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Feed Evaluation Methods: Performance, Economy and Environment

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Abstract

Feed evaluation methods aim to give information on the feeds to meet the nutritional needs of the animal. Therefore feed evaluation is needed to assess the nutritional value between feeds. The methods to express the feed value incline to measure mainly digestibility of the feedstuff. Many feed evaluation methods have been developed and modified over the years to predict the nutritional component of the feed. The nutritive value of ruminant feeds is assessed by the chemical composition, concentration and rate and extent of digestion of feed in the rumen. Chemical, digestibility and enzymatic methods are the main methods that have been used for feed evaluation. The Weende and detergent analysis systems are the commonly used chemical methods of feed evaluation. For many years, feed digestibility has been measured by in-vivo, in situ and in-vitro digestibility techniques. This paper aims to review the feed evaluation methods of chemical, digestibility and enzymatic with emphasis on performance/outcomes, economic consideration and environmental effects/ footprints.

Keywords: Feed evaluation methods, in-vitro, in-situ, and environmental effects.

Review article

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INTRODUCTION

Feed evaluation is aimed at giving information on the capacity of individual feeds to meet the nutritional requirement of the animal (Beever et al., 2000). Several feed evaluation methods have been developed and modified over the years to predict the nutritional component of feed (Dijkstra et al., 2005). Monogastric animals have less complex feed compositions which do not require extensive feed evaluations as it is in ruminants. The nutritive value of ruminant feeds is assessed by the chemical composition, concentration, rate and extent of digestion of feed in the rumen (Chumpawadee et al., 2007). Feed evaluation is important in predicting animal performance with a degree of accuracy (Cooke, 1988). Volden (2011) emphasized the importance of feed evaluation in ration optimization and the major economic contribution of feeds in modern cattle production. Proximate feed evaluation system by Weende's analysis was developed by Henneberg and Stohman divides carbohydrates into two; the initially assumed to be indigestible crude fibre and the soluble Nitrogen free extract (Henneberg and Stohman, 1860). This method however, does not give the true situation of crude fibre digestibility by rumen microbes. Van Soest and Wine (1967) used the Detergent analysis procedure to better characterize carbohydrates into the poorly digested cell wall and completely digested cell component. The most accurate way to evaluate the nutritional value of any feedstuff is the standard measure of digestibility. It involves post ruminal collections through duodenal or abomasal cannulation of the animal (Nocek, 1988). But it has many limitations; such as laborious, time-consuming, distress the animal and will not be suitable in terms of animal rights. The Nylon-bag (in-sacco) method was first used by Orskov and McDonald (1979) to measure protein degradability in ruminants. This method has become widely used but it has inherent factors that influence digestion. The in-vitro technique does not require the use of animal and as such is less time consuming and quite cost effective (Susmel et al., 1989). It has better reproducibility and repeatability because of there is better control over factors that causes variations. This paper aims to review the chemical, digestibility and enzymatic methods of feed evaluation with emphasis on performance/outcomes, economic consideration and environmental effects / footprints.

FEED EVALUATION METHODS

Chemical, digestibility and enzymatic methods are the main methods that have been used for feed evaluation. The Weende and detergent analysis system are the commonly used chemical methods of feed evaluation. For many years, feed digestibility has been measured by in-vivo, in-situ and in-vitro digestibility techniques.

1. Chemical Method

Since the nineteenth century, the evaluation of feed has been based on its proximate composition (crude fibre, crude fat, minerals, ash, Nitrogen free extract and moisture (Wood and Badve, 2001). Chemical analysis of ruminant feeds includes the determination of dry matter content (DM), organic matter (OM), structural carbohydrate (Fibre and Non-Starch Polysaccharide NSP), soluble carbohydrate, crude fat, crude protein and inorganic matter of the feed (France et al., 2000).

The proximate feed evaluation system (Weende) developed by Henneberg and Stohman divides carbohydrates into two; the initially assumed to be indigestible crude fibre and the soluble nitrogen free extract (Henneberg and Stohman, 1860). This method however, does not give the true situation of crude fibre digestibility by rumen microbes. Van Soest and

Wine (1967) used the Detergent analysis procedure to better characterize carbohydrates into the poorly digested cell wall and completely digested cell component using Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Acid Detergent Lignin (ADL) respectively. This process was able to show that the digestion of feeds using NDF divides the feed into 2 components which differ nutritionally (cell content and cell wall). The cell contents are available nutritionally to the animal while the cell wall part of the feed is not completely digested (Lucas, 1964). The major digestible constituent of the feed's cell wall is largely dependent on the degree of lignification (Van Soest and Marcus, 1964; Osbourn and Terry, 1977). Van Soest detergent analysis has become the most widely used method for evaluating structural carbohydrate (France et al., 2000). Cellulose, hemicellulose and lignin are the major components of the NDF, while cellulose and hemicellulose are the main components found in ADF. Studies have shown good correlation between ADF and dry matter digestibility while NDF revealed a good indication of dry matter intake (DMI) (Wood and Badve, 2001). The use of chemical composition alone is not sufficient to estimate animal intake and in-vivo digestibility. Also, non–structural carbohydrates have been difficult to analyse with this method because of their complex starch and sugar constituent.

Crude protein (CP) is calculated from the nitrogen content using the Kjedahl procedure. This involves acid digestion and distillation. The most widely used method in recent times is the Dumas method which involves combustion and determination of released gaseous Nitrogen (France et al., 2000). These methods measure Nitrogen rather than protein. The measured Nitrogen is multiplied by 6.25 to determine the approximate protein content of the feed.

The Near Infra-red Spectroscopy (NIRS) is used to measure the light absorption of different chemical bond at a range of spectrum between 1100-2500nm. This is a more recent non-traditional chemical method used to more accurately measure the CP (Landau et al., 2006). The two critical aspects of the NIRS calibration are linearity and accuracy. The coefficient of determination (R2), i.e., the proportion of variability in the reference data accounted for by the regression equation is the indicator for linearity. The standard error of calibration (SEC) represents the variability in the difference between predicted values and reference values when the equation was developed from the calibration data set. After a calibration has been set up that features high R2 and SEC, a validation method is needed, in which predictive accuracy is evaluated.

2. Digestibility Methods

In feed evaluation techniques besides the chemical methods, other methods have been developed to characterize feeds with respect to their digestibility. These techniques include the in-vivo, in-situ, and in-vitro methods.

2.1 In-vivo Method

The most accurate way to evaluate the nutritional value of any feed stuff is to feed it to the appropriate class of animal using feeding trials which is the standard measure of digestibility. It involves post ruminal collections through duodenal or abomasal cannulation of the animal. Two types of cannulas have been used; re-entrant duoedenal and simple 'T' cannulas. T cannulas require spot sampling and indigestible solid and liquid phase markers. Digestive phase markers are not required with re-entrant cannula because they conduct total digesta collection. The Cannulas are fixed in such a way as to prevent intestinal blockage and injuries to the nervous system (Nocek, 1988). The most common nutrient measured by in-vivo technique is protein. There is great variability in the estimate of in-vivo digestibility, as many methods have been employed through the years in many research trials. These include

total faecal collection, use of chromic oxide as a marker, indigestible ADF/NDF as a marker, and rare earths that have been sprayed on fibre or indigestible fibre (Church, 1993). The recovery of these markers is measured to estimate digestibility. Two commonly used methods are incremental and differential techniques. Studies have shown that the in-vivo method is the most physiological although it has its own inherent limitations (Nocek, 1988). Studies have shown that contamination of digesta flow with endogenous protein, variations in digesta flow, microbial markers and animal differences are major sources of variation in this process (Solaiman et al., 1982; Ellis et al., 1982; Whitelaw et al., 1984). In-vivo digestibility methods are the standards by which other feed evaluation techniques are compared although they tend to have variation associated with inherent factor (Nocek, 1988).

2.2 In-situ (In Sacco) Method

The Nylon bag (in Sacco) method was first used by Orskov and McDonald (1979) to measure protein degradability in Ruminants. It involves the suspension of test feed in the rumen of fistulated animals. It allows for adequate interaction of feed in the ruminal environment (Nocek, 1988). It is used as reference method for feed analysis, because it is a dynamic method. Rumen environment (pH, Temperature, enzymes etc.) is better simulated using in-situ technique which has been used for many years to predict feed digestion (Chalupa, 1975; NRC, 1985). The end point degradability of the feed component is determined after incubation of feeds in nylon-dacron bags in the rumen. Rate of feed degradability have also been measured when the nylon bags are incubated for different lengths of incubation time.

The nylon bag method has become widely used but it has inherent factors that influence digestion. Digestion is affected by the formulation of the diet, bag pore size, feed sample size, feed particle size and animal differences (species, sex, age and physiological state) (Weakley et al., 1983; Susmel et al., 1989; Nocek, 1988). Microbial contamination, differences in sample preparation, processing and bag type also have their impact on digestion (Madsen and Hvelplund, 1994). Several recommendations to reduce these variations were made. Post ruminal washing, reduction in bag pore size, sample size to bag surface area and microbial correction were recommended (Lindberg, 1981; Nocek, 1988). Therefore standardization of in-vivo technique using the best parameters and conditions is of high importance in estimating true feed digestibility.

2.3 In-vitro Methods

In-vitro dry matter digestibility (IVDMD), in-vitro gas production (IVGPT) and enzymatic methods are used for estimating in-vitro digestibility.

2.3.1 In-vitro dry matter digestibility method (IVDMD)

In-vitro dry matter digestibility method (IVDMD) is used widely to determine feed digestibility. Holden (1999) in his study affirms the high correlation of in-vitro to in-vivo digestibility method. In-vitro digestibility is generally lower than in-vivo digestibility in non-forages (Wood and Badve, 2001). Over the years various methods to determine in-vitro digestibility has been developed and modified (Holden, 1999).

According to Tilley and Terry's two-stage in-vitro digestibility method (TT), the feeds are incubated for 48 hrs in rumen liquor then they are digested in pepsin. As reported by Wood and Badve (2001) the relative simplicity and usefulness of data obtained from the Tilley and Terry (TT) method had made it a widely used although it was not able to predict

accurately the digestibility of tropical forages. Although it was designed to measure endpoint digestibility, it could also be used to assess the intermediate point of slowly-digested forages.

Over the years, the reagents used in the Tilley and Terry (TT) method have been modified to improve precision. The methodologies however, did not bring about modifications that improve the labour efficiency of assays or the running of multiple samples simultaneously in a single vessel (Holden, 1999).

2.3.2 In-vitro gas production technique (IVGPT)

In-vitro gas production technique (IVGPT) has been used for decades to simulate ruminal fermentation of feed and feedstuffs (Rymer et al., 2005). The basic principle of IVGPTs is to ferment feed under controlled laboratory conditions with the use of natural rumen microbes subjected to different treatments. They are incubated at 39 °C with a mixture of rumen fluid, buffer and minerals for a certain time period, typically 24, 48, 72, 96 or 144 h. The amount of total gas produced during incubation per gram of dry matter (DM) of feed samples degraded is measured (Storm et al., 2012; Wood and Badve, 2001).

In recent years, the increasing interest in greenhouse gas (GHG) emissions from agriculture has resulted in further studies and modification of the traditional IVGPTs to include measurement of methane production (Pellikaan et al., 2011). Analysis of the gas composition is done to measure the in-vitro production of methane (Storm et al., 2012).

Daisy II Apparatus; a new development by (ANKOM Technology corp, Fairport NY), allows multiple feed samples to be analysed simultaneously. This comes with great improvement in labour efficiency and the potential to improve the accuracy of assay. Holden (1999) compared the TT and Daisy II methods for predicting dry matter digestibility (DMD) with the buffer recommended by ANKOM for both systems. The results of his experiment showed good correlation between the two systems, proving that Daisy II could be used to predict the in-vitro dry matter digestibility of forages and grains.

2.3.3 Enzymatic in-vitro digestibility technique

Enzymatic in-vitro digestibility technique is used to measure protein and carbohydrate digestibility. Aufrere and Cartailler (1988) measured in-vitro degradability of feed proteins by incubating feed for 1h and 24 h using a phosphosborate buffer containing proteolytic enzyme extracted from Streptomyces griseus. Susmel et al. (1989) measured the in-vitro degradability of 16 ruminant feeds using this technique. His study revealed significant differences in the protease degradability values for many of the feeds at 1h and 24 h compared to those of the in-situ. The 1h values showed high correlation with the in-situ values while the 24h values were poorly correlated (Yu et al., 2000). Poos- Floyd et al. (1985) showed that increase in enzyme incubation time of feed decreases the correlation between the in-situ and in-vitro degradability. The influence of incubation time was attributed to the possible enzymatic inhibition caused by products of degradation due to the closed system used in in-vitro protein degradation (Krishnamoorthy et al., 1983; Crawford et al., 1978).

There was good correlation between the effective degradability in-situ and the obtained using proteolytic enzymes (Yu et al., 2000). The assessment of protein solubility using only buffers did not show similar high correlation with the in-situ values. (Krishnamoorthy et al., 1983; Poos-Floyd et al., 1985; Sauvant et al., 1987; Broderick et al., 1988). Similarly, it was found that protein solubility with only buffer cannot be used to predict protein degradation of concentrated feeds with good precision (Madsen and Hvelpund 1985). Single enzyme and broad spectra fungal and bacterial enzyme sources have also been

used (Nocek, 1988) however, in-vitro degradability of protein using Aufrère method by enzymatic hydrolysis for 1h or an intermediate time of >1h and <24h has proved to be a promising laboratory procedure that can be used to predict the rate and extent of in-situ degradation with high accuracy (Yu et al., 2000).

Energy feed digestibility can also be predicted using enzymes. It is a two-step process. It involves first the pre or post treatment of feed using chemicals (HCl or detergent) and/or enzymes (amylase, pepsin, pronase) while the second step is the enzymatic action with the use of cellulase alone or a mixture with other enzymes (amylase and hemicellulose) (Aufrère and Michalet- Doreau, 1988). There are infinite variations for enzymatic degradability with different but little residual variation in standard deviation results obtained (De Boever et al., 1984). It is a simple method and its repeatability is satisfactory (Aufrère and Michalet-Doreau, 1988). The study carried out through the European Economic Community by Van Der Meer (1982, 1983) to evaluate repeatability of the enzymatic method showed little variations within the same laboratory but recorded large laboratory to laboratory variations amongst the 34 laboratories.

Enzymatic techniques give great precision in the measurement of protein and carbohydrate digestibility than is obtained from chemical or biological methods (Nocek, 1988). De Boever et al. (1984) in his study comparing 18 methods of enzymatic degradability on 31 concentrates with known digestibility showed that pepsin-cellulase gave the best predictions for enzymatic degradability.

ECONOMIC CONSIDERATION

Near Infra-red Spectroscopy (NIRS) in recent years, has been found to be preferable to traditional chemical methods as long as it is calibrated correctly. This is because it is more accurate, fast, with high precision and quite cost effective, although it has to be calibrated against already existing traditional methods. (France et al., 2000)

Amongst the digestibility methods, the in-vivo method (total collection technique) is the most reliable method of measuring digestibility of feed. Unfortunately, however, it has proved to be time consuming, laborious and expensive. It is not practical for all possible feeding situations in practice and is not possible to carry out as routine laboratory work (Zewdie, 2019; France et al., 2001).

The in-situ digestibility method is expensive, time consuming and requires the use of rumen fistulated animals (Wood and Badve 2001; Susmel et al., 1989). Its laboratory to laboratory repeatability and reproducibility is poor.

Few samples can be run at one time compared to the TT method. The in-situ technique is however, useful for evaluating kinetic rates of digestion in ruminants using multiple incubation times and computer models (Nocek, 1988). There is need for standardization of the process to obtain better digestibility predictions.

The in-vitro technique does not require the use of animal and as such is less time consuming and quite cost effective (Susmel et al., 1989). It has better reproducibility and repeatability because of there is better control over factors that causes variations. It also has high precision in predicting in vivo dry matter digestibility (Majbeesh et al., 2000). Majbeesh et al., (2000) studied to determine the reliability of the Daisy II method proved that the Daisy II method is easier and less time consuming to determine in-vitro dry matter digestibility than the TT method. He affirmed that it was useful to predict in vivo digestibility with relatively small variations.

The in-vitro gas production method is useful for feed ranking and has the potential to replace in-sacco and other existing in-vitro digestibility methods (Wood and Badve, 2001). Its high precision in assessing the daily production of methane (CH_4) also makes it one of the methods employed to determine the enteric emission of methane (a greenhouse gas) in ruminants

Digestion methods using enzymes have several advantages over those with ruminal microbes. They are low cost, less time consuming and do not require the use of cannulated animals. Comparative studies of several methods for estimating feed digestibility has revealed that enzymatic degradability gives more accurate results compared to in-vitro digestibility. (Van Der Meer, 1982; Mathiesien and Moller, 1983; De Boever et al.,1984).

ENVIRONMENTAL EFFECTS/ FOOTPRINT

Studies on the environmental foot prints of both chemical and digestibility methods are limited. Over the years, the in-vitro gas production method has been used to measure the emission of CH_4 (Methane); a Green House Gas from analysed feed sample with the aim of investigating mitigation strategies for methane emissions in ruminants. This makes the study of data on methane emission combined with rumen metabolism and digestibility possible (Johannes et al., 2011). This helps understand the correlation between Methane production and metabolism. There are similarly good methods such as the chamber method, CO_2, the Intergovernmental Panel on Climate Change (IPCC) and SF6 tracer techniques that are already been used for measuring and estimating methane emissions from ruminants (Storm et al., 2012).

CONCLUSIONS

Feed evaluation is of high importance in assessing the nutritive value of feed with the intent of optimizing animal performance. Several methods have been developed, evaluated and modified over the years to achieve this. Efficient utilization of feed and animal performance largely influences the total cost of feed. The economic impacts (advantages and disadvantages) of the individual methods and the potential of some evaluation techniques in assessing and possibly mitigating environmental foot prints is of additional value in the study of animal nutrition specifically and in agriculture as a whole.

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