio of hot carcass weight to live weight at slaughter. The carcasses were then split into two by cutting through the backbone and then stored in a cooler at 4°C.

After 24 h in the cooler, carcass length was measured on the right half of the carcass as a distance between the cranial face of the first rib and the tip of the aitch bone. The belly was fabricated from the right half of the carcass according to the procedure of UN/ECE standard for porcine carcasses and cuts (ECE 1997) and the leaf fat and the attached ribs and cartilages were removed. Approximately 14'' × 19'' belly was cut out and subjected to the belly flex test according to the procedure of Rentfrow et al. (2003). Briefly, the carcass was centered on a polyvinyl chloride pipe (3.5" diameter) mounted perpendicularly on a board marked with a 1 inch grid matrix with the skin side down and the chine side against the board. Lateral and vertical flexes were calculated as the average of the lateral and vertical left and right flexes determined relative to the grid matrix on the left and right side of the board, respectively (Figure 5.1). About 50 g leaf fat was removed for belly fat fatty acid analysis.

The left half of the carcass was evaluated for backfat thickness, loin depth and loin eye area (LEA). Midline backfat thickness was measured perpendicular to the skin at the first and last rib and at the last lumbar. The carcass was cut using the Hobart meat cutting machine (The Hobart Mfg. Co. Ltd., Toronto, Canada) between the 10th and 11th ribs to determine the 10th rib fat thickness, loin depth and loin eye area. The outline of the loin eye was traced on an acetate paper and the loin eye area was later determined using a 0.25 cm^2 grid. Samples of subcutaneous fat were obtained from the area of 10th and 11th ribs for backfat fatty acid and fat color analysis, respectively. The samples, about 50 g for fatty acid analysis and approximately 8 cm × 10 cm in dimension for fat color analysis, were carefully separated from the attached muscle. Fat samples were stored in a -80°C freezer until required for further analysis.

Fat color was evaluated for the Commission International de l'Eclairage (CIE) L* (lightness), a* (red-green scale) and b* (yellow-blue scale) values (CIE 1976) using a Minolta Spectrophotometer CM-3500d (Minolta Co., Ltd. Osaka, Japan). The spectrophotometer was calibrated using the manufacturer's zero calibration and white, standard calibration caps. The L* scale ranged from 0% to 100%, that is, the higher the value, the lighter the color, a* scale ranged from negative (green) to positive (red) and b* scale ranged from negative (blue) to positive (yellow). Each sample was read thrice.

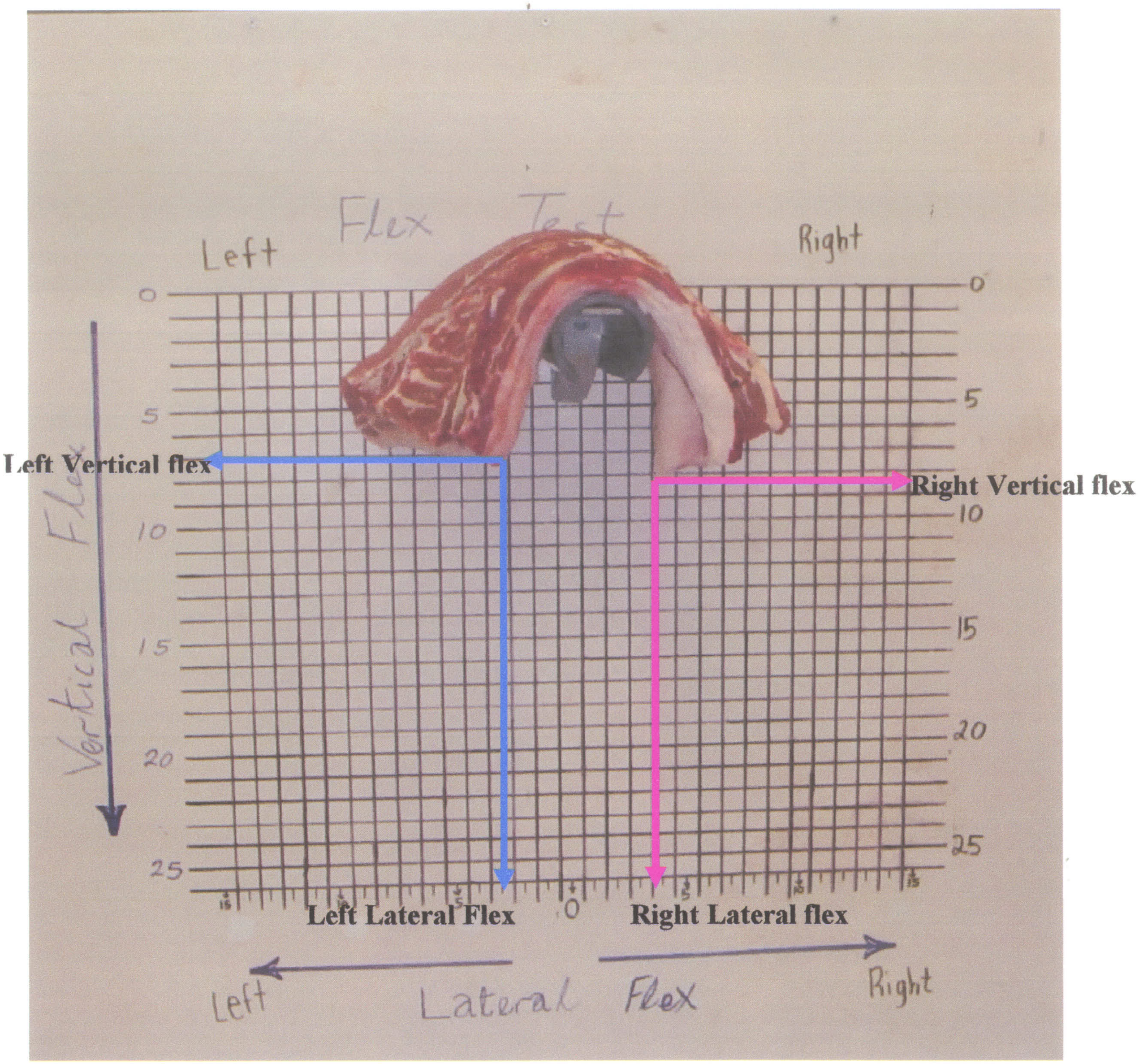


Figure 5.1. Lateral and vertical belly flex measurement

5.3.3 Fatty Acid Analysis

Feed ingredient samples (corn and barley) and belly fat and backfat samples were analyzed for fatty acids. A representative sample of each grain ground through a 1 mm sieve and thoroughly mixed was subjected to lipid extraction as described in manuscript I according to AOAC (1990) procedures. Extracted oil was methylated following the procedure of Folch et al. (1957). Briefly, 1 mL of hexane was added to 100 mg of the extracted oil and then 0.1 mL of the mixture was evaporated to dryness under nitrogen gas in a warm water bath (30°C) using an evaporation unit equipped with a heating system (N-evap, Organomation Associates Inc., Berlin, USA). Then 1 mL of toluene and 1.2 mL of methanolic HCl were added and the tubes tightly capped before being placed in an oven set at 80°C for 60 min. Samples were then cooled to room temperature for 10 minutes before adding 1 mL each of deionized water and hexane and the mixture vortexed for 20 seconds and centrifuged (TJ-6 Centrifuge, Beckman, USA) for 4 min at 2000 rpm. The hexane layer was transferred into a clean tube and 2 mL of water was added, vortexed and centrifuged for 4 min. Part of the hexane layer was transferred into a gas chromatograph vial and the cap secured.

Belly fat and backfat samples were extracted and methylated according to the procedures of Folch et al. (1957). Briefly, 500 mg of adipose tissue was weighed into a glass tube containing 10 mL of a mixture of 2:1 chloroform methanol and 0.01% of butylated hydroxytoluene. The tissue was then homogenized with a tissue homogenizer (Polytron, Kinematica GMBH, Luzern-Schweiz, Switzerland). The mixture was filtered through a Whatman #4 filter paper into a clean screw top tube. To the filtrant, 2.3 mL of 0.73% sodium chloride was added and the mixture was vortexed and centrifuged (GS-6

Centrifuge, Beckman, USA) for 10 min at 1500 rpm. The top layer was removed and discarded. The side of the tube was rinsed down with 2 mL of a theoretical upper phase solution (chloroform:methanol:water 3:48:47) and the remaining top layer was discarded. The bottom layer was transferred into a 15 mL screw top tube, evaporated to dryness under nitrogen in a 30°C water bath. The tube was vortexed after rinsing the side down twice with 1 mL chloroform. The sample was then methylated as described above for the feedstuffs.

Fatty acid methyl esters were analyzed using a Hewlett-Packard 5890A gas chromatograph equipped with an autosampling injection system HP 7673. The 100 m long column, Agilent HP-88 capillary column (J and W Scientific, Folsom, U.S), was made of fused silica coated with 88% cyanopropyl aryl siloxane (0.25 mm i.d. and 0.2 μm film thickness). The column temperature started at 50°C and after 1 min, it increased at a rate of 20°C/min to 160°C and held at this level for 23 min. The temperature then increased at a rate of 2°C/min to 210°C and was held there for 7 min. To clean the column between samples, the column temperature was increased at a rate of 20°C/min to 240°C and was held at that level for 5 min. The flame ionization detector temperature was kept constant at 300°C. The fatty acid methyl esters were identified using a methyl ester standard GLC-461 (Nu Check Prep, Inc., MN, USA).

5.3.4 Statistical Analysis

All data were subjected to analysis of variance as a randomized complete block design using GLM procedures of SAS (SAS Inst., Inc., Cary, NC). The effects of block (n=8), gender (n=2) and dietary treatment (n=3) were included in the model as sources of variation. The individual pig was considered as the experimental unit. When a significant F-value ($P < 0.05$) was indicated by the ANOVA, dietary treatment means were separated and compared using Tukey's test. Belly fat and backfat fatty acid profiles were compared using the t-test.

5.4 RESULTS AND DISCUSSION

The fatty acid profiles of barley and the two corn cultivars are presented in Table 5.2. Barley had a higher amount of saturated fatty acids (SFA) compared with the two corn cultivars, with the amount of myristic acid (14:0), palmitic acid (16:0) and arachidic acid (20:0) in barley being at least 367%, 50%, and 306%, respectively, higher than in the two corn cultivars. However, the two corn cultivars had higher amounts of oleic acid compared with barley. This observation is consistent with previous research showing that corn has a higher amount of unsaturated fatty acids compared with barley (NRC 1998; Carr et al. 2005). There were differences in the fatty acid profiles of the two corn cultivars (Table 5.2), which further confirms reports of variability in the chemical and nutrient composition of corn (Sproule et al. 1988; Adeola and Bajjalieh 1997; Moeser et al. 2002; Yin et al. 2002). The fatty acid profiles of the corn cultivars evaluated in the current study were similar to the values reported by Rentfrow et al. (2003). Compared with the report of Carr et al. (2005), corn and barley samples evaluated in this study had lower amounts of palmitic acid (16:0), palmitoleic acid (16:1) and stearic acid (18:0) but higher values for linoleic (18:2) and linolenic acid (18:3). In the barley and corn samples evaluated in the current study, palmitic acid and linoleic acid constituted the highest

Table 5.2. Fatty acid profiles in barley and the corn cultivars used in the experimental diets[z]

		Corn	
Fatty acid (%)	Barley	39M27	39W54
Capric (10:0)	0.16 ± 0.00	0.16 ± 0.02	0.13 ± 0.01
Myristic (14:0)	0.28 ± 0.00	0.03 ± 0.02	0.06 ± 0.02
Palmitic (16:0)	17.19 ± 0.12	10.32 ± 0.08	11.44 ± 0.21
Palmitoleic (16:1)	0.19 ± 0.03	0.13 ± 0.02	0.13 ± 0.02
Stearic (18:0)	1.57 ± 0.11	1.77 ± 0.04	2.00 ± 0.10
Oleic (18:1)	14.35 ± 0.20	30.24 ± 0.04	25.67 ± 0.16
Linoleic (18:2)	57.02 ± 0.12	54.61 ± 0.20	57.73 ± 0.29
Linolenic (18:3)	0.35 ± 0.00	0.48 ± 0.03	0.50 ± 0.02
Arachidic (20:0)	5.64 ± 0.13	1.26 ± 0.01	1.39 ± 0.01

[z]Mean ± standard deviation

proportion of saturated and total unsaturated fatty acids, respectively (Table 5.2), and this observation is comparable with the reports of Rentfrow et al. (2003) and Carr et al. (2005).

5.4.1 Growth Performance

There were no treatment × gender interactions ($P > 0.10$) in any of the parameters measured for growth performance, therefore only the effects of treatment and gender are presented. Average daily feed intake, ADG and gain:feed ratio (G:F) are presented in Table 5.3. There were no differences ($P > 0.10$) in ADFI, ADG and G:F of pigs fed the barley-based diets compared with those fed diets based on either of the two corn cultivars during any phase of the study. Likewise, there were no dietary effects ($P > 0.10$) on the overall ADFI, ADG and G:F. This observation is consistent with the results of Lampe et al. (2004) showing no differences ($P > 0.05$) in ADFI, ADG and G:F of growing-finishing pigs fed barley-based diet compared to those fed corn-based diets. Likewise, Carr et al. (2005) failed to show any differences ($P > 0.05$) in ADFI, ADG and G:F of pigs (45 to 80 kg BW) fed a barley- based diet and those fed a corn-based diet.

The gender effect was observed only for ADFI and ADG in phase II and ADFI in phase III. In phase II, barrows had higher ($P = 0.036$) ADFI and ADG ($P = 0.0352$) compared with gilts. In phase III, barrows ate more feed than gilts ($P = 0.0443$), which is consistent with previous studies (Hahn et al. 1995; Warnants et al. 1996; Hyun et al. 2004). However, G:F was comparable ($P > 0.10$) between gilts and barrows in all the three phases, an observation that is similar to the findings of Warnants et al. (1999) and Piedrafita et al. (2001). Overall, ADG of barrows tended to be higher ($P = 0.0720$)

Table 5.3. Effects of diet and gender on growth performance of growing-finishing pigs[z]

Item	Barley	39M27	39W54	SEM[y]	*P* value	Barrow	Gilt	SEM[y]	*P* value
Initial BW, kg	40.69	41.50	42.00	0.38	0.1004	41.6	41.2	0.64	0.4138
Final BW, kg	107.90	107.25	108.13	1.19	0.8537	108.3	107.2	0.87	0.4386
Phase I (38-50 kg)									
ADG, kg	0.84	0.86	0.92	0.04	0.4643	0.89	0.87	0.04	0.7046
ADFI, kg	1.90	2.03	1.95	0.07	0.4830	2.01	1.91	0.04	0.2488
G:F	0.44	0.43	0.49	0.02	0.1633	0.45	0.47	0.02	0.4878
Phase II (50-80 kg)									
ADG, kg	0.86	0.80	0.89	0.05	0.3951	0.92*a*	0.78*b*	0.03	0.0352
ADFI, kg	2.40	2.42	2.56	0.08	0.3203	2.57*a*	2.35*b*	0.03	0.0360
G:F	0.33	0.33	0.35	0.02	0.8196	0.36	0.32	0.01	0.1293
Phase III (80-110 kg)									
ADG, kg	0.84	0.89	0.97	0.05	0.2273	0.92	0.87	0.06	0.4113
ADFI, kg	2.75	2.80	3.02	0.09	0.1169	2.97*a*	2.74*b*	0.07	0.0443
G:F	0.30	0.31	0.31	0.02	0.8947	0.31	0.31	0.02	0.7520
Overall (38-110 kg)									
ADG, kg	0.85	0.85	0.93	0.03	0.1170	0.91	0.84	0.01	0.0732
ADFI, kg	2.35	2.41	2.51	0.06	0.2719	2.52*a*	2.33*b*	0.03	0.0333
G:F	0.36	0.36	0.39	0.01	0.2867	0.37	0.37	0.01	0.7624

[z]Values are least square means

[y]Pooled standard error of the least square means.

a,b Values within a row and gender bearing different letters differ ($P < 0.05$).

compared with that of gilts. As observed in phase II and III, overall ADFI of barrows was higher ($P = 0.0333$) than that of gilts. However, there were no effects ($P > 0.10$) of gender on the overall G:F.

The values obtained for ADG, ADFI and G:F for barley- and corn-based diets in the current study were similar to the values reported in previous studies (NRC, 1998; Dial et al. 2001; House et al. 2002, Carr et al. 2005).

5.4.2 Carcass characteristics

Carcass characteristics of pigs fed barley- and corn-based diets are shown in Table 5.4. There were no differences ($P > 0.05$) in dressing percentage, carcass length, backfat thickness, loin depth and loin eye area among dietary treatments. This agrees closely with the findings of Carr et al. (2005) showing similarity in the carcass and fat quality of pigs fed corn- and barley-based diets. Likewise, Hyun et al. (2004) did not find any differences in the carcass characteristics of pigs that were fed diets based on different cultivars of corn. The values for the above mentioned characteristics obtained in the current study were comparable to the published values for pigs fed barley- and corn-based diets (Camp et al. 2003; Shelton et al. 2003; Carr et al. 2005).

The belly firmness measured with the belly flex test was not affected by dietary treatment ($P > 0.10$). The values observed for the belly flex test for pigs that received corn cultivar 1 and corn cultivar 2 were higher than the values reported by Rentfrow et al. (2003) who reported 14 inches and 10 inches for vertical and lateral flex, respectively, for a similar size of belly for pigs fed conventional corn-based diet. However, the trend was the same in that, in the current study, the vertical flex had higher values compared with

Table 5.4. Effects of diet and gender on carcass characteristics of growing-finishing pigs[z]

Item	Barley	39M27	39W54	SEM[y]	*P* value	Barrow	Gilt	SEM[y]	*P* value
Dressing percent	81.8	84.3	83.0	0.87	0.1928	83.0	83.0	0.34	0.9785
Carcass length, cm	81.6	82.4	82.0	0.97	0.8624	81.7	82.3	0.97	0.5748
Midline backfat									
First rib, cm	3.1	3.3	3.2	0.15	0.7607	3.2	3.2	0.09	0.8575
Last rib, cm	2.5	2.3	2.6	0.19	0.4888	2.5	2.3	0.13	0.3231
Last lumbar, cm	2.1	1.9	2.0	0.22	0.8646	2.0	2.0	0.18	0.9567
10th rib fat, cm	2.0	2.0	1.9	0.16	0.8043	2.1	1.8	0.10	0.1792
Loin depth, cm	6.8	6.5	6.1	0.31	0.3758	6.3	6.8	0.11	0.2547
Loin eye area, cm^2	49.4	48.5	45.4	1.92	0.2859	45.2*a*	50.6*b*	1.50	0.0320
Vertical belly flex, cm	15.6	17.1	16.1	1.24	0.7500	15.6	17.1	0.91	0.3181
Lateral belly flex, cm	14.4	14.4	14.1	1.58	0.9867	15.3	13.2	0.97	0.2878
Back fat color[x]									
L*	82.0	81.8	82.0	0.4	0.9578	82.1	81.7	0.29	0.5255
a*	11.3	11.5	12.0	0.31	0.4228	11.6	11.6	0.19	0.9048
b*	1.9	1.5	1.7	0.23	0.2964	1.7	1.7	0.21	0.9102

[z]Values are least square means

[y]Pooled standard error of the lsmeans.

[x]L* = lightness; a* = redness; b* = yellowness

a,b Values within a row and gender bearing different letters differ ($P < 0.05$).

the lateral flex. Belly flex of pigs fed the barley-based diet was similar to that of pigs fed the corn-based diets though this could not be compared to previous research because this approach has not yet been used previously to measure belly firmness in pigs fed barley-based diets.

There was no effect of dietary treatment on the CIE L*a*b* fat color ($P > 0.10$). Barley, corn cultivar 1 and corn cultivar 2 produced fat tissues that were similar in lightness (L*), redness (a*) and yellowness (b*). Similar to the result of the present study, Carr et al. (2005) did not find any differences ($P < 0.05$) in L*, a* and b* backfat color of pigs fed barley-based diet compared to those fed corn-based diets. Feeding diets based on corn as opposed to barley to finishing pigs has been associated with deposition of yellow fat due to the higher concentration of carotenoids in corn. However, similar to other studies, the results of the current study show that the presence of carotenoids in yellow corn grown in Manitoba does not have any negative effect on the carcass fat color in finishing pigs.

Of all the carcass parameters measured, only the LEA was significantly affected by gender. Gilts had higher ($P = 0.032$) LEA compared with barrows, which is consistent with the findings of Cromwell et al. (1993) and Hahn et al. (1995) showing that gilts utilize more dietary energy for protein deposition than lipid deposition compared with barrows. This observation is also consistent with the well established fact that gilts are generally leaner than barrows. There were no effects ($P > 0.10$) of treatment × gender interaction on any of the carcass quality parameters evaluated.

5.4.3 Fatty acid profiles of the backfat and belly fat

The effects of dietary treatment and gender on the profile of fatty acids in backfat are presented in Table 5.5. Pigs on the barley-based diet tended to have higher pentadecanoic acid (15:0) ($P = 0.0829$), palmitoleic acid (16:1) ($P = 0.0805$) and heptadecanoic acid (17:0) ($P = 0.0842$) compared with those fed the diet based on corn 39W54. Pigs on the barley-based diet had a higher ($P < 0.05$) concentration of heptadecenoic acid (17:1) ($P < 0.05$) in their backfat compared with those that received diets based on corn. The concentration of eicosenoic acid (20:1) in the backfat of pigs fed diets based on barley and corn 39M27 was higher ($P < 0.05$) compared with those fed corn 39W54. The backfat of pigs fed diet based on corn 39W54 had higher ($P < 0.05$) concentration of linoleic acid (18:2) and polyunsaturated acids (PUFA) compared with pigs fed diet based on barley. Linoleic acid (18:2) is the only PUFA that was significantly ($P = 0.0376$) affected by dietary treatment and it is probably the component responsible for the dietary differences observed in the concentration of PUFA in the backfat of the pigs. Other authors have reported a positive correlation between linoleic acid (18:2) and PUFA in pork fat (Averette Gatlin et al. 2002; Rentfrow et al. 2003). Despite the fact that the backfat from pigs fed diet based on corn 39W54 had a higher concentration of PUFA compared with those fed diet based on barley, the concentration of PUFA in the backfat of all pigs irrespective of dietary treatment were within the range (less than 23%) recommended for salami making (Warnants et al. 1998). The fatty acid profiles of backfat of pigs fed barley and corn diets in the current study are comparable to the values reported by Carr et al. (2005) for these feedstuffs. The differences in the fatty acid composition of barley and the two corn cultivars used in the current study did not

Table 5.5. Effect of diet and gender on backfat fatty acid profiles in finishing pigs[z]

Fatty acid	Barley	39M27	39W54	SEM[y]	*P* value	Barrow	Gilt	SEM[y]	*P* value
Capric (10:0)	0.08	0.08	0.09	0.01	0.4844	0.08	0.08	0.01	0.8024
Lauric (12:0)	0.08	0.09	0.09	0.01	0.2071	0.09	0.09	0.01	0.3773
Myristic (14:0)	1.51	1.56	1.49	0.06	0.6623	1.54	1.50	0.05	0.6219
Pentadecanoic (15:0)	0.05	0.04	0.04	0.01	0.0829	0.05	0.04	0.01	0.3343
Palmitic (16:0)	27.58	27.57	26.32	0.82	0.4653	27.54	26.77	0.64	0.4359
Palmitelaidoic (16:1t)	0.41	0.43	0.37	0.04	0.4333	0.38	0.43	0.03	0.2478
Palmitoleic 16:1	2.36	2.22	1.90	0.13	0.0805	2.23	2.10	0.08	0.4235
Heptadecanoic (17:0)	0.30	0.23	0.22	0.02	0.0842	0.25	0.26	0.01	0.7390
Heptadecenoic (17:1)	0.23*a*	0.16*b*	0.13*b*	0.02	0.0070	0.17	0.17	0.01	0.9512
Stearic (18:0)	16.00	15.69	15.74	0.75	0.9552	16.04	15.59	0.89	0.6160
Oleic (18:1)	34.07	33.69	33.85	1.02	0.9663	33.71	34.04	0.89	0.7849
Linoleic (18:2)	11.33*a*	14.48*ab*	15.60*b*	1.01	0.0376	13.02	14.59	0.83	0.2076
Linolenic (18:3)	0.25	0.30	0.28	0.02	0.2142	0.28	0.28	0.01	0.7087
Arachidic (20:0)	1.11	0.97	0.99	0.07	0.3960	1.07	0.98	0.04	0.2745
Eicosenoic (20:1)	0.84*a*	0.84*a*	0.64*b*	0.06	0.0473	0.81	0.74	0.06	0.3603
Eicosadienoic (20:2)	0.53	0.62	0.57	0.04	0.4373	0.56	0.59	0.05	0.5593
Eicosatrienoic (20:3)	0.08	0.07	0.08	0.01	0.7730	0.08	0.08	0.01	0.8728
Behenoic (22:0)	0.39	0.38	0.38	0.03	0.9227	0.36	0.40	0.03	0.3116
Docosapentaenoic (22:5)	0.10	0.09	0.09	0.01	0.6191	0.09	0.09	0.01	0.7917
SFA[x]	47.73	47.25	45.99	1.38	0.6633	47.54	46.44	1.49	0.5068
MUFA[w]	40.18	37.38	37.50	1.25	0.2741	38.62	38.04	1.40	0.7186
PUFA[v]	12.37*a*	15.62*ab*	16.74*b*	1.04	0.0385	14.09	15.73	0.89	0.1979
UFA[u]	52.55	53.00	54.24	1.39	0.6801	52.71	53.82	1.48	0.5040
SFA:UFA	0.93	0.90	0.85	0.05	0.5685	0.92	0.87	0.05	0.4163

[z]Values are least square means.

[y]Pooled standard error of the least square means.

[x]Total saturated fatty acids.

[w]Monounsaturated fatty acids.

[v]Polyunsaturated fatty acids.

[u]Total unsaturated fatty acids.

a,b Values within a row and diet bearing different letters differ ($P < 0.05$).

affect the deposition of total saturated fatty acids (SFA) and total unsaturated fatty acids (UFA) in the backfat of pigs. The concentration of SFA and UFA in the backfat was similar ($P > 0.05$) across dietary treatments. There were no effects ($P > 0.10$) of gender and treatment × gender interaction on backfat fatty acid profiles.

The effects of the dietary treatment and gender on the fatty acid profiles of belly fat are shown in Table 5.6. Pigs fed the barley-based diet had a higher ($P = 0.0519$) concentration of palmitic acid (16:0) and a lower ($P = 0.0048$) concentration of eicosatrienoic acid (20:3) in the belly fat compared with those fed diet based on corn 39W54. The concentration of heptadecanoic acid (17:0) and heptadecenoic acid (17:1) were higher ($P < 0.05$) in the pigs fed the barley-based diet compared with those fed either diets based on corn. Pigs fed the barley-based diet tended to have higher concentration of pentadecanoic acid (15:0) ($P = 0.079$), SFA ($P = 0.0788$) and SFA:UFA ratio ($P = 0.0879$) but lower concentration of oleic acid (18:1) ($P = 0.0721$) and linoleic acid (18:2) ($P = 0.0654$), PUFA ($P = 0.0623$) and UFA ($P = 0.0828$) in their belly fat compared with those fed diets based on corn 39W54. Although, the concentration of linoleic acid (18:2) ($P < 0.0654$) and PUFA ($P = 0.0623$) in the belly fat of pigs that received diet based on corn 39W54 tended to be higher compared with those that received barley-based diet, the values were still within the recommended range of less than 14% and 15%, respectively, required for quality bacon processing (NPPC 2000). This observation is in agreement with the belly flex results showing no differences in the belly firmness across dietary treatments. Furthermore, the concentration of linoleic acid in the backfat and belly fat among dietary treatments was within the accepted value of

Table 5.6. Effect of diet and gender on belly fat fatty acid profiles in finishing pigs[z]

Fatty acid	Barley	Cultivar 1	Cultivar 2	SEM[y]	*P* value	Barrow	Gilt	SEM[y]	*P* value
Capric (10:0)	0.10	0.11	0.10	0.01	0.6866	0.11*c*	0.09*d*	0.01	0.0227
Lauric (12:0)[x]	0.10	0.11	0.10	0.01	0.1743	0.11*c*	0.09*d*	0.01	0.0037
Myristic (14:0)	1.59	1.73	1.53	0.08	0.0281	1.74*c*	1.50*d*	0.07	0.1933
Pentadecanoic (15:0)	0.04	0.04	0.03	0.01	0.0790	0.05*c*	0.04*d*	0.01	0.0364
Palmitic (16:0)	29.74*a*	29.17*ab*	26.12*b*	0.95	0.0519	29.56	27.12	0.95	0.0683
Palmitelaidoic (16:1t)	0.37	0.31	0.30	0.03	0.2058	0.31	0.34	0.01	0.3327
Palmitoleic 16:1	2.15	2.05	1.81	0.21	0.5242	2.13	1.87	0.13	0.3339
Heptadecanoic (17:0)	0.28*a*	0.19*b*	0.20*b*	0.02	0.0091	0.23	0.22	0.01	0.7574
Heptadecenoic (17:1)	0.17*a*	0.11*b*	0.10*b*	0.01	0.0024	0.13	0.12	0.01	0.4332
Stearic (18:0)	19.48	18.05	16.41	1.13	0.1954	18.73	17.22	0.97	0.2936
Oleic (18:1)[x]	32.27	32.98	36.03	1.10	0.0721	31.29*c*	36.23*d*	1.69	0.0039
Linoleic (18:2)	10.08	11.63	13.45	0.90	0.0654	11.35	12.09	0.48	0.5149
Linolenic (18:3)	0.26	0.26	0.26	0.02	0.9475	0.23*c*	0.28*d*	0.01	0.0228
Arachidic (20:0)	0.93	0.79	0.90	0.06	0.2418	0.89	0.86	0.04	0.7209
Eicosenoic (20:1)	0.62	0.55	0.53	0.05	0.4201	0.57	0.56	0.02	0.9354
Eicosadienoic (20:2)	0.36	0.38	0.46	0.04	0.1871	0.38	0.42	0.02	0.4334
Eicosatrienoic (20:3)	0.05*a*	0.06*ab*	0.07*b*	0.01	0.0048	0.06	0.06	0.01	0.6936
Behenoic (22:0)	0.32	0.30	0.34	0.02	0.3521	0.32	0.32	0.02	0.8927
Docosapentaenoic (22:5)	0.09	0.08	0.08	0.01	0.6268	0.08	0.08	0.01	0.3783
SFA[w]	53.20	51.11	46.31	1.97	0.0788	52.37	48.05	1.93	0.1012
MUFA[v]	36.15	36.61	39.43	1.46	0.2624	35.66	39.13	1.72	0.0785
PUFA[u]	10.93	12.47	14.45	0.93	0.0623	12.20	13.04	0.52	0.4727
UFA[t]	47.09	49.08	53.88	1.93	0.0827	47.86	52.17	1.93	0.1022
SFA:UFA	1.18	1.05	0.87	0.09	0.0879	1.12	0.95	0.08	0.1273

[z]Values are least square means

[y]Pooled standard error of the least square means.

[x]Effect of treatment × gender interaction ($P < 0.05$).

[w]Saturated fatty acids.

[v]Monounsaturated fatty acids.

[u]Polyunsaturated fatty acids.

[t]Total unsaturated fatty acids.

a,b Values within a row and diet bearing different letters differ ($P < 0.05$).

c,d Values within a row and gender bearing different letters differ ($P < 0.05$).

less than 30%; above this value, oxidative rancidity becomes a serious problem (Houben and Krol 1980). From these results, the variability in fatty acid composition of the corn cultivars evaluated in this study (Table 5.2) had no negative effect on fat firmness as both cultivars supported deposition of fatty acids into the belly fat and backfat of pigs in the same way.

Contrary to the observed pattern of fatty acid deposition in the backfat of barrows and gilts, the belly fat of barrows had higher concentration of capric acid (10:0), lauric acid (12:0), myristic acid (14:0) and pentadecanoic acid (15:0) but lower concentration of oleic (18:1) and linolenic acid (18:3) compare with gilts ($P < 0.05$). The effect of gender tended to be significant for palmitic acid ($P = 0.0683$) and monounsaturated fatty acids (MUFA) ($P = 0.0785$). However, there were no differences ($P > 0.10$) in the belly fat concentration of SFA, PUFA, UFA and SFA: UFA ratio of barrows and gilts. Differences in the profile of fatty acids deposition in gilts and barrows have been reported by other authors. For example, Warnants et al. (1999) reported higher ($P < 0.01$) concentration of palmitic and SFA but lower ($P < 0.01$) concentration of eicosenoic acid (20:1), eicosadienoic acid (20:2) and eicosatetraenoic acid (20:4) in the backfat of barrows compared with gilts. Likewise, Piedrafita et al. (2001) reported that gilts had higher ($P < 0.01$) concentration of linoleic (18:2), linolenic acid (18:3) and UFA but a lower ($P < 0.01$) concentration of stearic (18:0) in the backfat compared with barrows. From the results of the current and previous studies, it is evident that gilts tend to deposit more UFA compared with barrows. Although in the current study, gender had no effect on the fatty acid profiles of the backfat as observed by previous authors, the differences were clearly shown in the fatty acid profiles of the belly fat.

There was a treatment × gender interaction ($P < 0.05$) on lauric acid (12:0) and oleic acid (18:1) contents of the belly fat. While there was no difference ($P > 0.05$) in the lauric acid concentration in the belly fat of gilts and barrows receiving barley and corn 39M27 diets, the barrows fed corn 39W54 had a higher ($P = 0.0175$) value compared with the gilts (0.12% vs 0.08%). Similarly, the gilts fed corn 39W54 had a higher ($P = 0.0347$) concentration of oleic acid in their belly fat compared with the barrows but the concentration was not different for the gilts and barrows on barley and corn 39M27 diets.

The difference between the concentration of linoleic acid (18:0), SFA, MUFA, PUFA and UFA in the backfat and belly fat within dietary treatments is shown in Table 5.7. There were no differences ($P > 0.05$) in the concentration of linoleic acid, SFA, MUFA, PUFA and UFA in the backfat and belly fat and this suggests that deposition of these fatty acids in the belly fat and backfat were similar.

5.5 CONCLUSIONS

The results suggest that the feeding value of Manitoba-grown corn cultivars in terms of pig performance and carcass characteristics was comparable to barley. Pigs fed corn-based diets had similar fat color and the concentration of total saturated and unsaturated fatty acids compared with those fed the barley-based diet. Variability in the fatty acid profiles of the corn cultivars evaluated in this study did not have any effect on the fatty acid profiles of the backfat and belly fat as the concentration of SFA, MUFA, PUFA and UFA deposited in the backfat and belly fat of pigs fed diets based on the two cultivars was not different. Within each diet, the deposition of saturated and unsaturated

Table 5.7 Comparison of the amount of different fatty acids in the backfat and belly fat of pigs fed diets based on barley and two corn cultivars[z]

	Barley		39M27		39W54		SEM[y]	
Fatty acid	Back	Belly	Back	Belly	Back	Belly	Back	Belly
Linoleic (18:2)	11.4	10.3	12.5	10.5	15.2	13.1	1.16	1.26
SFA[x]	47.7	53.2	47.3	51.1	46.0	46.3	1.46	2.03
MUFA[w]	40.2	36.2	37.4	36.6	37.5	39.4	1.31	1.69
PUFA[v]	12.4	10.9	15.6	12.5	16.7	14.5	0.96	0.83
UFA[u]	52.6	47.1	53.0	49.1	54.2	53.9	1.47	2.03

[z]Values are least square means

[y]Pooled standard error of the least square means.

[x]Saturated fatty acids

[w]Monounsaturated fatty acids

[v]Polyunsaturated fatty acids

[u]Total unsaturated fatty acids

fatty acids into belly fat and backfat was comparable and in all cases, the amounts were within desired levels for safe storage and processing requirements. Manitoba corn cultivars can be fed to swine without any negative effects on growth performance and carcass and fat characteristics.

6.0 GENERAL DISCUSSION

The recent increase in the acreage and tonnage of corn production in Manitoba has stimulated interest in its use in swine feed. However, because the chemical and nutrient composition of corn, like other feedstuffs, varies with location and cultivar (Singh et al. 2000; Schmidt et al. 2002; Yin et al. 2002), it is critical that the nutritional value of the locally available cultivars for swine is determined. Such information is valuable in designing effective feeding programs incorporating Manitoba-grown corn in swine diets. Furthermore, cumulative temperature measurements such as CHU are employed as a means of measuring growth and development of corn in areas with low temperatures such as Manitoba (MAFRI undated). In this system, both the field location and corn cultivars are rated on the basis of CHU accumulation and requirement, respectively, to determine the appropriate cultivar for a particular location. However until now, the impact of the CHU rating of corn cultivars on their nutritional profile has not been addressed.

The nutrient and chemical composition of a feedstuff reflect only its potential as a feedstuff for a certain class of livestock. To better describe the nutritive value of any ingredient, in vivo experiments using the livestock species to which the ingredient will be fed must be completed. Measurements of nutrient digestibility, animal performance and product quality are commonly used as indicators of the feeding value of feed ingredients. In this thesis, a series of experiments were conducted to characterize the nutritive value of Manitoba-grown corn cultivars for swine through the determination of chemical and nutrient composition, performance of growing-finishing pigs and carcass and fat characteristics of finishing pigs fed Manitoba-grown corn-based diets.

In Manuscript I, the impact of field location and CHU on the chemical and nutrient composition of Manitoba-grown corn cultivars was evaluated. The results from this experiment showed that nutrient and chemical composition of corn varies with location, which is in agreement with findings of previous studies. Corn cultivars from the high CHU rated area had a higher amount of DM, which implies that high CHU allows corn more time to mature and deposit more DM in the kernels. Indeed, as observed in the current study, Moss et al. (2001) reported that the DM content in the whole plant increased with increased grain maturity. It was expected that the CP content of the corn cultivars evaluated will follow the same pattern as the DM content, but instead the cultivars grown in the low CHU rated area contained higher amount of CP, ADF, ash, total and phytate phosphorus compared with those grown in the high CHU rated area. This observation could be explained by the fact that the protein content in the whole corn plant declines as the plant matures (Wiersma et al. 1993). Also, the observation by Liang et al. (1993) that N uptake and corn grain N content were reduced with an increase in CHU rating of field location irrespective of fertilizer rate and water input may help explain why the CP content of cultivars grown in the high CHU rated area was lower compared with those grown in the low CHU rated area. This observation might also be due to differences in the growing conditions, such as topography, soil texture and precipitation, in the two locations. In the present study, the soil texture of the low CHU rated area was loamy while that of the high CHU rated area was sandy. Sattell et al. (1999) reported that corn has the capacity to increase its N uptake, and hence high CP:DM ratio, under adequate soil N and moisture content, a condition that is more likely to exist in loamy soil texture than in sandy soil. It is also possible that high CHU rated area favors more starch deposition which will then decrease the concentration of other nutrient components.

The yield of corn cultivars from the low CHU rated area was higher compared with that of cultivars from the high CHU rated area (165 vs. 129 bu ac^{-1}). However, this result is contrary to the results of Dwyer et al. (1991) and Liang et al. (1993) who reported higher yield in an area with high CHU compared to an area with low CHU (9.5 vs 8.3 Mg ha^{-1}). The reason for the observed difference in response of yield to CHU rating of field location between the current study and that of Dwyer et al. (1991) and Liang et al. (1993) could be due to differences in growing conditions.

In general the nutrient and chemical composition of all the corn cultivars evaluated was similar to or higher than values reported in previous studies (Ortega et al. 1986; Sproule et al. 1988; Burgoon et al. 1992; Adeola and Bajjalieh 1997; Spencer et al. 2000; Veum et al. 2001; Moeser et al. 2002). As expected, the chemical and nutrient composition of corn varied with geographical location. The low CHU rated cultivars had higher nutrient content compared with the high CHU rated cultivars.

The feeding value of Manitoba-grown corn cultivars for swine was further evaluated in a study designed to determine the digestible energy, CP and AA contents in some selected Manitoba-grown corn cultivars (Manuscript II). This study utilized the two most widely grown cultivars, 39M27 and 39W54, from three locations in Manitoba, representing areas with low, moderate and high CHU. These cultivars were included in the cultivars that were evaluated in Manuscript I. Following the same trend observed in Manuscript I, the results show that digestible energy and CP and AA were variable with location. Also, digestible energy, protein and AA varied with cultivar, an observation that could be explained by the differences in genetic composition of corn cultivars. The variability due to cultivar in the digestible energy and nutrient content of corn observed in the present study is in agreement with the findings of Yin et al. (2002).

As stated previously, a complete assessment of the feeding value of a feedstuff should include evaluation of its effects on animal performance and carcass quality. Thus, in Manuscript III, the two corn cultivars that are most widely grown in Manitoba (i.e. 39M27 and 39W54, same as Manuscript II) were evaluated in this respect using barley as the control. The results show that pig performance as indicated by ADG, ADFI and G:F was not influenced by dietary treatment. On the basis of these results and those of others (Lampe et al. 2004; Carr et al. 2005), it can be concluded that pig feeds based on corn or barley should support similar performance as long as the diets are formulated to meet the pig's nutrient requirements. A major concern regarding the use of corn in finishing pig diet is that it could negatively affect carcass fat color and fatty acid composition because it contains a higher amount of carotenoid and unsaturated fatty acids compared with barley (NRC 1998). However, in agreement with the results of Carr et al. (2005), the results of the current study showed that the fat color and fatty acid profiles of pigs fed corn-based diets and those fed barley-based diets were comparable. Likewise, no effects of dietary treatment were observed on carcass quality measurements such as dressing percentage, LEA, loin depth, midline fat thickness, 10th rib fat depth, belly firmness and fat color. Although the chemical and nutrient composition (Manuscript I) and digestible energy and nutrient contents (Manuscript II) of the corn cultivars evaluated in Manuscript III vary, this was not reflected in pig performance and carcass characteristics. The present data therefore indicate that corn cultivars evaluated in this study supported the performance of growing-finishing pigs and carcass characteristics to the same extent despite variability in nutrient composition.

It can, therefore, be concluded that Manitoba-grown corn cultivars have an excellent nutritional profile. Corn heat units as well as field location affect chemical and nutrient composition of corn. The digestible energy, protein and AA contents of corn vary with field location and cultivar and this should be considered when formulating diets for swine. Manitoba-grown corn can be included in growing-finishing swine diets without impairing growth performance and carcass and fat qualities.

7.0 CONCLUSIONS

Based on the results obtained in this thesis, it can be concluded that:

1. Nutrient and chemical composition and agronomic parameters of corn vary with location.

2. Corn heat units rating affects nutrient composition and agronomic parameters of corn with low CHU rated cultivars having higher crude protein content and bushel weight compared with high CHU rated cultivars.

3. Digestible energy and nutrient contents of corn vary with cultivar and field location and this should be considered when formulating swine diets.

4. Corn-based diets support similar pig performance as does barley-based diets.

5. Feeding corn-based diets to pigs produce similar carcass characteristics as barley-based diets.

6. Corn-based diets produce similar fatty acid profiles in the belly fat and backfat of pigs as does the barley-based diet. The difference in the fatty acid profile of barley and corn does not produce a corresponding effect on total amount of saturated fatty acids and total amount of unsaturated fatty acids in the belly fat and backfat.

7. Feeding corn-based diets to finishing pigs produce similar fat color as barley-based diet.

8. Manitoba corn cultivars can be incorporated into swine diets without having any negative effect on growth performance, carcass characteristics and fat quality.

Future Research:

1. Studies should be conducted to determine the effects of growing conditions such as soil texture, soil moisture content, fertilizer type and quantity, row spacing and plant density on the nutritional quality of grain corn. This will help to understand the growing conditions that are critical to nutritional quality of grain corn.

2. Additional research should also be conducted to determine the effect of CHU accumulation on nutrient uptake, starch and nutrient deposition in corn kernel and its net effect on nutritional quality of grain corn.

3. Studies should be conducted to determine effects of CHU rating of corn and CHU accumulation on nutrient digestibility.

4. Nutritional benefits of low phytate phosphorus to total phosphorus ratio in Manitoba-grown corn in terms of phosphorus digestibility and phosphorus excretion should be investigated.

5. Future research should evaluate the concentration of carotenoids in Manitoba-grown corn cultivars and the effects of CHU rating of corn, CHU accumulation at field location and cultivar on caroteinoids concentration in corn. This will help to clarify the contradictory effects of feeding corn to pigs on pork fat color in previous studies.

8.0 REFERENCES

Adeola, O. 2001. Digestion and balance techniques in pigs. Pages 903-916 *in* A. J. Lewis and L. L. Southern, eds. Swine Nutrition, 2nd ed. CRC Press Boca Raton, Florida, USA.

Adeola, O. and Bajjalieh, N. L. 1997. Energy concentration of high oil corn varieties for pigs. J. Anim. Sci. **75**: 430-436.

Agricultural Research Council. 1981. The nutrient requirements of pigs. Agricultural Research Commonwealth Agric. Bereaux, Slough, UK.

Ajakaiye, A., Fan, M. Z., Archbold, T., Hacker, R. R., Forsberg, C. W. and Phillips, J. P. 2003. Determination of true digestive utilization of phosphorus and the endogenous phosphorus outputs associated with soybean meal for growing pigs. J. Anim. Sci. **81**: 2766-2775.

Association of Official Analytical Chemists. 1990. Official Methods of Analysis. 15th ed. AOAC, Washington, DC.

Averette Gatlin, L., See, M. T., Hansen, J. A., Sutton, D. and Odle, J. 2002. The effects of dietary fat sources, levels, and feeding intervals on pork fatty acid composition. J. Anim. Sci. **80**: 1606-1615.

Averette Gatlin, L., See, M. T., Hansen, J. A. and Odle, J. 2003. Hydrogenated dietary fat improves pork quality of pigs from two lean genotypes. J. Anim. Sci. **81**: 1989-1997.

Begna, S. H., Hamilton, R. I., Dwyer, L. M., Stewart, D. W. and Smith, D. L. 1999. Effects of population density on the vegetative growth of leafy reduced-stature maize in short-season areas. J. Agron. Crop Sci. **182**: 49-55.

Berg, E. P. 2001. Swine nutrition, the conversion of muscle to meat, and pork quality. Pages 631-658 *in* A. J. Lewis and L. L. Southern, eds. Swine Nutrition, 2nd ed. CRC Press Boca Raton, Florida, USA.

Bikker, P., Verstegen, M. W. A., Campbell, R. G., and Kemp, B. 1994. Digestible lysine requirement of gilts with high genetic potential for lean gain, in relation to the level of energy intake. J. Anim. Sci. **72**: 1744-1753.

Burgoon, K. G., Hansen, J. A., Knabe, D. A. and Bockholt, A. J. 1992. Nutritional value of quality protein maize for starter and finisher swine. J. Anim. Sci. **70**: 811-817.

Burson, D. 2001. Procedures for estimating pork carcass composition. National Pork Producers Council Fact Sheet 04341, Desmoine, IA.

Butts, C. A., Moughan, P. J., Smith, W. C., Reynolds, G. W. and Garrick, D. J. 1993. The effect of food dry matter intake on endogenous ileal amino acid excretion determined under peptide alimentation in the 50 kg liveweight pig. J. Sci. Food Agric. **62**: 235-243.

Camp, L. K., Southern, L. L. and Bidner, T. D. 2003. Effect of carbohydrate source on growth performance, carcass traits, and meat quality of growing-finishing pigs. J. Anim. Sci. **81**: 2488-2495.

Campbell, H., Choo, T. M., Vigier, B. and Underhill, L. 2002. Comparison of mycotoxin profiles among cereal samples from eastern Canada. Can. J. Bot. **80**: 526-532.

Canadian Council on Animal Care. 1993. Guide to care and use of experimental animals. Vol. 1, 2nd ed. CCAC Ottawa, ON.

Carr, S. N., Rincker, P. J., Killefer, J., Baker, D. H., Ellis, M. and McKeith, F. K. 2005. Effects of different cereal grains and ractopamine hydrochloride on performance, carcass characteristics, and fat quality in late-finishing pigs. J. Anim. Sci. **83**: 223-230.

Carreker, J. R., Adames, W. E. and Morris, H. D. 1972. Corn yields in relation to rainfall and cropping treatments. J. Soil Water Conserv. **27**: 117-120.

Carroll, A. L., Eggert, J. M. Schinckel, A. P. and Richert, B. T. 1999. Effects of high oil corn and duration of conjugated linoleic acid (CLA) supplementation on pig growth, pork quality and carcass composition. Proc. Purdue University Swine day, West Lafayette, Indiana, USA.

Carter, C. E., Halverson, B., Rogers, J. S. and Musgrave, M. 1990. Effect of excess soil water on sweet corn yield. Trans-A-S-A-E. **33**: 1203-1207.

Cherney, D. J. R. and Cox, W. J. 1992. Corn forage fiber composition and in vitro digestibility as influenced by nitrogen fertilization. Proc. American Forage and grassland Council.

Clowes, E. J. and Zijlstra, R. T. 2003. September. Dealing with low quality wheat and barley. What's new. [online] Available: http://prairieswine.usask.ca/whatsnew/September2003/LowQualityGrains.htm [20 Sept. 2004]

Commission Internationale d'Eclairage. 1976. Supplement 2 to CIE Publication No. 15 (E-1.3.1) 1978, 1971/(TC-1-3). Recommendations on uniform color spaces-color difference equations, psychometric color terms. Commission Internationale de l'Eclairage, Paris, France.

Crampton, E. W. and Harris, L. E. 1969. Applied Animal Nutrition. 2nd ed. W.H. Freeman and Company, USA.

Cromwell, G. L., Cline, T. R., Crenshaw, T. D., Ewan, R. C., Hamilton, C. R., Lewis, A. J., Mahan, D. C., Miller, E. R., Pettigrew, J. E. Tribble, L. F. and Veum, T. L.

1993. The dietary protein and (or) lysine requirement of barrows and gilts. J. Anim. Sci. **71**: 1510-1519.

D'Alfonso, T. H. 2002. Global corn quality variability. [Online] Available: www.ontariocorn.org/ocpmag/as1000rr.html [15th Oct. 2004]

Darragh, A. J., and Hodgkinson, S. M. 2000. Quantifying the digestibility of dietary protein. J. Nutr. **130**: 1850S-1856S.

Dial, G. D., Rademacher, C., Freking, B. and Weaver, M. 2001. Diagonising problems in the grow-finish phase of production. [online] Available: http://www.gov.mb.ca/agriculture/livestock/pork/bab01s02.html [13 Feb. 2005]

Dijak, M., Modarres, A. M., Hamilton, R. I., Dwyer, L. M., Stewart, D. W., Mather, D. E. and Smith, D. L. 1999. Leafy reduced-stature maize hybrids for short-season environments. Crop Sci. **39**: 1106-1110.

Drury, C. F. and Tan C. S. 1995. Long-term (35 years) effects of fertilization, rotation and weather on corn yields. Can. J. Plant. Sci. **75**: 355-362.

Durst, P. T. and Beegle D. B. 1999. Nitrogen fertilization of corn. Agron. Fact **12**:1-6

Duvick, D. N. 1992. Genetic contributions to advances in yield of U.S. maize. Maydica **37**: 69-79.

Duvick, D. N. 1997. What is yield? Pages 19-29 in G. O. Edmeades, B. Bänziger, H. R. Mickelson and C. B. Pena-Valdivia eds. Developing drought and low N-tolerant maize. CIMMYT, El Batan, Mexico.

Dwyer, L. M., Hamilton, R. I., Hayhoe, H. N. and Royds, W. 1991. Analysis of biological traits contributing to grain yield of short- to mid-season corn (*Zea mays* L.) hybrids. Can. J. Plant Sci. **71**: 535-541.

Economic Commission for Europe. 1997. UN/ECE standard for porcine carcasses and cuts. Available [Online] http://www.unece.org/trade/agr/standard/meat/porcine/porcine.e/porky2.pdf [15 Sept. 2004].

Ellis, M. and McKeith, F. K. 1999. Nutritional influences on pork quality. National Pork Producers Council Fact Sheet 04422, Des Moines, IA.

Emerick, R. J., Carlson, C. W. and Winterfeld, H. L. 1961. Effect of heat drying upon the nutritive value of corn. Poult. Sci. **40:** 991-995.

Fan. M. Z. and Sauer, W. C. 1995. Determination of apparent ileal amino acid digestibility in barley and canola meal for pigs with direct, difference and regression methods. J. Anim. Sci. **73**: 2364-2374.

Fan, M. Z., Sauer, W. C. and Li, S. 1993. The additivity of the apparent ileal digestible amino acid supply in barley, wheat and canola meal or soybean meal diet for growing pigs. J. Anim. Physiol. Anim. Nutr. **70**: 72-81

Fan, M. Z., Archbold, T., Sauer, W. C., Lackeyram, D., Rideout, T., Gao, Y., de Lange, C. F. M. and Hacker, R. R. 2001. Novel methodology allows simultaneous measurement of true phosphorus digestibility and the gastrointestinal endogenous phosphorus outputs in studies with pigs. J. Nutr. **131**: 2388–2396.

Farnham, D. E. 2001. Row spacing. plant density, and hybrid effects on corn grain yield and moisture. Agron. J. **93**: 1049-1053.

Folch, J., Lees, M. and Stanley, G. H. 1957. A simple method for the isolation and purification of total lipids from animal tissues. J. Biol. Chem. **226**: 497-509.

Frank, J. W., Richert, B. T., Schinckel, A. P., Belstra, B. A., Amass, S. F. and DeCamp, S. A. 1998. Effects of environment, genotype, and health management system on pig growth performance and carcass characteristics. Proc. Purdue University swine day, West Lafayette, Indiana, USA.

Fulton, J. M. 1970. Relationships among soil moisture stress, plant populations, row spacing, and yield of corn. Can. J. Plant Sci. **50**: 31-38.

Furuya, S. and Kaji, Y. 1991. Additivity of the apparent and true ileal amino acids supply in barley, maize, wheat or soybean meal based diets for growing pigs. Anim. Feed Sci. Technol. **32**: 321-331.

Gabert, V. M., Jørgensen, H. and Nyachoti, C. M. 2001. Bioavailability of amino acids in feedstuffs for swine. Pages 151-186 *in* A. J. Lewis and L. L. Southern, eds. Swine Nutrition, 2nd ed. CRC Press Boca Raton, Florida, USA.

Garlipp, G. W. E. A. 1976. The influence of rainfall on maize grain yield. Agroplantea **8**: 21-22.

Granfeldt, Y. E., Drews, A. W. and Björck, I. M. E. 1993. Starch bioavailability in arepas made from ordinary or high amylose corn: Concentration and gastrointestinal fate of resistant starch in rats. J. Nutr. **123**: 1676–1684.

Hahn, J. D., Biehl, R. R. and Baker, D. H. 1995. Ideal digestible lysine level for early- and late-finishing swine. J. Anim. Sci. **73**: 482-489.

Haug W. and H. J. Lantzsch. 1983. Sensitive method for the rapid determination of phytate in cereals and cereal products. J. Sci. Food Agric. **34**: 1423-1426.

Herman, R. A., Philips, A. M., Collins, R. A., Tagliani, L. A., Claussen, F. A., Graham, C. D., Bickers, B. L., Harris, T. A. and Prochaska, L. M. 2004.

Compositional equivalency of Cry1F corn event TC6275 and conventional corn (*Zea mays* L.). J. Agric. Food Chem. **52**: 2726-2734.

Hess, V. and Sève, B. 1999. Effects of body weight and feed intake level on basal ileal endogenous losses in growing pigs. J. Anim. Sci. **77**: 3281-3288.

Holck, J. T., Schinckel, A. P., Coleman, J. L., Wilt, V. M., Senn, M. K., Thacker, B. J. and Grant, A. L. 1998. An evaluation of growth performance in swine raised in commercial and unrestricted environments. Proc. Purdue University swine day, West Lafayette, Indiana, USA.

Houben, J. H. and Krol, B. 1980. Acceptability and storage stability of pork products with increased levels of polyunsaturated fatty acids. Meat Sci. **5**: 57-70.

House, J. D., Abramson, D., Crow, G. H. and Nyachoti, C. M. 2002. Feed intake, growth and carcass parameters of swine consuming diets containing low levels of deoxynivalenol from naturally contaminated barley. Can. J. Anim. Sci. **82**: 559-565.

Hyun, Y., Bressner, G. E., Ellis, M., Lewis, A. J., Fischer, R., Stanisiewski, E. P. and Hartnell, G. F. 2004. Performance of growing-finishing pigs fed diets containing Roundup Ready corn (event nk603), a nontransgenic genetically similar corn, or conventional corn line. J. Anim. Sci. **82**: 571-580.

Jensen, A. M., Terrill, S. W. and Becker, D. E. 1960. Nutritive value of corn dried at 140°, 180°, and 220° Fahrenheit for swine of different ages. J. Anim. Sci. **19:** 629-638.

Johnson, L. A., Baumel, C. P., Hardy, C. L. and White, P. J. 1999. Identifying valuable corn quality traits for starch production. Iowa State University university extension. [Online] Available: http://www.extension.iastate.edu/Publications/EDC194.pdf [13th November 2004].

Johnston L. J. and Anderson, P. T. 1996. Use of waxy corn as feed for livestock. J. Anim. Sci. 74(Suppl. 1): 33 (Abstr.).

Just A., Jørgensen, H. and Fernández, X. 1981. The digestive capacity of ceacum-colon and the value of nitrogen absorbed from the hind gut for protein synthesis in pigs. Br. J. Nutr. **46**: 209-219.

Karlsson, A. H., Klont, R. E. and Fernández, X. 1999. Skeletal muscle fibres as factors for pork quality. Lives. Prod. Sci. **60**: 255-269.

Knowlton, K. F., Radcliffe, J. S., Novak, C. L., and Emmerson, D. A. 2004. Animal management to reduce phosphorus losses to the environment. J. Anim. Sci. **82**: E173-E195.

Kornegay, E. T. 1996. Nutritional, environmental, and economic considerations for using phytase in pig and poultry diets. Pages 277-302 *in* E. T. Kornegay, ed. Nutrient Management of Food Animals to Enhance and Protect Environment. CRC Press, Boca Raton, Florida.

Kuo, S., B. Huang and R. Bembenek. 2001. Effect of winter cover crops on soil nitrogen availability, corn yield, and nitrate leaching. Scientific World Journal. **1**: 22-29.

Lampe, J. F., Mabry, J. W., Baas, T. and Holden, P. 2004. Comparison of grain sources (barley, white corn, and yellow corn) for swine diets and their effects on meat quality and production traits. Iowa State University Animal Industry Report, ASL-R1954.

Li, S., and Sauer, W. C. 1994. The effect of dietary fat content on amino acid digestibility in young pigs. J. Anim. Sci. **72**: 1737-1743.

Liang, B. C., MacKenzie, A. F., Kirby, P. C. and Polius, J. 1993. Nutrient uptake of corn in relation to water inputs, corn heat units, fertilizer, and plant populations. J. Plant Nutr. 16: 601-617.

Liang, B. C., MacKenzie, A. F., Kirby, P. C. and Remillard, M. 1991. Corn production in relation to water inputs and heat units. Agron. J. **83**: 794-799.

Lilburn, M. S. and Dale N. 1989. Research note: Characterization of two samples of corn that vary in bushel weight. Poult. Sci. **68**: 857-860.

Lin, F. D., Knabe, D. A. and Tanksley Jr, T. D. 1987. Apparent digestibility of amino acids, gross energy and starch in corn, sorghum, wheat, barley, oat groats and wheat middlings for growing pigs. J. Anim. Sci. **64**: 1655-1663.

Loyns, R. M. A. 2002. Manitoba Corn Growers Association vs U.S. Corn Exports (An application of regional market rules under Canadian Trade Remedy Law). Pages 2-24 *in* R. M. A. Lyons, K. Meilke, R. D. Knutson and A. Yunez-Naude, eds. Proc. Eighth Policy Disputes Information Workshop, Puerto Vallarta, Jalisco, Mexico. [online] Available: http://www.farmfoundation.org/policysystems.htm [15 May 2004].

Lutz, J. A. Jr., Camper, H. M. and Jones, G. D. 1971. Row spacing and population effects on corn yields. Agron. J. **63**: 12-14.

Mahmoudjafari, M.,Kluitenberg, G. J., Havlin, J. L., Sison, J. B. Schwab, A. P. 1997. Spatial variability of nitrogen mineralization at the field scale. Soil Sci. Soc. Am. J. **61**:1214-1221.

Major, D. J., Gage, S. H., Shaykewich, C. F. and Pelton, W. L. 1978. Variability and trends of corn heat units on the Canadian prairies. Int. J. Biomet. **22**: 235-241.

Manitoba Agriculture, Food and Rural Initiatives. 2003. December. Manitoba grain and oilseeds industry profiles by sector. [Online]. Available: http://www.gov.mb.ca/agriculture/statistics/pdf/aac04s05.pdf [2 January 2004].

Manitoba Agriculture Food and Rural Initiatives. Undated. Corn Production in Manitoba. [online]. Available: http://www.gov.mb.ca/agriculture/crops/specialcrops/bii01s00.html [2 January 2004].

Mavromichalis, I. and Baker, D. H. 2000. Effects of pelleting and storage of a complex nursery pig diets on lysine bioavailability. J. Anim. Sci. **78**: 341-347.

Milner, C. K. and Woodforde, J. 1965. The effect of heat in drying on the nutritive value of wheat for animal feed. J. Sci. Food Agric. **16**: 369-373.

Miner, J. R. 1999. Alternatives to minimize environmental impact of large swine production units. J. Anim. Sci. **77**: 440-444.

Modarres, A. M., Dijak, M., Hamilton, R. I., Dwyer, L. M., Stewart, D. W., Mather, D. E. and Smith, D. L. 1998. Leafy reduced-stature maize hybrid response to plant population density and planting patterns in a short growing season area. Maydica. **43**: 227-234.

Moeser, A. J., Kim, I. B., Van Heugten, E. and Kempen T. A. T. G. 2002. The nutritional value of degermed, dehulled corn for pigs and its impact on the gastrointestinal tract and nutrient excretion. J. Anim. Sci. **80**: 2629-2638.

Moss, B. R., Reeves, D. W., Lin, J. C., Torbert, H. A., McElhenney, W. H., Mask, P. and Kezar, W. 2001. Yield and quality of three corn hybrids as affected by broiler litter fertilization and crop maturity. Anim. Feed Sci. Tech. **94**: 43-56.

Moter, V. and Stein, H. H. 2004. Effect of feed intake on endogenous losses and amino acid and energy digestibility by growing pigs. J. Anim. Sci. **82**: 3518-3525.

National Pork Producers Council. 1998. Pork quality targets. National Pork Producers Council Fact Sheet 04366, Des Moines, IA.

National Pork Producers Council. 2000. Pork composition and quality assessment procedures. National Pork Producers Council, Des Moines, IA.

National Research Council. 1998. Nutrient Requirements of Swine.10th rev. ed. National Academy Press, Washington, DC.

Noblet, J. and J. M. Perez. 1993. Prediction of digestibility of nutrients and energy values of pig diets from chemical analysis. J. Anim. Sci. **71**: 3389-3398.

Norwood, C. A. 2001. Planting date, hybrid maturity, and plant population effects on soil water depletion, water use, and yield of dryland corn. Agron. J. **93**: 1034-1042.

Nyachoti, C. M., de Lange, C. F. M. and Schulze, H. 1997. Estimating endogenous amino acid flows at the terminal ileum and true amino acid digestibilities in feedstuffs for growing pigs using the homoarginine method. J. Anim. Sci. **75**: 3206-3213.

Nyachoti, C. M., McNeilage-Van de Wiele, E. M., de Lange, C. F. M. and Gabert, V. M. 2002. Evaluation of the homoarginine technique for measuring true ileal amino acid digestibilities in pigs fed a barley-canola meal-based diet. J. Anim. Sci. **80**: 440-448.

Ohh, S. J., Allee, G. L., Behnke, K. C., and Deyoe, C. W. 1983. Effect of particle size of corn and sorghum grain on performance and digestibility of nutrients for weaned pigs. J. Anim. Sci. **57**(Suppl. 1): 260 (Abstr.).

Omogbenigun, O. F., Nyachoti , C. M. and Slominski, B. A. 2003. The effect of supplementing microbial phytase and organic acids to a corn-soybean based diet fed to early-weaned pigs. J. Anim. Sci. **81**: 1806-1813.

O'Quinn, P. R., Nelssen, J. L., Goodband, R. D., Knabe, D. A., Woodworth, J. C., Tokach, M. D. and Lohrmann, T. T. 2000. Nutritional value of a genetically improved high-lysine, high-oil corn for young pigs. J. Anim. Sci. **78**: 2144-2149.

Ortega, E. I., Villegas, E. and Vasal, S. K. 1986. Comparative study of protein changes in normal and quality protein maize during tortilla making. Cereal Chem. **63**: 446-451.

Piedrafita, J. Christian, L. L. and Lonergan, S. M. 2001. Fatty acid profiles in three stress genotypes and relationships with swine, carcass and meat quality traits. Meat Sci. **57**: 71-77.

Plett, S. 1992. Comparison of seasonal thermal indices for measurement of corn maturity in a prairie environment. Canadian J. Plt. Sci. **72**: 1157-1162.

Pomeranz, Y. and Bechtel, D. B. 1978. Structure of cereal grain as related to end-use property. Proc. International cereal and bread congress. American Association of Cereal Chemists, Inc. USA.

Porter, P. M., Hicks, D. R., Lueschen, W. E., Ford, J. H., Warnes, D. D. and Hoverstad, T. R. 1997. Corn response to row width and plant population in the northern Corn Belt. J. Prod. Agric. **10**: 293-300.

Powers, W. 2004. Practices to reduce odor from livestock production. Iowa State University Extension Publication. Available [Online] http://www.extension.iastate.edu/Publications/PM1970A.pdf [13 March 2004]

Prache, S., Priolo, A. and Grolier, P. 2003. Persistence of carotenoid pigments in the blood of concentrate-finished grazing sheep: Its significance for the traceability of grass-feeding. J. Anim. Sci. **81**: 360-367.

Prasanna, B. M., Vasal, S. K., Kassahun, B. and Singh, N. N. 2001. Quality protein maize. Current Sci. **81**: 1308-1319.

Priolo, A., Prache, S. Micol, D. and Agabriel, J. 2002. Reflectance spectrum of adipose tissue to trace grass-feeding in sheep: Influence of measurement site and shrinkage time after slaughter. J. Anim. Sci. **80**: 886–891.

Qi, G., Diao, Q., Tu Y., Wu, S. and Zhang, S. Undated. Nutritional evaluation and utilization of quality protein maize (QPM) in animal feed. Available http://www.fao.org/ag/aga/workshop/feed/papers/14guang.doc [6 April 2004]

Rademacher, M., Sauer, W. C. and Jansman, A. J. M. 2000. Standardized ileal digestibility of amino acids in pigs. Degusa-Hülls AG publication, Frankfurt, Germany.

Rademacher, M. 2001. Dietary modifications may minimize nitrogen excretion. Feedstuffs. **73** (17): 11-13.

Reece, F. N., Lott, B. D., and Deaton, J. W. 1985. The effects of feed form, grinding method, energy level, and gender on broiler performance in a moderate (21°C) environment. Poult. Sci. **64**: 1834-1839.

Rentfrow, G., Sauber, T. E. Allee, G. L. and Berg, E. P. 2003. The influence of diets containing either conventional corn, conventional corn with choice white grease, high oil corn, or high oil high oleic corn on belly/bacon quality. Meat Science. **64**: 459-466.

Ridley, W. P., Sidhu, R. S., Pyla, P. D., Nemeth, M. A., Breeze, M. L. and Astwood, J. D. 2002. Comparison of the nutritional profile of glyphosate-tolerant corn event

NK603 with that of conventional corn (*Zea mays* L.). J. Agric. Food Chem. **50**: 7235-7243.

Robertson, J. B. and Van Soest, P. J. 1977. Dietary fiber estimation in concentrate feedstuffs. J. Anim. Sci. **45** (suppl. 1): 254.

Robertson, W. M., Jaikaran, S. Jeremiah, L. E., Salmon, D. F., Aherne, F. X. and Landary, S. J. 1999. Meat quality and palatability attributes of pork from pigs fed corn, hulless barley or triticale based diets. Proc. Advances in Pork Production.[Online] Available: http://www.banffpork.ca/proc/1999pdf/Meats.pdf [18 Aug. 2005].

Rooney, L. W. and Pflugfelder, R. L. 1986. Factors affecting starch digestibility with special emphasis on sorghum and corn. J. Anim. Sci. **63**: 1607–1623.

Roozeboom, K. L. and Herrman, T. J. 2001. Grain quality components of corn hybrids. Kansas State University Agric. Expt. Statn. and Coop. Extn. Service. Manhattan, Kansas. Keeping up with research, SRL 130.

Sattell, R., Buford, T., Murray, H., Dick, R. and McGrath, D. 1999. Cover crop dry matter and nitrogen accumulation in western Oregon. Available [Online] http://eesc.orst.edu/agcomwebfile/edmat/em8739.pdf [19 July 2004]

Sauer, W. C., Jørgensen, H. and Berzins, R. 1983. A modified nylon bag technique for determining apparent digestibilities of protein in feedstuffs for pigs. Can. J. Anim. Sci. **63**: 233-237.

Sauer, W. C. and Ozimek, L. 1986. Digestibility of amino acids in swine: results and their practical application: a review. Livest. Prod. Sci. **15**: 367-388.

Schmidt, J. P., A. J. DeJoia, R. B. Ferguson, R. K. Taylor, R. K. Young and J. L. Havlin. 2002. Corn yield response to nitrogen and multiple in-field locations. Agron. J. 94: 798-806.

Schneider, J. D., Carter, S. D., Park, J. S. and Morillo, T. B. 2004. Determination of metabolizable energy concentration of corn samples for growing pigs. J. Anim. Sci. **82** (suppl. 2): 79.

Scott, P. M. 1997. Multi-year monitoring of Canadian grains and grain-based foods for trichothecenes and zearalenone. Food Addit. Contam. **14**: 333-339.

Shackelford, S. D., Miller, M. F., Haydon, K. D., Lovegren, N. V., Lyon, C. E. and Reagan, J. O. 1990. Acceptability of bacon as influenced by the feeding of elevated levels of monounsaturated fats to growing-finishing swine. J. Food Sci. **55**: 621-624.

Shelton, J. L., Payne, R. L., Johnston, S. L., Bidner, T. D., Southern, L. L., Odgaard, R. L. and Page, T. G. 2003. Effect of chromium propionate on growth, carcass traits, pork quality, and plasma metabolites in growing-finishing pigs. J. Anim. Sci. **81**: 2515-2524.

Singh, V., R. A. Moreau, A. E. Haken, S. R. Eckhoff and K. B. Hicks. 2000. Hybrid variability and effect of growth location on corn fiber yields and corn fiber oil composition. Cereal Chem. **77**: 692-695.

Skoch, E. R., Binder, S. F., Deyoe, C. W., Allee, G. L., and Behnke, K. C. 1983. Effects of pelleting conditions on performance of pigs fed a corn-soybean meal diet. J. Anim. Sci. **57**: 922-928.

Snow, J. L., Stein, H. H., Ku, P. K. and Trottier, N. L. 2004. Amino acid digestibility and nitrogen utilization of high oil, high lysine, and waxy maize fed to growing pigs. Anim. Feed Sci. Technol. **113**: 113-126.

Spencer, J. D., Allee, G. L. and Sauber, T. E. 2000. Phosphorus bioavailability of the normal and genetically modified low-phytate corn for pigs. J. Anim. Sci. **78**:675-681.

Sproule, A. M., Saldivar, S. O., Bockholt, A. J. and Gregg, E. J. 1988. Nutritional evaluation of tortillas and tortilla chips from quality protein maize. Cereal Foods World. **33**: 233-236.

Srinivasan, V. S. 2001. Bioavailability of Nutrients: A Practical Approach to In Vitro Demonstration of the Availability of Nutrients in Multivitamin-Mineral Combination Products. J. Nutr. **131**: 1349S-1350S.

Stein, H. H., Aref, S. and Easter, R. A. 1999. Comparative protein and amino acid digetsibilities in growing pigs and sows. J. Anim. Sci. **77**: 1169-1179.

St. John, L. C., Grundy, S. M. and Smith, S. B. 1987. Fatty acid profiles and sensory and carcass traits of tissues from steers and swine fed an elevated monounsaturated fat diet. J. Anim. Sci. **64**:1441-1447.

Sunde, M. L., Din, M. G. and Holm G. P. 1976. Feeding value of low bushel weight corn and propionic acid treated corn for broiler chicks. Feedstuffs. **48 (15)**: 18-20.

Swantek, P. M., Zimprich, R. C., Marchello, M. J. and Harrold, R. L. 1996. Performance and carcass characteristics of grow-finish pigs fed waxy corn. J. Anim. Sci. **74**(Suppl. 1): 287 (Abstr.).

Tollenaar, M. and Lee, E. A. 2002. Yield potential, yield stability and stress tolerance in maize. Field Crop Res. **75**: 161-169.

Van Soest, P. J. and Wine, R. H. 1967. Use of detergent in the analysis of fibrous feeds IV. Determination of plant cell wall constituents. J. Assoc. Off. Anal. Chem. **50**: 50.

Veum, T. L., Ledous, T. R., Raboy, V. and Ertl D. S. 2001. Low-phytic acid corn improves nutrient utilization for growing pigs. J. Anim. Sci. **79**: 2873-2880.

Warnants, N. M., Van Oeckel, M. J. and Boucque, C. V. 1996. Incorporation of dietary polyunsaturated fatty acids in pork tissues and its implications for the quality of the end products. Meat Sci. **44**: 125-144.

Warnants, N. M., Van Oeckel, M. J. and Boucque, C. V. 1998. Effect of incorporation of dietary polyunsaturated fatty acids in pork backfat on the quality of salami. Meat Sci. **49**: 435-445.

Warnants, N. M., Van Oeckel, M. J. and Boucque, C. V. 1999. Incorporation of dietary polyunsaturated fatty acids into pork fatty tissues. J. Anim. Sci. **77**: 2478-2490.

Wiersma, D. W., Carter, P. R., Albrecht, K. A. and Coors, J. G. 1993. Kernel milkline stage and corn forage yield, quality, and dry matter content. J. Prod. Agric. **6**: 23-24.

Williams, C. H., David, D. J. and Lismoa, O. 1962. The determination of chromic oxide in fecal samples by atomic absorption spectrophotometry. J. Anim. Sci. **59**: 381-389.

Wondra, K. J., Hancock, J. D., Behnke, K. C., and Stark, C. R. 1995a. Effects of mill type and particle size uniformity on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. **73**: 2564-2573.

Wondra, K. J., Hancock, J. D., Behnke, K. C., Hines, R. H., and Stark, C. R. 1995b. Effects of particle size and pelleting on growth performance, nutrient digestibility, and stomach morphology in finishing pigs. J. Anim. Sci. **73**: 757-763.

Yin, Y. L., Gurung, N. K., Jeaurond, E. A., Sharpe, P. H., and de Lange, C. F. M. 2002. Digestible energy and amino acid contents in Canadian varieties of sorghum, pearl millet, high-oil corn, high-oil-high-protein corn and regular corn samples for growing pigs. Can. J. Anim. Sci. **82**: 385-391.

Zebrowska, T. 1973. Digestion and absorption of nitrogenous compounds in the large intestine in pigs. Rocz. Nauk Roln. Ser. B. Zootech. **95**: 85-90.

Zijlstra, R., Freeman, P. and Kuchenski, L. 2003. Fine tuning feed barley for hogs. Western Grains Research Magazine. Prairie Swine Center, Saskatoon, Saskatchewan, Canada.[online] Available: http://www.westerngrains.com/n_researchMag/rm_0311a.html [8 Aug. 2004].

ZiRong, X., LiChun, Q., YouLiang, X. and JianYi S. 2002. Effect of barley instead of corn in ration on carcass, meat quality and digestive organ in finishing swine. Chinese J. Vet. Sci. **22**: 522 [in Chinese, English abstract].

9.0 APPENDIX

Agronomic data of corn cultivars from two locations in Manitoba (St. Pierre and Reinland) evaluated in Manuscript I

		St. Pierre			Reinland		
Cultivar Name	CHU Rating	Yield bu ac^{-1}	Bushel weight lb bu^{-1}	Moisture %	Yield bu ac^{-1}	Bushel weight lb bu^{-1}	Moisture %
2791	2275	200	60.79	19.0	134	59.82	21.8
K083	2100	169	60.63	19.2	121	59.18	16.3
K080	2125	140	64.96	17.1	112	63.35	17.8
K108LL	2250	172	62.23	19.6	129	59.98	17.0
N02-K1	2100	149	61.59	19.6	105	59.82	18.0
N03-D8	2200	145	62.07	17.2	124	63.51	15.4
HL 2093	2225	142	60.30	14.4	134	60.14	13.9
HL 2017	2200	144	62.71	16.3	137	62.39	17.4
HLX 2023	2200	138	61.43	18.0	117	59.66	17.5
DKC26-75	2200	159	62.55	18.1	144	58.54	17.1
DKC27-12	2250	148	65.76	18.8	122	61.11	17.1
DKC27-15	2250	162	62.87	17.5	141	61.43	21.0
39R34	2225	175	63.67	16.9	127	63.35	15.9
39P78	2050	150	64.80	15.8	104	60.95	14.3
39W54	2100	162	63.67	15.9	118	60.14	14.5
39T71	2250	181	62.55	17.9	114	63.03	17.6
39T68	2250	181	63.03	16.4	118	61.43	18.1
39F45	2000	108	63.67	17.1	100	60.95	16.9
39M27	2150	169	63.51	16.6	125	60.30	15.3
X0772XT	2250	180	61.43	18.8	145	62.55	15.2
N06-J6	2300	151	62.55	18.3	111	61.43	19.8
MZ130	2300	168	62.23	15.5	137	60.63	15.4
MZ18-02RR	2350	164	66.08	17.7	131	59.98	18.1
HL 2222	2375	177	60.14	15.7	136	59.50	17.8
HL B260	2375	177	61.43	17.0	135	59.98	15.7
BIXX10	2300	171	61.27	18.9	121	60.47	17.3
DAXXAR	2300	174	62.23	20.6	125	61.27	17.7
LEXXIC	2450	189	59.50	19.9	137	58.22	21.6
X2475	2359	155	59.02	16.5	135	56.62	17.9
2338	2300	159	59.18	19.0	145	57.58	16.6
DKC29-95	2350	150	62.07	16.0	134	60.30	16.7
DKC33-08	2450	175	62.23	16.8	139	58.54	17.1
39H85	2500	192	59.02	17.9	130	58.86	15.1
39H84	2450	185	58.86	19.1	125	60.79	15.1
39G12	2300	195	60.30	20.7	161	61.27	17.2
39T70	2300	156	60.14	16.5	138	61.27	15.5