NUTRITIONAL EVALUATION OF DEHULLED AND YELLOW SEEDED CANOLA MEALS IN POULTRY

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by

Joseph Simbaya

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ABSTRACT

The study was conducted to evaluate the nutritive value of dehulled (DCM) (*Brassica napus* L, cv. Westar) and yellow seeded (YSM) (*Brassica compestris* L, cv. Parkland) canola meals in poultry. Meals of commercial (CCM) and brown seeded (BSM) (*Brassica napus* L, cv. Westar) canola were used as controls. The CCM and DCM were obtained from Can Amera Foods, Altona and POS Pilot plant, Saskatoon, respectively while those of BSM and YSM were prepared in the laboratory. Compared to the other meals, DCM had significantly higher and lower levels of protein and glucosinolates, respectively while BSM was higher in the content of total dietary fibre (TDF) and neutral detergent fibre (NDF). The levels of non-starch polysaccharides (NSP) were highest and lowest in YSM and DCM, respectively. However, both meals had similar NDF values. The protein composition of amino acids were similar in all the meals apart from DCM which had slightly higher values. There were no major differences among meals when amino acids were evaluated as percentage of protein in the meal. A study with precision-fed cockerels showed true metabolizable energy (TMEn) values to be higher in DCM and CCM than in YSM and BSM which had similar levels. There was generally low NSP availability in all the meals and comparison among meals showed DCM to have a lower value than the other meals. True amino acid availabilities (TAAA) were slightly higher in DCM and CCM though there were no significant differences among meals. A one week digestibility study with intact and cecectomised laying hens fed semi-purified diets containing 45% canola meal indicated no major differences in the digestibility of lipids, energy, NSP and

amino acids between intact and cecectomised hens. In contrast to the precision fed cockerel assay, the laying hen digestibility study showed BSM to have relatively better amino acid digestibilities than the other meals while YSM tended to have the lower values. Based on glucosinolate content and color of the meal, the data indicate that DCM was subjected to excessive heat treatment during processing which may have influenced nutrient availability in this meal. The results on a two week growth trial with one week old cockerels indicated no major differences between meals in supporting chick performance. However, there were trends to indicate CCM to be of better feeding quality than the other meals.

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LIST OF ABBREVIATIONS

ADF	Acid detergent fibre
ANOVA	Analysis of variance
AOAC	Association of official analytical chemists
BSM	Brown seeded canola meal
BWG	Body weight gain
CCM	Commercial canola meal
CF	Crude fibre
CM	Canola meal
CPC	Canola pressed cake
CRD	Completely randomized design
DM	Dry matter
DCM	Dehulled canola meal
EDTA	Ethylene diamine tetraacetic acid
EE	Ether extract
DMSO	Dimethylsulphoxide
GLC	Gas-liquid chromatography
GLM	General linear models
GIT	Gastrointestinal tract
HCL	Hydrochloric acid

HG-RSM	High glucosinolate rapeseed meal
IU	International unit
NA	Not available
ND	Not detected
NDF	Neutral detergent fibre
NDF-CP	Neutral detergent fibre crude protein
NDIP	Neutral detergent insoluble polysaccharides
NDSP	Neutral detergent soluble polysaccharides
NSP	Non-starch polysaccharides
RSM	Rapeseed meal
SAS	Statistical analysis system
SBM	Soybean meal
SCWL	Single comb white leghorns
SEM	Standard error of the mean
TAAA	True available amino acids
TANSP	True available non-starch polysaccharides
TDF	Total dietary fibre
TMA	Trimethylamine

TMEn	Nitrogen-corrected true metabolizable energy
VFA	Volatile fatty acids
YSM	Yellow seeded canola meal

1.0. INTRODUCTION

The largest single source of supplementary protein used for livestock and poultry feeding is soybean meal (Hannock *et al.*, 1990). In recent years, because of economical and/or agro-political reasons, it has become advantageous in most countries to replace soybean meal or part of it with locally produced protein rich vegetable feeds, usually referred to as soybean meal replacers. The most common soybean meal replacers used in poultry diets are rapeseed/canola meal, corn gluten meal, ground nut meal, sesame meal and sunflower meal (Opstivedt *et al.*, 1992). The problem with these feedstuffs is that they generally contain less metabolizable energy and protein than soybean meal and the amino acid profile in most of them is less well suited to meet animal requirements.

According to Hulan and Proudfoot (1981), rapeseed/canola meal can only replace soybean meal if differences in energy, protein and amino acids especially lysine are compensated. Improvements in the quality of rapeseed/canola meal have been a major objective that has led to the development of new canola varieties by plant breeders. The oil and protein composition of canola has made the crop to be an important protein source in many countries (Bjergegaard *et al.*, 1991). However, despite these advances in plant breeding, presence of anti-nutritive factors such as dietary fibre, phytic acid, polyphenols and glucosinolates still limit the unrestricted use of canola meal in livestock and poultry diets (Shahidi, 1991).

While there is evidence that there could be benefits from further glucosinolate

reductions in the meal (Bell, 1991), the major concern is the high dietary fibre present in canola (Carr and McDonald, 1991). Fibre, which is known to adversely affect meal digestibility also produces other adverse effects (Bjergegaard *et al.*, 1991). The high dietary fibre in canola is due to the higher proportion of hulls in canola seed which are known to be the major source of dietary fibre in the meal (Bell and Keith, 1987). Enhancement in the meal quality and consequently it's utilisation may be achieved by changes in the carbohydrate components as a result of genetic selection programs and/or innovations in crushing technology or dietary manipulation (Carr and McDonald, 1991). The fact that yellow seeded canola contains lower hull fractions than brown seeded varieties makes selection for yellow seed coat colour a priority in plant breeding in an effort to reduce dietary fibre and improve the meal nutritional value (Bell, 1984). Earlier efforts to reduce dietary fibre content through dehulling did not give satisfactory results due to high glucosinolate content and the finer texture in the resulting meal (Bayley and Hill, 1975). With newly developed canola varieties and advances in industrial crushing plants, it is worth re-examining the dehulling process.

This study was undertaken to evaluate the nutritive quality of newly developed yellow seeded canola (*Brassica compestris L,* cv. Parkland) and dehulled brown seeded (*Brassica napus L,* cv. Westar) canola meals through investigations on chemical composition, nutrient digestibility and chick growth assays. Brown seeded canola (cv. Westar) and commercial canola (Can Amera foods) meals were used as controls.

2.0. LITERATURE REVIEW

2.1. Introduction

Canola is the name given to all double low (<2% erucic acid and <30μg/g glucosinolates) rapeseed (*Brassica napus L.* and *Brassica compestris L.*) varieties currently grown in Canada. Although Canada is one of the leading producers of Canola, it is relatively a new comer to the development and production of rapeseed (Bell, 1982). Plants of Brassica species have been important components of human diet since antiquity (Downey, 1965; Tsunoda *et al.*, 1980). Prior to field cultivation of rapeseed, it's seeds were gathered for oil which was used for lighting and soap making (Bell, 1984). It is not clear when rapeseed became a food crop in addition to it's earlier uses. Greek writers reported the use of rape in Europe as far back as the pre-Christian era. In China and Japan the crop was introduced through the Korean peninsula about 2000 years ago, though it must have occurred much earlier in India. In Europe, field cultivation of rape became common in the 13th century and by the 19th century it had already spread eastward and northward into the Scandinavian countries as well as Russia and Poland (Bell, 1984).

In Canada, apart from forage rape which was grown by early settlers, commercial production of rapeseed began in 1942 with the primary aim of supplying lubricants for marine engines (Ohlson, 1972). The first rapeseed variety with edible oil, Golden, was released in 1954 and was followed by several others (e.g. Nugget, Tanka and Target

from *B. napus* varieties and Arlor, Echo and Polar from *B. compestris* varieties) (Ohlson, 1972). These varieties had a higher oil content than the original Argentine and Polish rapeseed types and were characterised by high glucosinolate and erucic acid levels averaging 100 μmoles g^{-1} and 35-40% in *B. napus* cultivars and 70 μmoles g^{-1} and 20-30% in *B. compestris* cultivars, respectively. In 1968, the first low erucic acid variety, Oro, was introduced only to be followed by several others until 1974 when the first double low variety, Tower, was released (Bell, 1984; Olhson, 1972). The name Canola was adopted in 1979 and by 1981 the production of high glucosinolate rapeseed (HG-RSM) varieties had nearly ceased (Canola Council of Canada, 1986).

Currently canola is grown for it's superior oil quality and it is the third most important oil crop after soybeans and palm oil (Carr and McDonald, 1991). World production in 1990 averaged 24 million metric tons with China, India, Canada, and the EEC countries contributing most of the production. About 90% of canola oil is used for human food products such as margarine, salad oil and cooking oil (Canola Council of Canada, 1988). Canola meal, the product remaining after oil extraction is important for livestock and poultry feeding. The meal does not only have a high protein content (40%) but also has a well balanced amino acid composition (Canola Council of Canada, 1986). Canola oil protein concentrate and canola protein isolate have a potential as human foods.

The quality and utilisation of canola meal depends on the concentration of anti-nutritive factors. Despite low concentrations, glucosinolates still restrict the use of the meal in some livestock and poultry diets. Tannins, phytic acid and sinapine, which are

also found in canola, impair animal performance (Heaney and Fenwick, 1982). The high fibre content in canola is well documented and it's effect on the nutritive value of the meal well known (Bell, 1984). It does not only affect the apparent metabolizable energy of the meal but also reduces the digestibility and utilisation of other nutrients (Rundgren, 1983; Slominski and Campbell, 1990).

It is clear that the quality of the meal is not yet perfect and the challenge for the future is to improve it's nutritive value and utilization in livestock and poultry feeding. In processing plants, efforts are being made to reduce the fibre content through dehulling (Bell, 1982; Clandinin, *et al* 1986) and to improve protein availability by incorporating optimum processing temperatures. In plant breeding, selection programmes are geared towards yellow seeded varieties which have lower hull fractions compared to dark seeded varieties. Another possibility for the future is through the use of dietary enzymes to enhance the utilization of structural carbohydrates present in canola (Slominski and Campbell, 1990). Research on tannins, polyphenols, phytates, sinapine and indeed glucosinolates will continue as scientists seek additional quality in the meal.

2.2. Nutrient Composition of Canola Meal

2.2.1. Protein and Amino acids

Canola meal has gained wide acceptance in recent years as a high quality protein supplement in livestock and poultry diets (Robblee *et al.*, 1986; Salmon, 1979; McKinnon and Christensen, 1989). This has come about as a result of reduction in the meal glucosinolate levels that has occurred due to advances in genetic selection. The protein and amino acid contents of canola meal (CM) compare favourably with those of soybean meal (SBM) (Table 1.), though the protein of CM has more of the sulphur amino acids (cystine and methionine) and less lysine than that of SBM (Bell, 1984). Thus, the two meals tend to complement each other when used together in animal feed rations (Clandinin *et al.*, 1981).

The diluting effect of hulls on protein and amino acid content of the meal is well known. Due to difficulties in separating hulls from the cotyledons, the protein content of hulls has not been determined with certainty (Bell and Shires, 1982). The value ranges from 11 to 16% and most of this protein is resistant to hydrolysis by the enzymes of the of gastrointestinal tract (GIT) (Finlayson, 1974). Dehulling of canola seed is known to increase the meal protein level to about 50%, which is associated with an increase of 12% in amino acids. The increase in protein and amino acids contents in the meal is caused by a lessening of the diluting effect of dietary fibre from hulls (Zuprizal *et al.*, 1991b).

TABLE 1. Protein and amino acid composition of canola meal samples and soybean meal (% of crude protein).

	Meal samples[1]			
Amino acid	1.[a]	2.[b]	3.[c]	4.[a]
Protein (N x 6.25)	41.00	42.90	47.00	45.01
Alanine	4.56	4.10	NA[2]	4.20
Arginine	6.11	6.29	7.10	6.44
Asp. acid	8.03	8.23	NA	11.20
Cystine	1.23	1.66	NA	0.65
Glu. acid	16.69	19.67	NA	18.00
Glycine	4.96	5.66	NA	4.60
Histidine	2.81	2.42	3.57	2.40
Isoleucine	3.98	3.57	4.50	4.69
Leucine	6.97	7.25	7.26	7.49
Lysine	5.98	5.38	4.96	6.22
Methionine	1.78	1.63	NA	1.40
Phen. alanine	4.01	3.64	4.40	4.80
Proline	7.00	8.32	NA	4.89
Serine	4.39	4.41	NA	5.00
Threonine	4.50	4.22	4.70	3.80
Tryptophan	1.16	1.17	1.27	1.20
Tyrosine	2.46	3.01	2.95	2.80
Valine	5.11	4.24	4.98	5.00

Source: a= Clandinin *et al.*, 1981.
: b= Blair *et al.*, 1986.
: c= Bell, 1991.

[1]1- Commercial canola meal, 2.- Wester canola meal, 3.- Dehulled canola meal and 4.- Soybean meal.

NA[2]- Not Available.

There is some evidence to indicate a relationship between protein content and seed colour, with yellow seeded varieties having a higher protein content than dark seeded varieties (Stringam *et al.*, 1974). Since the endosperm (embryo and cotyledon) protein content of the two varieties is similar (Stringam *et al.*, 1974), the differences between the two meals may be explained by a diluting effect of hulls. Yellow seeded hulls are known to be thinner and less lignified than dark seeded hulls which results in yellow seeded canola having a higher proportion of oil and protein containing cotyledons than dark seeded canola varieties.

Available data in the literature on nitrogen and amino acid digestibility (Table 2.) indicate that SBM has higher values than CM though Barbour and Sim (1991) reported no significant differences on the availability of essential amino acids between CM and SBM. It should be noted that dehulling of canola seed improves the digestibility of protein and amino acids to approach that of SBM (Zuprizal *et al.*, 1991a). This improvement in protein and amino acid digestibility is a result of the removal of the indigestible amino acids present in the hulls (Sarwar *et al.*, 1981). Variations in protein and amino acid availability in various canola seed cultivars and meals have been observed though most of these were not statistically significant (Muztar and Slinger, 1980).

The recommended inclusion rates of CM in poultry rations are 10 and 20% for layers and broilers, respectively (Clandinin *et al.*, 1986). When used as the sole protein supplement in laying hens, CM tends to result in reduced egg production (Campbell and Slominski, 1991b) and where egg production is normal there is an increase in the production of smaller and medium sized eggs compared to hens fed SBM diets which

TABLE 2. True amino acid digestibility in canola meal, dehulled canola meal and soybean meal (% of amino acid in the meal).

Amino acid	Canola meal	Dehulled canola meal	Soybean meal
Nitrogen	73.4	82.3	84.5
Aspartic acid	81.1	85.8	90.2
Threonine	75.2	84.0	87.8
serine	76.2	85.0	91.1
Glutamic acid	84.2	90.4	92.4
Alanine	81.9	86.6	87.2
Valine	78.6	86.0	88.8
Methionine	93.5	95.0	95.6
Isoleucine	79.7	86.4	89.8
Leucine	82.1	87.6	89.4
Tyrosine	74.9	84.7	89.2
Phenylalanine	82.2	88.4	90.0
Lysine	76.9	81.4	87.5
Arginine	81.2	84.3	85.2
Cystine	73.4	78.1	80.5
Mean	80.1	86.0	88.9

Source: Zuprizal *et al.*, 1991a.

have a higher percentage of extra large eggs (Campbell, 1991; Summers, 1991). Reduced feed intake has been observed in both broilers and layers fed CM (Lee *et al.*, 1984; Campbell, 1987; Summers, 1991). This may be the main factor responsible for reduced egg size and depressed performance associated with CM based diets in layers and broilers respectively (Summers, 1991). When lysine is supplemented to CM based diets the performance of birds is similar to that of those fed SBM based diets (Campbell, 1987). It should be mentioned that there is enough evidence in literature to indicate that other factors (anti-nutritive factors), through their effect on feed intake rather than protein *per se,* are responsible for reduced bird performance when CM is used at high levels in poultry rations (Campbell and Slominski, 1991a).

2.2.2. Low molecular Weight Carbohydrates

Detailed information about the type and occurrence of various canola carbohydrates is important for both plant breeders and animal nutritionists. Although the high fibre content is well documented as the major cause of reduced energy digestibility in canola, the specific carbohydrate components that may be responsible for this problem have not been delineated (Bell, 1984). Various types of carbohydrates in canola that may individually or collectively influence the nutritive value of the meal may be rationalised from the sugar component profile (Slominski and Campbell, 1990).

Polysaccharides of feed materials fall into two broad categories, the unavailable (insoluble cell wall or structural) and the soluble or available (storage) polysaccharides (Southgate and Johnson, 1987). In this section only the soluble carbohydrates will be discussed. The structural polysaccharides will be discussed in Section 2.4. Rapeseed/canola meal contains sucrose, galactooligosaccharides (e.g. stachyose and raffinose) and starch as the major reserve polysaccharides. The low digestibility and negative effects of oligosaccharides on the true metabolisable energy (TMEn) content of SBM was reported by Leske *et al.* (1988). These effects may be caused by the bonding of galactooligosaccharides to structural polysaccharides or other structures that may limit their exposure to microbial α-galactosidase. Their low concentrations in feedstuffs may also slow the microbial enzyme reactions due to substrate limitations (Coon *et al.*, 1990). Furthermore, stachyose and raffinose are not nutritionally favoured since they are known to cause intestinal gas-forming profiles (Calloway *et al.*, 1971). Apart from sucrose which is slightly higher in yellow seeded canola, there are no significant differences between canola varieties in the composition of low molecular weight carbohydrates (Siddiqui and Wood, 1977).

2.2.3. Minerals (Ash)

The mineral content in canola has not been regarded as a problem area as far as the nutritive quality of the meal is concerned (Bell, 1984). The meal contains greater

levels of most minerals than SBM (Table 3.). Even though, the availability of minerals from CM is lower than that from SBM (Clandinin *et al.*, 1986; Ward *et al.*, 1991), CM is still considered a better source of most minerals (Nwokolo *et al.*, 1976) because of the relatively high level of minerals in CM. There are good reasons to suspect that the higher levels of dietary fibre and phytic acid in CM are responsible for the lowered mineral availability (Nwokolo and Bragg, 1977). Dietary fibre and/or phytic acid may also bind exogenous minerals which may explain the reduced mineral availability observed in CM supplemented diets (Summers, 1991). The utilization of CM minerals can be improved by the use of certain exogenous enzymes (Cellulase and phytase) in CM supplemented diets (Ward *et al.*, 1991). This phenomenon may be explained by the reduction in the binding and encapsulating effect of minerals by phytate and dietary fibre, respectively.

2.2.4. Vitamins

Despite the fact that CM is not considered to be a major source of dietary vitamins, it is relatively a better source of choline, biotin, folic acid, niacin, riboflavin and thiamin than SBM which is only superior in supplying pantothenic acid (Clandinin *et al.*, 1986). Canola vitamins are not associated with any anti-nutritive effects, except that choline, one of the products of sinapine decomposition in the gut is known to cause fishy odour in some strains of brown-egg laying hens (Goh *et al.*, 1979a).

TABLE 3. Mineral and vitamin composition of canola meal and soybean meal.

Component	Canola meal	Soybean meal
Minerals		
Calcium %	.68	.29
Phosphorus %	1.17	.65
Sodium %	.03	.03
Chloride %	.02	.04
Potassium %	1.29	2.00
Magnesium %	.64	.27
Copper mg/kg	10.40	21.50
Iron mg/kg	159.20	120.00
Iodine mg/kg	.80	.15
Manganese mg/kg	53.90	29.30
Selenium mg/kg	1.00	.10
Zinc mg/kg	71.40	27.00
Vitamins		
Choline %	.67	.28
Niacin mg/kg	160.00	29.00
Pantothenic acid mg/kg	9.50	16.00
Thiamin mg/kg	5.20	4.50
Riboflavin mg/kg	3.70	2.90
Folic acid mg/kg	2.30	1.30
Biotin mg/kg	.90	.30

Source: Canola Council of Canada, 1988.

2.2.5. Lipids (Ether extract)

The amount and composition of lipids in CM depend on the residual oil remaining after canola oil extraction and the amount of gums added back to the meal. Gums are derived from canola oil refining and consist of phospholipids, glucolipids and variable amounts of triglycerides and fatty acids (Bell, 1984). In addition to reducing meal dustiness, gums tend to increase it's metabolizable energy and also serve as a source of essential fatty acids (Canola Council of Canada, 1988). In poultry up to 6% gums have been added to the meal without any detrimental effects in either laying or growing chickens (Robblee *et al.*, 1978). Considerable amount of research is currently in progress to study and promote the use of full fat canola as a source of energy and protein in poultry rations (Summers, 1991; Nwokolo and Sim, 1989). Whether it would be economical to feed the high quality canola oil to animals is still a matter of debate among nutritionists and politicians alike.

2.3. Anti-Nutritive Factors Affecting Canola Meal Quality

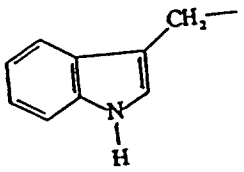
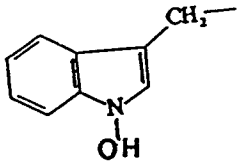
2.3.1. Glucosinolates

Glucosinolates are still the major anti-nutritive compounds in CM (Bell, 1984; Heaney and Fenwick, 1982) limiting the use of this protein supplement in livestock and

poultry diets (Slominski and Campbell, 1987). There are over 100 known glucosinolates in plant species though only a few are common in plants of the cruciferae family (Table 4). All glucosinolates have a similar general molecular structure and only differ in the **R** radical which is also the most reactive part of the molecule. A number of amino acids are involved in the biosynthesis of glucosinolates (Larsen, 1981). Aliphatic glucosinolates are mostly synthesized from methionine whereas tyrosine forms the basis for the benzyl and phenyl ethel groups of aromatic glucosinolates and indole glucosinolates are derived from tryptophan (Daun, 1984; Craig, 1990).

Methods of glucosinolate analyses prior to 1977 did not include indole glucosinolates and hence these were not included in the total detected glucosinolate content of RSM/CM (Thies, 1977). In 1978, McGregor reported that indole glucosinolates occur in significant amounts and that there is little difference between RSM and CM. It has now been established that indole glucosinolates make up about 40-60% of total glucosinolates in CM though the anti-nutritive effects of these compounds have not been fully established (Slominski and Campbell, 1988). Total glucosinolate content in canola may also be influenced by weed seed contamination, of which mustard weed (*Sinapis avernsis*) and stinkweed (*Thlaspi arvense*) are the most prominent (Bell *et al.*, 1991; Campbell and Slominski, 1990). Weed-seed contamination in the meal is demonstrated by the presence of allyl and 4-hydroxybenzyl type of glucosinolates (Slominski and Campbell, 1989). The contaminating seeds are difficult to separate during canola seed cleaning and tend to reflect the adequacy of weed control in the field (Bell and Keith, 1991).

TABLE 4. Major glucosinolates found in *Brassica napus* and *B. compestris* canola varieties.

Common name	Semi-systematic name	R-group
Sinigrin	allyl-	$CH_2{=}CH{-}CH_2{-}$
Gluconapin	3-butenyl-	$CH_2{=}CHCH_2CH_2{-}$
Glucobrassicanapin	4-pentenyl-	$CH_2{=}CH(CH_2)_2CH_2{-}$
Progoitrin	2-OH-3-butenyl-	$CH_2{=}CH{-}CH(OH){-}CH_2{-}$
Napoleiferin	2-OH-4-pentenyl-	$CH_2{=}CHCH_2CH(OH)CH_2{-}$
Glucobrassicin	3-indolyl-methyl-	
Neoglucobrassicin	1-OH-3-indolyl-methyl-	

Source: Hanley *et al.*, 1983 and Bell, 1984.

Intact glucosinolates *per se* are not harmful, their toxicity and anti nutritive effects depend on the concentration of their hydrolytic products (Hill, 1979; Fenwick and Curtis, 1980). Canola contains an enzyme system, myrosinase (thioglucoside glucohydrolase EC 3.2.3.1), which hydrolyses glucosinolates upon contact in the presence of moisture (Fenwick and Curtis, 1980). Depending on the conditions, the hydrolytic products include the non toxic glucose and bisulphate moieties and the toxic compounds isothiocyanates, oxazolidinethiones, thiocyanates, epithionitriles and nitriles as well as some minor compounds (Tookey *et al.*, 1980). In addition, glucosinolates are susceptible to thermal degradation, especially indole glucosinolates which yield 3-indoleacetonitrile, 4-hydroxy-3-indoleacetonitrile and free thiocyanate ion upon degradation (Slominski and Campbell, 1989). To reduce the concentration of hydrolytic products in the meal, it is important to inactivate the myrosinase enzyme in order to minimise glucosinolate hydrolysis. In the commercial manufacture of CM, heat treatment is applied to ehance oil extraction which also assists in inactivating the myrosinase enzyme and thereby minimising glucosinolate hydrolysis (Campbell and Slominski, 1990). The extent and rate of myrosinase inactivation depends on the temperature, time of heating and moisture applied in the crushing process. Heat treatment also assists in solvent removal and drying of the meal.

The concentration and composition of glucosinolates in the seed and meal of some rapeseed/canola varieties are shown in Table 5. Adverse effects associated with dietary glucosinolates include feed intake reduction, weight gain depression and organ toxicity (Hill, 1979; Campbell and Slominski, 1991a). It is widely recognised that RSM is

TABLE 5. Glucosinolate contents in rapeseed/canola seed and products (μmoles g^{-1}).

Glucosinolate	Seeds		Meals[1]	
	Midas[a]	Westar[a]	CPC[b]	CCM[a]
Aliphatics				
3-butenyl	32.2	2.90	7.29	2.70
4-pentenyl	8.90	0.20	2.52	0.40
2-OH-3-butenyl	98.50	5.30	12.88	5.50
2-OH-4-Pentenyl	5.10	0.00	1.06	0.20
Indoles				
3-indolylmethyl	0.30	0.80	0.57	0.30
4-HO-3-pentenyl	8.80	8.70	11.46	2.30
Contaminants[2]				
Allyl	--	--	1.70	0.10
4-OH-benzyl	--	--	2.63	2.80
Totals				
Aliphatics	144.70	8.40	23.75	8.80
Indoles	9.10	9.50	12.03	2.60
Contaminants	--	--	4.33	2.90
Overall	153.80	17.90	35.78	14.30

[1]CPC= Canola press cake, CCM= Commercial canola meal.

[2]= from stinkweed, brown mustard and wild mustard.

Source: a- Slominski and Campbell, unpublished results.
: b- Keith and Bell, 1991.

goitrogenic and that this effect can not be prevented by dietary iodine supplementation (Bell, 1984). Leg weaknesses exhibited by swollen hocks, in broiler chicks fed CM, are often associated with dietary glucosinolates as a consequence of reduced feed intake.

Laying hens fed CM as the sole protein supplement exhibit reduced egg production where feed intake is decreased and Thomke *et al.* (1983) observed a relationship between feed intake and dietary glucosinolate concentration. However, Campbell and Slominski (1991b) noted no relationship between feed intake and glucosinolate levels in layers fed CM. It should be mentioned however that despite normal feed intake and egg production, they observed an increase in the production of small and medium sized eggs in birds fed CM compared to those fed SBM based diets which had a higher percentage of extra large eggs. Mortality from liver haemorrhage in laying hens is also associated with glucosinolate levels in the diet though it is difficult to pin point the threshold levels required to alleviate the problem (Campbell and Slominski, 1991b). This latter response, however, is the major reason for the current upper limit of 10% of the diet for canola meal usage in laying flocks.

2.3.2. Dietary Fibre

Canola seeds contain 16.5-18.5% hulls (Appleqvist and Olhson, 1972) which is equivalent to 30% hulls in the oil extracted meal (Bell and Shires, 1982). The amount and composition of hulls which make up the greater part of canola dietary fibre have

significant effects on the nutritive value of the meal. Sarwar *et al.* (1981) reported that inclusion of RSM/CM hulls in poultry diets resulted in reduced protein digestibility more than could be accounted for by simple dietary dilution. Removal of hulls is known to improve nutrient digestibility (Leslie *et al.*, 1973, Seth and Clandinin, 1973; Bayley and Hill, 1975). Currently, efforts are being made to improve CM nutrient availability by dehulling the seed (Bell, 1984; Slominski and Campbell, 1990; Zuprizal *et al.*, 1991a).

Variations in CM fibre content is somewhat related to seed coat colour. Yellow seeded varieties contain relatively less dietary fibre than brown seeded varieties as indicated by Stringam *et al.* (1974). Slominski and Campbell (1990) concluded that yellow seeded canola have a higher non-starch polysaccharides (NSP) content than brown seeded varieties which tend to be higher in lignin and other associated polyphenols. However, it should be pointed out that Theander *et al.* (1977) reported that the lignin content in the two types of canola was similar and that the difference in the fibre content between the two canolas was in the content of polyphenols. Consequently, yellow seeded canola has a preferred dietary fibre composition and selection for yellow seed coat colour in plant breeding is of priority in an effort to improve the nutritive value of the meal (Bell, 1984; Slominski and Campbell, 1991).

2.3.3. Sinapine

Rapeseed/canola meal contains sinapine (6-18g/kg) an ester of sinapic acid and choline (Mueller *et al.*, 1978; Curtis *et al.*, 1978) which has been associated with fishy odour in some strains of the brown-egg laying hens (Hobson-Frohock *et al.*, 1975; 1977; Goh, *et al.*, 1979a). The extent of the odour is directly related to the amount of sinapine in the diet. The taint is known to be caused by the presence of trimethylamine (TMA) in eggs (Goh *et al.*, 1979a). Under normal circumstances, TMA which is produced from the choline moiety of sinapine by the enteric bacteria, is rapidly converted to odourless nitrous oxide by a microsomal enzyme (TMA oxidase) found in liver and kidney (Hill, 1979). In genetically defective hens, there is a lowered capacity for synthesizing TMA oxidase in it's fully active form (Buttler *et al.*, 1982). Thus, the route for TMA metabolism is interrupted and as TMA builds up in the blood stream it passes into the developing ova and accumulates in the egg and thus results in fishy odour. The average tainting threshold level is about 1μg/g of egg contents (Griffiths *et al.*, 1979; Goh *et al.*, 1979b; 1982b).

When RSM/CM sinapine is hydrolysed to sinapic acid and choline before being incorporated in the diet, no tainted eggs were produced (Goh *et al.*, 1979b) since choline was absorbed in the small intestine of the birds (Tayaranian and Henkel, 1991). The compound can be hydrolysed by ammoniation or by treatment with an alkali solution such as calcium hydroxide (Fenwick *et al.*, 1979; Goh *et al.*, 1982a) or sodium carbonate (Tayaranian and Henkel, 1991). However, these methods are not economically viable and

elimination of sinapine by breeding new CM varieties is unlikely or at least quite remote (Buttler and Fenwick, 1984). The only effective possibility for the future is in the removal of the metabolic defect in laying flocks. Breeding programs are under way in Europe and Pearson and Buttler (1983) have indicated that it may be possible to eliminate the carriers of the defect within three generations.

2.3.4. Phytic Acid

Phytic acid is a calcium-magnesium salt of inositol hexaphosphoric acid found in seeds of most cereals and legumes (Cromwell, 1991). Anti-nutritive properties of phytic acid are due to it's ability to chelate minerals (e.g. calcium, phosphorous, magnesium, zinc, iron etc.) and thereby reducing their bioavailability (Khan *et al.*, 1991).

The higher concentration of phytic acid in CM is of great concern with respect to the nutritional availability of most minerals including calcium and phosphorous (March,1991). For instance, of the 1.2% phosphorous in CM 78-87% of it is in form of phytic acid (Nwokolo and Bragg, 1980). The utilization of phytate chelated minerals depend on the microbial phytase activity in the gut and varies with species and age of the animal (March, 1991). The composition of the diet may also affect phytase activity through it's influence on phytase-producing microbes and the phytase activity naturally present in certain feedstuffs (mostly cereals). Canola meal has little phytase activity, which should be expected as any inherent enzyme activity in the meal is inactivated by

the heat applied during meal processing (March, 1991). Monogastric animals, especially poultry, lack the enzyme and as such phytate chelated minerals are poorly utilized (Cromwell, 1991; Nelson, 1968; Nwokolo and Bragg, 1977). This was further confirmed by Summers (1991) who demonstrated a depressing effect of phytic acid on the availability of calcium, phosphorous, magnesium and zinc from CM in poultry. However, the availability of manganese and copper was not correlated to the phytic acid content in the meal. The reduced calcium utilization not only in CM based diets but also in calcium supplemented CM diets indicates that phytic acid was the main factor interfering with calcium utilization in CM based diets and this may explain the leg problems which are often associated with reduced feed intake in broilers.

2.3.5. Tannins

Tannins are a family of complex phenolic polymers found in two groups, the hydrolysable and condensed tannins (Halsam, 1966). Even though both groups have been identified (Hill 1979), RSM/CM tannins are mainly of the condensed type and these are primarily found in the seed coat (Durkee, 1971 and Theander *et al.*, 1977). Tannin content in canola varies between 1.5 and 3.2% (Fenwick and Hogan, 1976) with the amount being related to the seed coat colour (Stringam *et al.*, 1974). Yellow seeded varieties contain less tannins than dark seeded canola varieties (Theander *et al.*, 1977; Slominski and Campbell, 1990).

Tannins are responsible for the dark colour, bitter taste and astringency in canola products and their oxidised products may form complexes with essential amino acids, enzymes and other proteins (Naczk and Shahidi, 1991). The ability of tannins to form complexes with metal ions was cited by Seth and Clandinin (1973) as a possible connection between CM based diets and leg weakness in broilers. The reducing effect of tannins on metabolizable energy value was reported by Yapar and Clandinin (1972), though the lowered feed intake associated with the astringent taste of tannins (Tamir and Alunot, 1970) has not yet been substantiated.

2.4. COMPOSITION OF CANOLA CELL WALL MATERIALS

2.4.1. General Overview

Plant cell walls consist of a series of polysaccharides which are classified into a limited number of structural families within which members contain certain features in common (Table 6). Within each family, members exhibit variations in the nature of sugar units, side chains and other modifying features (e.g. ether and ester functional groups), which are responsible for the differences in their physical and physiological properties and consequently for their nutritional and metabolic functions (Kato, 1981). As in most higher plants, cellulose, hemicellulose and pectic substances are the major polysaccharides found in canola (Table 7). These compounds together with the non

TABLE 6. Major structural polysaccharides of plant cell wall materials

General category	Structural classification
Cellulose	β-D-Glucans (1-4)-linkages
Pectic substances	Galacturonans and rhamnogalacturonans Arabinans Galactans and arabinogalactans[1]
Hemicelluloses	Xylans [including arabinoxylans and (4-)-methyl glucuronoxylans] β-D-Glucans (1-3 and 1-4-linkages) β-D-Glucan-callose (1-3-linkages) Xyloglucans (1-4-β-D-glucans with attached side chains)
Other polysaccharides	Arabinogalactans[11] Glucuronomannans

Source: Aspinall, 1980

Arabinogalactans of type[1] are essentially linear and contain 4-linked β-D-galactan chains, where as those of type[11] contain branched 3- and 6- linked β-D-Galactan chains. These may occur in part as proteoglycans or polysaccharide-protein conjugates.

TABLE 7. Carbohydrate content of brown seeded and yellow seeded canola samples (% dry matter).

Component	Brown seeded	Yellow seeded
Glucose and fructose	0.5	0.6
Sucrose	7.7	9.8
Oligosaccharides[1]	2.5	2.4
Fructosans	Tr[2].	Tr.
Starch	2.5	2.6
Non-starch polysaccharides	17.9	21.4
Cellulose	4.6	6.0
Hemicellulose/pectin	13.3	15.4
Lignin+polyphenols	8.0	3.2
Total carbohydrates	31.1	36.8
Total fibre	30.1	27.3

[1]= Galactooligosaccharides (mostly raffinose & stachyose).
Tr[2]= Trace.

Source: Slominski, 1991.

carbohydrate components (i.e. lignin, polyphenols and structural proteins) of plant cell walls make up the bulk of dietary fibre (Graham, 1988; Theander and Åman, 1979).

2.4.2. Cellulose

Cellulose forms the most important part of the structural framework of plant cell wall materials (Aspinall, 1982) and is the major cell wall polysaccharide in canola (Robertson *et al.*, 1986; Slominski and Campbell, 1990). The polysaccharide is made up of long (1-4)-β-D-glucosyl residues which exist in an extended organised manner to form microfibrils (Kato, 1981). The units within and between microfibrils are held together by hydrogen bonds (Aspinall, 1982). The microfibrils are often surrounded by a matrix of other non-cellulosic cell wall constituents which are adsorbed to the surface of the microfibril or may exist as separate heteroglucans intermingled with the outer glucan chains (Kato, 1981). These non-cellulosic materials are often impossible to remove without the destructive degradation of cellulose (Van Soest, 1982). The binding of cellulose with other cell wall components may be important in that it prevents cellulose fibres from adhering to each other to form enormous aggregates that would be difficult or impossible to degrade (Albersheim, 1978).

2.4.3. Hemicellulose

This is the most complex and difficult component to comprehend of all the plant cell wall materials (Van Soest, 1987). Hemicellulose is a mixture of polysaccharides that

have a common β-(1-4)-glucosyl linkage in the xylan core polymer (Kato, 1981). A variety of other branching sugar polymers occur in the main chain. The major hemicellulose polysaccharides include:-

a. Xylans. These make up the bulk of the hemicellulose fraction and are characterised by D-xylopyranosyl residues joined together by (1-4)-β-linkages (Kato, 1981). Attached to the main chain are the short side chains of 4-0- methyl-D-glucuronic acid residues (Siddiqui and Wood, 1977). The 4-0-methyl- glucoxylans are a structural characteristic of the leguminous plants and may be used to distinguish dicotyledons from monocotyledons which have a common L- arabinofuranosyl residues attached to the (1-2)- α- 4-0-methyl-D- glucopyranosyl uronic acid residues (Siddiqui and Wood, 1977).

b. Xyloglucans. Xyloglucans are characterised by a repeating heptasaccharide unit consisting of four residues of 4-β-linked glucose units and three terminal xylose residues. The xylosyl residues are linked to the C-6 of three glucosyl residues. Side chains of 0-β-D-galactosyl (1-2) α-D-xylosyl residues may be present in the chain.

c. Glucomannans. These make up only a small portion of the hemicellulose fraction (Timell, 1964) and are composed of (1-4)-β- linked mannose and glucose residues. The mannose and glucose residues are in a 3:1 ratio and both are randomly distributed in the chain. About 50% of the mannosyl residues are substituted with 0-acetyl groups distributed between C-2 and C-3 (Lindberg *et al.*, 1973).

d. β-D-Glucans. Not so common in dicotyledons but mostly found in the endosperm cell walls of monocotyledons (cereals) are the cellulose related β-D- Glucans. These are made up of a repeating structure of (1-3) and (1-4)-β- linked D-glucose units in which

each callose unit is alternated with two (1-4)-β- glucose units (Anderson *et al.*, 1984; Labavitch and Ray, 1978).

2.4.4. Pectic Substances

Pectic polysaccharides make up the major portion of the non-cellulosic cell wall polysaccharides in rapeseed/canola (Siddiqui and Wood, 1977; Slominski and Campbell, 1990). This is a group of closely related but structurally different polysaccharides (Aspinall, 1982). The group is characterised by (1-4)-α-linked galactan (pectic acid) chain to which varying proportions of residues are present as methyl esters. The major polysaccharides in this group include:-

a. Rhamnogalacturonnans. The basic structure for these polysaccharides is composed of galactopyranosyluronic acid residues in which α-linked L-rhamnose residues are interspersed as methyl esters. The rhamnose components may occur as rhamnosyl (1-4)-galactopyranosyl uronic acid residues (Aspinall, 1981, McNeil *et al.*, 1979).

b. Arabinogalacturonnans. Arabinogalactans of plant origin fall into two main classes (Siddiqui and Wood, 1977). Those associated with pectic substances are composed of (1-3)-β- linked -D-galactopyranosyl residues to which (1-6)-β-galactooligosaccharides are attached (Kato, 1981). There are usually both pyranosyl and furanosyl residues in rapeseed/canola arabinogalactans (Larm *et al.*, 1975). These often contain terminal residues of L-arabinose and D-galacturonic acids and occasionally may have some doubly branched D-galactose residues (Siddiqui and Wood, 1977).

c. Arabinans and Galactans. These polysaccharides contain separate galactans and

arabinans. The arabinan portion is composed of a highly branched chain of (1-5)-α-linked arabinofuranosidic residues while the main chain of galactose polysaccharide is composed of (1-4)-β-galactan residues (Aspinall, 1973; Siddiqui and Wood, 1974; Larm *et al.*, 1975). The arabinosyl residues of rapeseed/canola pectic polysaccharides are mostly present as mono or disaccharide side chains (Aspinall and Jiang, 1974). Other sugar units in the molecule include D-xylose, L-fucose and D-apiose which are rare and may occur as 2-0- methyl esters in short chains of not more than three units (Aspinall, 1973; Darvill *et al.*, 1978).

Other carbohydrates that may be found in rapeseed/canola and other dicotyledonous plants include gums and mucilages. Gums, which have been characterised in mustard seeds (Grant *et al.*, 1969; Theander *et al.*, 1989) are hydrophillic polysaccharides consisting of β-(1-4)- mannose units in the main chain with single galactose units branching at the C-6 position of the moiety whereas mucilages are a group of highly branched polysaccharides.

2.4.5. Non Carbohydrate Component of Plant Cell Wall Materials

Also included in the dietary fibre fraction are the non-carbohydrate components of plant cell wall materials of which lignin, polyphenols and structural proteins are the most important (Asp *et al.*, 1983). Lignin, the major non-carbohydrate component in cell wall materials, is a propanoid polymer with a complex and as yet undetermined three

dimensional structure (Graham, 1988). It is synthesized by a complex polymerisation process of cinamyl, coniferol, ρ-coumaryl and sinapyl alcohols (Freudenberg and Neish, 1968; Sakakibara, 1977; Theander *et al.*, 1989). It is partly bound to the hemicellulose and cellulose fractions of cell walls and contributes to their nutritional and physical properties in the gut (Theander *et al.*, 1989). Closely associated with lignin are polyphenolic compounds of which tannins, cutin and waxes make up the greatest contribution (Theander, 1991). Tannins are often bound to protein complexes and may result in an overestimate of lignin content in cell wall materials (Carré and Brillouet, 1986; Asp *et al.*, 1983).

Plant cell walls of a wide range of plants contain a hydroxyproline rich glycoprotein (Lamport, 1965). This protein may account for 2-10% of the plant cell walls and up to 20% of the amino acid residues in the protein are hydroxyproline (Lamport, 1965). Other amino acids in the molecule include serine, histidine, lysine, tyrosine and valine. Most of the hydroxyproline residues in the chain are linked together by a tri- or tetrasaccharide of arabinofuranose moiety (Lamport, 1977; Akiyama and Kato, 1977) whereas the serine residues are galactosylated (Lamport, 1977). It is therefore not surprising that arabinose and galactose form the major carbohydrate components of this glycoprotein. Since cell wall components are known to be poorly digested by poultry (Carré and Brillouet, 1986; Carré *et al.*, 1990), it is very unlikely that this protein can be utilised. In heat processed feed materials, there may be a presence of Maillard browning reaction products (Van Soest, 1987). These are produced by the condensation of reducing sugar (i.e. glucose) residues with a free amino group of an amino acid (e.g.

lysine) in the presence of heat followed by polymerisation to form a substance possessing all the physical properties of lignin (Van Soest, 1987).

2.4.6. Analytical Characterisation of Cell Wall Polysaccharides

In recent years, there has been an upsurge of interest in the study of fibre in monogastric animals mainly as a result of increased availability of high fibre feeds, development of more sophisticated and accurate techniques of analysis and the realisation that fibre affects both the rate and extent of assimilation of other dietary components (Graham, 1988). The major problem in fibre analysis has been to define and develop proper analytical methods for it's characterisation (Trowell *et al.*, 1976; Theander *et al.*, 1989). Dietary fibre was initially defined as the plant cell wall remnants that are resistant to hydrolysis by human alimentary enzymes (Trowell, 1976). The definition has now been narrowed to include only the non-starch polysaccharides (i.e. cellulose, hemicellulose, pectic substances, galactooligosaccharides) and lignin that are resistant to endogenous secretions of the human gastrointestinal tract (Trowell *et al.*, 1976). Whether resistant starch (heat retrograded amylose) and Maillard reaction products are considered as dietary fibre is still a matter of debate. Characterisation of cell wall polysaccharides require structure determination with respect to sugar composition, linkage types, ring sizes and anomeric configurations (Aspinall, 1982). Thus, any determination of these polysaccharides that is to answer all the questions posed will require the use of a number

of different methods which can not be done in a reasonable space of time for routine work (Kato, 1981).

Historically, analysis of fibre was based on crude fibre determination which is the organic residue remaining after a feed sample has been refluxed with a weak acid followed by a weak alkali (Van Soest, 1982). The method measures the least digestible fibrous fraction which includes mainly cellulose and lignin which make up only a small and variable component of dietary fibre (Graham, 1988). Replacement of this technique has long been advocated (Southgate and Johnson, 1987; Van Soest and McQueen, 1973).

Detergent methods were developed by Van Soest and his colleague (1967) for fibre analysis of forages used in ruminant diets. These methods, neutral detergent fibre (NDF) and acid detergent fibre (ADF), represent the residue recovered after a feed sample has been treated with an anionic detergent solution containing ethylene diamine tetraacetic acid (EDTA), and a cation acid detergent solution, respectively. NDF, which is supposedly meant to measure plant cell wall materials is mostly composed of hemicellulose, cellulose and lignin but not some of the pectic substances and other soluble polysaccharides often present in dicotyledonous plants (Graham, 1988). NDF of starchy feeds (i.e. cereals) is often contaminated with starch and it has been proven necessary to heat treat the feed (Terry and Outen, 1973) or residue (Mongeau and Brasaard, 1979) with bacterial amylases to remove residual starch. The ADF component is often contaminated with some hemicellulose (Graham, 1988). It is thus clear that the detergent methods are not ideal for the characterisation of plant cell wall constituents.

Currently, there are two main procedures for the characterisation of plant cell

walls (dietary fibre), the gravimetric and the chemical methods (Theander, 1991). Both procedures involve the removal of hydrophillic and lipophilic materials by extraction with 80% ethanol and/or chloroform and also the removal of starch and protein (enzymatically) from feed samples (Theander and Åman, 1979). Most commonly used enzymes are thermal-stable bacterial α-amylase (i.e. Termamyl), protease and amyloglucosidase (Theander and Åman, 1979). Resistant starch in heat treated feeds has to be solubilised by dimethylsulphoxide (DMSO) before enzyme hydrolysis (Englyst and Cummings, 1988). The residue may then be fractionated into water soluble and water insoluble components by precipitating the soluble components in 80% ethanol or 95% ethyl alcohol.

The gravimetric procedure measures dietary fibre as the sum of the water soluble and water insoluble components (Asp *et al.*, 1983; Theander and Westerlund, 1986). Also included in the gravimetric methods is a procedure where cell walls (dietary fibre) are determined as the difference between organic matter content and the sum of starch, sucrose, oligopolysaccharides, crude protein and crude fat contents (Åman and Hesselman, 1984). Although gravimetric procedures do not give information on the chemical composition of the different types of fibres present (Asp et al., 1983) they may allow for the prediction of nutritive value and estimate of the degradability of the feed materials in the gastrointestinal tract (Carré and Brillouet, 1986).

The chemical procedures allow for the hydrolysis of separate sugar units in the polysaccharides and the subsequent characterisation of neutral non-starch polysaccharides (NSP) as alditol acetates by gas liquid chromatography (GLC) (Englyst and Cummings,

1988). In this regard, the unstable uronic acids are determined by colorimetric methods (Englyst and Cummings, 1984) or decarboxylation (Theander, 1991). The residue recovered after NSP hydrolysis may be washed, dried and gravimetrically analyzed as Klasson lignin (Theander *et al.*, 1989).

2.4.7. Effect and Utilisation of Fibre in Monogastric Animals

The role of dietary fibre in human beings is no longer questioned as this food component is known to have a corrective effect on a number of diseases associated with low fibre diets (Carré and Brillouet, 1985). However, there is still lack of data concerning the fibres in feedstuffs especially those fed to non-ruminant animals (Carré and Brillouet, 1986). Graham (1988) remarked that a better understanding of the complex effects of fibre on assimilation in pigs can only result from a detailed knowledge of the chemical and physical properties of fibre present in the diet. It has now been established that fibre can control both the rate and extent of assimilation of other dietary components.

In monogastric animals, the major part of digestion takes place in the small intestines by the host digestive enzymes which hydrolyse most of the alimentary components except for the non-starch polysaccharides (Schutte *et al.*, 1992). The extent of dietary fibre digestion in poultry is influenced by chemical composition, water solubility and degree of lignification of the fibre fractions in the diet (Bach Knudsen *et al.*, 1987). The digestibility of cell wall polysaccharides in poultry is limited by lack of

microbial activity in the lower GIT. This is because of a short colon and the ingesta-fractionation mechanism which allows only soluble and very fine particles to enter the caecum (McNab, 1973). Thus, most of the insoluble dietary fibres are not degraded in poultry (Table 8.).

Often, as fibre content of the diet increases, chickens (Pettersson and Åman, 1991) and pigs (Graham, 1988) tend to have an increased voluntary feed intake in an effort to maintain energy intake levels. However, intake is usually limited by bulky fibrous materials especially those that have a high water holding capacity. Fibrous diets are often associated with an increased rate of gastrointestinal transit time and emptying rate. The reduced transit time usually results in reduced contact time in each GIT section and hence lowered digestion and absorption rates.

Besides affecting the time of digestion and absorption, dietary fibre is often associated with lowered digestibility in monogastric animals, which is attributed to both the presence of indigestible fibre materials in the gastrointestinal tract and the effect of different fibre components on the availability of other nutrients (Graham, 1988). Insoluble cell wall materials encapsulate nutritive components such as starch, proteins and fats and act as a physical barrier to nutrient hydrolysis and utilisation in the small intestine (Hesselman and Åman, 1986). Soluble polysaccharides contain anti-nutritive factors which give rise to viscous solutions which retard gastrointestinal transit and delay gastric emptying rate (Jenkins *et al.*, 1978; Blackburn *et al.*, 1984). They are also able to form a thin layer on the surface of the GIT and impede nutrient absorption. Consequently, these conditions initiate a sense of satiety (Sellers, 1977) and result in

TABLE 8. Digestibility of non-starch polysaccharides from various feedstuffs in growing pigs and poultry (% of intake)

Animal	Source	Digestibility	Reference
Pigs	Barley	52.4	Graham *et al.*, 1988
Pigs	Beetpulp	53.7	Vervaeke *et al.*, 1991
Pigs	Wheat	55.2	Chabeauti *et al.*, 1991
Cockerels	Soybean meal	13.0	Carré *et al.*, 1990
Laying hens	Canola meal	2.6	Slominski and Campbell, 1990
Ducks	Wheat bran	8.9	Carré *et al.*, 1990
Cockerels	Lupin fibre	0.1	Carré *et al.*, 1985

Source: Slominski, 1991.

reduced nutrient uptake (Burnett, 1966; Johnsson and Gee, 1981). The gel-forming (viscous) compounds have been identified as water soluble pentosans (xylose and arabinose) in rye and wheat (Ward and Marquardt, 1987; Fengler and Marquardt, 1988) and β-D-glucan polysaccharides in barley (Hesselman and Åman, 1986).

The influence of dietary fibre on metabolism of bile acids and cholesterol in animals has been demonstrated (Kritchevsky and Story, 1986). Theander *et al.* (1989) reported that supplementation of a fibre rich brewers grain in pigs resulted in lowered serum cholesterol and bile acid levels. It is believed that soluble polysaccharides may reduce serum cholesterol concentration by draining bile acids from the enterohepatic system (Kay and Truswell, 1977; Anderson *et al.*, 1984). Young animals, especially chicks, are said to be in a state of bile acid deficiency and are unable to replenish the excreted acids to the same extent as older birds (Serafin and Nasheim, 1970) which may lead to reduced fatty acid digestibility. Dietary supplementation of bile acids in the chick, often result in increased absorption of saturated fatty acids (Kussaiabati *et al.*, 1982).

3.0. MATERIALS AND METHODS

3.I. Preparation of Treatment Canola Meals

Commercial (CCM) and dehulled (DCM) canola meals were obtained from Can Amera Foods (Altona, Canada) and POS Pilot Plant (Saskatoon, Canada), respectively. Seeds of brown seeded (*Brassica napus L,* cv. Westar) and yellow seeded (*Brassica compestris L,* cv. Parkland) canola were obtained from a commercial source in Winnipeg. The seeds were crushed to pass through a 1.5mm screen using a Willey mill standard model No.5 grinder (Authur H. Thomas Compony, Philadelpha, USA.) and defatted by soaking in *n*-hexane for two days after which the *n*-hexane was drained from the meal. The residual solvent in the meal was removed by drying the meal overnight at room temperature in a fumehood chamber. The dried meal was spread on aluminium trays (about 1.5cm depth) and autoclaved in a laboratory autoclave (American Steriliser Compony of Canada, Brampton, Ontario.) for 20 minutes at 105°C (timing started after the required temperature was attained). The autoclaved meal was dried overnight in a fumehood chamber at room temperature. It was then reground to pass through a 1mm sieve before being re-defatted in a soxlet apparatus with n-hexane for four hours. The prepared meals from each canola type (YSM and BSM) were mixed for 15 minutes in a Hobart feed mixer (Hobart Manufacturing Compony limited, Toronto, Canada) to obtain a homogenous material.

3.2. Chemical Analysis of Canola Meal Samples

Representative samples of each meal were taken and analyzed in duplicates for moisture, crude protein, ether extract and ash using established standard methods of analysis (AOAC, 1984). Neutral detergent fibre (NDF) was determined by the method of Goering and Van Soest (1970). Gross energy in the meals was determined on an adiabatic bomb colorimeter (Parr Instrument Compony, Moline, Illinois) and amino acids on *LKB Biochrom 4151 Alpha plus* (Biochrom, Science Park, Cambridge, UK.) amino acid analyzer following 24 hours of hydrolysis in 6N HCL acid at 110°C. Methionine and cystine were hydrolysed and analyzed after 20 hours of oxidation with performic acid. Glucosinolates and myrosinase activity were analyzed by gas liquid chromatography using the procedure of Thies (1977) as modified by Slominski and Campbell (1987).

Non-Starch polysaccharides were analyzed by gas liquid chromatography (neutral sugars) and colorimetry (uronic acids) using the procedures of Englyst and Cummings (1988) with minor modifications of Slominski and Campbell (1990). In this analysis, treatment samples were hydrolysed with sulphuric acid after solubilisation of starch with dimethyl sulphoxide (DMSO). The hydrolysed sugars were converted to alditol acetates by acetic anhydride with *N*-methylimmidazole (N-MetIm) catalysing the acetylation process. *Myo-inositol* was used as the internal standard. Neutral sugars as alditol acetates were analyzed by gas liquid chromatography on a Varian vista 6000 gas chromatograph equipped with a flame ionisation detector and a 402 integrating computer. A sodium salt of glucuronic acid was used to prepare an absorbency response curve for the colorimetric

determination of uronic acids. All calculated values were multiplied by a factor of 0.9 to correct for the dissociated water molecules in polysaccharide moieties.

To determine an estimate of lignin and associated polyphenols in the meals, NDF residues were obtained as described above and analyzed for crude protein, ash and NSP. Lignin was calculated as the difference between NDF and the sum of NDF-ash, NDF-crude protein and NDF-NSP. Determined neutral detergent non-starch polysaccharides were termed as neutral detergent insoluble polysaccharides (NDIP). The difference between total NSP and NDIP was termed neutral detergent soluble polysaccharides (NDSP). Total dietary fibre (TDF) in each meal was calculated as the sum of NDSP and NDF in the treatment samples.

3.3. Digestibility Trials

3.3.1. True Available Nutrients

A precision-fed cockerel bioassay of Sibbald (1986) with minor modifications of Campbell and Zhang (unpublished data) was used to determine the true availability of energy (TMEn), amino acids (TAAA) and non starch polysaccharides (TANSP) in canola treatment meals. Mature Single Comb White Leghorn (SCWL) cockerels were placed in individual wire cages in an environmentally controlled room. The birds received 16 hours of light/day and had free access to fresh water throughout the experimental period.

Following a 28 hour fasting period, the cockerels were force-fed 25g of canola meal treatment samples and excreta was collected quantitatively over the next 48 hours on trays placed under the cages. Twelve birds were fed each treatment meal and the assay was conducted twice. To determine an estimate of endogenous energy and nitrogen excretion, excreta from two groups of 24 cockerels each was collected for 48 hours following 28 hours of fasting. In both cases, it was assumed that the gastrointestinal tract (GIT) of the birds was empty prior to and following the 48 hour collection period. The collected excreta samples were frozen, freeze dried and weighed after equilibrating to atmospheric temperature for 24 hours. Excreta samples from each treatment were pooled and ground to pass through a 1mm screen and taken for gross energy, amino acids and NSP analysis as described in the chemical analysis section. True availability of analyzed nutrients were calculated according to the equations of Sibbald (1986).

3.3.2. Nutrient Digestibility Assay

Single Comb White Leghorn (SCWL) layers (48 weeks old) were used in this study. The hens were kept in individual wire mesh cages and had an *ad libitum* supply of feed and water prior to and during the experimental period. The hens received 16 hours of light daily. In order to assess the possibility of hindgut fermentation, both intact (normal) and cecectomised hens were used in the study. The birds were cecectomised according to the procedure of Payne *et al.* (1971).

Semi purified diets consisting of 45% canola meal were formulated (Table 9.) and fed to seven intact and seven cecectomised hens (14 birds/treatment diet) for six days. Chromic oxide (Cr_2O_3) was used as an indigestible marker. The first 4 days were used as the adjustment period and excreta samples from each hen were collected on the last two days by placing a metallic tray under the cage. The collected excreta was frozen in liquid nitrogen within one hour of voiding after which it was freeze dried and ground in a coffee grinder after equilibrating to atmospheric temperature for a day. Daily feed intake during the study was determined by feed weigh backs.

Feed and excreta samples were analyzed in duplicate for amino acids, non-starch polysaccharides and gross energy as described in the chemical analysis section. Lipids were assessed according to the procedure of Marchello *et al.* (1971) and chromic oxide according to Williams *et al.* (1963). Coefficients of feed and nutrient digestibility (amino acids, NSP, energy and lipids) were calculated according to the equations shown below:-

(a). % Diet Digestibility = [1-(%Cr_2O_3 in Feed/%Cr_2O_3 in Excreta)] X 100

(b). % Nutrient Digestibility =

[1 - (%Nutr. in Excr./%Nutr. in Feed X %Cr_2O_3 in Feed/%Cr_2O_3 in Excreta.)]

TABLE 9. Composition of digestibility trial diets (% of the diet).

Ingredient.	Diets[1] 1.	2.	3.	4.
Sucrose	40.85	40.85	40.85	40.85
YSM[2]	45.00	–·–	–·–	–·–
CCM[3]	–·–	45.00	–·–	–·–
BSM[4]	–·–	–·–	45.00	–·–
DCM[5]	–·–	–·–	–·–	45.00
Limestone	8.00	8.00	8.00	8.00
Biophosphorus	1.00	1.00	1.00	1.00
Sunflower oil	3.50	3.50	3.50	3.50
Vitamins[6]	1.00	1.00	1.00	1.00
Minerals[7]	.35	.35	.35	.35
Cr_2O_3	.30	.30	.30	.30
TOTAL	100.00	100.00	100.00	100.00

[2].- Yellow seeded canola meal, [3].- Commercial canola meal, [4].- Brown seeded canola meal and [5].- Dehulled canola meal.

[1]. All contained 17.1% crude protein and 2817 kcal/kg metabolizable energy.
[6]. Contained 8250 IU vit. A, 1000 IU vit. D_3, 5.46 IU vit. E, .0112mg vit. B_{12}.
[7]. Manganese 55mg, Zinc 50mg, Iodized salt 2.5g/kg diet.

3.4. Chick Feeding Trial

A feeding trial was conducted for two weeks to determine the feeding value of canola meal based experimental diets. Treatment diets consisting of 20% canola meal (diets 1-4) were formulated as shown in Table 10. Diet 5 was formulated to be iso nitrogenous to the other canola meal diets (diets 1-3) by adding 17% DCM and 3% alphacell (fibre). Alphacell was used as a biologically inert filler material.

Prior to the onset of the experiment, day old (SCWL) cockerels were housed in thermal controlled starter battery cages with raised wire floors in an environmentally regulated room. The chicks were exposed to 24 hours of light and received an *ad libitum* supply of fresh water and a standard broiler starter diet (Feed-rite starter pellets). On day eight, chicks were weighed and those close to the group average were randomly allocated to experimental diets. Six groups of 6 birds each were assigned to each diet and group feed intake and weight in each cage were measured weekly to facilitate the calculation of body weight gain and feed conversion ratio.

TABLE 10. Composition of feeding trial treatment diets (% of the total diet)

Ingredient	Diets 1	2	3	4	5
Wheat	67.65	67.65	67.65	67.65	67.65
YSM[1]	20.00	–·–	–·–	–·–	–·–
BSM[2]	–·–	20.00	–·–	–·–	–·–
CCM[3]	–·–	–·–	20.00	–·–	–·–
DCM[4]	–·–	–·–	–·–	20.00	17.00
Soybean meal	4.00	4.00	4.00	4.00	4.00
Fish meal	4.00	4.00	4.00	4.00	4.00
Sunflower oil	1.00	1.00	1.00	1.00	1.00
Limestone	1.30	1.30	1.30	1.30	1.30
Phosphorous	.70	.70	.70	.70	.70
Vitamins[5]	1.00	1.00	1.00	1.00	1.00
Minerals[6]	.35	.35	.35	.35	.35
Alphacell	–·–	–·–	–·–	–·–	3.00
TOTAL	100.00	100.00	100.00	100.00	100.00

[1]= Yellow seeded canola meal, [2]= Brown seeded canola meal, [3]= Commercial canola meal, [4]= Dehulled canola meal.

[5]. Supplied Vitamins (per kg diet) :-
A , 8250.0 IU; D_3=1000.0 IU; E , 10.9 IU; B_{12} , .0115mg; K , 1.1mg; Niacin, 53.3mg; Folic acid , .75mg; Biotin , .25mg; Riboflavin , 5.5mg and Choline; 781.2mg.

[6]. Supplied (mg/kg diet) :- Manganese , 55; Zinc , 50; Iron , 80; Copper , 5; Selenium , .1; Iodized salt, 2.5g/kg.

3.5. Statistical Analysis

All collected data were analyzed on the University of Manitoba computer mainframe using the analysis of variance (ANOVA) and general linear model (GLM) procedures of Statistical Analysis System (SAS inc., 1989). Differences between various treatment means were compared and separated by Tukey's studentized range (HSD) test of significance at $P \leq .05$ level. The digestibility and feeding trial assays were analyzed as completely randomized designs (CRD).

4.0. RESULTS AND DISCUSSIONS

4.1. Chemical Analysis of Canola Meal Samples

The chemical composition of the four canola meal samples are presented in Table 11. The dry matter (DM) content ranged from 90.30% in YSM to 93.35% in DCM meal with CCM and BSM having 90.65% and 91.40%, respectively. The differences in dry matter content of the meals may be attributed to varying processing and drying conditions to which the meals were exposed. The same reasoning may be used to explain the differences observed in the meal ether extract content. This is especially true for ether extract since the oil content in canola meal depends on the residual oil remaining after canola oil extraction and the amount of gums added back to the meal (Bell, 1984). However, since BSM contained more ether extract than YSM and considering that the two meals were processed under the same laboratory conditions with no gums added back to each meal, it may be stated that oil in yellow seeded canola is easier to extract than that in brown seeded canola. This may be an important factor in reducing the cost of canola oil extraction. The ash content in CCM was significantly higher than in YSM and DCM which had similar levels. The ash level in BSM was significantly lower than in CCM but statistically similar to that in YSM and DCM. Bell and Keith (1991) reported that the ash content in commercial canola meal tends to vary with the composition of the seed processed and the soil and growing conditions under which the seed was grown.

TABLE 11. Proximate composition of canola meal samples used in the experiments (% of dry matter).

	Canola meals[1]				
Component	YSM	BSM	CCM	DCM	SEM
Dry matter	90.30[a]	91.40[a]	90.65[a]	93.35[a]	.290
Crude protein	41.13[b]	41.54[b]	40.77[b]	47.19[a]	.147
Ether Extract	1.59[c]	3.97[a]	3.51[ab]	2.73[b]	.109
Ash	7.69[b]	6.37[b]	8.12[a]	7.62[b]	.023

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled canola meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

This may be the explanation for the low ash content in BSM compared to that in YSM, although it could also be due to the effect of hulls since dark coloured hulls are known to have lower ash content than yellow coloured hulls (Bell and Shires, 1982). The 7.62% ash content reported for DCM is in close agreement to the 7.60% reported by Bell (1991) on dehulled Westar canola meal. Dehulling of the seed does not seem to have any effect on the dry matter and ash contents of the meal (Zuprizal et al., 1991a).

The crude protein contents in all the meals were similar apart from the DCM which had a significantly higher level. The high protein content in DCM was mainly a result of removing the hulls which are known to have a lower protein content than the cotyledons (Bell and Shires, 1982). The amino acid composition in BSM and YSM was comparable to that of CCM (Table 12) which is in support of the findings of Mutzar and Slinger (1982) and Bell (1991) who reported minor differences in protein and amino acid composition of meals manufactured from different rapeseed/canola varieties. With the exception of phenylalanine, lysine and arginine, all amino acids were higher in DCM than in the other meals, however, only aspartic acid, threonine, glutamic acid, glycine, methionine, isoleucine and leucine were statistically different. The difference in amino acid content between DCM and the other meals was due to the high protein content in this meal. When total amino acid values were compared to crude protein levels in the meals, the later was higher in all the treatments. This confirms Bell's (1984) conclusion that the correct factor for converting canola nitrogen to protein is 5.53 instead of 6.25 which tends to overestimate the protein level in the meal. The 5.53 factor, however, may underestimate the protein level as was evidenced in this study and that of Salmon *et al.*

TABLE 12. Amino acid composition in canola meal samples used in the experiments (% of dry matter).

	Canola meals[1]				
Amino Acid	YSM	BSM	CCM	DCM	SEM
Asp. acid	3.32^{b}	3.06^{d}	3.16^{c}	3.49^{a}	.011
Threonine	1.87^{b}	1.89^{b}	1.75^{c}	2.04^{a}	.011
Serine	1.99^{a}	1.98^{a}	1.98^{a}	2.24^{a}	.033
Glu. acid	7.52^{c}	8.07^{b}	8.04^{b}	9.56^{a}	.052
Proline	2.92^{a}	2.93^{a}	3.07^{a}	3.21^{a}	.103
Glycine	2.10^{b}	2.17^{ab}	2.21^{ab}	2.52^{a}	.046
Alanine	1.89^{a}	1.87^{a}	2.00^{a}	2.19^{a}	.051
Cystine	1.01^{b}	1.07^{b}	1.07^{b}	1.23^{a}	.008
Valine	1.58^{a}	1.51^{a}	1.59^{a}	1.65^{a}	.093
Methionine	.97^{bc}	1.04^{b}	.93^{c}	1.16^{a}	.011
Isoleucine	1.18^{ab}	1.16^{ab}	1.09^{b}	1.25^{a}	.018
Leucine	2.74^{b}	2.75^{b}	2.74^{b}	3.21^{a}	.039
Tyrosine	1.18^{a}	1.04^{a}	1.05^{a}	1.18^{a}	.070
Phe. alanine	2.06^{a}	1.82^{a}	1.82^{a}	1.99^{a}	.160
Histidine	1.13^{a}	1.12^{a}	1.19^{a}	1.26^{a}	.020
Lysine	2.36^{a}	2.34^{a}	2.30^{b}	2.36^{a}	.003
Arginine	2.15^{a}	2.05^{a}	2.12^{a}	2.21^{a}	.056
Total	37.97^{b}	37.87^{b}	38.09^{b}	42.74^{a}	.240

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- dehulled canola meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

(1991). The conversion factor in both cases was around 5.80, which should be the recommended value for converting canola nitrogen to protein. The higher crude protein and amino acid levels in DCM meal compared to the other canola meals is in conformity with the findings of Bell (1991) and Zuprizal *et al.* (1991a) who made similar observations. The increase is a result of removing the diluting effect of hulls in the meal which are also known to contain relatively low levels of amino acids (Finlayson, 1974).

To compare the composition and quality of protein in each meal, amino acid contents were evaluated as percentage of crude protein in the meal (Table 13). It was noted that there were few significant differences in the amino acid composition of protein among meals except for the YSM which had a significantly higher aspartic acid, threonine and lysine but a lower glutamic acid levels than other meals. This may be related to type of canola as YSM was the only compestris variety in the study. Significantly higher levels of cystine were recorded in BSM. To investigate the effect of dehulling on protein amino acid profile, amino acid composition of BSM was compared to that of DCM since both were prepared from Westar seed. Dehulling the seed decreased the concentration of serine, proline, cystine, valine, isoleucine, phenylalanine, lysine and arginine. However, the decreases were only statistically significant for lysine and cystine. These findings are in close agreement to those of Zuprizal *et al.* (1991a) who reported decreased threonine, serine, valine, tyrosine, phenylalanine, lysine, and tyrosine concentrations in dehulled rapeseed meal. Picard and Darcy-Vrillon (1985) noted lysine levels in dehulled canola meal to be lower than in whole seed meals whereas Bell (1991) observed low lysine, tryptophan, tyrosine, valine and threonine in dehulled meal

TABLE 13. Amino acid composition in canola meal samples used in the experiments (% of crude protein).

	Canola meals[1]				
Amino Acid	YSM	BSM	CCM	DCM	SEM
Asp. acid	8.07[a]	7.36[c]	7.75[b]	7.40[c]	.023
Threonine	4.54[a]	4.33[b]	4.28[b]	4.32[b]	.023
Serine	4.85[a]	4.76[a]	4.85[a]	4.75[a]	.079
Glu. acid	18.28[b]	19.42[a]	19.75[a]	20.27[a]	.128
Proline	7.09[a]	7.06[a]	7.52[a]	6.80[a]	.257
Glycine	5.10[a]	5.22[a]	5.43[a]	5.35[a]	.111
Alanine	4.60[a]	4.50[a]	4.91[a]	4.64[a]	.124
Cystine	2.45[c]	2.83[a]	2.63[b]	2.61[bc]	.019
Valine	3.85[a]	3.63[a]	3.90[a]	3.49[a]	.228
Methionine	2.36[a]	2.50[a]	2.28[a]	2.47[a]	.026
Isoleucine	2.89[a]	2.79[a]	2.69[a]	2.66[a]	.038
Leucine	6.67[a]	6.62[a]	6.72[a]	6.81[a]	.096
Tyrosine	2.86[a]	2.50[a]	2.57[a]	2.50[a]	.167
Phe. alanine	5.00[a]	4.37[a]	4.46[a]	4.21[a]	.380
Histidine	2.74[a]	2.70[a]	2.92[a]	2.67[a]	.050
Lysine	5.74[a]	5.64[b]	5.64[b]	5.00[c]	.006
Arginine	5.74[a]	4.95[a]	5.19[a]	4.68[a]	.137

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled canola meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

than in hulls. All these findings support the reports of Sarwar *et al.* (1981) who found hull proteins (mainly testa) to be higher than dehulled meal protein (mainly cotyledons) in lysine, threonine, valine, aspartic acid,glycine, serine and tyrosine.

Glucosinolate contents in the CM treatments are as presented in Table 14. Apart from DCM which had considerably lower levels, there were no differences in the total glucosinolate content among CM samples. The results for BSM and CCM were comparable to the values 14.30 and 17.22 μmoles g^{-1} obtained by Slominski and Campbell (unpublished results) and Bell *et al.* (1991) for the two meals. Variations in the glucosinolate content of the meals prepared from different crushing plants has been demonstrated (Bell and Keith, 1991). These differences do not only reflect regional and cultivar variations, but also the differences in the processing conditions to which the seeds are subjected. The extent of glucosinolate destruction in the meal tend to vary with the processing temperature in the desolventizing-toaster phase (Campbell and Cansfield, 1983). This is especially true for indole glucosinolates which are known to have high thermal susceptibility (Campbell and Slominski, 1990). In this regard, the significantly lower indole glucosinolates (4-hydroxy-3-indolylmethyl and 3-indolylmethyl) in DCM indicates that the meal was processed at higher temperatures and/or for a longer time than the other meals as was also apparent from the dark meal colour. The low glucosinolate levels in DCM confirms the conclusion by Bell (1991) that in addition to glucosinolate destruction in the desolventizing-toaster phase, the meal expanding process results in extensive glucosinolate destruction. Thus, the reduced glucosinolate content in DCM, which is contrary to the expectations since glucosinolates are primarily

TABLE 14. Glucosinolate contents in canola meal samples used in the experiments (μmoles g^{-1} of oil free meal).

	Canola meals[1]			
Glucosinolate	YSM	BSM	CCM	DCM
Allyl	ND[2]	ND	0.1	ND
3-butenyl	2.9	3.5	3.3	1.3
4-pentenyl	1.6	0.3	0.5	0.1
2-OH-3-butenyl	5.6	7.3	6.2	2.2
2-OH-4-pentenyl	1.0	0.1	0.1	0.0
4-OH-benzyl	ND	ND	1.4	ND
3-indolylmethyl	0.1	0.4	0.2	0.1
4-OH-3-indolylmethyl	3.3	3.4	2.6	0.4
Myrosinase activity[3]	ND	ND	ND	ND
Totals				
Aliphatics	11.1	11.2	10.1	3.6
Indoles	3.4	3.8	2.8	.5
Contaminants[4]	ND	ND	1.5	ND
Overall Total	14.5	15.0	14.4	4.1

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled canola meal.

ND[2]- Not detected.

[3]Myrosinase activity (μmoles/hour/g.) - Estimated by the glucosinolate assay procedure without the heating step following incubation of meal with water (autolysis) for one hour.

[4]Glucosinolates (allyl and 4-hydroxybenzyl) from weed seeds as a result of contamination in the meal.

constituents of the cotyledons, reflects damage by the high processing temperatures and/or longer residence time during processing. The high heating temperatures and/or longer heating periods are also of major concern regarding meal protein and amino acid quality. The presence of allyl and 4-hydroxybenzyl glucosinolates in the CCM demonstrates weed seed contamination in the meal. Allyl glucosinolate indicates brown mustard (*Brassica juncea*) or stinkweed (*Thlaspi arvensi*) contamination and 4-hydroxybenzyl indicates contamination from wild mustard (*Sinapis arvensi*) (Bell *et al.*, 1991). Contaminating seeds are not separated in canola seed cleaning and tend to reflect the adequacy of farm weed control. The two glucosinolates, especially 4-hydroxy-benzyl, are known to be heat stable and are quite difficult to destroy during CM manufacturing (Slominski and Campbell, 1988; Bell and Keith, 1991). The absence of myrosinase activity in all the CM treatment samples reflect the effectiveness of the processing conditions employed to inactivate the enzyme. The importance of this step in producing a good quality meal with minimal toxicological potential from glucosinolate hydrolytic products has long been recognised (Bell, 1984).

Total dietary fibre (TDF) and other fibre components in canola meal samples are shown in Table 15. Significantly higher values were recorded in BSM for both NDF and TDF whereas YSM and DCM meals had the lowest levels of NDF and TDF, respectively. The results for TDF content in YSM and BSM are in support of the reports of Slominski and Campbell (1991) and Stringam *et al.* (1974) who reported dark seeded canola to have higher fibre content than yellow seeded canola. The low TDF content in DCM confirms earlier findings (Bell, 1991) and was mainly due to the removal of hulls

TABLE 15. Composition of dietary fibre components in canola meal samples used in the experiments (% of dry matter).

	Canola meals[1]				
Component[2]	YSM	BSM	CCM	DCM	SEM
NDF	19.45^{b}	27.89^{a}	25.28^{a}	20.37^{b}	.299
NDIP	12.05^{a}	11.40^{ab}	12.25^{b}	8.45^{ab}	.225
NDSP	10.93^{a}	7.88^{b}	5.89^{c}	6.00^{c}	.090
NDF-Ash	1.54^{d}	8.92^{a}	2.47^{c}	3.55^{b}	.022
NDF-CP	3.45^{ab}	2.99^{b}	2.86^{b}	4.13^{a}	.078
Lignin	2.41^{b}	4.55^{b}	7.65^{a}	4.25^{b}	.214
NSP	22.98^{a}	19.28^{b}	18.14^{c}	14.67^{d}	.060
TDF	30.38^{b}	35.78^{a}	31.19^{b}	26.35^{c}	.297

[1]YSM- Yellow seeded canola meal, BSM- Brown Seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled Canola Meal.

[2]NDF- Neutral detergent fibre, NDIP- Neutral detergent insoluble polysaccharides, NDSP- Neutral detergent soluble polysaccharides, NDF-CP, Neutral detergent fibre crude protein, NSP- Non-starch polysaccharides, TDF- Total dietary fibre.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

which are the main source of dietary fibre in canola meal (Bell and Shires, 1982). The NDF content did not follow the same trend as TDF because treatments contained varying levels of soluble dietary fibre components and NDF does not contain the water/EDTA soluble fibre components which make up a considerable portion of TDF in canola and other leguminous plants. Using the same argument Theander et al. (1989) concluded that NDF values should be treated with caution as they tend to underestimate dietary fibre values. The NDF content in DCM was slightly less than that reported by Bell (1991) who concluded that dehulled canola meal contain 24-25% neutral detergent fibre.

Analysis of NDF residues showed YSM to have a significantly higher level of neutral detergent soluble polysaccharides (NDSP) than all the other treatments, but when the level of neutral detergent insoluble polysaccharides (NDIP) was evaluated, again YSM together with CCM had significantly higher values than that of DCM and BSM. It is possible that the high NDSP and NDIP in YSM was due to the higher NSP content in the meal. Commercial canola meal and the dehulled meal had the lowest NDSP content which again may be due to the low NSP levels in these meal. These differences were confirmed by calculating the NDIP and NDSP values as percentages of total NSP (not shown). The high protein level in DCM neutral detergent residues is in agreement with the findings of Moshtaghi Nia and Ingalls who reported the increased nitrogen content in NDF to be attributed to the less soluble protein and some of the heat denatured protein. However, the increased NDF-protein in DCM could also be a result of the Maillard browning reaction which is often associated with overcooked feedstuffs (Van Soest, 1987). The high NDF ash in BSM can not be explained with certainty though it

may be speculated that some kind of chemical binding occurred during meal processing or in NDF recovery. However, this does not explain why the same reaction did not occur in YSM which was processed in the same manner or why the effect was not evident for all meals as a consequence of NDF recovery in the analysis.

Lignin and associated polyphenols content were highest and lowest in CCM and YSM, respectively. The unusually high NDF-ash in BSM influenced the lignin value, which would have been closer to that of CCM, thus confirming earlier findings that dark seeded canola have a higher lignin and associated polyphenols content than yellow seeded canola (Theander *et al.*, 1977; Slominski and Campbell, 1991). The presence of lignin in DCM meal signifies that some seed coat hulls remained in the meal, though it may also serve to indicate the presence of Maillard reaction products which have similar properties to lignin (Van Soest, 1987).

Seed size is also an important factor affecting the oil, protein and fibre content in canola. Stringam *et al.* (1974) stated that seed from yellow seeded canola are smaller and contain thinner hulls which make them heavier as they tend to have a higher proportion of protein and oil containing embryos than brown seeded canola. To confirm these findings, weights of 1000 seeds from different cultivars of yellow and brown seeded canola varieties were compared (Table 16). The results do not support earlier reports on seed colour and size, but seem to indicate that seed weight may vary even among seeds of the same variety depending on agronomic growing conditions as may be demonstrated by the brown seeded canola (cv. Westar) samples. Seed size is also affected by the growing season with winter cultivated seeds being bigger than summer cultivated

TABLE 16. Seed size in yellow and brown coloured canola varieties (mg/1000 seeds).

Variety	Seed colour	Seed size
Horizon	yellow	2.99
Colt	yellow	2.52
Parkland	yellow	2.43
Legend	brown	2.15
Westar[1]	brown	3.13
Westar[2]	brown	2.81

Westar[1&2] were from different batches.

seeds (Downey, 1983). The same author also studied the relationship between seed size and protein, oil and fibre contents and observed that the brown seeded variety, Torch, which was smaller in size, to have less oil and protein and a higher fibre content than yellow coloured variety, Sarson, which was bigger in size. Thus, the genetic make up together with agronomic conditions rather than size *per se,* have more effect on seed oil, protein and fibre contents.

Plant cell walls are composed of a series of structural polysaccharides built up by a number of monosaccharide units. An example of a gas liquid chromatogram showing the hydrolysed canola meal neutral sugar constituents as alditol acetates is presented in Figure 1 and the amount of individual sugar components in Table 17. Yellow seeded canola contained higher levels of virtually all the NSP components than the other meals, which would appear to be a reflection of the total NSP content rather than qualitative changes in the sugar profiles between treatments. This latter effect was demonstrated in an earlier study (Slominski and Campbell, 1990). The NSP results for YSM and BSM agree with the report of Slominski and Campbell (1991) that yellow seeded canola contain higher levels of NSP than dark seeded canola although the values reported in the current study were high. The CCM had less NSP content than BSM which was mainly caused by lower glucose and uronic acids in CCM. This could have been caused by loss or destruction of soluble polysaccharides during meal processing. Dehulled canola meal had the lowest NSP content mainly because of hull removal from the meal.

The source of various sugar components from canola treatments can not be stated with certainty from this study. However, earlier studies have shown that glucose, the

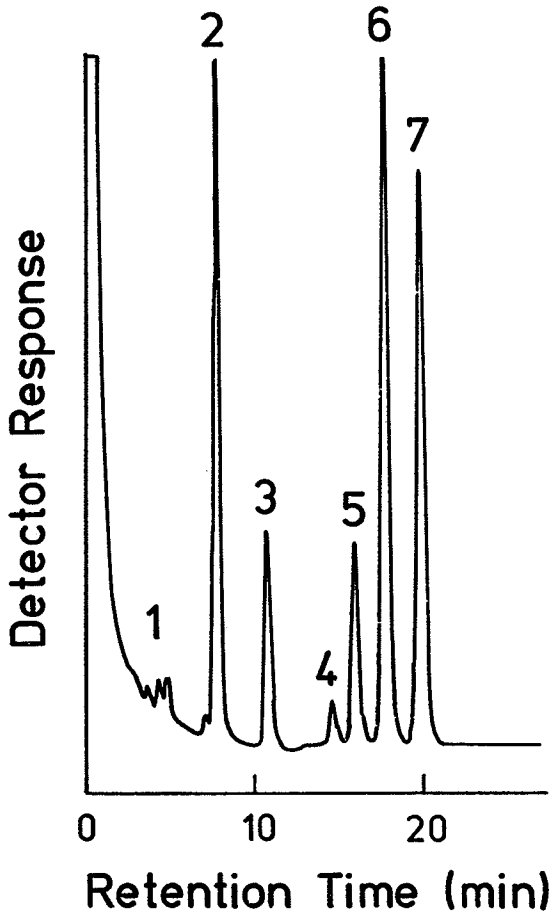


FIGURE 1. Profile of canola meal neutral sugar constituents hydrolysed as alditol acetates: 1. rhamnose, 2. arabinose, 3. xylose, 4. mannose, 5. galactose, 6. glucose and 7. myo-inositol (internal standard).

TABLE 17. Non-starch polysaccharides in canola meal samples (mg/g of dry matter).

	Canola meals[1]				
Component	YSM	BSM	CCM	DCM	SEM
Rhamnose	2.53[a]	2.25[a]	1.89[a]	2.32[a]	.31
Arabinose	47.90[a]	40.50[b]	36.00[b]	35.75[b]	.70
Xylose	21.30[a]	15.60[a]	19.05[a]	15.60[a]	.91
Mannose	4.75[a]	4.04[b]	4.01[b]	3.26[c]	.05
Galactose	18.90[a]	16.85[b]	16.10[b]	14.35[c]	.19
Glucose	72.05[a]	62.40[b]	61.80[b]	44.60[c]	1.06
Uronic acids	62.51[a]	51.17[b]	42.57[c]	30.06[d]	.30
Total	229.8[a]	192.8[b]	181.4[c]	146.7[d]	.06

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled canola meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

major sugar constituent released, is mostly from cellulose present in the hull cell walls (Carré and Brillouet, 1986; Robertson *et al.*, 1986). In this regard, the low glucose level in DCM confirms that a substantial amount of hulls were removed from the meal. However, not all glucose in canola is from cellulose, as a number of hemicellulosic polysaccharides(e.g. amyloids and xylans) also contain glucosyl residues.The origin of other sugar residues can be assessed from the compositional data relative to the component carbohydrates. Uronic acids in canola samples may have been from galacturonic acids in pectic polysaccharides or glucuronic acids in hemicelluloses but since canola and other leguminous plants are known to have a high content of pectic polysaccharides, it may be stated that most of the uronic acids in the samples were from galacturonic acid. Also common to the pectic substances would be arabinose and galactose sugar components which have been found in arabinogactans, arabinans and/or galactans (Siddiqui and Wood, 1977; Larm *et al.*, 1976). In addition to being found in pectic polysaccharides, galactose and arabinose have also been reported to be major constituents of non cellulosic neutral polysaccharides of Swede rapeseed meal (Robertson *et al.*, 1986). Rhamnose and xylose make up important components of rhamnogalacturonans and xylan polysaccharides, respectively, both of which have been identified in rapeseed/canola (Siddiqui and Wood, 1977).

4.2. Digestibility Assays.

4.2.1. True Availability of Canola Meal Components

The amount of true metabolizable nutrients varied considerably among CM samples (Table 18). True Metabolizable Energy (TMEn) was significantly higher in DCM than in CCM which in turn was significantly higher than the similar level in YSM and BSM. The TMEn values for the YSM and BSM were slightly lower than that of commercial canola meal average value 9.71 MJ/kg evaluated by Zhang and Campbell (in press) and agreed with the findings of Mutzar and Slinger (1982) who reported no significant differences between meals from *Brassica napus* and *Brassica compestris* canola varieties. However, since lipids are considered to be the major contributing components to the metabolizable energy content of the meal and considering the fact that YSM had less ether extract content than BSM, it may be stated that the TMEn content in YSM would have been higher than that in BSM had the two meals contained similar ether extract levels. In this regard, higher TMEn content in CCM compared to YSM and BSM may be due to ether extract content which would reflect the effect of gums added back to the meal during meal manufacture (Bell, 1984). Drying of the meal to remove solvents could also have contributed to increased energy content in the meal since steam pelleting is known to increase metabolizable energy level in the meal. Being laboratory prepared meal, YSM and BSM were not exposed to the same conditions as CCM. The higher TMEn content in DCM is in agreement with earlier reports which concluded that dehulling of canola results in increased metabolizable energy content in meal (Seth and

TABLE 18. True availability of various canola meal constituents.

Constituent	Canola meals[1] YSM	BSM	CCM	DCM	SEM
TMEn[2]	9.311[c]	9.184[c]	10.046[b]	11.011[a]	.041
TA-NSP[3]	13.230[a]	16.370[a]	11.570[b]	5.290[c]	.548
NSP[4]	3.041[a]	3.157[a]	2.100[b]	.778[c]	.915
Amino acids (% of amino acids in the meal)					
Asp.	89.06[a]	84.31[b]	88.02[a]	89.30[a]	.435
Thr.	83.40[b]	78.97[c]	83.81[b]	87.31[a]	.467
Ser.	85.50[ab]	80.68[b]	86.56[a]	88.83[a]	.774
Glu.	92.77[ab]	91.13[b]	92.71[ab]	93.73[a]	.288
Pro.	84.52[a]	82.76[a]	85.82[a]	87.15[a]	.958
Gly.	81.42[b]	80.25[b]	84.13[ab]	88.12[a]	.702
Ala.	87.72[ab]	84.12[a]	89.13[a]	89.28[a]	.697
Cys.	84.79[a]	83.69[a]	85.67[a]	87.95[a]	.653
Val.	82.85[ab]	80.60[b]	86.31[a]	87.22[a]	.775
Met.	93.20[a]	92.87[a]	94.56[a]	96.08[a]	.660
Iso.	80.44[c]	81.33[bc]	85.65[ab]	86.37[a]	.667
Leu.	87.54[bc]	85.10[c]	90.13[ab]	91.24[a]	.406
Tyr.	79.29[a]	64.98[a]	69.07[a]	76.46[a]	7.176
Phen.	90.19[ab]	87.43[b]	89.79[ab]	92.40[a]	.433
His.	88.39[b]	88.02[b]	88.77[b]	93.17[a]	.392
Lys.	87.34[a]	86.58[a]	87.59[a]	89.05[a]	.854
Arg.	81.90[a]	80.43[a]	87.63[a]	86.64[a]	1.290
Total	86.99[bc]	84.66[c]	88.01[ab]	89.91[a]	.387

[1]YSM- Yellow seeded canola meal, BSM- Brown seeded canola meal, CCM- Commercial canola meal and DCM- Dehulled canola meal.

TMEn[2]- True metabolizable energy corrected for N excretion (MJ/kg meal), TA-NSP[3]- Total available non-starch polysaccharides as % of NSP in the meal and NSP[4]- non-starch polysaccharides percentage of the meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

Clandinin, 1973; Beylay and Hill, 1975). The increase in TMEn results from the removal of hulls which are known to depress metabolizable energy content because of their higher dietary fibre content (Sarwar *et al,*. 1981).

Table 18 also shows data on the availability of non-starch polysaccharides (NSP) in different canola meal samples. The availability of NSP were evaluated as a percentage of the meal and also as percentage of the total NSP in the meal. When considered as percentage of the meal, there were no statistical differences between YSM and BSM, despite differences in total NSP and TDF content. Significantly lower availability values were noted for DCM. When NSP availability was considered as percentage of total NSP in the meal, contrary to the expectations, BSM tended to have slightly higher availability values than YSM which had a higher NSP content but less lignified cell walls. The availability values were again lowest in DCM which indicates that the NSP remaining after dehulling the meal are almost completely unavailable in poultry. There was a generally low NSP availability in all CM treatments which is in support of the conclusions made by Carré and Brillouet (1986) that the ability of domestic birds to digest plant cell walls is very minimal. The low NSP availability in poultry may be explained by the fact that due to the ingesta- fractionation mechanism, only soluble and very fine particles are able to enter the ceca (McNab, 1973). The colon of the domestic bird is also shorter than that of other monogastric animals and it's microflora is said to be devoid of cellulase activity (McNab, 1973).

The amino acid availability in the four canola samples ranged from 64.96 to 96.08%. For some unknown reason, tyrosine had the lowest and most variable

availability in all the treatments whereas methionine was the most available with availability values ranging from 92.87% in BSM to 96.08% in DCM. These results are closely related to those of Zuprizal *et al.* (1991a) who also reported methionine to be the most available amino acid (93.5 to 95.6%) in commercial and dehulled canola meals. Similar results have also been reported by Salmon (1984). Contrary to our findings, these authors reported cystine to have the lowest and most variable availability which was explained by increased cystine destruction in excreta compared to the meal samples. Other amino acids which had relatively low availability values include threonine, valine, glycine, cystine, isoleucine and arginine.

Brown seeded canola meal had the lowest availability values for most amino acids, even though most of them were not significantly different from those of YSM. The availability of all DCM amino acids was very close to that of CCM amino acids, with only threonine and histidine showing significantly higher values. The availability of CCM amino acids were in turn higher than those of YSM and BSM, but again most of them were not significantly different. Total amino acid availability in CCM was similar to that in YSM which may reflect the similarity in total dietary fibre and protein content in the two meals. Dehulling the seed resulted in improved availability of most amino acids, thus confirming the reports of Bayley and Hill (1975) and Leslie and Clandinin (1973). Hulls do not only contain indigestible amino acids, but the dietary fibre in hulls is also known to interfere with amino acid availability (Sarwar *et al.*, 1981). It is worth noting that the availability of cystine, arginine and lysine, the most limiting amino acids in CM (Summers and Leeson, 1978) were not significantly improved by dehulling the seed. For

lysine, our results were less supportive to the findings of Zuprizal *et al.* (1991b) who reported lysine availability to be improved by 5 percentage points by dehulling. The lowered increase in lysine availability in this study could be due to increased processing temperatures which are known to have a reducing effect on lysine availability (Parsons *et al.*, 1992). Availability of lysine is of particular concern considering that the content of this amino acid was lowered by dehulling. Thus, any increase in lysine availability would tend to compensate for the reduced content. It should be noted however, that most of the lysine in hulls would not be available to poultry (Finlayson, 1974).

4.2.2. Nutrient Digestibility in Canola Meal Based Purified Diets

Feed intake and dry matter digestibilities in the semi-purified diets containing 45% canola meal were as presented in Table 19. There were no significant differences between intact and cecectomised laying hens with regard the intake or digestibility of experimental diets. In addition, comparisons among treatments showed that all the diets were consumed and digested to the same extent. Normally, animals tend to increase voluntary feed intake with increased dietary fibre (Graham, 1988) to compensate for reduced nutrient concentration and/or digestibility in the diet. This trend was not apparent in this study which may have been due to the fact that the differences in total dietary fibre among meals were not very significant compared to those in other studies.

Despite the fact that there were no significant differences between intact and

TABLE 19. Feed intake (g/day) and dry matter digestibility (%) of canola meal based experimental diets.

Treatment[1]	Feed intake			Digestibility		
	i.[2]	c.	x.	i.	c.	x.
DCM	94.66	101.77	96.96	65.69	65.59	65.75
CCM	106.69	102.88	102.32	63.75	66.27	65.00
BSM	98.69	107.86	102.94	67.16	66.08	66.62
YSM	101.14	99.00	97.84	65.50	62.61	64.06
SEM	4.18	4.18	3.47	.96	.96	.73

[1]DCM= Dehulled canola meal, CCM= Commercial canola meal, BSM= Brown seeded canola meal and YSM= Yellow seeded canola meal.

i[2]= intact hens, c= cecectomised hens and x= meal average.

TABLE 20. Nutrient digestibility in canola meal based semi-purified diets (% of nutrient in the diet).

Nutrient		Canola meal diets[1] YSM	BSM	CCM	DCM	SEM
Lipids						
	i[2]	40.29	48.59	64.52	60.89	2.002
	c	44.74	50.07	71.32	63.59	2.002
	x	42.52[d]	49.33[c]	67.92[a]	62.41[b]	1.440
Energy						
	i	69.49	70.99	70.92	72.41	.843
	c	67.66	69.32	71.79	70.87	.843
	x	68.57[b]	70.15[ab]	71.36[a]	71.64[a]	.589
NSP	i	10.44	5.13	2.55	6.12	3.173
	c	4.82	7.14	3.54	7.03	3.173
	x	7.63[a]	6.14[a]	3.04[a]	6.58[a]	2.087

[1]YSM= Yellow seeded canola meal, BSM= Brown seeded canola meal, CCM= Commercial canola meal and DCM= Dehulled canola meal.

i[2]= intact hens, c= cecectomised hens and x= meal average.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

cecectomised hens in the digestibility of lipids in the semi-purified diets (Table 20.), there was a trend among cecectomised hens to have a slightly higher lipid digestibility than intact birds in all the treatments. Assuming both types of birds had similar excretion of endogenous lipids, the apparently higher digestibility values in cecectomised birds may be explained by the presence of volatile fatty acids (VFAs) in the excreta of intact birds as a result of caecal microbial fermentation of dietary fibre. That is, if the VFAs were not completely absorbed but instead excreted in the faeces, they could have inflated the value of excreted lipids thereby lowering the digestibility value. Comparisons among treatments showed the CCM based diet to have a significantly higher lipid digestibility than the other diets with the lowest value being recorded for YSM. In this regard, the results might reflect the ether extract levels in the meals assuming the dietary supplemented lipids were digested to the same extent in all the diets and that all the birds had similar excretion of endogenous lipids. The low YSM lipid digestibility is in support of Bell and Shires (1982) who reported the digestibility of oil in yellow seeded (R 500) hulls to be less than that in brown seeded (Tower) hulls. The higher lipid digestibility in DCM relative to BSM suggested that dehulling of the seeds resulted in increased lipid digestibility as was demonstrated by Sarwar *et al.* (1981). However, since CCM did not differ significantly from DCM, the increase in lipid digestibility could also have been due to processing, especially since YSM and BSM were not heat/moisture treated as DCM and CCM.

The digestibility of energy in the diets was similar to that of lipids with no significant differences between intact and cecectomised laying hens. However, apart from

those fed CCM based diet, the intact birds tended to have slightly higher energy digestibility than the cecectomised hens which may be attributed to the presence of microbial activity in the caecum resulting in the production and utilisation of VFAs. Similar observations were made by Han and Parsons (1990) who concluded that using cecectomised hens may underestimate the amount of energy utilized from feedstuffs by conventional (intact) birds. Dehulling the seed resulted in a slight increase in energy digestibility though the value was not significantly different from those of BSM and CCM. Comparisons between the two laboratory prepared meals revealed that BSM had similar energy digestibility with YSM. The trend of an apparently lower energy digestibility value in YSM may be due to the lower ether extract concentration in the meal. It may also be attributed to the high NSP content, since NSP have been shown to have a depressing effect on dietary energy digestibility (Schutte *et al.*, 1991). The reasons for the non significant increase in energy digestibility in DCM relative to CCM and BSM may be due to the decomposition of simple carbohydrates and/or the higher processing temperatures used in the meal since it is known that lower energy availability is caused by the Maillard reaction between carbohydrates and free amino groups of amino acids (i.e. lysine.) as was discussed above where lysine availability in the DCM treatment did not reflect an improvement relative to the other meals.

The digestibility of NSP in CM based diets ranged from 3.04% in CCM to 7.83% in DCM with no significant differences among treatments or between intact and cecectomised birds within diets. The 3.04% recorded in CCM is in close agreement to the 3.00% obtained for the same meal by Slominski and Campbell (1990) who also noted

no significant differences between intact and cecectomised laying hens on the digestibility of canola meal NSP. The tendency for the slightly higher NSP digestibility in the other treatments compared to CCM may be related to the processing conditions or the type and/or carbohydrate composition of the seeds utilised in meal manufacture. This is because the composition of dietary fibre of the meal and the extent of heating during meal manufacture tend to affect the availability of carbohydrates. It should be noted, however, that the digestibility values were not as variable as may be portrayed by the pooled standard error of the means (SEM). When NSP digestibility was calculated as percentage of NSP in the diet, all the results were between 0.3% and 0.7% which may not be considered to be very variable in most circumstances. The observed statistical variability was also exacerbated by the presence of negative values in the data. These may have been caused by the excretion of non dietary polysaccharides the most common of which are in form of endogenous polysaccharides (e.g. α-glucohydrolase) or microbial glycoproteins (Southgate and Johnson, 1987). However, considering the excretion of individual sugar units (not shown), most of the negative values were recorded in arabinose and xylose and to a lesser extent galactose which may be associated with the low digestibility of these polysaccharide constituents in the chicken. All arabinose excretions must have come from a dietary source since this sugar component is very scarce in animal and microbial tissues (Carré *et al.*, 1990).

The generally low NSP digestibility in all the experimental diets, which is in confirmation to earlier findings (Carré and Brillouet, 1986; Longstaff and McNab, 1989; Carré *et al.*, 1990), shows that the caeca of birds does not contribute significantly to the

digestion of fibre in the GIT. However, considering that galactose based NSP (galactooligosaccharides) are bound to structural polysaccharides or other non identified compounds (Coon *et al.*, 1990) and that they are supposedly only degraded through bacterial fermentation suggests that some fermentation of carbohydrates does occur in the GIT of birds and the end- products of this fermentation (VFAs) may be absorbed and be a potential source of energy for the bird (Schutte *et al.*, 1992). However, it should be noted that the net energy released from carbohydrate fermentation is appreciably low relative to the requirement (Moran, 1982).

As was indicated in the digestibility of other CM components, there were no significant differences between intact and cecectomised hens in the digestibility of amino acids hence only the means are presented in Table 22. The results were agreement with the findings of Raharjo and Farrell (1984) who reported minor differences between intact and cecectomised cockerels on the digestibility of amino acids. However, Johns *et al.* (1986) and Greens *et al.* (1987) concluded cecectomy to yield lower digestibility for amino acids in some feedstuffs but not others. Cystine and tyrosine had the lowest and most variable digestibility in all the treatments just as was noted with the (TAAA) data collected with adult cockerels. The digestibility values obtained in laying hens were lower than the TAAA values which was as expected. Glutamic acid, methionine, leucine and phenylalanine had the highest digestibility values in all the treatments. The digestibility of most amino acids did not differ significantly among meals with most of the values ranging between 76 and 80%. When comparisons were made between treatments, the results showed the BSM based diet to have a relatively better overall amino acid

TABLE 21. Digestibility of amino acids in canola meal based diets (% of amino acid in the diet).

	Canola meal diets[1]				
Amino acid	YSM	BSM	CCM	DCM	SEM
Asp. acid	77.28^{ab}	78.18^{a}	76.84^{ab}	74.95^{b}	.739
Threonine	71.72^{ab}	74.45^{a}	69.09^{b}	72.07^{ab}	1.278
Serine	72.32^{b}	75.80^{a}	73.36^{ab}	74.86^{ab}	.791
Glut. acid	84.84^{b}	87.38^{a}	86.40^{a}	85.60^{a}	.525
Proline	75.42^{a}	78.24^{a}	75.57^{a}	77.21^{a}	1.161
Glycine	72.69^{b}	77.21^{a}	74.09^{ab}	72.53^{b}	.889
Alanine	77.82^{b}	80.22^{ab}	80.98^{a}	81.23^{a}	.948
Cystine	71.80^{a}	74.35^{a}	68.45^{ab}	66.43^{a}	1.549
Valine	76.46^{a}	75.53^{a}	76.11^{a}	76.77^{a}	.808
Methionine	84.24^{ab}	86.62^{a}	79.79^{b}	86.87^{a}	1.267
Isoleucine	77.61^{a}	76.07^{a}	77.41^{a}	79.18^{a}	.994
Leucine	79.66^{a}	79.96^{a}	82.56^{a}	82.54^{a}	.814
Tyrosine	59.62^{b}	60.58^{b}	61.41^{ab}	69.53^{a}	2.166
Phen. alanine	82.25^{a}	80.67^{a}	83.38^{a}	82.61^{a}	.758
Histidine	80.85^{a}	82.46^{a}	80.43^{a}	81.66^{a}	.970
Lysine	78.58^{ab}	80.38^{a}	79.77^{ab}	77.07^{b}	.741
Arginine	77.08^{a}	78.51^{a}	79.22^{a}	79.97^{a}	1.262
Total	77.91^{b}	80.36^{a}	78.05^{b}	80.41^{a}	.709

[1]YSM= Yellow seeded canola meal, BSM= Brown seeded canola meal, CCM= Commercial canola meal and DCM= Dehulled canola meal.

Means bearing different superscript letters within a row are significantly ($P \leq .05$) different.

digestibility than the other treatment diets with the lowest values being recorded in YSM. Total amino acid digestibility was similar in DCM and BSM. Comparisons between DCM and BSM revealed that dehulling of the seed resulted in some amino acids becoming more digestible while others were less digestible. Notable digestibility decreases were recorded in glycine, cystine and lysine and the increases were in tyrosine and methionine. The lack of significant increases in amino acid digestibility as a result of dehulling may be attributed to higher processing temperatures which have been reported to influence amino acid digestibility (Parsons *et al.*, 1991; 1992).

4.3. Chick Feeding Trial.

All the data obtained from the chick growing assay indicated no significant differences among treatment diets (Table 22.). The chicks exhibited a normal growing pattern with no mortality or any noticeable abnormalities throughout the experimental period. The data on feed intake revealed a trend among chicks fed DCM#2 and BSM based diets to have a comparatively higher intake during the two week study period than chicks fed other diets. The trends of higher feed intake in these diets may be associated with lower dietary energy which is known to increase feed consumption in birds. The same reason could be responsible for the trends of lower feed consumption in CCM and DCM#1 since these meal had higher TMEn than YSM and BSM. Factors other than dietary energy may be responsible for an apparently low feed intake trend observed in

TABLE 22. Feed intake (g/day), body weight gain (g) and feed conversion ratio in chicks fed Canola meal based diets.

Ration[1]	Feed intake		Weight gain		Feed conversion	
	Wk1	Wk2	Wk1	Wk2	Wk1	Wk2
DCM#1	100.67	239.05	45.68	115.15	2.207	2.076
DCM#2	105.18	244.75	45.80	113.18	2.309	2.164
CCM	100.43	242.22	46.68	117.58	2.152	2.060
BSM	104.95	246.23	45.67	113.72	2.314	2.177
YSM	101.77	240.50	43.60	108.15	2.356	2.234
SEM	2.024	3.449	1.643	2.958	.072	.047

[1]DCM#1 and DCM#2= Dehulled canola meal included at 20 and 17%, respectively; CCM= Commercial canola meal, BSM= Brown seeded canola meal and YSM= Yellow seeded canola meal.

YSM. The same trends were exhibited on body weight gains (BWG) with higher BWG being noted in DCM#1 and CCM based diets. Apart from YSM where there was a trend to suggest a lower value, the BWG values after the first week were similar in all the treatments. The observed trend which suggests a slightly higher BWG in CCM and DCM#1 based diets may be in response to the higher energy and/or protein content in the meals. This was especially true for DCM#1 which was fed at a higher protein level than the other meals. The fact that there was a trend among chicks fed DCM#2 based diet to have a comparatively lower performance than those fed CCM based diet demonstrates that the nutrients in DCM were not readily available to the chicks. The same reasoning may be used to explain the trends of lower body weight gains observed in chicks fed YSM based diet.

The results on feed conversion ratio (FCR) tend to confirm the trends on feed intake and body weight gain. FCR was comparatively higher in the week one than week two in all the meals. This may be due to the fact that chicks had just switched to marsh type of feed from a pelleted type which was less dusty and had a higher nutrient concentration. In both weeks, there were trends to suggest higher and lower feed efficiency in CCM and YSM based diets, respectively. Trends of lower FCR in CCM and DCM#1 based diets compared to the other diets reflects the higher TMEn and amino acid content in these diets. However, the availability of nutrients in DCM may have been lower than that in other meals since it did not support a better FCR despite having a higher protein and amino acid concentration than the other meals.

5.0 CONCLUSIONS AND RECOMMENDATIONS.

5.1. Conclusions

The results of this study indicate no major differences in the chemical composition of canola meals apart from the dehulled meal which had a higher crude protein and lower glucosinolates levels than the other meals. Dehulling the seeds resulted in an increase of most amino acids mainly as a result of reduced diluting effect from hull cell walls. The amino acid profile of crude protein in all the meals was similar though there was a slight decrease in lysine, proline and phenylalanine and an increase in glutamic acid and leucine in the dehulled canola meal. Data on dietary fibre components revealed BSM to have the highest TDF and NDF levels. Despite the high TDF and NSP levels in YSM, the meal had the lowest NDF content which indicates that the meal had the highest level of soluble fibre components as was confirmed by the higher NDSP levels. Levels of NSP were highest and lowest in YSM and DCM, respectively. Despite differences in the NSP levels, there were no differences in the composition of NSP between treatments. The DCM had lower TDF and NSP values than all the other meals. The results on lignin were not conclusive due to higher NDF-ash in BSM. However, apart from DCM, YSM had the lowest lignin levels to indicate that yellow seeded canola is less lignified than dark seeded canola varieties.

True metabolizable energy (TMEn) and the digestibility of lipids and energy were significantly higher in DCM and CCM than in the two laboratory prepared meals which

had similar levels. The availability of NSP in the precision fed cockerel assay was significantly higher in YSM and BSM than in DCM and CCM. These results tend to suggest that the NSP remaining after dehulling the meal are almost unavailable in poultry, though this view was not supported by the laying hen digestibility assay. Availability values of amino acids were higher in the precision-fed cockerel assay than in the laying hen digestibility trial. In all the treatments, tyrosine and arginine had the lowest and most variable digestibility values in the precision-fed cockerel assay whereas in the laying hen digestibility trial, it was tyrosine and cystine which were least digestible. Methionine, glutamic acid, aspartic acid and phenylalanine were the most avialable amino acids in both assays. Treatment results between the two assays were somehow conflicting on amino acid digestibility and/or availability. The precision-fed cockerel assay indicated DCM and CCM to have a better amino acid availability values than the other meals whereas the laying hen digestibility assay showed DCM and BSM to have a relatively better amino acid digestibility. There were no significant differences between intact and cecectomised laying hens in the digestibility of all canola components. The precision-fed cockerel assay results were higher than the laying digestibility results mainly because of the correction for endogenous excretion of nutrients in the former.

The chick growing assay indicated no significant differences among canola meals though there were trends to indicate a slightly better nutritive quality in CCM. The performance of chicks fed DCM based diets (DCM#1 and DCM#2) was not as good as could be expected though the former supported a better chick performance than the latter due to a higher energy and amino acid content. The digestibility of YSM nutrients and

the performance of chicks fed YSM based diets shows that the reduced fibre content in yellow seeded canola varieties did not resulted in improved nutritive value.

5.2. Recommendations/Suggestions.

1. Since the meals were prepared under different conditions, it's possible that the differences in nutrient digestibilities and/or availabilities were due to differences in processing conditions to which the meals were subjected. It is therefore, worth considering the evaluation of different canola meals prepared under similar commercial processing conditions.

2. Since the results on dehulled canola meal were not as good as could be expected, it is possible that improvements can still be made in the processing conditions. The most likely possibility may be in finding optimum processing temperatures and/or time which would result in reduced nutrient destruction during meal manufacture.

3. Since the chemical composition of YSM is comparable to that of CCM and BSM and the fact that the reduced fibre content in the meal did not result in improved feeding quality in poultry, it would be worthwhile to evaluate the feeding quality of this meal in other monogastric animals, especially pigs which have a higher capacity of hindgut fermentation.

4. The cause of higher NDF-ash in BSM which resulted in inconclusive lignin results need to be evaluated to see if it has any significant effects on dietary nutrient

need to be evaluated to see if it has any significant effects on dietary nutrient availabilities.

5. The high variation in the NSP digestibility, which occurred mainly as a result of low digestibility, needs to be decreased. This may be done by increasing the number of birds in the study.

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