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ESTIMATION OF CRUDE FIBRE CONTENT OF A FEED FROM ITS ADF VALUE WHERE THERE IS NO LABORATORY SERVICE

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ABSTRACT: Because of the cost and inaccessibility of laboratory facilities, animal feed formulation at the farm level, in many parts of Ethiopia, is based on feed database information. However, nowadays many laboratories are phasing out the Weende crude fiber (CF) method of analysis. The fiber content of feeds available in most feed databases (including the sub-Saharan Africa feeds composition database) are a result of detergent method analysis (NDF, ADF and lignin). However, CF is still used in poultry feed formulation and forage analysis for horses, in addition to the neutral detergent fiber (NDF) fraction for determining fiber in different countries. Since there is a statistically ($P<0.01$) difference between the CF and acid detergent fiber (ADF) value of a feed, ADF can't be used directly in place of CF. Therefore, this work aims to formulate a regression equation that could roughly estimate the CF level of a feed from its NDF and ADF values. Considering the strong multicollinearity between NDF and ADF, this study developed separate models for ADF and NDF and compared them based on R^2 and Akaike Information Criterion (AIC), and the ADF-based model provided a better fit. The equations 0.79×ADF−0.460.79, 0.01+0.79×ADF, and 1.37+0.62×ADF have effectively predicted CF for cereal grains and beans, pulses and byproducts, and also oilseed meals and cakes, respectively. For grass forages, the equation 3.38+0.76×ADF, tested on 10 forages, showed potential but remains unreliable due to its R^2 value below 0.8. Finally, it is concluded that this approach provides a practical alternative for estimating CF where laboratory services or database information are unavailable.

Keywords: CF, Estimation, Feed database information, Prediction, Regression, Model.

INTRODUCTION

Dietary carbohydrates can be divided into two basic fractions: fiber and non-fiber carbohydrates (Mirzaei-Aghsaghali and Maheri-Sis, 2011). Fiber is any component in feed that is not digested by mammalian enzymes (Jha and Mishra, 2021). Based on its solubility in water fibers can be grouped into soluble fiber (which dissolves in water) and insoluble fiber. The proximate analysis system developed by the Weende Experiment Station in Germany classified carbohydrates in feed into a more digestible component called nitrogen-free extract (NFE) and a less digestible fibrous component called crude fiber (Singh and Kim, 2021). Crude fiber is a plant cell structural component, including cellulose, hemicelluloses, lignin, and pectin (An et al., 2021; Musa, 2021). The proximate analysis system underestimates the true fiber in the feed. A major problem with this procedure is that the acid and base used in the analysis solubilize some of the true fiber (particularly hemicelluloses, pectin, and lignin), and some cellulose is partially lost too (Musa, 2021). The proximate analysis system only represents a small fraction of the fiber content (average 80% of hemicellulose or pentosans, 50-90% lignin and 50-80% cellulose recovery) (Van Soest and McQueen, 1973). The CF method has a complete recovery of pectins (Möller, 2014).

The other analysis process using neutral and acid detergents by Vax Soest (1963) categorized fiber into neutral detergent fiber (NDF) comprising of cellulose, hemicellulose and lignin, and acid detergent fiber (ADF), largely consisting of cellulose and lignin (Singh and Kim, 2021). The Van Soest detergent fiber system is also affected by unreliability and falls short of accounting for all non-starch polysaccharides (NSP) in the poultry feed ingredients (Singh and Kim, 2021). Non-starch polysaccharides are complex carbohydrates found predominantly in plant cell walls and include components like cellulose, hemicellulose, and pectin. Unlike starch, NSPs cannot be digested by non-ruminants due to their structural complexity and cross-linking, which limits their availability as an energy source.

The Neutral Detergent Fiber (NDF) method has been criticized for not adequately recovering pectin, which is an important part of the cell wall matrix in plants. This omission can lead to an incomplete understanding of the fiber content and its digestibility in poultry diets (Van-Soest et al., 1991). A relatively new feed composition analysis method is Near Infrared Reflectance spectroscopy (NIR). Though NIR method allows rapid and least cost determination of multiple nutrients and characteristics of feeds or forage, it is not available in many places of Ethiopia including the pioneer agricultural university-Haramaya.

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Because of the cost and inaccessibility of laboratory facilities, animal feed formulation at the farm level, in many parts of Ethiopia, is based on feed database information. However, nowadays many laboratories are phasing out the CF method of analysis. The fiber content of feeds available in most feed databases (including the sub-Saharan Africa feeds composition database) is more of a result of detergent method analysis (NDF, ADF and lignin). However, CF is still used in poultry feed formulation (Singh and Kim, 2021) and forage analysis for horses, in addition to the NDF fraction for determining fiber (Hoffgård, 2022) in different countries. Therefore, the objective of this work is to formulate a regression equation that could roughly estimate the CF level of a feed from its NDF and ADF values.

MATERIALS AND METHODS

Regression models were developed to estimate the CF level of feeds (that could be determined using the Weende proximate analysis system) from their ADF and ADF level using R 4.4.1. The data were taken from Makkar et al. (2024) and INRAE (2024a). First, two candidate models (i.e. using NDF or ADF as predictor variables) were developed for each feed category (i.e. grass forages, cereals grain and bran, pulse seed and byproducts, and oilseed byproducts) and compared using the analysis of variance (ANOVA) in R. Finally, the best-performed model for each feed category was selected for its applicability using a paired sample t-test between the actual and predicted CF values for its non-significance tells us its goodness of fit.

The sample size is determined using Green (1991) and Memon et al. (2020) formula: n=104+k; where, n and k are the number of sample size and predictors, respectively. The predator in this case was one (i.e. NDF or ADF) and the minimum sample size would be 105.

The model used in this study was: $Y = \beta_0 + \beta_1\chi_1 + e$; where Y is the response variable (i.e. CF), β_0 is the intercept of the regression line, corresponding to the predicted values when χ_1 (i.e. NDF or ADF) are zero. $\beta_1\chi_1$ is the regression coefficient (β_1) on the independent variables (χ_1 i.e. NDF or ADF). e is the model error (residuals), which defines how much variation is introduced in the model when estimating Y.

RESULTS AND DISCUSSION

Table 1 presents the correlation between CF, NDF, and ADF. The strong correlation between NDF and ADF suggests the presence of high multicollinearity between them indicating they can't be used together in model formulation to predict CF from detergent fiber results. Therefore, separate Models were formulated for ADF and NDF. Choct (2016) noted that, though, the proportion of cellulose and to a lesser extent lignin extracted can be highly variable depending on the ingredient, CF, more or less, represents cellulose and lignin (i.e. ADF) content. However, since there is a significant ($P<0.01$) difference between ADF and CF (Table 1) we can't directly use ADF in place of CF.

Figures 1 and 2 as a partial residual plot showing the linearity assumption of a predictor's (i.e. ADF and NDF) relationship with the dependent variable CF. Both figures show a linear relationship of predator with CF. Where a partial residual plot shows the linear relationship between predictors and dependent variables a linear model can be used (Fox, 2015).

The partial residual plot indicates both the magnitude of the linearity variance and the linearity magnitude and position (Roy et al., 2020).

Table 2 below presents the model parameters and parameters used to compare the models in estimating CF of different categories of feeds from their ADF and NDF contents. In all feed categories, the R^2 value of model one was higher, and the Akaike Information Criterion (AIC) value was lower than model 2. The Delta AIC (ΔAIC) values were much greater than 10. The R2 value of model one ranges from 0.75 to 0.94. Except for grass forages, the R2 value of model one of the feed categories was greater than 0.80. The R2 value equal to 0.8 clearly indicates a very good regression model performance, regardless of the ranges of the ground truth values and their distributions (Chicco et al., 2021). Lower AIC indicates a better fit. If ΔAIC >10, there is strong evidence that the model with the lower AIC is better (Burnham and Anderson, 2002).

Table 1 - Correlation and difference between variables in different feed categories

Parameters	grass forages (Roughages)	Cereal grain and bran	pulse seed and byproducts	Oilseed byproducts
Correlation (NDF and ADF)	0.85	0.86	0.91	0.92
Mean difference between ADF and CF (i.e ADF-CF)	6.14	2.63	4.14	8.61
t-value	-21.97	-11.069	-8.7222	-11.739
SEM	0.74	1.07	1.51	1.81
P-value	< 0.01	< 0.01	< 0.01	< 0.01

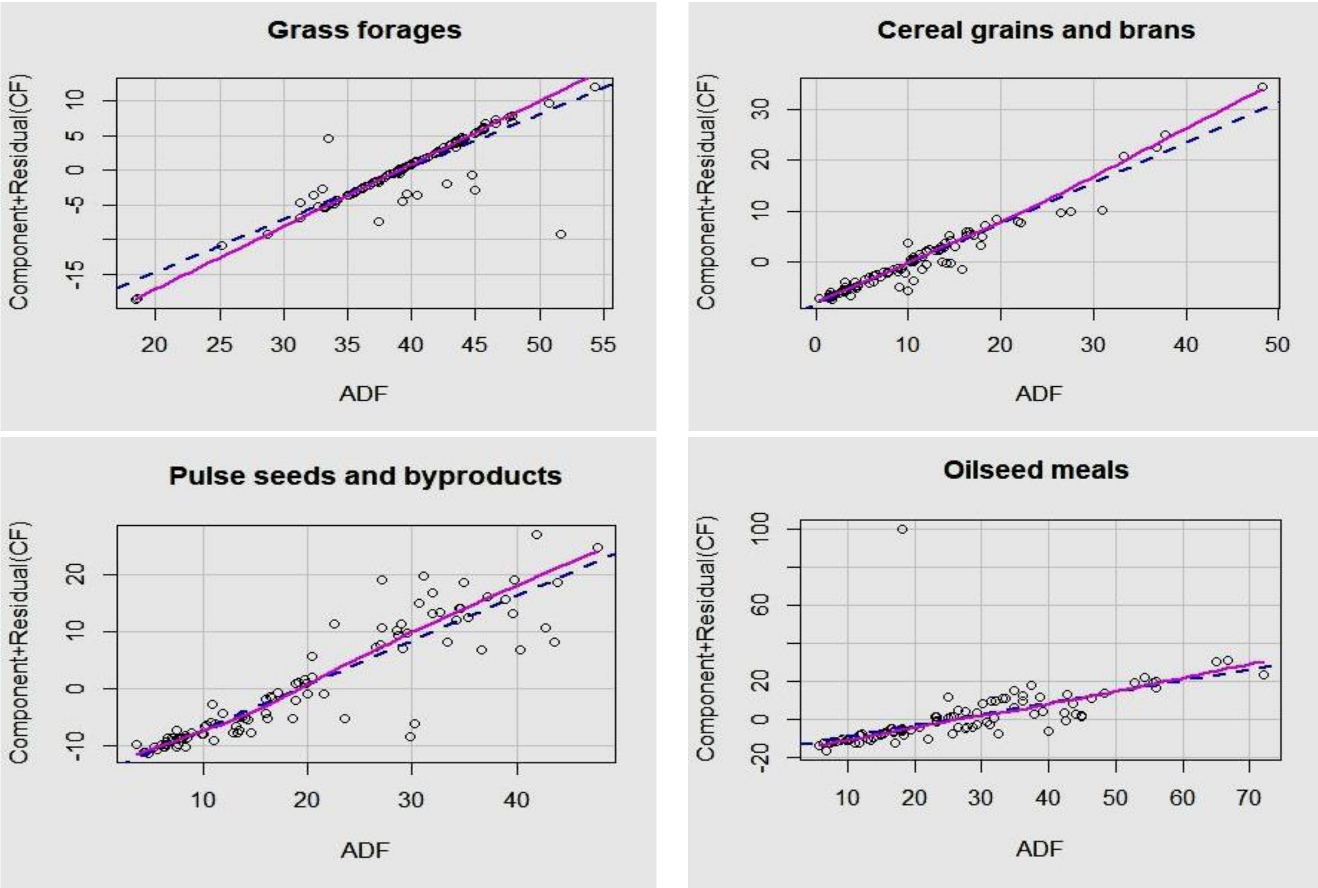

Figure 1 - Trends of the relation between CF and acid detergent fiber (ADF)

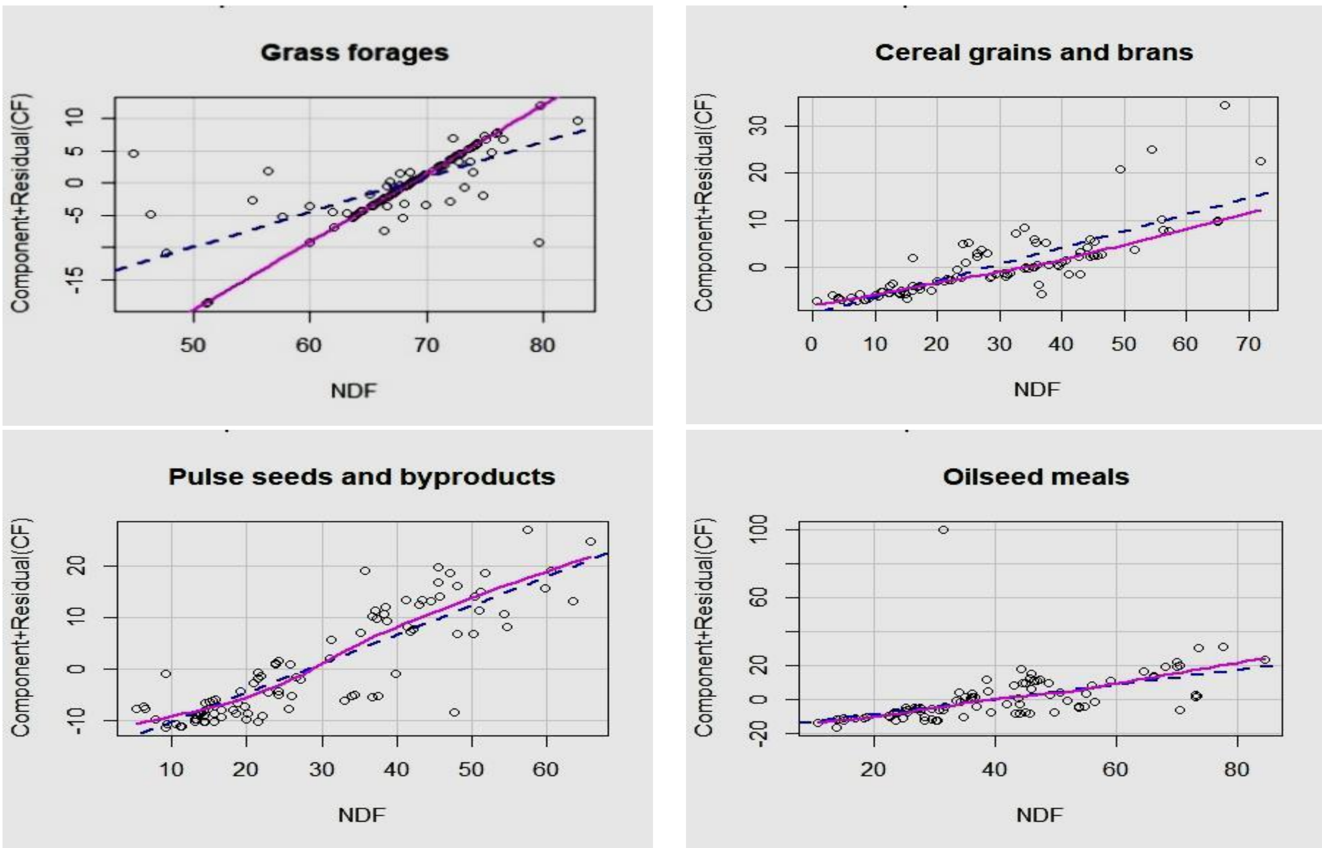

Figure 2 - Trends of the relation between CF and the neutral detergent fiber (NDF).

Table 2: Estimation of CF of a feed based on its NDF and ADF values.

Models	Model parameters				Model comparison parameters		
	β_0 (Intercept)	β_1 (Coefficient)	R^2	P-value	RSS*	AIC	ΔAIC
grass forages (roughages)							
Model-1: CF~ADF	3.38 ± 1.73	0.76 ± 0.04	0.7454[a]	<0.001	684.54[b]	508.24	73.65
Model:2:CF~NDF	-3.90 ± 3.71	0.55 ± 0.05	0.4932[b]	<0.001	1362.49[a]	581.89	
SE			0.07		0.60		
P-value			**		**		
Cereals grains and brans							
Model-1: CF~ADF	-0.46 ± 0.27	0.79 ± 0.02	0.9403[a]	<0.001	297.33[b]	413.27	184.11
Model:2:CF~NDF	-1.72 ± 0.80	0.35 ± 0.02	0.6555[b]	<0.001	1716.87[a]	597.38	
SE			0.10		0.61		
P-value			**		**		
Pulse and their byproducts							
Model-1: CF~ADF	0.01 ± 0.78	0.79 ± 0.03	0.8308[a]	<0.001	1808.20[b]	607.50	46.66
Model:2:CF~NDF	-0.65 ± 1.05	0.56 ± 0.03	0.7373[b]	<0.001	2808.19[a]	654.16	
SE			0.08		0.91		
P-value			**		**		
Oilseed meals and cake							
Model-1: CF~ADF	1.37 ± 0.89	0.62 ± 0.03	0.8025	<0.001	2282.64[b]	632.20	72.93
Model:2:CF~NDF	-0.19 ± 1.51	0.45 ± 0.04	0.6070	<0.001	4541.94[a]	705.13	
SE			0.07		1.11		
P-value			**		**		

RSS: Residual Sum of Squares

Crude fiber estimation from ADF of grass forages

Table 3 presents the difference between the actual and estimated CF values of 11 grass forages. The paired t-test result indicated no significant difference (P>0.05) between the actual and the predicted values of CF. The predicted CF value of orchard grass was 34.54 and 37.58% of DM. In agreement with this finding, the CF value of Orchard grass was reported to range from 30.2% (Joanna et al., 2007) to 46.45% of DM (Farshadfar, 2012). Glatter et al. (2021) also reported the CF value of meadow hay (35.6%) which is similar to the predicted value of Orchard grass Orchard grass. The 32.94% predicted value of the bamboo leaves reported in this research agrees with the 33.19 % reported by Antwi-Boasiako et al. (2011). Shahowna et al. (2013) reported 54.3 and 47.4 % CF for fresh and fermented sugar cane bagasse, similar to the 48.07% predicted CF value for the same feed using the regression equation developed for grass forages or roughages. The predicted CF value of German grass (33.93%) was within the range of CF value of the German grass at the 3rd (28.30%) and 1st (38.93%) cut reported by Islam et al. (2018). Rahman et al. (2024) also reported the CF value of German grass to be 34.7%. This sight variation in CF content is due to the difference in stage maturity when the sample was analyzed. The predicted CF value (29.14%) for roadside grass was within the range of 32.25 to 36.09 % reported by Haryono et al. (2020) for different cultivars of the roadside grass.

Table 3 - Differences between original CF and model-1 predicted CF for some grass forages*

Feed type/name		Original CF (%)	Literature Source	Predicted CF (%)
Orchardgrass (*Dactylis glomerata* L): mid-bloom		33.00	Schroeder (2004)	34.54
Orchard grass (*Dactylis glomerata* L): late-bloom		37.00	“	37.58
Sorghum-Sudan-grass Timothy:				
Late vegetative		27.00	Schroeder (2004)	25.42
Mid-bloom		31.00	“	30.74
Late bloom		31.00	“	45.18
Roadside grass (*Stenotaphrum secundatum*)		46.27	Selim et al. (2022)	29.14
Banana leaves		29.35	“	31.35
Bamboo leaves		35.56	“	32.94
Sugar cane bagasse		37.89	“	48.07
German grass (*Echinochloa polystachya*)		39.84	“	33.93
King grass (*Pennisetum purpureum*)		36.10	Tuturoong et al. (2019)	35.22
Mean		34.91[a]		34.92[a]
Original vs Predicted CF	SE of the difference		2.59	
	t-value		-0.0041	
	P-value		0.9968	

* The original crude fiber (CF) used in this table are not used in the model formulation

Crude fiber estimation from ADF of cereals grain and bran

Table 4 presents the differences between the original CF and the CF predicted from ADF using the model for some cereals grain and brans. The insignificant (P>0.05) difference observed between the actual and the predicted CF value suggests the good fit of the model in predicting CF from ADF. The CF value of 3.32% predicted from ADF of maize grain was found within the range (2.8 to 4.5%) reported by Fufa et al. (2019) and Rose and Gupta (2018), respectively. The predicted value also falls within the range 2.62 to 3.93 reported by Radosavljević et al. (2020).

Hossain et al. (2008) reported 11.38% CF for wheat bran, similar to the 11.64% CF predicted from the ADF of wheat bran. In agreement with this Liu et al., (2024) also reported 10.94% of CF for wheat bran. The CF values of 3.2% and 5.23% predicted from ADF of wheat and barley grain, respectively, were similar to 3.0% and 5.23% reported for wheat and barley grain by Hossain et al. (2008) and Venslovas et al. (2024), respectively. The CF values of 5.81, 5.44, and 7.05% predicted from ADF of Sorghum grain were similar to 5.90, 5.40, and 6.50 % reported by Kumar et al. (2019) for different sorghum varieties. In agreement with this finding Treviño-Salinas et al. (2021) also reported 6.07 to 9.09 % of CF for different varieties of sorghum grains. The CF value of 4.17% predicted from the ADF of Sorghum HB2 was similar to the 4.17% reported by Banna and Arifuddin (2024).

Table 4 - Differences between original CF and model-1 predicted CF for some cereals grain and bran *

Feed type/name	ADF (%)	Original CF (%)	Literature source	Predicted CF (%)
Maize grain	4.79	1.10	Jaishankar et al. (2021)	3.32
Wheat bran	15.32	14.07	Ning et al. (2022)	11.64
Wheat	4.63	2.71	“	3.20
Barley grains	7.20	9.0	Asma et al. (2021)	5.23
Corn	3.96	1.82	Sheikhhasan et al. (2020)	2.67
Sorghum HB1	7.94	1.96	Salinas et al. (2006)	5.81
Sorghum HB2	5.86	2.67	“	4.17
Sorghum HB3	9.51	4.17	“	7.05
Sorghum HB4	24.24	9.02	“	18.69
Sorghum HB5	25.47	6.80	“	19.66
Sorghum HB7	7.47	1.71	“	5.44
Mean		5.00[a]		7.90[a]
Original vs Predicted CF	SE of the difference		2.23	
	t-value		-1.9943	
	P-value		0.07409	

* The ADF and original CF used in this table are not used in model formulation. CF: crude fiber;; ADF: acid detergent fiber

Crude fiber estimation from ADF of pulse seeds and byproducts

Table 5 presents the differences between the original CF and the CF predicted from ADF using the model formulated for pulse seeds and byproducts. The insignificant (P>0.05) difference observed between the original and the predicted Cf value suggests the ability of the model to predict CF from ADF. The CF values of 27.98%, 32.48%, and 9.16% predicted from ADF of the cowpea haulms, cowpea Pod husks, and faba bean seeds, respectively, were similar to 27.5%, 31.8 %, and 8.9 % reported by Antwi et al. (2014), Abebe and Alemayehu (2022) and Micek et al. (2015), respectively for similar ingredients. The CF value of 5.15% predicted from ADF of cowpea seed was also comparable to the 5.66% reported by Gutema and Tolesa (2024). The CF value of 11.31% predicted from ADF of Lupin seed was found within the range (10.0 to 16.0%) reported by Abraham et al. (2019). Uzun and Okur (2023) also reported 11.75 % CF for Blue lupin. The CF values of 5.15% and 7.36% predicted values from ADF of the Adzuki bean and pigeon pea were similar to the 4.71 ± 0.54 % and 6.6% reported by Sai-Ut et al. (2010) and Saxena et al. (2010), respectively. The CF values of 4.32%, 7.81% and 5.90% predicted from ADF of Chickpea, Faba bean, and Common vetch were comparable to the 3.9 %, 7.72 %, and 3.80–7.17 % reported by INRAE (2024b), Smit et al. (2021), and Huang et al. (2017), respectively.

Crude fiber estimation from ADF of Oilseed byproducts

Table 6 presents the differences between the original CF and the CF predicted from ADF using the model formulated for oilseed byproducts. The insignificant (P>0.05) difference between the original and the predicted CF suggests the ability of the model to predict CF from ADF. The CF values of 8.31%, and 4.64% predicted from ADF of rapeseed cake and Soybean meal were similar to the 7.9 % and 4.40% reported by the National Dairy Development Board (2012) of India and Makkar et al. (2024), respectively. In agreement with this finding Tang et al. (2024) also reported 8.26 % CF for rapeseed cake.

The CF value of 10.93% predicted from ADF of canola meal was in the range 8.97 to 11.4 % reported by Birmani et al. (2019). Kaiser et al. (2022) also reported 10.1% CF of the canola meal. The CF value of 17.92% predicted from ADF of Noug seed cake was similar to the 17.65 % reported by Amare et al. (2021). The CF value of 17.12% predicted from ADF of Sesame meal was less than the 9.86 % reported by Elfaki and Unal (2023). The Difference is due to their ADF content. The former had 25.41% ADF, while the latter had 13.83%. The CF value of 15.11% predicted from ADF of Sunflower cake was within the range (11.6-23.89%) reported by Swain et al. (2023). The CF values of 8.44% and 4.68% predicted from the ADF of flaxseed cake and soybean meal were similar to the 8.8 % and 5.44 % reported by Nehmeh et al. (2022) and Etiosa et al. (2018), respectively. Dunmire et al. (2021) also reported CF values ranging from 4.27 to 5.17% for soybean meal produced from different varieties of soybean, which is similar to the above-mentioned predicted CF value for soybean meal.

Table 5 - Original CF and model-1 predicted CF for some pulse seeds and byproducts *

Feed type/name	NDF (%)	ADF (%)	Original CF (%)	Literature source	Predicted CF (%)
Cowpea haulms	49	35.4	29.9	Li et al. (2021)	27.98
cowpea Pod husks	54.2	41.1	31.8	"	32.48
faba bean seeds	22.06	11.58	9.72	Meng et al. (2021)	9.16
cowpea seed	16.6	6.5	5.6	Makkar et al 2024	5.15
Lupins (al bus)	17.2	14.3	10.27	Sipas et al. (1997)	11.31
Adzuki bean	12.70	6.50	4.76	"	5.15
Pigeon pea	13.70	9.30	8.07	"	7.36
Chickpea Kabuli	11.90	5.46	2.93	"	4.32
Faba bean	12.79	9.87	8.41	"	7.81
Common vetch	21.90	7.46	5.10	"	5.90
		Mean	11.656 [a]		11.662 [a]
Original vs Predicted CF		SE of the difference		4.5733	
		t-value		-0.012801	
		P-value		0.9901	

* The NDF, ADF, and original CF used in this table are not used in the model formulation. CF: crude fiber; NDF: neutral detergent fiber: ADF: acid detergent fiber

Table 6 - Original CF and model-1 predicted CF for some Oilseed byproducts *

Feed type/name	NDF (%)	ADF (%)	Original CF (%)	Literature sources	Predicted CF (%)
Rapeseed cake	17.80	26.03	11.19	Renata et al. (2018)	8.31
Soybean meal	8.21	5.28	3.89	Tanawong (2013)	4.64
Canola meal	22.64	15.42	10.50	"	10.93
Noug seed cake	34.5	26.7	22.0	Moges et al. (2016)	17.92
Sesame seed meal	37.50	24.25	9.00	Mahmoud and Wafaa (2014)	16.41
Cottonseed Cake	61.53	17.70	12.10	Idrissou et al. (2020)	12.34
Sesame meal	39.35	25.41	3.28	Omer et al. (2019)	17.12
Flaxseed cake	14.2	11.4	8.1	Niyonshuti and Kirkpinar (2024)	8.44
Sunflower cake	32.59	36.56	22.16	Renata et al. (2018)	15.11
Soybean	9.36	13.99	5.34	"	4.68
		Mean	10.76 [a]		11.59 [a]
Original CF vs Predicted CF		SE of the difference		2.6353	
		t-value		-1.6653	
		P-value		0.1198	

CF: crude fiber ;NDF: neutral detergent fiber; ADF: acid detergent fiber

CONCLUSION

Where there is no laboratory service and the database information for crude fiber values for a feed in question, it is possible to estimate the CF value from the ADF value of a feed. Since there is a statistically significant (P<0.01) difference between the CF and ADF value of a feed, ADF can't be used directly in place of CF. The regression equation 0.79 *ADF - 0.46, 0.01+0.79 *ADF, and 1.37+0.62 *ADF can be used for cereals grains and brans, pulse and their byproducts, and oilseed meals and cake, respectively. However, for the R2 value less than 0.8, the regression equation 3.38 +0.76 *ADF formulated for grass forages, even though tested on 10 forages and found effective, the model is not reliable.

DECLARATIONS

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Supplementary Information

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Author's Contribution

I contribute to data analysis, interpretation, discussion, and the write-up of the manuscript.

Competing interests

The author has not declared any competing interests.

Consent to publish

The author has reviewed and approved the final manuscript for publication.

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