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

By

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A Thesis

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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.

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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.

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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.

Item	Year				
	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