Characterization of carbohydrates and proteins in *Phalaris minor* seeds by Cornell net carbohydrate and protein system

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The present study was conducted to characterize carbohydrate and protein fractions in *Phalaris minor* seeds (a novel feedstuff) in comparison to conventional energy sources fed to livestock. The crude protein of *P. minor* seeds was similar to wheat and was higher ($P < 0.05$) than other conventional cereal grains evaluated. *P. minor* seeds recorded the highest ($P < 0.05$) level of ether extract, total ash, lignin, neutral and acid detergent insoluble protein. *P. minor* seeds had lower ($P < 0.05$) level of total carbohydrates than conventional cereal grains. Wheat grains exhibited highest ($P < 0.05$) level of non-structural carbohydrates followed by maize, *P. minor*, pearl millet and barley. Protein fractions P_{B1} and P_{B2} in *P. minor* seeds were similar to maize. Total digestible nutrients in *P. minor* seeds were higher ($P < 0.05$) than pearl millet and barley. *P. minor* seeds could be considered as promising energy supplement for livestock as indicated by its chemical constituents.

Keywords: Carbohydrate and protein fractions, digestibility, *Phalaris minor* seeds.

DAIRY animals in India are fed by-products of cereal crops, oil seeds and locally grown fodder. In some situations, there is a shortage of these by-products to meet the demands of the livestock population. Due to ever increasing human population, land is primarily used for growing food crops, and there is little scope for increasing the area under fodder production. In such a situation, the increased demand for milk caused by an increase in population, urbanization and buying capacity is to be met by increasing productivity of dairy animals coupled with more efficient use of the available feed resources[1].

However, there is a shortage of conventional feedstuffs in India to the tune of 41% concentrate feed ingredients, 35.6% green fodder and 26% dry crop residues for feeding livestock[2]. In order to meet the nutrient requirements of animals and to achieve the targets of milk production, we need to improve either the utilization efficiency of already existing feed ingredients/nutrients or tap into new unconventional feed resources. *Phalaris minor* (little seed canary grass) is a fast spreading weed in wheat fields in many countries of the world. It belongs to the family Graminae found in large quantities, especially in the Northern states of India, where rice–wheat rotation is predominant. However, information about its nutritive value and livestock feed is scanty.

The Cornell Net Carbohydrate and Protein System (CNCPS, version 5), on the basis of degradation rate, partitions carbohydrates in feeds into four fractions, viz. carbohydrate fraction A (C_A, rapidly degradable sugars); fraction B_1 (C_{B1}, intermediately degradable starch and pectins); fraction B_2 (C_{B2}, slowly degradable cell wall); and fraction C (C_C, unavailable/lignin-bound cell wall). This system separates the protein into three fractions, viz. protein fraction A (P_A, non-protein nitrogen); fraction B (P_B, true protein) and fraction C (P_C, unavailable/lignin-bound protein). Protein fraction B is further divided into B_1 (P_{B1}), B_2 (P_{B2}) and B_3 (P_{B3}) subfractions of rapid, intermediate and slow degradation rate respectively. Different carbohydrate and protein fractions are utilized by rumen microbes and animals differently[3], indicating the importance of their estimation in feedstuffs. This study was therefore conducted to generate information on the nutrient components of *P. minor* seeds, especially in terms of carbohydrate and protein fractions to expand the inventory of the already existing feed resources.

Samples of common energy feeds fed to livestock, viz. maize (*Zea mays*), wheat (*Triticum aestivum*), pearl millet (*Pennisetum typhoides*), barley (*Hordeum vulgare*) and unconventional energy supplement, viz. *Phalaris minor* seeds were collected from various places (Farm section of National Dairy Research Institute, Karnal and local market). The samples were dried in hot air oven (60°C, 24 h) and then grounded to pass through 1.0 mm sieve and stored in plastic containers for chemical estimation.

Samples were analysed for dry matter (DM; ID 934.01), Kjeldahl N (ID 984.13), ether extract (EE; ID 920.39) and ash content (ID 942.05), using the standard procedures[4]. CP content of samples was determined using semiauto-analyser (Kel PlusClassic-DX, Pelican). Cell wall fractions (NDF, ADF, cellulose and lignin) were estimated sequentially using the standard procedure[5]. NDF was estimated using heat stable α-amylase (Sigma A3306, Sigma-Aldrich, USA). NDF and ADF were expressed inclusive of residual ash. Lignin content was determined by treating cellulose with 72% sulphuric acid.

Carbohydrate fractions were estimated according to CNCPS[6] (version 5). Total carbohydrate (TCHO) content was determined by taking the difference of CP, EE and ash content from 100. Starch content of samples was estimated using polarimetric method[7]. CP fractions of energy feeds were determined according to CNCPS[6]. NDIP, ADIP and NPN were estimated following standard methods[8]. To estimate soluble protein (SP), the feed samples were treated with borate-phosphate buffer, tertiary butyl alcohol and sodium azide solution[9]. The N estimated in the residue represents the insoluble protein fraction. SP was calculated by difference from total CP.

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To derive the TDN_{1X} values (at maintenance level), a summative approach was applied[10] by estimating the concentration (% DM) of truly digestible non-fibrous carbohydrates (td NFC), truly digestible crude protein (td CP), truly digestible fatty acids (td FA) and truly digestible neutral detergent fibre (td NDF) for each feed[11] using the equations below

$$\text{td NFC} = 0.98[100 - \{(\text{NDF} - \text{NDIP}) + \text{CP} + \text{EE} + \text{ash}\}] \times \text{PAF}, \quad (1)$$

$$\text{td CP} = [1 - \{0.4 \times (\text{ADIP/CP})\}] \times \text{CP}, \quad (2)$$

$$\text{td FA} = \text{EE} - 1, \quad (3)$$

$$\text{td NDF} = 0.75 \times (\text{NDFn} - \text{L}) \times [1 - (\text{L/NDFn})^{0.667}], \quad (4)$$

$$\text{TDN}_{1X} = \text{td NFC} + \text{td CP} + (\text{td FA} \times 2.25) + \text{td NDF} - 7, \quad (5)$$

where TDN_{1X} = Total digestible nutrients (at maintenance level), NDIP = Neutral detergent insoluble protein, PAF = processing adjustment factor (1 for most feeds), ADIP = acid detergent insoluble protein, NDFn = NDF – NDIP, L = acid detergent lignin. All values are expressed as % DM.

To estimate IVDMD of energy supplements, rumen contents were collected at 0 h in thermos flask (maintained at 39°C) from fistulated male buffaloes (Murrah breed) maintained on standard diet[10]. The rumen contents were immediately brought to the laboratory, blended and filtered through 2-layered muslin cloth and bubbled with CO_2 for use as inoculum.

Approximately 375 mg of the substrate was incubated at 39°C for 24 h in triplicates in 100 ml calibrated glass syringes containing test feed and buffered rumen fluid[12,13]. Blank and standard hay were run in triplicates with each set. After 24 h, the contents of the syringes were transferred to spoutless beakers (500 ml) by dissolving in neutral detergent solution. Beakers were kept on heater and refluxed at 100°C for 1 h from when the boiling started. The contents in the beakers were filtered under vacuum through pre-weighed sintered (G1) crucibles and washed with hot water. The crucibles containing residue were oven-dried (65°C for 48 h) and weighed. IVDMD was calculated using the following equation

$$\text{IVDMD (\%)} = \frac{[S - (R - B)]}{S} \times 100,$$

where S is the weight of substrate (mg), R the weight of dried residue after treatment with neutral detergent solution (mg), and B is the weight of dried residue of representative blanks treated with neutral detergent solution.

The data was analysed by the one-way ANOVA procedure of SAS (2003), using the following linear model

$$Y_{ij} = \mu + F_i + E_{ij},$$

where Y_{ij} is the value of the response variable in the jth observation (or replication) for the ith factor, μ the overall mean, F_i the fixed effect of the ith energy supplement ($i = 1$ to 5), E_{ij} is the random error assumed to be distributed normally, and independently with mean zero and constant variance, i.e. NID $(0, \sigma^2)$.

The post-hoc comparison of means was done for the significant difference by Tukey's *b* and significant difference among energy sources was considered at $P < 0.05$ level. The coefficients between the chemical components and IVDMD were correlated using the Pearson method. To determine DM digestibility, the stepwise multiple regression method was used to develop prediction equations using various chemical components as predictors, with 30 observations (5 energy sources with 6 replications) for each variable.

OM content in *P. minor* seeds was lower ($P < 0.05$) than conventional cereal grains (Table 1). This might be attributed to the higher ($P < 0.05$) total ash content in *P. minor* seeds. CP content of *P. minor* seeds was similar to that of wheat and was higher ($P < 0.05$) than other conventional cereal grains evaluated. *P. minor* seeds recorded highest ($P < 0.05$) EE, total ash and AIA. *P. minor* seeds had higher ($P < 0.05$) NDF content than maize and wheat, however, it was lower ($P < 0.05$) than pearl millet and barley. The hemicellulose content of *P. minor* seeds was similar to that of maize, though it was lower ($P < 0.05$) than pearl millet and barley. ADF, lignin, NDIP and ADIP levels were also highest ($P < 0.05$) in *P. minor* seeds. Starch content of *P. minor* seeds was similar to that of barley, but it was lower ($P < 0.05$) than other conventional cereal grains evaluated.

P. minor seeds recorded lower ($P < 0.05$) total carbohydrates (TCHO) than conventional cereal grains (Table 2). Non-structural carbohydrates (NSC) varied significantly among the energy sources, with wheat exhibiting the highest ($P < 0.05$) content followed by maize, *P. minor*, pearl millet and barley. C_A fraction (% TCHO) differed widely from 2.25% in pearl millet to 18.48% in wheat, with *P. minor* seeds having higher ($P < 0.05$) value than the conventional cereal grains, except wheat. C_{B1} fraction in *P. minor* seeds was similar to barley, however, it was lower ($P < 0.05$) than other conventional cereal grains. Fraction C_{B2} was highest ($P < 0.05$) in barley and lowest ($P < 0.05$) in wheat with *P. minor* seeds containing higher ($P < 0.05$) levels of C_{B2} than maize and wheat. The C_C fraction was lower ($P < 0.05$) in conventional cereal grains than *P. minor* seeds.

NDIP was highest ($P < 0.05$) in *P. minor* seeds followed by barley and it was similar among maize, wheat and pearl millet (Table 3). ADIP content also followed a

Table 1. Chemical composition (g kg DM^{-1}) of *Phalaris minor* seeds and conventional energy sources

Parameter	*P. minor*	Maize	Wheat	Pearl millet	Barley	SEM[a]
Organic matter	924.6[a]	986.7[c]	987.7[c]	980.3[bc]	975.3[b]	6.3
Crude protein	123.3[c]	90.3[a]	120.3[c]	94.0[a]	109.0[b]	3.6
Ether extract	62.7[d]	42.3[c]	20.0[a]	30.0[b]	21.0[a]	4.3
Total ash	75.3[d]	13.0[a]	11.7[a]	20.0[b]	25.0[c]	6.3
Acid insoluble ash	45.0[b]	nd	nd	nd	4.7[a]	4.7
Neutral detergent fibre	244.7[c]	199.3[b]	178.0[a]	382.0[d]	400.7[e]	24.8
Acid detergent fibre	102.3[d]	54.7[b]	44.7[a]	54.3[b]	90.0[c]	6.1
Hemicellulose	143.3[b]	144.7[b]	133.3[a]	327.7[d]	310.7[c]	23.5
Cellulose	55.0[c]	18.3[a]	14.7[a]	17.7[a]	46.7[b]	4.5
Lignin	20.3[c]	2.0[a]	5.7[ab]	4.0[ab]	7.7[b]	1.8
NDIP	40.0[c]	17.7[a]	26.3[b]	17.0[a]	29.0[b]	2.3
ADIP	27.0[b]	4.7[a]	5.7[a]	4.7[a]	4.7[a]	2.4
Starch	500.0[a]	650.0[d]	620.0[c]	540.0[b]	506.7[a]	16.3

Means with different superscripts within the same row differ significantly ($P < 0.05$).
[a]SEM, Standard error of the mean. NDIP, Neutral detergent insoluble protein; ADIP, Acid detergent insoluble protein; nd, not detected.

Table 2. Carbohydrate fractions in *P. minor* seeds and conventional energy sources

Parameter	*P. minor*	Maize	Wheat	Pearl millet	Barley	SEM[a]
TCHO (% DM)	73.87[a]	85.43[b]	84.80[b]	85.60[b]	84.50[b]	1.21
NSC (% TCHO)	65.79[c]	78.21[d]	80.48[e]	56.25[b]	53.82[a]	2.93
Starch (% NSC)	76.02[a]	83.11[b]	77.04[a]	96.02[c]	94.15[c]	2.27
C_A (% TCHO)	15.79[c]	13.21[b]	18.48[d]	2.25[a]	3.15[a]	1.79
C_{B1} (% TCHO)	50.00[a]	65.00[d]	62.00[c]	54.00[b]	50.67[a]	1.63
C_{B2} (% TCHO)	27.60[c]	21.23[b]	17.91[a]	42.63[d]	44.00[e]	2.89
C_C (% TCHO)	6.61[c]	0.56[a]	1.61[ab]	1.12[ab]	2.18[b]	0.59

Means with different superscripts within the same row differ significantly ($P < 0.05$).
[a]SEM, Standard error of the mean. TCHO, Total carbohydrates; NSC, Non-structural carbohydrates; C_A, Fraction A; C_{B1}, Fraction B1; C_{B2}, Fraction B2; C_C, Fraction C.

Table 3. Protein fractions (% CP) of *P. minor* seeds and conventional energy sources

Parameter	*P. minor*	Maize	Wheat	Pearl millet	Barley	SEM[a]
NDIP	32.76[c]	19.89[a]	21.58[ab]	18.08[a]	26.25[b]	1.50
ADIP	21.67[b]	5.15[a]	4.74[a]	5.21[a]	4.31[a]	1.99
NPN	12.04[a]	20.89[c]	32.92[d]	17.77[b]	18.84[bc]	1.86
SP	17.61[a]	26.68[b]	45.97[e]	31.53[c]	33.40[d]	2.48
P_A	12.04[a]	20.89[c]	32.92[d]	17.77[b]	18.84[bc]	1.86
P_{B1}	5.57[a]	5.80[a]	13.05[b]	13.76[b]	14.56[b]	1.12
P_{B2}	49.62[c]	53.43[c]	32.44[a]	50.39[c]	40.34[b]	2.14
P_{B3}	11.10	9.73	15.93	13.50	21.04	1.54
P_C	21.67[b]	5.15[a]	4.74[a]	5.21[a]	4.31[a]	1.99

Means with different superscripts within the same row differ significantly ($P < 0.05$).
[a]SEM, Standard error of the mean. NDIP, Neutral detergent insoluble protein; ADIP, Acid detergent insoluble protein; NPN, Non-protein nitrogen; SP, Soluble protein; P_A, Fraction A; P_{B1}, Fraction B1; P_{B2}, Fraction B2; P_{B3}, Fraction B3; P_c, Fraction C.

similar trend with *P. minor* seeds having the highest ($P < 0.05$) value. However, both NPN and soluble protein levels were lowest ($P < 0.05$) in *P. minor* seeds and highest ($P < 0.05$) in wheat. Fraction P_A was highest ($P < 0.05$) in wheat and lowest ($P < 0.05$) in *P. minor* seeds. Fraction P_{B1} in *P. minor* seeds was similar to that of maize. P_{B2} constituted the bulk of protein fractions in all energy sources, with *P. minor*, maize and pearl millet showing higher ($P < 0.05$) values than wheat and barley. Fraction P_{B3} in *P. minor* seeds was similar to conventional energy sources evaluated. However, unavailable protein fraction P_C was lower ($P < 0.05$) in the conventional cereal grains than *P. minor* seeds.

Wheat contained the highest ($P < 0.05$) content of truly digestible NFC (Table 4). The truly digestible CP in *P. minor* seeds was similar to that of wheat and barley.

Table 4. TDN content and IVDMD (%) of *P. minor* seeds and conventional energy sources

Parameter	*P. minor*	Maize	Wheat	Pearl millet	Barley	SEM[a]
td NFC (% DM)	52.33[c]	65.92[d]	68.24[e]	48.12[b]	46.39[a]	2.44
td CP (% DM)	11.25[bc]	8.85[a]	11.81[c]	9.21[a]	10.71[b]	0.31
td FA (% DM)	5.27[d]	3.23[c]	1.00[a]	2.00[b]	1.10[a]	0.43
td NDF (% DM)	11.25[b]	10.97[b]	8.91[a]	22.04[c]	22.22[c]	1.55
TDN_{1X} (% DM)	79.69[c]	86.01[e]	84.21[d]	76.87[b]	74.80[a]	1.14
IVDMD (%)	74.40[a]	89.87[c]	91.70[d]	89.91[c]	79.46[b]	1.84

Means with different superscripts within the same row differ significantly ($P < 0.05$).
[a]SEM, Standard error of the mean; td NFC, Truly digestible non-fibrous carbohydrates; td CP, Truly digestible crude protein; td FA, Truly digestible fatty acid; td NDF, Truly digestible neutral detergent fibre; TDN, Total digestible nutrients; IVDMD, *In vitro* dry matter digestibility.

Table 5. Correlation between chemical composition and IVDMD

Chemical constituents	IVDMD (%)	Protein fractions	IVDMD (%)	Carbohydrate fractions	IVDMD (%)
OM	0.85*	CP	–0.30	TCHO	0.78*
CP	–0.30	NDIP	–0.77*	NSC	0.60*
EE	–0.65*	ADIP	–0.73*	C_A	0.24
Total ash	–0.87*	NPN	0.88*	C_{B1}	0.82*
Acid insoluble ash	–0.80*	SP	0.81*	C_{B2}	–0.45
NDF	–0.40	P_A	0.88*	C_C	–0.79*
ADF	–0.94*	P_{B1}	0.32		
Hemicellulose	–0.19	P_{B2}	–0.40		
Cellulose	–0.92*	P_{B3}	–0.04		
ADL	–0.79*	P_C	–0.73*		
NDIP	–0.68*				
ADIP	–0.72*				
Starch	0.82*				

*Significant at $P < 0.05$; see footnotes in Tables 1, 3 and 4.

P. minor seeds contained the highest ($P < 0.05$) content of truly digestible fatty acids. The truly digestible NDF content in *P. minor* seeds was similar to maize. TDN content of *P. minor* seeds was lower ($P < 0.05$) than maize and wheat, but it was higher ($P < 0.05$) than pearl millet and barley. IVDMD (24 h post-incubation) was highest ($P < 0.05$) in wheat (91.70%) and lowest ($P < 0.05$) in *P. minor* seeds (74.40%).

CP, EE, total ash, AIA, NDF, ADF, cellulose, ADL, NDIP and ADIP of energy feeds were negatively associated with IVDMD, whereas OM ($r = 0.85$*) and starch ($r = 0.82$*) were positively associated with IVDMD (Table 5). NDIP (% CP), ADIP (% CP), P_{B2} (% CP), P_{B3} (% CP) and P_C (% CP) fractions of protein were also negatively related with IVDMD ($r = –0.77$*, $r = –0.73$* and $r = –0.40$, $r = –0.04$ and $r = –0.73$*), whereas other protein fractions, viz. NPN, SP and P_A showed positive relation with IVDMD.

IVDMD showed positive association with TCHO (% DM), NSC (% TCHO), C_A (% TCHO) and C_{B1} (% TCHO) carbohydrate fractions of energy feeds with *r* values of 0.78*, 0.60*, 0.24 and 0.82* respectively whereas C_{B2} (% TCHO) and C_C (% TCHO) fractions of carbohydrates were negatively correlated with IVDMD for energy feeds.

Linear regression equations derived from 30 observations of proximate and cell wall constituents of energy feeds were better predictors of DM digestibility (%) with R^2 value of 0.99, followed by protein fractions ($R^2 = 0.96$) and carbohydrate fractions ($R^2 = 0.95$). However, R^2 value was high in all three equations, indicating its utility to predict DM digestibility of energy feeds.

Chemical properties of feedstuffs for carbohydrate and protein fractions are unique. Therefore, selection of feed ingredients based on CNCPS evaluation will be more logical for formulating efficient diets for livestock. To the best of our knowledge, this is the first report on evaluation of *P. minor* seeds by CNCP system.

The nutritive value of a ruminant feed is given/resolved by the level of its chemical components, as well as their rate and extent of digestion. The results of proximate constituents and cell wall fractions of conventional cereal grains obtained in the present study agree with those reported earlier[14,15]. Our results also agree with those of Kaur *et al.*[16] who reported that the CP of *P. minor* seeds was comparable with that of wheat, but higher than

Table 6. Linear regression equations to predict DM digestibility (%) from chemical components, protein and carbohydrate fractions of energy sources

Regression equation	MSE	R^2	*P*-value
DMD = 55.281 + (1.897 × OM) – (1.004 × CP) – (0.911 × NDF) – (0.691 × ADF) – (1.911 × ADL) – (0.831 × starch) – (0.850 × TDN)	0.13	0.99	<0.001
DMD = 81.803 – (0.297 × NDIP) + (0.400 × NPN) – (0.0902 × P_{B3})	0.85	0.96	<0.001
DMD = –88.202 + (0.567 × TCHO) – (0.180 × NSC) + (1.339 × starch) + (2.121 × C_A) – (0.0541 × C_{B2})	1.21	0.95	<0.001

maize, whereas total ash, NDF and ADF in *P. minor* seeds were higher than maize and wheat. Similarly, Harrold and Nalewaja[17] analysed weed seeds, viz. wild buckwheat, wild oats, wild mustard, pigweed and reported that ash, CP and EE were higher in weed seeds than cereals.

C_A fraction in *P. minor* seeds was higher than conventional cereal grains except wheat, indicating that *P. minor* seeds contained higher levels of fast degrading sugars and organic acids. Low C_{B1} fraction in *P. minor* indicated low starch and soluble fibre content. However, higher fractions of C_{B2} in *P. minor* seeds indicate high content of digestible fibre. Furthermore, fraction C_C (unavailable carbohydrates) is also high in *P. minor* seeds due to high lignin content in *P. minor* seeds. The total carbohydrates and NSC (% TCHO) in conventional cereal grains observed in the present study corroborate well with those reported by Das[18]. Kamble *et al.*[15] reported starch (% NSC) content of most of the grains to be more than 90%. However, starch values of cereal grains in this study are in tune with those reported earlier[18,19]. Lower C_A fractions in pearl millet reported earlier[15] might be due to the high starch content. C_{B1} and C_{B2} fractions of cereal grains in the present study were within the same range reported in the literature[18]. Contrary to the present findings, Kamble *et al.*[15] documented higher values for C_C fraction of conventional cereal grains. This might be attributed to higher NDF and lignin content reported in that study. However, our results agree with those of Chen *et al.*[20] who reported that maize grain contained negligible amount of fraction C_C. Lower C_C fraction in conventional cereal grains indicates that most of the carbohydrates derived from grains are available to the animals.

ADIP and soluble protein of conventional cereal grains were similar to the reported observations[19]. In the present study, soluble protein was lowest in maize grains amongst the conventional energy sources, thereby substantiating the findings reported earlier[21]. Soluble protein content of *P. minor* seeds was lower ($P < 0.05$) than maize. Soluble protein in most feedstuffs may be considered an index of NPN constituents[9]. This justifies well with the lower P_A (NPN) fraction in *P. minor* seeds when compared to maize. The values of fractions P_{B1}, P_{B2}, P_{B3} and P_C of conventional cereal grains obtained in the present study agree with those reported earlier[19]. Fraction P_{B1} (soluble true protein) in *P. minor* seeds was similar to that of maize. Fraction P_{B2} (intermediate degradability) represented a large proportion of total protein in energy feeds, and was similar among *P. minor* seeds, maize and pearl millet. The fraction P_{B3} (slowly degraded protein) was similar in *P. minor* seeds and conventional cereal grains. *P. minor* seeds contained the highest ($P < 0.05$) level of fraction P_C. Fraction P_C depicts the protein associated with cell wall of the plant, which accounts for its insolubility[22] as it consists of lignin bound N and Maillard reaction products. This fraction appears to be indigestible and the quantity apparently digested is poorly used by the ruminants and cannot provide amino acids post-ruminally[9,23].

Nutrient composition of feeds as reported earlier[6,10] suggested similar TDN values of conventional cereal grains to those observed in the present study. IVDMD measurement has been widely used to evaluate the nutritional quality of feeds. This is due to its high correlation with *in vivo* digestibility. The results of *in vitro* study agree with the findings of Kaur *et al.*[16] who reported that DM digestibility was higher ($P < 0.05$) in wheat grains followed by maize and *P. minor* seeds.

Our observations substantiate the findings of Chaurasia *et al.*[24] who reported that fraction C_A was positively correlated, whereas fraction C_C was negatively correlated with the IVDMD of tree leaves, shrubs and grasses. The present results agree with those of Madibela and Modiakgotla[25] who reported high negative correlation between IVDMD and ADF.

The present results showed that DM digestibility (%) can be predicted from a linear combination of chemical constituents, viz. organic matter, CP, NDF, ADF, ADL, starch and TDN. The variables, viz. ether extract, hemicellulose and cellulose did not significantly add to the ability to predict DM digestibility and were not included in the final equation. The improvement in prediction of DM digestibility on inclusion of CP levels in our study is in line with that reported by Khazaal *et al.*[26], who indicated that prediction of *in vivo* digestibility was improved by inclusion of CP content. In the second equation, the carbohydrate fractions, C_{B1} and C_C were not included in the equation as they did not significantly add to the ability of equation to predict DM digestibility. The third equation indicated that DM digestibility can be predicted from a linear combination of protein fractions, viz. NDIP, NPN and P_{B3}. These findings indicated that the chemical composition of feed consumed has a direct influence on digestibility. Determining the digestibility of feeds by *in vivo* method is arduous and expensive as it requires large quantities of feed, and is unsuitable for single feedstuffs. The *in vivo* method is also subject to errors linked with inate animal variation and the use of microbial markers. Thus, prediction equations to determine DM digestibility provide a rapid alternative to *in vivo* study.

The results of the present study revealed that *P. minor* seeds had higher EE, total ash, AIA, ADF, cellulose, ADL, NDIP and ADIP content in comparison to conventional cereal grains. The CP content of *P. minor* seeds was similar to that of wheat, but higher than other conventional cereal grains like maize. C_{B1} fraction (starch and pectins) in *P. minor* seeds was similar to barley, whereas C_{B2} (slowly degradable cell wall) fraction was higher ($P < 0.05$) than maize and wheat. Among the protein fractions, *P. minor*, maize and pearl millet contained higher ($P < 0.05$) levels of protein fraction P_{B2} (intermediately degraded protein) than wheat and barley. TDN content of *P. minor* seeds was higher ($P < 0.05$) than pearl millet and barley. Keeping in view the above mentioned facts, *P. minor* seeds can be considered as promising energy supplement for livestock.

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