Quality Characteristics of Yellow-Seeded *Brassica* Seed Meals: Protein, Carbohydrates, and Dietary Fiber Components

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A comprehensive evaluation of the nutritive profiles of the meals derived from 26 *Brassica* seed meals of yellow-seeded *B. napus*, *B. rapa*, *B. juncea*, and *B. carinata* genotypes and 7 samples of conventional brown-seeded canola was undertaken. The evaluation involved the analyses of sucrose, galactooligosaccharides, protein, total dietary fiber, ash, and residual fat. The fiber components determined included nonstarch polysaccharides, lignin and polyphenols, cell wall protein, and minerals. On average, in comparison to brown-seeded, yellow-seeded types contained more sucrose (8.7% vs 7.5%) and protein (44.5% vs 42.7%) but similar amounts of oligosaccharides (2.3% vs 2.5%), ash (6.9% vs 7.0%), and nonstarch polysaccharides (20.4% vs 19.7%). Dietary fiber averaged 28% for yellow-seeded samples (minimum 22%, maximum 32%) and 33% for brown-seeded samples (minimum 28%, maximum 36%) and was negatively correlated ($r = -0.71$) with protein content. Lower dietary fiber content in yellow-seeded samples as compared to brown-seeded samples was reflected in a lower content of lignin with associated polyphenols (4.3% vs 8.2%) and less wall-inserted protein (2.3% vs 3.3%) and minerals (0.7% vs 2.4%) associated with the fiber fraction. It may be surmised that future cultivars of yellow-seeded *Brassica* oilseed crops will have improved nutritive value.

Keywords: *Brassica meal; protein; carbohydrates; dietary fiber; seed color*

INTRODUCTION

It is generally agreed that canola meal could be more competitive in the marketplace if it had more protein, more digestible energy, and less dietary fiber (Bell, 1993). The selection for yellow-seed coat color, a characteristic related to low fiber content, has been one of several approaches undertaken to improve the nutritive value of canola meal. In addition to containing less fiber, seeds of yellow-seeded strains in comparison to brown-seeded strains of *Brassica rapa* have been shown to be significantly higher in oil and protein contents (Stringam et al., 1974). Thinner hulls were reported to be directly responsible for the lower fiber content in yellow-seeded *B. rapa*. Specifically, yellow hulls have been found to be low in lignin (Theander et al., 1977) and crude fiber (Daun and DeClercq, 1988) and have been shown to contain less neutral detergent fiber than brown hulls (Bell and Shires, 1982). Recent results from our laboratory indicated a total dietary fiber content for yellow-seeded *B. rapa* of 27% on average. The fiber level was a reflection of a relatively high content of nonstarch polysaccharides (NSP) at the expense of lignin and polyphenols, with the overall dietary fiber level being 3 percentage units below that for brown-seeded samples (Slominski and Campbell, 1990; Slominski et al., 1994a). This fiber profile, however, is characteristic of *B. rapa* canola since in most of the earlier studies this species was the only source of yellow-seeded samples. It is only recently that plant breeders have been able to incorporate the yellow-seed character into the agronomically important *B. napus* canola. Also, plant breeders have recently developed canola-quality forms of *B. juncea*, a species known for its pure yellow seed coat. Under western Canadian conditions *B. juncea* suffers less from heat and drought stress and matures earlier than *B. napus*. Such characteristics are the basis for high yields of oil and low chlorophyll content in the seed (Rakow and Raney, 1993).

The objective of this study was to evaluate protein, carbohydrates, and dietary fiber components of seed meal of yellow- and brown-seeded strains of *B. napus*, *B. rapa*, *B. juncea*, and *B. carinata*.

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MATERIALS AND METHODS

The seed samples represented brown- and yellow-seeded strains/cultivars of *B. napus* (3 brown, 3 yellow), *B. rapa* (2 brown, 6 yellow), *B. juncea* (1 brown, 16 yellow), and *B. carinata* (1 brown, 1 yellow). *B. napus* and *B. rapa* strains tested were of canola-quality type and by definition contained less than 30 μmol/g of aliphatic glucosinolates. Ten of the 16 yellow-seeded *B. juneca* strains were of canola quality; the remaining 6 *B. juncea* strains and *B. carinata* were high in glucosinolate content. All plant materials were grown in field plots at the Agriculture and Agri-Food Canada research farm at Saskatoon, SK, Canada. In preparation for analysis, the seeds were crushed and extracted with *n*-hexane for 2 h in a Soxhlet apparatus. Following drying under a fumehood, the meals were ground to pass through a 1 mm sieve and were re-extracted with hexane for 8 h.

ANALYTICAL PROCEDURES

Meal samples were analyzed for protein (Kjeldahl N × 6.25), ash, and ether extract using established standard methods of

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Table 1. Chemical Composition of Meals Derived from Brown- and Yellow-Seeded *Brassica* Species (Percent of Dry Matter)

component	type of sample: brown-seeded ($n = 7$)[a]	yellow-seeded ($n = 26$)[b]
sucrose	7.5 ± 1.0[b c]	8.7 ± 1.3[a]
oligosaccharides[d]	2.5 ± 0.5[a]	2.3 ± 0.6[a]
dietary fiber[e]	33.6 ± 2.8[a]	27.7 ± 2.3[b]
protein	42.7 ± 3.1[a]	44.5 ± 3.5[a]
ash	7.0 ± 0.5[a]	6.9 ± 1.1[a]
fat	2.9 ± 0.3[a]	2.7 ± 0.2[a]
total[f]	90.5 ± 1.4	89.7 ± 2.0

[a] Includes samples of *B. napus* ($n = 3$), *B. rapa* ($n = 2$), *B. juncea* ($n = 1$), and *B. carinata* ($n = 1$). [b] Includes samples of *B. napus* ($n = 3$), *B. rapa* ($n = 6$), *B. juncea* ($n = 16$), and *B. carinata* ($n = 1$). [c] Mean ± SD. Values within a row with no common superscript differ significantly ($P < 0.05$). [d] Includes raffinose and stachyose. [e] Includes nonstarch polysaccharides, lignin with associated polyphenols, cell wall protein, and cell wall minerals. [f] Corrected for cell wall protein and minerals present in the dietary fiber fraction.

analysis (AOAC, 1990). Sucrose and galactooligosaccharides were determined by gas−liquid chromatography according to the procedure described by Slominski et al. (1994a).

Dietary fiber was determined by a combination of neutral detergent fiber (NDF) and detergent-soluble NSP measurements and was calculated as the sum of NDF and detergent-soluble NSP (Slominski et al., 1994a). The method of Goering and Van Soest (1970) was used for the determination of NDF, except that the procedure was modified to exclude the use of decalin and sodium sulfite (Mascharenhas Ferreira et al., 1983). Nonstarch polysaccharides were determined by gas−liquid chromatography (component neutral sugars) and by colorimetry (uronic acids) using the procedure described by Englyst and Cummings (1984, 1988) with minor modifications (Slominski and Campbell, 1990). The content of NSP was measured in both the meals and the NDF residues. Detergent-soluble NSP was calculated as total sample NSP minus NSP present in the NDF residue. The contents of cellular protein (Kjeldahl nitrogen) and ash in NDF residue were also measured. The value for lignin and associated polyphenols was calculated by difference [NDF − (NSP + protein + ash)].

Seed size was determined in triplicate by weighing 100 seeds from each canola/rapeseed sample and was expressed as grams per 1000 seeds.

RESULTS AND DISCUSSION

The chemical composition of the *Brassica* meal samples is shown in Table 1. On average, in comparison to brown-seeded, yellow-seeded samples contained more sucrose, more protein, less fiber, and similar amounts of oligosaccharides and ash. These components accounted for approximately 90% of the dry matter of the meal in both types. The remaining (approximately 10%) dry matter may be assumed to consist of free glucose and fructose, sinapine (0.6−1.8%), soluble tannins (1.5−3.0%), phenolic acids, phytate (3−6%), glucosinolates (0.5−0.7%), and other minor components as reviewed by Bell (1993).

The sucrose and oligosaccharide contents in the meals (Table 1) were similar to those reported earlier for brown-seeded rapeseed (Theander et al., 1976; Finlayson, 1977) and yellow-seeded canola (Slominski et al., 1994a). The difference in sucrose content between the yellow- and brown-seeded samples was not as pronounced for the *B. napus*, *B. juncea*, or *B. carinata* samples as it was for the *B. rapa* samples (Table 2). This is in agreement with our earlier data showing 3−4 percentage points higher sucrose content in yellow-seeded *B. rapa* as compared to brown-seeded canola

Table 2. Protein, Carbohydrate, and Dietary Fiber Content of Meals Derived from Brown- and Yellow-Seeded *Brassica* Species (Percent of Dry Matter)

species/seed color	no. of samples	protein[a]	sucrose	oligo-saccharides[b]	dietary fiber[c]
B. napus					
brown	3	42.6[b]	8.3[a]	3.0[a]	34.1[a]
yellow	3	46.3[a]	9.7[a]	3.3[a]	27.5[a]
B. rapa					
brown	2	40.5[a]	7.1[b]	2.5[a]	35.0[a]
yellow	6	41.1[a]	9.9[a]	2.6[a]	28.5[b]
B. juncea					
brown	1	41.4	7.0	2.0	35.1
yellow	16	44.9	8.3	2.0	27.8
B. carinata					
brown	1	48.8	6.1	1.7	27.6
yellow	1	52.6	6.8	1.6	21.9

[a] N × 6.25. Values within *B. napus* or *B. rapa* species with no common superscripts differ significantly ($P < 0.05$). [b] Includes raffinose and stachyose. [c] Includes nonstarch polysaccharides, lignin with associated polyphenols, cell wall protein, and cell wall minerals.

(Slominski et al., 1994a). As sucrose is a highly digestible carbohydrate, its increased content in yellow-seeded canola would be expected to have a positive impact on the digestible energy content of the meal. This is not necessarily the case for galactooligosaccharides, which were reported in a recent study to have minimal effect on energy digestibility in poultry (Slominski et al., 1994b). Consequently, it is uncertain to what extent the relatively high amount of oligosaccharides such as that observed for *B. napus* canola (Table 2) would have on the nutritive value of the meal.

Dietary fiber content in yellow-seeded samples was found to be significantly lower, differing by 6 percentage points from that of the brown-seeded types (Tables 1 and 2). This relatively large difference is in contradiction to our earlier work (Slominski and Campbell, 1990; Slominski et al., 1994a); however, comparison of the two data sets showed that the yellow-seeded samples were of similar fiber content, while the brown-seeded canola samples for the earlier studies had lower fiber values of approximately 3 percentage points. Such a discrepancy could be explained by environmental conditions, genetic differences, or location as the canola samples used in our earlier studies were collected from different canola breeding stations in Canada and Sweden. Values for dietary fiber of rapeseed, which were determined as the sum of nonstarch polysaccharides and Klasson lignin, have recently been reported (Eriksson et al., 1994). The dietary fiber values were similar to those obtained in the current study and in addition also indicated variation between rapeseed types, with winter varieties showing higher dietary fiber values than summer varieties (34.4% vs 31.5%, respectively).

The protein content of the canola/rapeseed samples was shown to be related to seed color and, on average, was higher by 2 percentage points in yellow-seeded samples (Table 1). The difference in protein content due to seed color was less evident for *B. rapa* samples than for *B. napus*, *B. juncea*, and *B. carinata* samples, in which the increase in protein content averaged 3.8, 3.5, and 3.8 percentage points, respectively (Table 2). The relatively small increase in mean protein value for *B. rapa* canola may have been, in part, due to an exceptionally low (33.6%) protein content in one of the yellow-seeded samples. In general, the protein content was negatively correlated with dietary fiber level for all analyzed samples, regardless of seed coat color (Figure 1). The regressions of protein and fiber content for *B.*

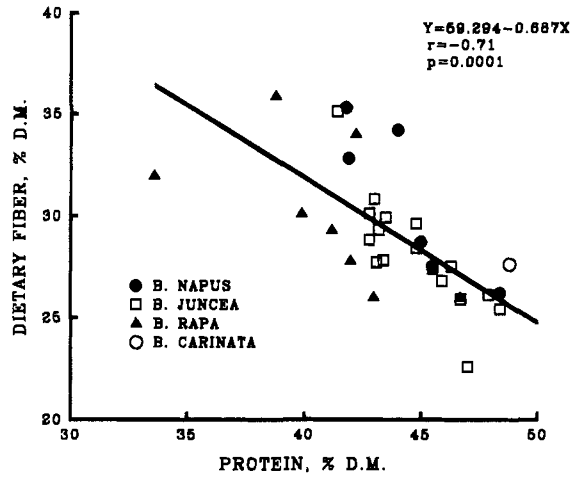

Figure 1. Relationship between the protein and dietary fiber contents of meals derived from selected strains/cultivars of *B. napus*, *B. rapa*, *B. juncea*, and *B. carinata*.

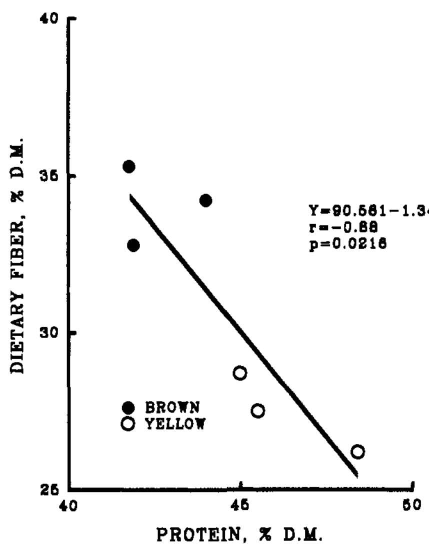

Figure 2. Relationship between the protein and dietary fiber contents of meals derived from brown- and yellow-seeded *B. napus*.

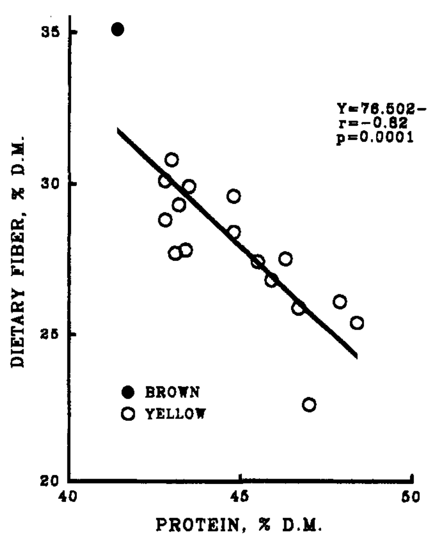

Figure 3. Relationship between the protein and dietary fiber contents of meals derived from brown- and yellow-seeded *B. juncea*.

napus (Figure 2) and *B. juncea* samples (Figure 3) showed relatively high correlation coefficients of 0.88 and 0.82, respectively, while the coefficient for *B. rapa* samples was only 0.59 (Figure 4). In this regard, the former samples had a large variation in protein and fiber contents among the samples, while the latter samples had average protein contents for both yellow- and brown-seeded types. It can be suggested from the results that the diluting effect of dietary fiber on protein content in *B. rapa* canola may not be as significant as was earlier portrayed (Sarwar et al., 1981; Stringam et al., 1974). This result agrees with other work from our laboratory in which the nutritive quality of yellow-seeded *B. rapa* canola was shown to be similar to that for brown-seeded *B. napus* canola (Simbaya, 1992; Slominski et al., 1994a). Apart from the brown-seeded samples which were limited in number in the current study, the yellow-seeded samples, including *B. juncea* (n = 16), *B. rapa* (n = 6), and to some extent *B. napus* (n = 3), showed a large variation in protein and fiber contents (Figures 2−4). Such variation may reflect differences in the seed size, oil content, and cotyledon cell size. Such factors should be taken into account in the breeding for new, improved varieties of yellow-seeded canola/rapeseed. Since only two samples of *B. carinata* were included in this study, the apparent differences in dietary fiber and protein contents between yellow- and brown-seeded types can only be considered as trends (Table 2). The extremely low fiber content in the yellow-seeded *B. carinata* sample is of particular interest as the protein content by consequence was elevated above 50%, a value higher than that reported for dehulled canola meal (45.9%) (Simbaya, 1992). This was also the case for selected samples of *B. napus* canola (i.e., line YN90-1018; 48.4% protein, 26.2% fiber) or *B. juncea* lines J90-2741 (47.0% protein, 22.6% fiber), J90-2736 (47.9% protein, 26.1% fiber), and J90-4316 (46.3% protein, 27.5% fiber) (specific data not shown).

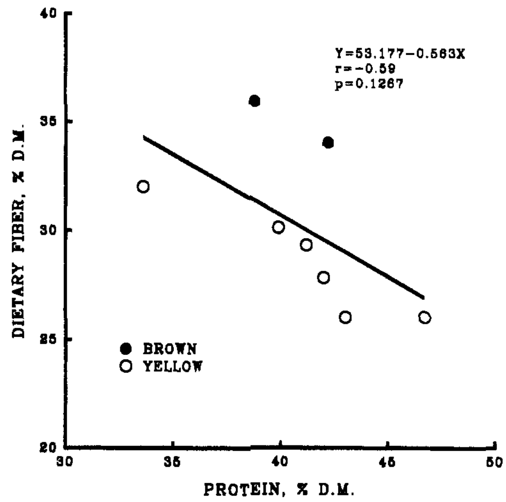

Figure 4. Relatioship between the protein and dietary fiber contents of meals derived from brown- and yellow-seeded *B. rapa*.

The composition of dietary fiber present in brown- and yellow-seeded samples is shown in Table 3. Yellow-seeded *B. rapa* showed the highest NSP content among the yellow-seeded samples, and this value differed by 2.7 percentage points from that of brown- and yellow-seeded *B. napus* canola, which were not different. A similar difference between brown-seeded *B. napus* and yellow-seeded *B. rapa* samples was noted in earlier work (Slominski et al., 1994a). Yellow-seeded *B. juncea* showed an intermediate NSP value with an average of 20.7% and a range from 17.7% to 22.6%. Very low NSP and thus dietary fiber values were characteristic of *B. carinata*.

Table 3. Composition of Dietary Fiber of Meals Derived from Brown- and Yellow-Seeded *Brassica* Species (Percent of Dry Matter)

species/seed color	no. of samples	NSP	protein	ash	lignin[a]
B. napus					
brown	3	18.6[a]	4.4[a]	1.9[a]	9.1[a]
yellow	3	18.6[a]	3.5[b]	0.7[b]	4.7[b]
B. rapa					
brown	2	20.1[a]	2.6[a]	3.0[a]	9.3[a]
yellow	6	21.3[a]	2.1[a]	0.6[b]	4.5[b]
B. juncea					
brown	1	23.3	2.9	1.2	7.6
yellow	16	20.7	2.2	0.8	4.1
B. carinata					
brown	1	18.3	2.1	5.0	2.8
yellow	1	15.0	1.6	2.3	3.0

[a] Includes lignin with associated polyphenols. Values within *B. napus* and *B. rapa* species with no common superscripts differ significantly ($P < 0.05$).

Table 4. Nonstarch Polysaccharide Profiles of Meals Derived from Brown- and Yellow-Seeded *Brassica* Species (Percent of Total)

component sugar	type of sample	
	brown-seeded ($n = 7$)[a]	yellow-seeded ($n = 26$)[b]
rhamnose	0.9	0.8
fucose	1.1	1.1
arabinose	21.8	22.9
xylose	8.0	8.6
mannose	1.9	1.9
galactose	9.5	9.0
glucose	30.5	30.0
uronic acids	26.3	25.7

[a,b] See Table 1 for type of samples.

As indicated in Table 4, a similar NSP component sugar profile was evident for both brown- and yellow-seeded samples, which indicates that changes in NSP for yellow-seeded canola are quantitative rather than qualitative in nature. This response has been shown in previous work (Slominski and Campbell, 1990; Slominski et al., 1994a), and since NSP accounts for a major portion of the dietary fiber of *Brassica* seed meals, future studies on the influence of dietary fiber on the nutritive quality of the meal should include an evaluation of potential differences in the total content of NSP among species and strains within species of canola.

Fiber components other than NSP, which include cell wall protein and ash and lignin with associated polyphenols, showed major differences (Table 3). The pronounced difference in lignin and polyphenol content between the brown- and yellow-seeded samples confirms earlier work from this laboratory (Slominski and Campbell, 1990; Slominski et al., 1994a). This fraction appears to be directly responsible for the seed color, and as indicated by Theander et al. (1977), polyphenols rather than lignin are predominant in brown-seeded rapeseed. However, samples of yellow-seeded *B. juncea* revealed a wide range in the content of lignin and polyphenols (minimum 2.5%, maximum 5.4%) without any major change in seed color as the samples were all of the fully yellow-seeded type. In this regard, relatively low lignin and polyphenol contents in yellow-seeded canola may have important repercussions with regard to the nutritive worth of the meal. While the digestibility of the meal may be improved due to lower cell wall lignification, there is a potential for increased solubility of structural polysaccharides. Soluble polysaccharides in cereal grains (i.e., β-glucan, arabinoxylan) have been shown to result in altered nutrient utilization (Graham and Aman, 1991). A weak negative correlation

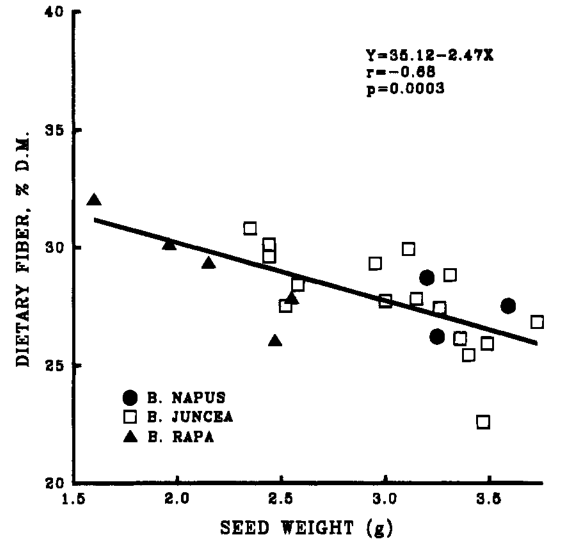

Figure 5. Relationship between the dietary fiber content in meal and seed weight of selected strains/cultivars of *B. napus*, *B. rapa*, and *B. juncea*.

between seed weight and fiber content in yellow-seeded samples (Figure 5) further elucidates this relationship and indicates the importance of canola cotyledons in determining the level and nature of dietary fiber. Thus, in contrast to the concept of the fiber in the hull fraction being the sole factor affecting nutrient utilization, the fiber associated with the seed cotyledons may also be of importance. Further work is needed to determine water solubility of fiber components and to investigate the nutritive properties of the soluble components of canola fiber including both structural (i.e., pectic substances, hemicelluloses) and nonstructural (i.e., mucilages, gums) polysaccharides. The association of carbohydrates with proteins in canola is also a factor that requires further study relative to the nutritive quality of the meal.

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