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Effect of variety, growing region and growing season on digestible energy content of wheats grown in Western Australia for weaner pigs

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Abstract

An experiment was conducted to examine the digestible energy (DE) content for weanling pigs in a cohort of wheats grown in Western Australia, and to establish relationships between DE content and their chemical composition. The 3 × 3 × 2 factorial experiment examined the wheat variety (Arrino, Stiletto and Westonia), growing location (high, medium and low rainfall zone) and harvest year (1999 and 2000). Pigs (no. = 5 per diet) aged about 28 days were given a diet at a level of 0·05 × live weight containing 900 g/kg of the wheat and an acid-insoluble ash marker for 10 days, with samples of faeces collected from each pig for the final 5 days. The average live weight of pigs was 6·6 (s.d. 0·77) kg. The DE content of wheats harvested in 1999 varied by up to 1·3 MJ/kg, while wheats harvested in 2000 varied by up to 1·8 MJ/kg. When the 2 years' data were combined, the DE content ranged from 12·5 to 14·4 MJ/kg. Both the variety and growing region significantly influenced (P < 0·05, P < 0·001, *respectively in year 1999;* P < 0·001, P < 0·01, *respectively in year 2000) the DE content of wheat. Also, DE content of wheat differed significantly due to growing season* (P < 0·001)*. Correlation studies between chemical composition and DE content of the wheats found significant inverse relationships between DE content and total xylose* (r = –0·719, P < 0·05)*, insoluble xylose* (r = –0·742, P < 0·05)*, neutral-detergent fibre* (r = –0·839, P < 0·01)*, total-P* (r = –0·833, P < 0·01)*, and phytate-P* (r = –0·753, P < 0·05) *contents with the wheats harvested in 1999. However, such relationships were not significant* (P > 0·05) *with the wheats harvested in 2000. In addition, the precipitation level (mm) during the growing season of wheats was strongly correlated* (r = –0·821, P < 0·01) *to the DE content of wheat in year 1999, but was not correlated in 2000. The results indicate that the genetic and environmental conditions during the growth of wheat have a significant impact on the utilization of plant energy in weaner pigs, and that greater attention needs to be paid to these influences in the assignment of energy values for wheats given to weaner pigs.*

Keywords: *digestible energy, piglets, seasonal variation, varieties, wheat.*

Introduction

Cereals such as wheat are the primary source of energy in diets for young pigs in many countries. The amount of energy in wheat digested by pigs and made available for maintenance and growth is not constant due mainly to its variable chemical composition. The wide variation in energy digestibility has been reported previously in wheat-based diets in pigs (Anderson and Bell, 1983; Ziljstra *et al*., 1999). It is known to be affected by digestible carbohydrates, such as starch and soluble fibre, in chickens (Rogel *et al*., 1987), and often by the amount of non-digestible carbohydrate components such as insoluble non-starch polysaccharides (NSP). This is because these NSP can exhibit anti-nutritional properties when included in young pig diets (Choct and Cadogan, 2001).

It is recognized that the variety (Anderson and Bell, 1983), growing region (Dusel *et al*., 1997) and growing season (Anderson and Bell, 1983; Choct *et al.,* 1999) influence both the chemical composition and available energy content of wheat for growing pigs (Taverner and Farrell, 1981; Zijlstra *et al*., 1999). In contrast, very little information is available concerning the nutritive value of wheat for young (weanling) pigs, which could be expected to differ from growing pigs because of their immature digestive tract and underdeveloped microflora that could result in the extraction of less energy (Pluske *et al*., 2001). Furthermore, there is a lack of simultaneous information on the digestible energy (DE) content of wheat for young pigs as affected by variety, growing environment and season. Such information is necessary for accurate diet formulation and efficient utilization of nutrients.

The purposes of the current study were to : (1) quantify the variation in DE content of wheat according to its variety and growing region over two growing seasons, and (2) establish correlations between DE content and chemical composition of wheats grown in south-western Australia.

Material and methods

Experimental design

A 3 × 3 × 2 factorial experiment was conducted with the respective factors being wheat variety (Arrino : Australian standard white noodle wheat (ASWN); Stiletto, and Westonia : Australian Premium White wheats (APW)), growing regions in south-western Australia (wheat grown in (1) high rainfall area, more than 450 mm annual precipitation; (2) medium rainfall area, between 325 and 450 mm annual precipitation, and (3) low rainfall area, less than 325 mm annual precipitation), and two growing seasons (1999 and 2000). The chemical compositions and DE contents of the nine wheat samples harvested in year 1999 were assayed within 1 month after harvest. The same experimental protocol was followed with the wheat harvested in year 2000 to examine the seasonal variation of DE content. This experiment was approved by the Murdoch University Animal Ethics Committee and the Animal Ethics and Experimentation Committee of the Western Australia Department of Agriculture.

Feeding and sample collection

Forty-five male pigs (Large White × Landrace) in each year weaned at approximately 21 days of age were obtained one week after weaning from a commercial supplier (Wandalup Farms, Mandurah, WA). The average live weight of pigs was 6·4 (s.d. 0·72) kg for the feeding trial with wheats harvested in 1999, and 6·7 (s.d. 0·80) kg for the trial with wheats harvested in 2000. Pigs were transported from the supplier to the Medina Research Centre. Upon arrival, the pigs were kept in individual wire-mesh floored metabolism crates in a metabolism room where the temperature was maintained as constant as possible (27±1ºC). Water was freely accessible during the whole experiment through a nipple drinker set in each crate. The pigs were weighed and randomly allocated in the room to each treatment (no. = 5 per treatment, completely random) according to their live weight. From the time of arrival, the pigs were offered their respective experimental diet for a 5-day adaptation period where the amount of food was restricted to 0·05 of live weight (about 0·9 of *ad libitum*). The diets were offered twice daily at 08:00 and 16:00 h. The diet composition is presented in Table 1. After 5 days adaptation, the pigs were re-weighed and the feeding level adjusted to the appropriate amount. Pigs were given food accordingly for a further 5 days, in which faecal samples were collected at 08:00, 10:00, 12:00, 14:00, 16:00 h and then kept at –20ºC. The faecal samples were later thawed, mixed, freeze-dried and ground through a laboratory hammer mill (1-mm screen) prior to chemical analysis.

Chemical analyses and calculation of DE content

Physical parameters such as screenings (%) and bushel weight (hectolitre weight, kg/hl) were measured using a method described by Metayer *et al*. (1993). The dry matter (DM), nitrogen (N), gross energy (GE), total starch, amylose, amylopectin, fast digestible starch, *in vitro* extract viscosity, neutral-detergent fibere (NDF), acid-detergent fibre (ADF), lignin, total phosphorus (P), phytate-P, phytase activity and NSP content of each wheat were determined as described previously (Kim *et al*., 2003).

Table 1 *The composition of the experimental diet offered to weaner pigs* (*g/kg, air-dry basis*)

Ingredients	g/kg
Test wheat	900
Canola oil	43·7
Dibasic calcium phosphate	30·0
Salt	2·8
Vitamin and mineral mix†	2·5
Choline chloride	1·0
Celite (acid-insoluble ash marker)	20·0

† Hogro Bronze Weaner and Grower (Rhone-Poulenc Animal Nutrition Pty Ltd., Queensland, Australia), provided the following nutrients per kg of air-dry diet. Vitamins: retinol 450 µg, cholecalciferol 0·75 µg, alpha-tocopherol 37·5 mg, phytylmenaquinone 2·5 mg, thiamine 1·5 mg, riboflavin 6·25 mg, pyridoxine 3 mg, cyanocobalamin 37·5 µg, calcium pantothenate 25 mg, folic acid 0·5 mg, niacin 30 mg, biotin 75 µg. Minerals: Co 0·5 mg (as cobalt sulphate), Cu 25 mg (as copper sulphate), I 1·25 mg (as potassium iodide), Fe 150 mg (as ferrous sulphate), Mn 100 mg (as manganous oxide), Se 0·5 mg (as sodium selenite), Zn 0·25 mg (as zinc oxide).

The DM, GE, acid-insoluble ash content of diet and faecal samples were determined for estimation of DE content of wheat. The GE content of wheat, diet, and faecal samples were determined using a Ballistic Bomb Calorimeter (SANYO Gallenkamp, Loughborough, UK). The acid-insoluble ash (Celite®) contents of diet and faecal samples were determined using the method described by Choct and Annison (1992). The DE content of wheat was determined with reference to the marker by subtracting the estimated DE contents of canola oil (National Research Council, 1998) from the DE content of the diet. The annual precipitation level (mm) and precipitation level during the growing period were presented in Kim *et al*. (2002).

Statistics
For DE content of wheat the treatment effects were assessed by analysis of variance for a factorial arrangement with the main effects being variety, growing region and growing season. The effects were considered as fixed effects in the model. Fisher's Protected LSD comparisons were used (at 5% significance level) for comparison of DE value between mean values of different varieties and growing regions, and between different variety × region × season combinations. Pearson's correlation analysis and stepwise regression analysis were used to examine the causes of DE content variation. All statistical analyses were conducted using the statistical package Minitab (Minitab Inc., PA).

Results

Variation in DE content
The variation in DE content of wheats is presented in Table 2. The DE content of nine wheats harvested in 1999 ranged from 12·5 to 13·8 MJ/kg (0·094 proportional difference), while the DE content of the nine wheats harvested in the year 2000 ranged from 12·6 to 14·4 MJ/kg (0·125 proportional difference). Combining the data of the 18 wheats over the two seasons, the DE content varied by 1·9 MJ/kg (12·5 to 14·4 MJ/kg).

Effect of variety and growing region on DE content
The DE content of wheat harvested over two growing seasons is presented in Table 2. In 1999, the DE content was significantly influenced by variety ($P < 0{\cdot}05$) and growing region ($P < 0{\cdot}001$), but the interaction between variety and growing region was not statistically significant. Among wheat varieties, Westonia had the highest DE content and wheats contained more DE when grown in the medium or low rainfall regions compared with wheats grown in the high rainfall region. Similar to wheat harvested in 1999, the DE content of wheats harvested in 2000 was significantly influenced by variety ($P < 0{\cdot}001$) and growing region ($P < 0{\cdot}01$), however, the

Table 2 *Effect of variety, growing region and growing season on digestible energy (DE) content (MJ/kg) of wheat from Western Australia determined with 28-day-old male pigs*†

		Season (S)							Statistics	
		1999	2000	Mean	s.e.	Minimum	Maximum	CV	Source	Significance
Variety (V)	Arrino	13·3	13·4	13·3[a]	0·11	13·6	13·9	0·0385		
	Stiletto	13·2	13·5	13·3[ab]	0·12	12·5	14·0	0·0415	V	***
	Westonia	13·6	14·2	13·9[bc]	0·11	13·4	14·4	0·0263	GR	***
Growing region (GR)										
(rainfall zone)‡	High	12·9	13·6	13·2[a]	0·13	12·5	14·1	0·0472	S	***
	Medium	13·6	13·5	13·5[b]	0·12	12·6	14·2	0·0390	V×GR	***
	Low	13·7	14·1	13·9[c]	0·09	13·5	14·4	0·0227	V×S	
Mean		13·3[a]	13·7[b]	13·5	0·07	12·5	14·4	0·0381	GR×S	**
s.e.		0·09	0·10	0·07					V×GR×S	**
Minimum		12·5	12·6	12·5						
Maximum		13·8	14·4	14·4						
CV		0·0340	0·0439	0·0381						

[a,b,c] Mean values with different superscripts within row or column are significantly different ($P < 0{\cdot}05$).
† Values are DE content (LS mean, air-dry basis) determined from 15 pigs per variety and 15 pigs per growing region in each year.
‡ High rainfall area: > 450 mm annual precipitation; medium rainfall area: 325-450 mm annual precipitation, and low rainfall area: < 325 mm annual precipitation.

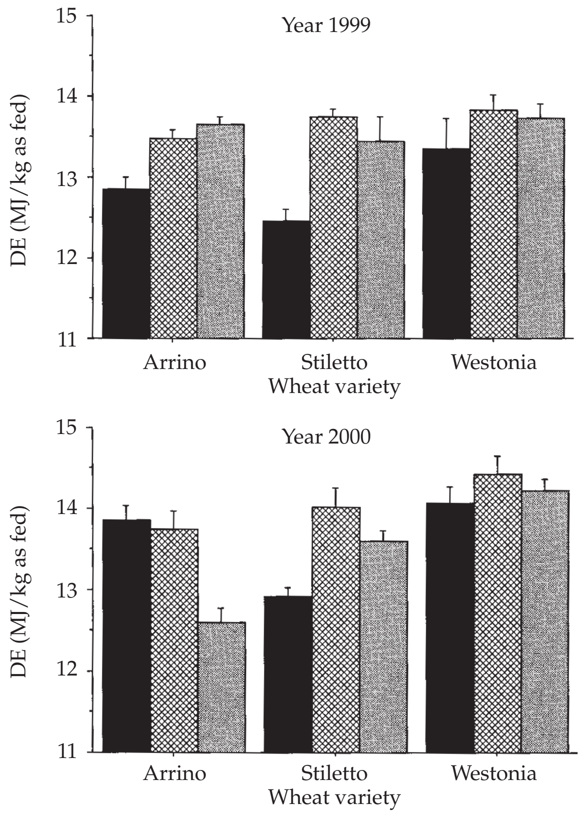
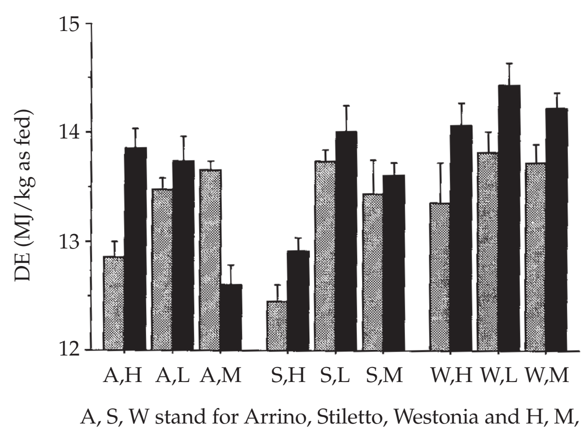


Figure 1 Digestible energy (DE) content of wheat (in years 1999 and 2000) as influenced by variety and growing region (black bars = high rainfall; hatched bars = low rainfall; grey bars = medium rainfall).

interaction between variety and growing region was significant ($P < 0{\cdot}001$). The high and low DE content resepctively of Arrino grown in the high and medium rainfall regions was responsible for this interaction (Figure 1).

In 1999, Westonia (13·6 ±0·11 MJ/kg) contained 0·3 and 0·4 MJ/kg ($P = 0{\cdot}013$) more DE compared with Arrino (13·3 (s.e. 0·11) MJ/kg) and Stiletto (13·2 (s.e. 0·12) MJ/kg), respectively. Wheats grown in the low (13·7 (s.e. 0·08) MJ/kg, $P < 0{\cdot}001$) and medium rainfall regions (13·6 (s.e. 0·12) MJ/kg, $P < 0{\cdot}001$) had 0·8 MJ and 0·7 MJ/kg more DE compared with wheats grown in the high rainfall region (12·9 (s.e. 0·15) MJ/kg), respectively. Similar to the 1999 cohort, the variety Westonia and wheat grown in the low rainfall region contained more DE in 2000. In 2000, Westonia (14·2 (s.e. 0·11) MJ/kg) contained 0·8 ($P < 0{\cdot}001$) and 0·7 MJ/kg ($P < 0{\cdot}001$) more DE compared with Arrino (13·4 (s.e. 0·18) MJ/kg) and Stiletto (13·5 (s.e. 0·15) MJ/kg), respectively. Wheats grown in the low rainfall region (14·1 (s.e. 0·11) MJ/kg) had 0·5 MJ ($P < 0{\cdot}05$) and 0·6 MJ/kg ($P < 0{\cdot}01$) more DE compared with wheats grown in the high (13·6 (s.e. 0·16) MJ/kg) and the medium rainfall regions (13·5 (s.e. 0·19) MJ/kg), respectively.

Overall, growing season significantly influenced the DE content of wheat ($P < 0{\cdot}001$), with wheats harvested in year 2000 containing more DE than wheats harvested in 1999 (13·7 *v.* 13·3 MJ/kg, $P < 0{\cdot}01$). Wheats grown in the high rainfall region had a significantly higher DE content in 2000 ($P < 0{\cdot}001$) compared with 1999 but the changes in DE contents of wheats grown in the medium and low rainfall regions were not significant. Between varieties, Westonia ($P < 0{\cdot}01$) had a significantly higher DE content in year 2000, while Stiletto showed a marginally increased DE content ($P = 0{\cdot}067$) and Arrino did not change. The variety × growing region × season interaction effect was fitted following preliminary analysis. Specifically, when fitting a model that included the main effects (i.e. variety, growing region and season), together with all two-, three-way interactions, the variety × growing region × season interaction effect was a significant source of variation for DE content ($P < 0{\cdot}01$, Figure 2). The major source of seasonal interaction was the ASWN wheat Arrino grown in the medium rainfall region, which decreased DE content in year 2000 while other wheats increased DE content in year 2000 compared with 1999.



A, S, W stand for Arrino, Stiletto, Westonia and H, M, L stand for high, medium, low rainfall regions

Figure 2 Effect of growing season (years 1999 (grey bars) and 2000 (black bars)) on digestible energy (DE) content of wheat. Variety: A = Arrino, S = Stiletto, W = Westonia; growing region: H = high rainfall, L = low rainfall, M = medium rainfall.

Table 3 *Correlations between chemical composition (dry matter basis) and digestible energy (DE) content (MJ/kg as fed) of wheat (no. = 9) harvested in 1999*†

	DE	T-xylose	I-xylose	NDF	PL	Total-P
T-xylose	–0·719*					
I-xylose	–0·742*	0·988***				
NDF	–0·839**	0·682*	0·703*			
PL	–0·821**	0·653	0·648	0·592		
Total P	–0·833**	0·470	0·447	0·840**	0·628	
Phytate-P	–0·753*	0·357	0·312	0·694*	0·668*	0·964***

† Abbreviations used: DE: digestible energy (MJ/kg as fed), T-xylose: total xylose (g/100 g dry matter (DM)), I-xylose: insoluble xylose (g/100 g DM), NDF: neutral-detergent fibre (g/100 g DM), PL: precipitation level (mm) during the growing season, total-P: total phosphorus (mg/100 g), phytate-P: phytate phosphorus (mg/100 g).

Correlation study

The chemical composition of the 18 wheats harvested over two growing seasons were presented in Kim *et al*. (2003). The relationship between the DE content of wheat and their physical and chemical compositions were calculated based on these data. The correlation coefficients for variables in relation to DE content of wheat harvested in the year 1999 are presented in Table 3. Total xylose, insoluble xylose, NDF, precipitation level during the growing season, total-P and the phytate-P levels in wheat were negatively correlated to the DE content. However, correlation studies with the wheats harvested in 2000 did not show any significant relationship to the various measurements, except a positive correlation to GE ($r = 0{\cdot}769$, $P = 0{\cdot}016$), soluble arabinose ($r = 0{\cdot}815$, $P = 0{\cdot}007$) and soluble arabinoxylan ($r = 0{\cdot}705$, $P = 0{\cdot}034$). When the combined data (wheats harvested in 1999 and 2000, no. = 18) were subjected to a correlation study, only total-P ($r = –0{\cdot}505$, $P = 0{\cdot}032$) was significantly correlated to the DE content of wheats.

Stepwise regression analysis was performed to find the factors contributing to variation in the DE content of wheats harvested in 1999, and the results are presented in Table 4. The total-P content and insoluble xylose content were responsible for 0·70 and 0·16, respectively, of variation in the DE content of wheats. The significant contributors for DE content of wheats harvested in 2000 were soluble arabinose (0·68), gross energy (0·08), and precipitation level (7%).

Discussion

Variation in the DE content of wheats for weanling pigs

The DE content of wheat, reviewed from the literature, can vary by up to 3·7 MJ/kg DM, ranging from 13·3 MJ/kg DM (Fuller *et al*., 1989) to 17·0 MJ/kg DM (Kopinski, 1997; Zijlstra *et al*., 1999). Examination of the DE content in Canadian wheats showed a 2·4-MJ/kg DM difference (14·6 to 16·9 MJ/kg DM) between cultivars (Anderson and Bell, 1983). Most studies reported in the literature show a 1- to 1·5-MJ/kg difference (Bowland, 1974; Batterham *et al*., 1980; Taverner and Farrell, 1981; Wiseman *et al*., 1982; Zijlstra *et al*., 1999; Wiseman, 2000). In the current study, a 1·3-MJ/kg (as fed) difference in wheats harvested in 1999 and a 1·8-MJ/kg (as fed) difference in wheats harvested in 2000 was observed. These results concur with most other studies reported previously (Wiseman *et al*., 1982; Zijlstra *et al*., 1999; Wiseman, 2000), and indicate the wide variation in DE content that exists for wheats given to weaner pigs in Western Australia.

However, the DE content may differ if the wheats are given to grower or finisher pigs as they have relatively developed endogenous enzyme and digestive systems compared to weanling pigs (Pluske *et al*., 2001). For example, the DE values of wheats reported in the literature ranged from 15·1 to 16·4 MJ/kg DM (no. = 8) in 25-kg pigs (Wiseman *et al*., 1982), from 14·6 to 16·9 MJ/kg DM (no. = 24) in 40-kg pigs (Anderson and Bell, 1983), from 15·6 to 17·0 MJ/kg DM (no. = 15) in 40-kg pigs (Zijlstra *et al*., 1999), and from 14·6 to 16·1 MJ/kg DM (no. = 16) in 25-kg pigs (Wiseman, 2000), while the DE value in the current study ranged from 13·8 to 15·8 MJ/kg

Table 4 *Stepwise regression analysis of the chemical composition (dry-matter basis) of nine wheats harvested in 1999 v. the digestible energy (DE) content (MJ/kg as fed)*†

Step	Variable	Partial R^2	Regression coefficient	s.e.	Significance
1	Total-P	0·7047	–0·006	0·001	**
2	PL	0·1621	–0·007	0·002	**

† Abbreviations used: DE: digestible energy (MJ/kg as fed), total-P: total phosphorus (mg/100 g dry matter), PL: precipitation level (mm) during the growing season.

DM (no. = 18) in 6-kg pigs, which is approximately 1 MJ/kg DM less extraction of energy from a given wheat-based diet. Although the cross-comparisons between different studies may not be valid due to the variable experimental conditions, such as use of marker and different sample collection methods, the observation that live weight of pigs is positively related to the digestibility coefficient of energy (Roth and Kirchgessner, 1984; Bell and Keith, 1989) may support the lower DE values observed in the current study. Development of increased digestive capacity of pigs with increasing live weight has been reported (Cunningham *et al.*, 1962; Kass *et al.*, 1980; Fernandez *et al.*, 1986). Nielsen (1962, cited in Fernandez *et al.*, 1986) observed that the small intestine continued to develop until the pig's live weight reached 20 kg, while the hind gut was still growing at 150 kg. It is likely that the increase in the age of pigs might enhance development of digestive and absorptive capacity in the small intestine and elevate colonization of carbohydrate-degrading micro-organisms in the large intestine, which results in older pigs being able to extract more energy from wheat-based diets (Just 1982a and b; Just *et al.*, 1983; Fernandez *et al.*, 1986).

Effects of variety and growing region on DE content of wheat

Since different varieties of wheats and wheats grown in different geographical locations contain variable levels of nutrients such as starch, protein, and fibre (Batterham *et al.*, 1980; Zijlstra *et al.*, 1999), these two factors have long been recognized as major factors influencing wheat DE content in pigs. Bhatty *et al.* (1974) found that soft wheat varieties contained higher starch, amylose, GE and DE contents than hard wheat varieties. The influence of variety on variation in DE content of wheat was well studied with Canadian wheats (Anderson and Bell, 1983). In this particular study, different varieties of wheats grown at a single site and harvested in the same year were offered to 40-kg pigs, and a 2·3-MJ/kg DM difference in DE content caused solely by variety was observed. Wheats collected from different locations in Australia also demonstrated the associations between climatic conditions in different growing sites and the energy content of the wheats when given to broiler chickens (Choct *et al.*, 1999). In the current study, variety and growing region significantly influenced the DE content of wheats harvested in 1999. Also, a significant variety × growing region interaction ($P < 0{\cdot}001$) was observed in wheats harvested in year 2000. Generally, the wheat variety Westonia (APW wheat) and wheats grown in low rainfall regions contained higher DE contents than other wheats and growing regions.

Relationship between chemical characteristics of wheats and DE content

A number of significant correlations between chemical characteristics of wheats and their DE content were established with wheats harvested in year 1999. However, the relationships with wheats harvested in year 2000 were not significant. This discrepancy may partly be explained by the significant change in chemical composition between the two seasons (Kim *et al.*, 2003). Crude protein, total starch, ADF, lignin, soluble NSP, and free sugar contents of wheat were significantly changed due to growing season (Kim *et al.*, 2003). Another possible explanation for the discrepancy is that the precipitation levels during the growing season were markedly decreased in 2000 (Kim *et al.*, 2002). Since the precipitation level was significantly correlated to the chemical composition of wheats (Kim *et al.*, 2002 and 2003), decreased precipitation in 2000 may, at least partly, have affected the chemical composition of wheats, and hence their DE contents. Nevertheless, total and insoluble xylose content, NDF content and the phytate-P content of wheats were inversely correlated to the DE content of wheats harvested in 1999. An inverse correlation between total xylose and DE content ($r = -0{\cdot}78$, $P < 0{\cdot}001$) has been reported previously (Zijlstra *et al.*, 1999). Also, a negative correlation between NDF levels and DE content was reported in Canadian wheats ($r = -0{\cdot}70$, $P < 0{\cdot}01$; Zijlstra *et al.*, 1999), and NDF was previously suggested as an accurate predictor of DE content in diets for pigs (King and Taverner, 1975). However, the correlation of DE content with phytate-P content has not been reported. In the present study, when the 2 years' data were combined and subjected to Pearson's correlation study, only the total-P and phytate-P contents were significantly correlated to the DE content of wheats. This finding may indicate that phytic acid in wheats can be a predictor for DE content over different varieties, growing environments, and different seasons, however the year-to-year variation still requires consideration.

Effect of growing season on DE content of wheat

Wiseman (1997) reported a 1·1-MJ/kg DM variation (14·6 *v.* 15·7 MJ/kg DM) in the DE content of wheat due to growing season from an identical variety grown in the same region, and a 1·0-MJ/kg (14·2 *v.* 15·2 MJ/kg air-dry basis) difference due to season was observed from an identical variety of wheat grown in the same region in an Australian study with wheat (Kopinski, 1997), both of which are in agreement with results of the current study. A similar seasonal variation was observed in a broiler chicken study (Choct *et al.*, 1999), where the apparent metabolizable energy (AME) value of 81 Australian wheats collected over 3 years showed a significant variation (1·3 MJ/kg DM, $P < 0{\cdot}01$) due to year of harvest.

In the current study, wheats grown in the high rainfall region had a significantly increased DE content in 2000 ($P < 0{\cdot}001$) whereas the DE contents of wheats grown in medium and low rainfall regions were similar. This significant seasonal variation in DE content in the high rainfall region could be explained, at least partly, by the differences in precipitation level in this region between 1999 and 2000. Rainfall during the growing season was markedly lower in 2000 (266 mm *v.* 406 mm) in this region (Kim *et al*., 2002). Since the precipitation level during the growing season was inversely correlated to DE content (Table 3), content of N, NDF, lignin and NSP of the wheats (Kim *et al*., 2003), the DE content of wheat in the high rainfall region may be altered due to the difference in precipitation in 2000. Another possible explanation for the variable DE content of wheat over seasons is differences in the agronomic practices used, such as N fertilization. Since N fertilization (0 or 180 kg N per ha) increased protein content (95 to 147 g/kg DM) in barley, and the fertilized barley increased N retention when given to growing pigs (Jorgensen *et al*., 1999), differences in agronomic practices between growing seasons may also explain some of the variation of DE content.

In conclusion, the present study revealed that the DE content in a cohort of wheats grown in Western Australia varied by up to 1·9 MJ/kg, on an as-fed basis. Both the variety and growing environment, especially precipitation levels during the growing season, were responsible for the significant variation, although other environmental influences such as fertilizer practices cannot be discounted. The seasonal differences in DE content of the wheats may also be a consequence of environmental differences, such as precipitation level, during the growth of wheats. In wheats harvested in 1999, fibre components such as NDF and insoluble xylose reduced the DE content from a given wheat. Such significant inverse relationships between the DE content and fibre content, however, were not replicated with wheats harvested in 2000. The significant correlation between DE content and total-P, which was the only parameter that was related to DE content in the combined (1999 and 2000) dataset, has potential as a possible predictor for rapid screening of DE in wheats for weanling pigs. The basis of the inverse correlation between total-P content of wheat and DE content is yet to be explored in wheat-based diets for weaner pigs. Diet formulations use average matrix data that cannot take into account such a wide variation in DE content, and this can cause less than optimal pig performance. Hence, the use of correlations between the DE content and chemical composition in wheat would be an important step in food management practices, and should go some way to accounting for seasonal and agronomic effects.

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