Research Article

Classification of Legume Quality Based on Chemical Composition and Digestibility Values using Multivariate Analysis

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Abstract | The quality of the legume crops used as ruminant feed sources must be determined based on their characteristics and quality. The quality of legumes is primarily determined by their protein content, In the matter of fact, some legumes are also contained high fiber that further influence ruminant digestibility rates. Hence, the present study aimed to classify the quality of feed legumes according to legume type, climatic region of plant origin, edible parts, chemical composition, and digestibility. A database was built from the Feedipedia website platform, where 236 leguminous plants were introduced. All legumes were then classified according to their legume type, climatic region of plant origin, and edible parts. All classified legumes were statistically analyzed using R Studio software through a multivariate analysis model, such as principal component analysis (PCA) and cluster analysis. Evidences showed that the PCA analysis was unable to differentiate legumes by their type, climatic region of plant origin, and edible parts. However, following nutrient content such as CP, EE, and GE of some legumes, they were positively related to digestibility rates, whereas some legumes were negatively related to the CF, NDF, ADF, and ash content. Moreover, based on their edible parts, the legume seeds which have high protein contents and are associated with high digestibility rates while the aerial and leaves parts were associated with high fiber and lower digestibility rates. From the cluster analysis, it was confirmed that some legumes had higher protein content and digestibility rates allocated in cluster 2, while in cluster 1 were legumes that had high fiber content with lower digestibility rates. In conclusion, good-quality legumes can be determined from their higher protein content with higher digestibility rates, while lower-quality legumes can be determined by their higher fiber content and lower digestibility rates.

Keywords | Legume, Nutrient content, Principal component analysis, Cluster analysis, Feed quality

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INTRODUCTION

Leguminous forages are widely recognized for their exceptional quality, characterized by high protein content and low fiber content. The protein content of legumes typically ranges from 18% to 36%, whereas the fiber content ranges from 3.3% to 18.3%, with varying levels of lipids, such as linoleic and linolenic acids, as well as bioactive compounds, including isoflavones, phenolic acids, saponins, and polyphenolic compounds (Bahadoran and Mirmiran, 2015). Recently, the use of legumes as animal feed has presented several advantages, particularly for ruminant livestock. These benefits include improved ruminant performance (Castro-Montoya and Dickhoefer, 2018; Simbaya, 2002), enhanced nutrient digestibility (Ratnawaty *et al.*, 2018), increased fat content in milk (Brito and Broderick, 2006), and reduced methane emissions (Zeleke *et al.*, 2006). Moreover, the high quality effects of feeding legumes to ruminants can be attributed to their protein, which can demolish animal growth and development, which is then converted into energy. Energy derived from proteins, lipids, and carbohydrates, which are constituents of the chemical composition of feed ingredients, is crucial for the survival of livestock (Guadayo *et al.*, 2019; Jayanegara *et al.*, 2019). Hence, digestibility is a measure of the quality of feed ingredients is digestibility (Darma *et al.*, 2023).

Legumes can be classified based on various criteria such as the type of stem, climate in which they are grown, and edible parts. According to stem type, legumes are divided into trees, shrubs, and herb legumes (Castro-Montoya and Dickhoefer, 2020). Herb legumes have mild stem structures and grow by trailing on the ground, climbing, and attaching to other trees or fences. Shrub legumes, on the other hand, have woody stems and grow to form shrubs, whereas tree legumes possess strong and upright stem structures and grow upward. Based on their growing region, legumes can be classified into tropical, subtropical, and temperate categories. Tropical and subtropical legumes have optimal growth temperatures slightly above 30°C, whereas temperate legumes have optimal growth temperatures below 30°C (Pitman dan Vendramini, 2020). The differentiation process of the morphological development and physiological responses of plants is also affected by climatic conditions (Myers *et al.*, 2014). Therefore, climate can be one of the factors that influence the chemical content of legumes. All leguminous plants morphological structures can not be used as animal feed, whereas ruminants can only digest the edible parts of plants, such as branches, leaves, pods, flowers, and seeds (Myers *et al.*, 2014; Soedarmanto *et al.*, 2022). Moreover, the chemical contents of the edible parts of legumes also vary. For example, the protein content in leaves is higher than that in stems (Shih *et al.*, 2011).

Numerous studies have been conducted on leguminous plants, with particular focus on their chemical composition and use in ruminants (Castro-Montoya and Albarrán-Portillo, 2023; Kelln *et al.*, 2023; Marsetyo *et al.*, 2020). In the fact, high forage digestibility can also have significant environmental impacts. According to Restirinani *et al.* (2016), feed with high digestibility can reduce methane production. This effect occurs because highly digestible feed accelerates the fermentation process and brief existence of feed in the rumen to reduce production methane from methanogen (Chaokaur *et al.*, 2015). To address this gap, it is crucial to identify the effects of growth type, growth climate, and edible parts of legumes on their chemical composition and digestibility. To discern the relationship between legume types and their chemical composition, a substantial dataset is required to identify patterns. Consequently, this study utilized a database from Feedipedia, employing a multivariate analysis approach. Multivariate analysis enables the simultaneous examination of multiple variables to identify patterns and characteristics within the data (Everitt, 1975). Furthermore, this analysis is widely employed to explore data patterns and classifications and has also found application in animal husbandry (Jayanegara *et al.*, 2011; Miedico *et al.*, 2022). Therefore, the objective of the present study was to classify leguminous plants according to the type of stem, climate region, edible parts, chemical composition, and digestibility rates using a multivariate analysis.

Table 1: Categories and number of legumes included in the present study.

Legume Categories	Legume Class	Number of Samples
Legume type	Shrub	89
	Tree	148
	Herb	78
Climatic region of plant origins	Tropical	143
	Subtropical	62
	Temperate	32
Edible part	Aerial part	131
	Leaves	31
	Pods	41
	Seeds	35

MATERIALS AND METHODS

Legume Dataset

This study obtained information on legume plants from Feedipedia (www.feedipedia.org), a joint project of INRAE, CIRAD, AFZ, and the FAO. Feedipedia is an open-access information system that provides data on the nature, presence, chemical composition, and nutritional value of nearly 1400 animal feeds worldwide. Moreover, Feedipedia provided a comprehensive overview of research findings on feed ingredients, particularly on leguminous

Table 2: Descriptive statistics of the chemical composition and digestibility values of legumes.

Variable	Legume type									Climatic region					
	Shrub			Tree			Herbs			Tropical			Subtropical		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
CP	17.66	6.38	36.13	16.42	6.48	39.47	18.51	4.92	26.58	17.63	5.22	29.63	16.42	7.12	43.37
CF	26.37	10.37	39.34	22.22	8.15	36.68	26.40	9.58	36.30	25.51	9.18	36.00	24.55	9.82	39.98
NDF	42.63	12.59	29.52	40.31	9.85	24.44	43.82	12.09	27.59	42.92	11.15	25.98	41.89	11.26	26.89
ADF	31.07	10.28	33.10	29.67	8.39	28.28	31.29	10.83	34.62	31.02	9.81	31.61	30.88	8.80	28.50
Lignin	7.66	3.10	40.45	9.32	4.84	51.91	7.19	3.12	43.39	8.30	4.08	49.13	7.94	3.55	44.74
EE	2.78	1.35	48.44	3.27	1.70	52.19	2.76	1.21	43.84	2.95	1.42	48.17	2.97	1.59	53.65
Ash	8.40	2.87	34.15	6.72	2.87	42.79	8.94	3.47	38.80	8.02	3.22	40.17	7.55	3.12	41.30
GE	18.57	0.66	3.57	18.67	0.71	3.80	18.48	0.64	3.49	18.58	0.70	3.79	18.61	0.64	3.43
OMD	68.77	13.36	19.43	77.47	10.77	13.90	68.24	11.21	16.42	70.95	12.73	17.94	73.35	11.50	15.68
ED	64.89	12.57	19.37	73.44	10.38	14.13	65.18	11.44	17.55	67.25	12.07	17.95	69.37	11.12	16.03
DE	11.91	2.55	2.01	13.52	2.24	16.57	12.03	2.19	18.17	12.35	2.37	19.16	12.82	2.30	17.96
ME	9.54	2.01	21.10	11.04	1.71	15.48	9.59	1.78	18.59	9.97	1.92	19.27	10.33	1.84	17.78

CP: Crude Protein; **CF** Crude Fiber; **NDF:** Neutral Detergent Fiber; **ADF:** Acid Detergent Fiber; **EE:** Ether Extract; **GE:** Gross Energy; **OMD:** Organic Matter Digestibility; Energy Matter Digestibility; **DE:** Digestible Energy; **ME:** Metabolize Energy; **SD:** Standard Deviation; **CV:** Coefficient of Variance; **SD:** Standard Deviation; **CV:** Coefficient of Variance.

Table 3: Descriptive statistics of the chemical composition and digestibility values of legumes (Cont.).

Variable	Climatic Region			Edible Part											
	Temperate			Aerial Part			Leaves			Pods			Seeds		
	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
CP	19.50	6.25	31.05	18.20	5.03	27.66	17.19	6.46	37.59	17.63	5.22	29.63	16.42	7.12	43.37
CF	22.40	10.93	48.80	26.66	9.72	36.44	23.74	9.46	39.84	25.51	9.18	36.00	24.55	9.82	39.98
NDF	38.39	14.46	37.67	43.41	11.83	27.25	41.21	11.67	28.33	42.92	11.15	25.98	41.89	11.26	26.89
ADF	27.38	12.31	44.98	31.28	10.46	33.45	30.02	9.71	32.35	31.02	9.81	31.61	30.88	8.80	28.50
Lignin	6.70	3.47	51.74	7.36	3.36	45.71	8.37	4.15	49.60	8.30	4.08	49.13	7.94	3.55	44.74
EE	2.96	1.38	46.55	2.88	1.24	43.01	3.01	1.58	52.58	2.95	1.42	48.17	2.97	1.59	53.65
Ash	8.61	3.29	38.20	8.93	2.78	31.16	7.41	3.33	44.98	8.02	3.22	40.17	7.55	3.12	41.30
GE	18.56	0.62	3.33	18.48	0.54	2.91	18.65	0.74	3.98	18.58	0.70	3.79	18.61	0.64	3.43
OMD	71.49	13.33	18.65	67.43	12.08	17.91	74.20	12.13	16.35	70.95	12.73	17.94	73.35	11.50	15.68
ED	68.74	14.10	20.52	64.65	12.45	19.26	70.02	11.53	16.47	67.25	12.07	17.95	69.37	11.12	16.03
DE	12.74	2.99	23.49	11.94	2.39	20.02	12.88	2.43	18.83	12.35	2.37	19.16	12.82	2.30	17.96
ME	10.15	2.40	23.68	9.48	1.93	20.33	10.46	1.92	18.34	9.97	1.92	19.27	10.33	1.84	17.78

CP: Crude Protein; **CF** Crude Fiber; **NDF:** Neutral Detergent Fiber; **ADF:** Acid Detergent Fiber; **EE:** Ether Extract; **GE:** Gross Energy; **OMD:** Organic Matter Digestibility; Energy Matter Digestibility; **DE:** Digestible Energy; **ME:** Metabolize Energy; **SD:** Standard Deviation; **CV:** Coefficient of Variance; **SD:** Standard Deviation; **CV:** Coefficient of Variance.

plant chemical content and digestibility rates in ruminants. However, there is currently a lack of widely available information regarding the classification of leguminous plants based on their chemical composition and digestibility It is database sourced from research whole the world published in journal. The database was then built on three subcategories based on the type of stem, climate in which they are grown, and edible parts, including legumes from families faboideae, caesalpiniodeae, and mimosoideae in the database, which consisted of information regarding their chemical contents and digestibility rates in ruminants (Table 2 and 3). It was recorded that approximately 387 legume species were included in the datasets. The z-score analysis was introduced to statistically verified that those legumes quantitative values are within reliable ranges. The z-score analysis was conducted using the following formula (Warner, 2016):

$$z = \frac{xi - \mu}{s}$$

where z is the z-score, xi the observed data value, μ is the mean of the data, and s is the standard deviation. Through normality ranges data with a z-score greater than 2 or smaller than -2 will be identified before values that are still within the normal according to biolgically value not to considered as outlier data and were removed from the database. Values falling outside the established z-score range and deemed biologically implausible were excluded from further analysis. As a result, 236 leguminous plant data points were obtained for further multivariate analysis. The legume categories and number of legume samples used are presented in Table 1.

The parameters utilized in this study were nutrient content of legumes, such as crude protein (CP, % of DM), crude fiber (CF, % of DM), neutral detergent fiber (NDF, % of DM), acid detergent fiber (ADF, % of DM) lignin (% of DM), ether extract (EE,% of DM), Ash (% of DM), and gross energy (GE, MJ/kg of DM). Digestibility values include: organic matter digestibility (OMD, %), energy matter digestibility (EMD, %), digestible energy (DE, MJ/Kg of DM), and metabolize energy (ME, MJ/Kg of DM). The classification of edible parts of legume forages and climate region were determined based on information from the Feedipedia website. Meanwhile for the type of stems, they were classified using the USDA plant database (https://plants.usda.gov) and divided into "herbs" (including forbs, vines, and herbs), "shrubs" (including sub-shrubs and shrubs), and "trees" (including shrub-trees and trees).

Statistical Analysis

The multivariate analyses employed in this study included correlation coefficient analysis, principal component analysis (PCA), hierarchical cluster analysis, and k-means cluster analysis. All statistical procedures were performed using R software version 16. Meanwhile for the multivariate analyses were conducted using the R vegan package version 2.5.6 (Oksanen *et al*., 2014). For the correlation analysis was used to measure the linear relationship between two random variables (Schober dan Schwarte, 2018). The correlation analysis was used the "corr" program code with the "pearson" method was executed in R Studio. The analysis results are presented in the form of a matrix table to simplify data interpretation.

The PCA analysis was performed using the "prcomp" code in R Studio whereas the algorithm includes data scaling, eigenvector value determination, and principal component formation. Briefly, the analysis began with data standardization to equalize the units. The software then the datasets were reduced and generated eigenvalues, and sequentially explained the variation in the reduced data. Furthermore, factor values are generated by forming new variables called principal components (Jollife dan Cadima, 2016). At the last, factor values were then visualized as biplots directed towards facilitating the data interpretation.

The cluster analysis used in the present study was K-means non-hierarchical cluster analysis, utilizing the program code "kmeans." The cluster analysis algorithm consisted three stages: dimension reduction, cluster identification, and result evaluation (Dalmaijer *et al*., 2022). The cluster analysis began by determining the number of clusters using the "silhouette" method. Data scaling and K-means cluster analysis were performed. The results of the analysis are visualized in the form of plots. Finally, the results of the analysis are evaluated and identified.

RESULTS AND DISCUSSION

Correlation between Nutrient Contents and Digestibility Values

The results of the correlation matrix are presented in Table 4. According to the Pearson correlation approach, some chemical composition variables were positively correlated with digestibility rates, whereas others were negatively correlated. All chemical composition variables were significantly correlated (p<0.01) with digestibility values, except for EE, which was significantly correlated (p<0.05). Protein content was positively correlated with the digestibility variables OMD (0.45), ED (0.51), DE (0.59), and ME (0.51). Proteins in ruminants are categorized into two types: rumen degradable protein (RDP) and rumen undegradable protein (RUP) (Savari *et al*., 2018). Both have different roles in ruminants. RDP will be degraded in rumen into NH_3 and amino acids. NH_3 will be used in the formation of microbial protein synthesis for carbohydrate degradation.

Meanwhile, RUP can passed through rumen and degrades into amino acids and mostly absorbed in the small intestine and delivered to the entire animal tissues that affects for growth, production, and reproduction (Putri *et al*., 2021). Therefore, as an essential compound, high protein content in legume forages may positively influence ruminant health and performance. Jayanegara *et al*. (2016) and Widodo *et al*., (2023) also showed that forage protein content had a strong positive relationship with digestibility rates. However, CP was negatively correlated with fiber components CF (-0.57), NDF (-0.55), ADF (-0.62), and lignin (-0.41). Some of fiber molecules in feed can bond with the protein, making it difficult for the livestock body to be degraded, and can adversely influence ruminant digestibility on feed intake (Hervik and Svihus, 2019). It is also confirmed that the fiber fraction molecules such as CF, NDF, ADF, and lignin were significantly negatively correlated (p<0.01) with

Table 4: Pearson's correlation matrix of chemical composition and digestibility values of legumes.

Variable	CP	CF	NDF	ADF	Lignin	EE	Ash	GE	OMD	EMD	DE	ME
CP	1.00											
CF	-0.57**	1.00										
NDF	-0.55**	0.68**	1.00									
ADF	-0.62**	0.77**	0.87**	1.00								
Lignin	-0.41**	0.35**	0.48**	0.57**	1.00							
EE	0.29**	-0.26**	-0.15*	-0.17**	0.06ns	1.00						
Ash	-0.10ns	0.26**	0.28**	0.29**	0.20**	0.10ns	1.00					
GE	0.39**	-0.05ns	-0.15*	-0.17**	-0.08ns	0.34**	-0.63**	1.00				
OMD	0.45**	-0.72**	-0.59**	-0.64**	-0.46**	0.14*	-0.46**	0.22**	1.00			
EMD	0.51**	-0.76**	-0.62**	-0.69**	-0.48**	0.16*	-0.43**	0.20**	0.96**	1.00		
DE	0.59**	-0.72**	-0.62**	-0.67**	-0.47**	0.22**	-0.43**	0.33**	0.85**	0.94**	1.00	
ME	0.51**	-0.73**	-0.61**	-0.67**	-0.47**	0.21**	-0.53**	0.34**	0.94**	0.98**	0.96**	1.00

CP: Crude Protein; **CF:** Crude Fiber; NDF: Neutral Detergent Fiber; **ADF:** Acid Detergent Fiber; **EE:** Ether Extract; **GE:** Gross Energy; **OMD:** Organic Matter Digestibility; Energy Matter Digestibility; **DE:** Digestible Energy; **ME:** Metabolize Energy, * Significant at p<0.05, ** Significant at p<0.01, **ns:** not significant p>0.05.

the digestibility variables OMD (-0.72, -0.59, -0.64, -0.46), ED (-0.76; -0.62; -0.67; -0.47), DE (-0.72; -0.62; -0.67; -0.47), and ME (-0.73; -0.61; -0.67; -0.47). Because some of leguminous forages that contain high fiber fractions consist of high hemicellulose and cellulose compounds that are difficult to digest by rumen microbes, and adversely affects the digestibility rates. Those evidence are in accordance with the Jayanegara *et al*., (2016) findings, showed that NDF and ADF consisted in feed particles commonly correlated with the negative organic matter digestibility.

EE is an organic material that is broken down into energy and has a significant positive correlation (p<0.05) with OMD (0.14) and EMD (0.16) as well as a highly significant positive correlation (p<0.01) with DE (0.22) and ME (0.21). Fat is one of energy sources for ruminants, especially dairy cattle, because it produces more ATP than proteins (Hervik and Svihus, 2019; Palmquist, 1994). In contrast, ash content was found to be significantly negatively correlated (p<0.01) with the digestibility variables OMD (-0.46), ED (-0.43), DE (-0.43), and ME (-0.53). Ash is the inorganic residue that the removal of water and organic matter or describes total mineral content of the feed (Thiex *et al*., 2012). In energy estimation, a higher ash content will result in lower feed energy. This is because ash is not an organic material that can be converted into energy. An overview of the energy content in the feed can be found in the GE content. GE represents the energy derived from feed organic matter such as carbohydrates, proteins, and fat (Jayanegara *et al*., 2019). The analysis showed that GE content was significantly positively correlated with the digestibility variables OMD (0.22), ED (0.20), DE (0.30), and ME (0.34). This positive correlation is consistent with the relationship between protein and fat, which also correlates positively with digestibility. Therefore, an increase of protein and fat will enhance the GE value of the feed.

Table 5: Eigenvalue of principal component (PC).

PC	Eigan value		
	Total	% Total variance	%cumulative
1	6.66	55.50	55.50
2	1.48	12.37	67.87
3	1.26	10.54	78.40
4	0.92	7.67	86.08
5	0.61	5.10	91.18
6	0.48	3.97	95.15
7	0.25	2.11	97.26
8	0.13	1.08	98.34
9	0.11	0.91	99.24
10	0.07	0.61	99.86
11	0.01	0.09	99.95
12	0.01	0.05	100.00

Principal Component Analysis (PCA)

The results of the PCA analysis in the form of eigenvalues and factor loadings will be visualized as graphs and plots for the reader to understand easily. This eigenvalue explains the data variation that can be explained based on the principal component (PC) formed; the higher the eigenvalue, the higher the data variation that the PC can explain. According to Kaiser (1960), only PCs with eigenvalues> 1.0, are used for data exploration. The PCA analysis showed that PC1, PC2, and PC3 had eigenvalues>1.0, and were able to explain 78.40% of the data (Table 5). PC1, PC2, and PC3 were further analyzed to determine the factor loading values of the variables formed in the three main components.

The factor loading value describes the correlation between the original variables and the variables formed by PCA. Stevens (Stevens, 2009) recommends a factor loading value of >0.60 can describe a strong correlation between variables. The factor-loading values are presented in Table 6.

Table 6: Factor loading of principal component (PC) whose eigenvalue>0.1.

Variable	PC1	PC2	PC3
CP	0.68	-0.02	0.43
CF	-0.83	0.25	-0.14
NDF	-0.78	0.25	-0.09
ADF	-0.84	0.25	-0.10
Lignin	-0.58	0.27	0.19
EE	0.25	0.25	0.82
Ash	-0.49	-0.64	0.47
GE	0.36	0.86	0.17
OMD	0.90	-0.01	-0.20
EMD	0.94	-0.05	-0.15
DE	0.93	0.05	-0.05
ME	0.94	0.10	-0.14

CP: Crude Protein; **CF:** Crude Fiber; **NDF:** Neutral Detergent Fiber; **ADF:** Acid Detergent.

In this study, PC1 showed a variance value of 55.50%. The variables that were formed and correlated with PC1 were CP (0.68), CF (-0.83), NDF (-0.78), ADF (-0.84), OMD (0.90), ED (0.94), DE (0.93), and ME (0.94). Positive and negative values indicate the relationship between variables; positive values indicate an increase, while negative values indicate a decrease. Fiber; EE: Ether Extract; GE: Gross Energy; OMD: Organic Matter Digestibility; Energy Matter Digestibility; DE: Digestible Energy; ME: Metabolize Energy.

In PC1, the digestibility variable had a positive connected with protein but a negative connected with the fiber component. This result was similar to that of the correlation analysis, which showed a connected between protein, fiber, and digestibility rates. It can be suggests that the protein and fiber content of the feed significantly associated to the digestibility rates. Digestibility rate is an essential aspect of feed quality; the higher the digestibility rate, the better the feed quality (Darma *et al.*, 2023). Feeding high-protein feed, such as legumes, can increase the digestibility of livestock feed (Araújo *et al.*, 2020; Truong and Trung, 2023). However, legumes have issues owing to the hemicellulose and cellulose content in their cell walls, making it difficult for rumen microbes to digest (Truong *et al*, 2022). However, some studies have found that rumen microbes can digest hemicellulose. According to Zhou *et al.* (2022), NDF that still contains hemicellulose and has a quadratic relationship with ruminant digestibility. This indicated that hemicellulose content of NDF can still be degraded by rumen microbes to the concentration level. Meanwhile, PC2 and PC3 were difficult to interpreted due to the limited variable components followed with factors higher than 0.6. In PC2 only ash and GE are correlated, while PC3 only EE. Unequivocally, the associated variables between PC1 and PC2 are shown in Figure 1, whereas the horizontal line represents PC1, and vertical line represents PC2.

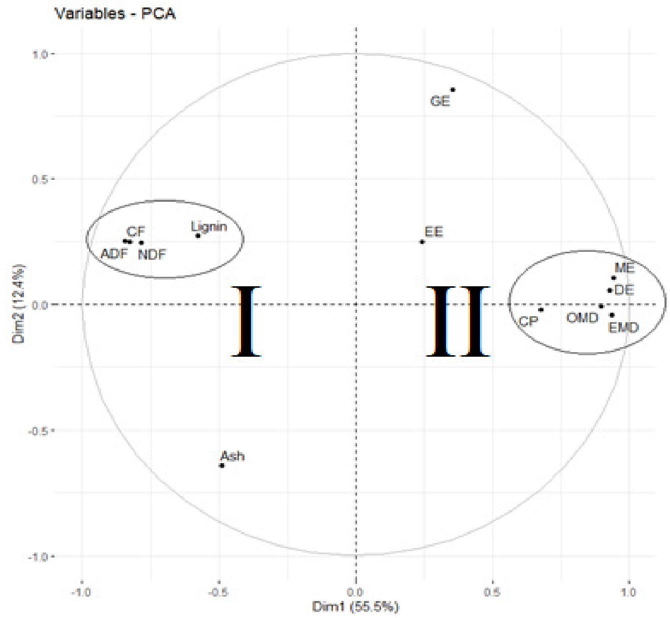

Figure 1: Relationship between variables with PC1 (X axis) and PC2 (Y axis).

Biplot visualization illustrated the relationship between the variables and leguminous data in this study. As shown in Figure 1, the leguminous plots in region I are legumes with high fiber components (CF, NDF, ADF, and lignin). Conversely, region II contained legumes with high crude protein content and digestibility. The results of the PCA score classification are shown in Figure 2. In the stem type category, legume plots were scattered across regions I and II. This shows that legumes with tree, shrub, and herb stem types do not show significant differences in chemical content; therefore, they do not affect the digestibility rate. According to Upadhyay *et al.* (2022), the factors that significantly affect the productivity and chemical content of plants are the soil, water, and fertilizer. The climate category showed the same results as the stem type (Figure 2). The classification of legume based on their typical region such as in the tropical, subtropical, and temperate regions were not significantly associated with their chemical contents (Figure 1). Legumes can grow in warm and cold environments and are able to adapt to maintaining their productivity (Krner, 2016; Lee *et al.*, 2017). This was assumed to be reason for no difference in the chemical content of the plant growth with the climate region category. Moreover, the edible part category also showed no significant difference in chemical composition. However, it was found that seed overall plot in region II, which was high in protein and digestibility rates (Figure 1). This indicated that leguminous seed parts contained high protein and digestibility rates.

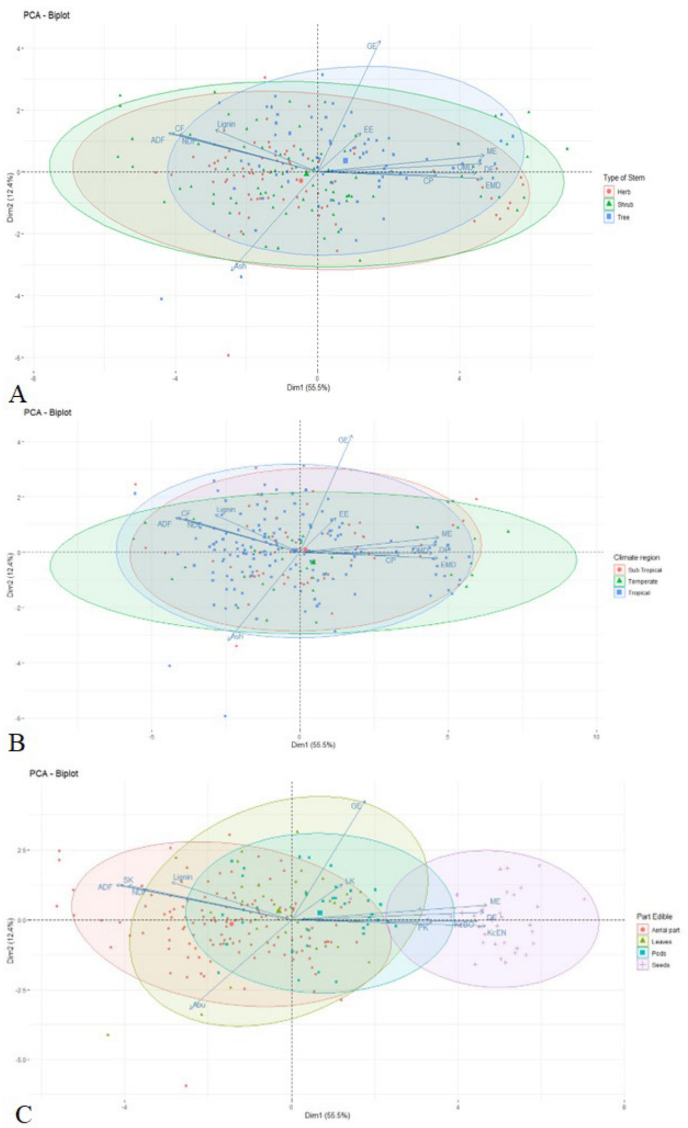

Figure 2: a: PCA score biplot on categories of legume type; **b:** climatic region; **c:** edible part.

Cluster Analysis

Cluster analysis is combines several objects based on their similarities. The formation of cluster analysis groups was based on the distance between the objects. The cluster analysis used is a non-hierarchical k-means cluster analysis, whose algorithm must first determine the number of clusters to be formed. One of the cluster optimization methods to be developed is the silhouette method (Figure 3). Determining the optimal point with this method by looking at the peak point of the graph; therefore, in this study, the number of clusters to be formed was two.

The results of the cluster analysis are shown in Figure 3. The red and blue plots represent clusters 1 and 2, respectively. The cluster analysis results are presented in Table 7. Cluster 1 was characterized by CF, NDF, ADF, Lignin, and Ash characteristics, and Cluster 2 by CP, EE, GE, OMD, EMD, DE, and ME characteristics. Result of this analysis was similar with correlation analysis and PCA which showed that protein was positively related to digestibility rates and fibre was negatively related, vice versa. Hence, legumes with high crude protein content potentially improve ruminant digestibility, while high fiber content, in contrary might lowered digestibility rates.

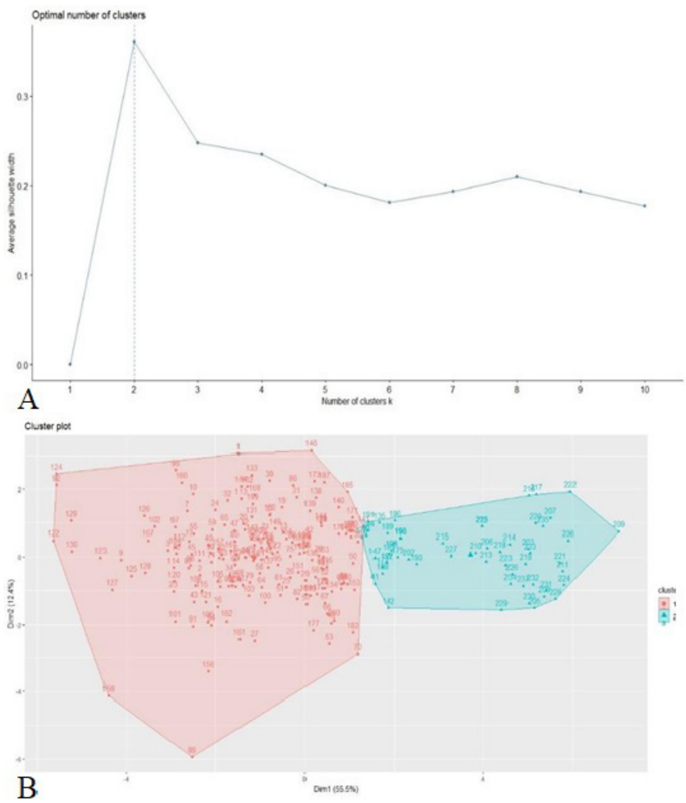

Figure 3: (a) Optimising the number of clusters using the silhoutte method; **(b)** legume plots with two clusters.

This can also be clearly seen in Table 8. It can be assumed that high protein legumes in Cluster 2 can be categorized as favourable legumes, while high fiber legumes in Cluster 1 can be categorized as unfavourable legumes. Protein has an essential role in livestock growth, productivity, and reproduction. Therefore, it is beneficial for livestock if the feed has a high protein content. In addition, protein can enhance feed digestibility, subsequently impacting environmental sustainability. It is crucial to prioritize feed with a high digestibility rate when selecting feed, particularly forage for animal feed. Numerous studies (Álvarez *et al*., 2022; Chaokaur *et al*., 2015; Kannan *et al*., 2017) have demonstrated that feeding highly digestible feed can reduce methane gas production, making it a potential strategy to mitigate methane gas emissions in livestock feed formulations. Legumes in cluster 2 can be a suitable option for providing forage to livestock. In contrast, high fiber can decrease digestibility, that negative impacts for livestock productivity (Castro-Montoya and Dickhoefer, 2018;

Table 7: Profiling and number of cluster members.

Cluster	CP	CF	NDF	ADF	Lignin	EE	Ash	GE	OMD	EMD	DE	ME
1	16	28.2	45.7	34	9.03	2.89	8.85	18.5	66.7	62.7	11.4	9.22
2	22.7	13.8	30	19	4.56	4.56	5.12	18.9	87.8	85	16.1	12.9
Identification on the number of cluster members per category												
Category				**Number of cluster members**								
				1	**Percentage in cluster (%)**			**2**		**Percentage in cluster (%)**		
All data in study				181	23.63			23.63		23.63		
Edible part												
	Aerial part			129	98.47			2		1.53		
	Leaves			28	90.32			3		9.68		
	Pods			25	60.98			16		39.02		
	Seed			0	0			35		100		
Plant origin climate												
	Tropical			113	79.02			30		20.98		
	Subtropical			44	70.97			18		29.03		
	Temperate			24	75.00			8		25.00		
Type of stem												
	Shrub			66	84.62			12		15.38		
	Tree			38	48.72			30		38.46		
	Herb			67	83.75			13		16.25		

CP: Crude Protein; **CF:** Crude Fiber; **NDF:** Neutral Detergent Fiber; **ADF:** Acid Detergent Fiber; **EE:** Ether Extract; **GE:** Gross Energy; **OMD:** Organic Matter Digestibility; Energy Matter Digestibility; **DE:** Digestible Energy; **ME:** Metabolize Energy.

Table 8: The highest and lowest quality legumes determined from the analysed database.

Species	Common names	Edible part	CP	CF	NDF	ADF	Lignin	EE	Ash	GE	OMD	EMD	DE	ME
Highest quality legumes														
Trigonella foenum-graecum	Fenugreek	Seed	26.2	1.0	15.5	2.9	3.6	6.4	4.0	19.7	96.0	95.0	18.9	15.2
Vicia sativa	vetch	Seed	28.4	4.7	15.7	7.5	0.9	1.5	4.0	18.9	92.5	91.1	17.2	13.8
Senna tora	Wild senna	Seed	18.2	4.6	21.3	13.0	3.4	7.4	9.1	18.6	92.5	88.0	16.2	13.3
Lens culinaris	Lentil	Seed	26.9	4.9	13.0	6.3	1.6	1.6	3.8	18.5	92.4	90.9	16.8	13.5
Phaseolus vulgaris	bean	Seed	24.8	5.2	20.0	7.6	0.2	1.7	4.6	18.6	92.3	90.6	16.8	13.6
Lowest quality legumes														
Crotalaria brevidens	Slenderleaf	Aerial part	12.7	42.5	57.8	40.0	11.5	2.9	5.8	19.5	32.1	30.6	6.0	4.7
Prosopis tamarugo	Tamarugo	Leaves	12.0	13.8	27.3	39.3	17.6	2.0	17.2	16.1	38.7	41.7	10.2	5.1
Vicia benghalensis	Purple vetch	Aerial part	11.0	39.8	65.8	47.7	13.3	3.7	8.5	18.4	44.0	42.0	7.8	6.2
Vicia faba	Faba bean	Aerial part	10.9	45.2	26.3	12.5	13.0	1.8	3.1	19.8	44.8	42.8	8.5	6.7
Cicer arietinum	Chickpea	Aerial part	5.4	41.0	65.6	46.9	11.9	1.0	7.4	18.1	45.0	41.4	7.5	6.1

Ratnawaty *et al*., 2018). However, fiber also essential as a main source of energy in ruminants. Fermentation of forage fiber will produce VFA that is used by cattle as their main energy (Guadayo *et al*., 2019). Most of legumes in this study were located in Cluster 1, approximately 180 plants species. Which means, further identification was performed based on previous legume categories.

Cluster 1 had the highest percentage of aerial parts in the edible category, whereas Cluster 2 had the highest percentage of seed parts. Aerial parts refer to the above ground portions of plants that ruminants can consume. The chemical composition of these parts varies considerably depending on the mixture of the edible parts used. Similarly, Hao *et al*. (2021) found that the whole edible part had a lower nutrient content than the leaves. Aerial parts, one of which is the stem, contain high lignin content that can decrease digestibility. In contrast, seed parts have a high protein content because of their role in developing new individuals, which require high protein levels for growth (El-Maarouf, 2022). The regional climate category and subtropical legumes dominated Cluster 2, whereas the tropical legumes dominated Cluster 1. According to Lee *et al.* (2017), plants in tropical areas have higher NDF and lower protein contents than those in temperate areas. Legumes in tropical regions receive more sunlight, prompting them to thicken their cell walls and reduce evaporation (Kering *et al.*, 2011). Climate significantly affects the structure and polysaccharides of plants, such as lignin, cellulose, and hemicellulose, resulting in variable cell wall compositions and fluctuations in the nutritional value of forage (Gang *et al.*, 2015; Lee *et al.*, 2017; Upadhyay *et al.*, 2022). In the stem type category, tree legumes dominated Cluster 2, while shrub legumes dominated Cluster 2. This study similar (Castro-Montoya and Dickhoefer, (2018) and Castro-Montoya and Albarrán-Portillo, (2023), Tree legumes have higher protein and lower NDF content than shrub legumes or herbs. High protein content correlated with high digestibility, making tree legumes more prevalent in Cluster 2. Conversely, shrub legumes had a lower protein content, mostly in cluster 1.

CONCLUSIONS AND RECOMMENDATIONS

Multivariate analysis showed that legume characteristics in the categories of stem type, regional climate, and edible parts had similar associations with chemical content and digestibility rates. This indicates that there were no specific differences among the three categories. However, the seeds were characterized by high protein content and digestibility rates. Furthermore, protein content was positively associated with ruminant digestibility, whereas the fiber content was vice versa showed negative association. Therefore, it can be concluded that the high quality legumes indicated by high protein content, whereas low quality legumes are high fiber content. In addition, legumes in cluster 2 can be used as forage for ruminants.

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NOVELTY STATEMENTS

This study provides a novel classification of leguminous plants based on chemical composition and digestibility using advanced multivariate analysis techniques, such as PCA and k-means cluster analysis. By integrating data from Feedipedia and categorizing legumes by stem type, climatic origin, and edible parts, this research highlights the distinct association between protein content and digestibility, and the inverse relationship with fiber components. These findings not only provide a comprehensive understanding of legume feed quality but also propose a practical framework for selecting high-quality forage to enhance ruminant performance and reduce environmental impacts.

AUTHOR'S CONTRIBUTIONS

Dedy Nanda Kurniawan: Investigation, formal analysis, methodology, software, visualization, writing - original draft.
Nahrowi Nahrowi: Validation, data curation, supervision, writing - review and editing.
Yulianri Rizki Yanza: Validation, data curation, supervision, writing - review and editing.
Vincent Niderkorn: Validation, supervision, writing - review and editing.
Anuraga Jayanegara: Conceptualization, validation, resources, data curation, supervision, writing - review and editing.

Availability of Data and Materials

The data will be made available from the corresponding author upon reasonable request.

Conflict of Interest

The authors declare that there is no conflict of interest.

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