Microwave Application for Animal Feed Processing to Improve Animal Performance

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Abstract

Feed nutritive value and its utilization by the animal are the two important factors that influence the profitability and sustainability of animal production systems. Microwave (MW) technology is one of the efficient technologies being used for physical processing of feed to improve feed nutritive value in the animal digestive system. Previous research has demonstrated that MW treatment may have been useful for improving feed digestibility and changing its utilization in animals' bodies. Crude protein (CP) is one of the most important nutrients, MW treatment is effective at reducing concentrate feed CP rumen degradability, potentially leading to more efficient utilization of protein in the ruminant intestine. It reduces the anti-nutritional factors present in the feeds, which can limit animals' intake and utilization. In this chapter, the application of MW treatment for feed processing and the prospects for the future use of MW technology in animal production systems will be discussed.

Keywords Digestibility · Forage · Concentrate · Processing · Ruminant · Crude protein digestibility

Introduction

Globally, Livestock farming plays a vital role in providing high quality animal origin food products (e.g. meat, milk, and egg) to the human diet (Chaudhry, 2008). With the rapid growing number of populations, animal production systems' continuous advancement is increasing important (Tona & Nutrition, 2018). Feed is considered to be the most important input to animal production systems (Behnke, 1996) as it often accounts for more than 50% of the total production cost. For ruminant livestock producers, obtaining high-quality feed at an affordable price is often challenging due to the competition from non-ruminant animal production systems and humans. Therefore, to achieve a sustainable and profitable ruminant production, careful use of feed resources and advancement in processing techniques, to improve feed quality, are important.

Feed processing technologies have been used to enhance the feeding value (voluntary feed intake × feed nutritive value) (Chapman et al., 2014; Ulyatt, 1981) of various feed resources (Coffey et al., 2016). Feed processing includes physical, chemical, and/or biological alteration of feed to improve its nutritive value, maximize the nutritional outputs, and reduce animal production costs (Rosentrater & Evers, 2018). In addition, feed processing can improve shelf life, detoxify poisonous substances, and deactivate anti-nutritional factors present in the feed (Stein & Bohlke, 2007). Feed processing in the livestock industries has a long history and was commenced in the early 1800s. Early examples of feed processing include soaking flint and dent corn in water to reduce its hard and flinty texture prior to it being fed to beef cattle (Matsushima, 2006).

The most common physical treatment method used to improve fibrous feed resources' utilization capability is grinding and pelleting (Uden & Technology, 1988). Extrusion is commonly used for fish feed production in the twenty-first century. This increases starch gelatinization and the cross-linking of proteins within the matrix, which improves the overall feed digestibility (Riaz, 2013). The other physical treatment method is steam treatment, which has proved to be effective in improving the digestibility of low-quality roughage feed (Liu et al., 1999; Rai & Mudgal, 1988). However, it requires considerably higher energy and a sophisticated high-pressure container. Chemical treatment methods include treatment of roughage with urea, sodium hydroxide, or urea molasses; this is widely used in developing countries where roughage like straw is the basal diet for large ruminants (Orskov, 1988). On the other hand, the ensiling of forages, using different biological additives for improving their nutritive value, is an example of biological processing (Orskov, 1988). More recently, research has concentrated on modifying the chemistry of feed to improve the feed's nutrient availability (Wagner et al., 2014) rather than only transforming the physical form of feed. While chemical processing has its merit, physical treatment is usually easier to implement. Microwave (MW) treatment is one of the physical treatment methods that has potential to achieve the abovementioned goal from feed processing and support the development of the animal industry.

Microwave Processing Technique

Microwave (MW) treatment is a nonionizing electromagnetic physical processing technique that has been commonly used in the human food industry (Chandrasekaran et al., 2013) due to its quick and energy-efficient heating for the improvement of food product quality (Ayappa et al., 1991), while having little or no negative impact on the chemical composition of the foods. The MW treatment has also been applied in the animal feed industry in recent years, specifically for concentrate and roughage feed processing to improve nutritive value (Brodie et al., 2012; Narimani et al., 2014; Sadeghi & Shawrang, 2006; Shishir et al., 2020). Previous research showed that in conjunction with sodium hydroxide, pre-treatment use of MW treatment reduced sugar content and removed the lignin, hemicellulose, and silicon from rice straw (Singh et al., 2014). In addition, MW treatment has been used to dry feed samples for further chemical analysis (Higgins & Spooner, 1986) and preservation purposes (Stein & Bohlke, 2007).

Microwave Treatment Effect on Feed Cell Microstructure

Rapid heating and steam explosions inside the cell during the MW treatment of plant material can have a considerable effect on the cell microstructure (Brodie, 2007). The MW treatment causes rapid intercellular moisture/bound water evaporation that lead to steam explosions inside the cell (Brodie et al., 2010; Choi et al., 2006; Torgovnikov et al., 2003). For example, Torgovnikov et al. (2003) demonstrated that there was a microcellular fracture in timber when treated with intense MW energy. Choi et al. (2006) found that MW treatment caused the destruction of the microstructure of soybean grain cells, which eventually increased the extraction of soluble soy protein. A similar result was also observed in rapeseed, which facilitated a better oil extraction due to MW heat treatment (Ponne et al., 1996; Wroniak et al., 2016). A recent study showed MW heating also increased the microporosity of the plant material, which improved the permeability of moisture and enzymatic accessibility (Chen et al., 2010). In the case of roughage feed, MW treatment significantly increased cell microstructure destruction (Fig. 1). In addition, analysis of microscopic images of treated and untreated forage hay revealed that the intensity variance is much higher in MW-treated forage hay than untreated forage hay (Shishir et al., 2020). The intensity variance in the image indicated that each pixel's smoothness of the MW-treated hay image is lower than the untreated forage hay image, which attributed to microcellular structure changes due to MW treatment (Aparna & Josemartin, 2017). Pre-treatment of plant fiber with MW weakens the intercellular strength. Brodie (2011)found that MW pre-treatment was effective in juice extraction from sugarcane. Sugarcane compressive strength was reduced by about 18% of its initial strength after MW treatment. Therefore, it is reasonable to assume that the energy required for crushing and breaking down the MW-treated plant fiber may be less during feed intake and digestion (Brodie et al., 2016).

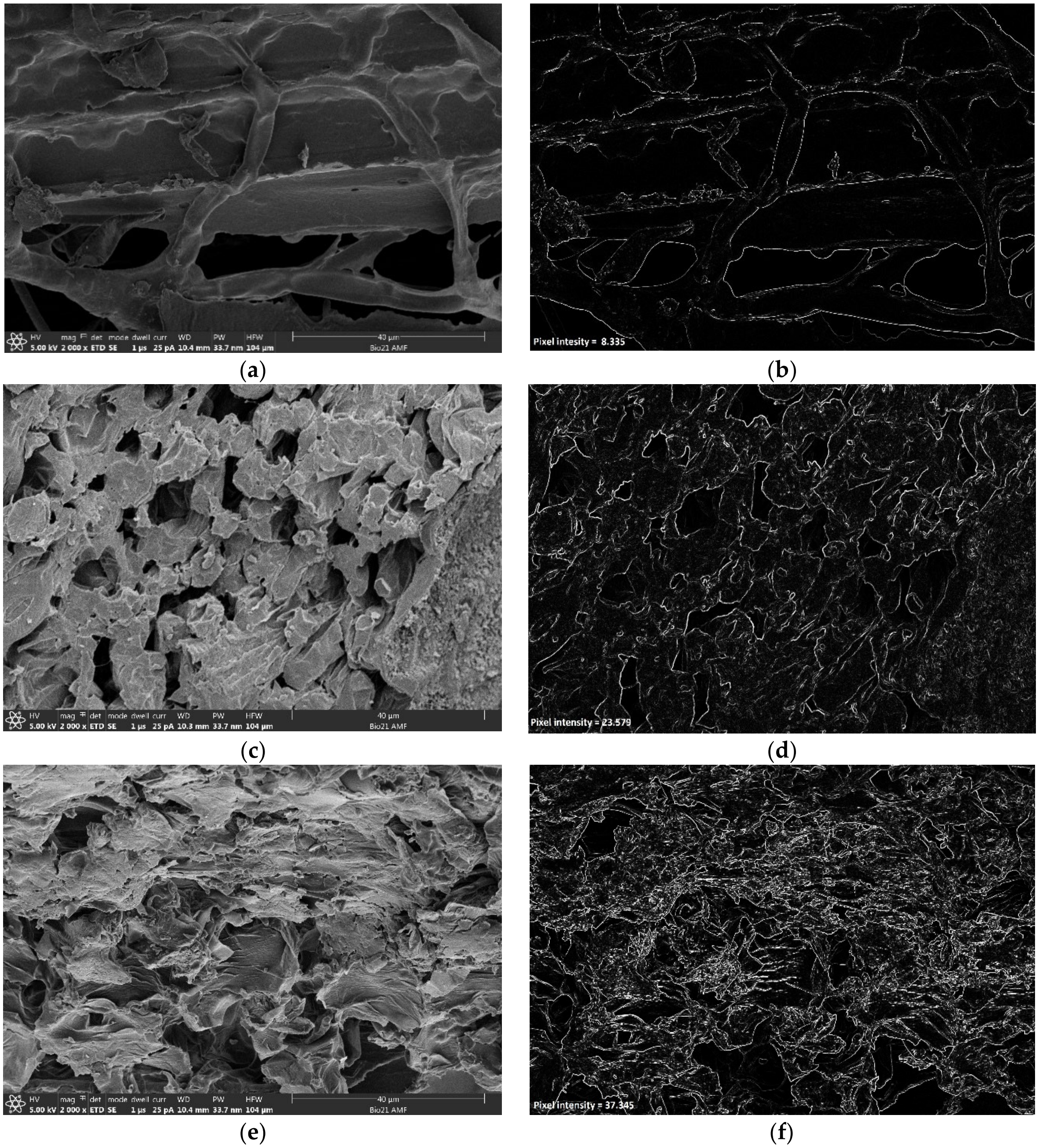

Figure 1. Scanning electron microscope images of wheat hay, (**a**,**b**) SEM and Fiji analytical image of untreated hay, respectively, (**c**,**d**) SEM and intensity variance image MW treated (taken from the top of the sample), respectively, (**e**,**f**) MW treated (taken from the center core of the sample), respectively. (Shishir et al., 2020)

Microwave Treatment and Feed Nutritive Value

The effect of MW treatment on different feed resources' nutritive values is shown in Table 1

Table 1. Effect of MW heat treatment on different feed resources nutritive value and animal performance.

Target feed resources	MW power (W)	Treatment time (seconds)	Moisture added	CP	Non-fiber CHO	NDF	ADF	*In vitro* DMD (Pepsin-cellulase)	*In saco* effective rumen DM degradability	*In vitro* gas production	*In vitro* intestinal CP digestibility	Animal trial	References
Roughage feed resources													
Lucerne chaff	750	0, 40 and 80	No	=	NM	NM	NM	↑	NM	NM	NM	↑ LWG (Sheep)	Brodie et al. (2012a)
Wheat straw	750	0, 240 and 480	No	=	NM	NM	=	NM	↑ (Yak's Rumen)	NM	NM	NM	Dong et al. (2005)
Concentrate feeds resource													
Canola meal	800	0, 120, 240 and 360	Yes	NM	NM	NM	NM	NM	↓	NM	↑	NM	Sadeghi and Shawrang. (2006a)
Canola seed	800	0, 120, 240 and 360	Yes	=	NM	=	ND	NM	↓	NM	↑	NM	Ebrahimi et al. (2010)
Soybean meal	800	0, 120, 240 and 360	Yes	NM	NM	NM	NM	NM	↓	NM	↑	NM	Sadeghi et al. (2005)
Corn/ Maize	800	0, 180, 300 and 420	Yes	NM	NM	NM	NM	NM	↓	NM	NM	NM	Sadeghi and Shawrang. (2006b)
Barley	800	0, 180, 300 and 420	Yes	NM	NM	NM	NM	NM	↓	NM	NM	NM	Sadeghi and Shawrang. (2008)

Cotton seed meal	800	0, 120, 240 and 360	Yes	NM	NM	NM	NM	NM	↓	NM	↑	NM	Sadeghi and Shawrang. (2007)
Safflower seed	900	0 and 180	Yes	NM	NM	NM	NM	NM	↓	↑	↑	NM	Paya et al. (2014)
Sunflower seed	1000	0 and 360	No	NM	NM	NM	NM	NM	NM	↑	NM	NM	Maheri-Sis et al. (2011)
Sorghum	900	0, 180, 300 and 420	Yes	NM	NM	NM	NM	NM	NM	↑	NM	↑ DMD/ OMD (Sheep)	Khajehdizaj et al. (2014)
Sorghum	900	0, 180, 300 and 420	Yes	NM	NM	NM	NM	NM	NM	↑	NM	NM	Parnian et al. (2013)
Wheat				NM	NM	NM	NM	NM	NM	↑	NM	NM	
Sorghum	900	0, 180 and 300	NS	NM	NM	NM	NM	NM	NM	↑	NM	NM	Bootes et al. (2012)
Corn/ Maize				NM	NM	NM	NM	NM	NM	↑	NM	NM	
Wheat				NM	NM	NM	NM	NM	NM	ND	NM	NM	
Guar meal	900	0, 120, 240 and 360	Yes	NM	NM	NM	NM	NM	ND	↓	↑	NM	Narimani et al. (2014)
Oak nut	900	0, 120, 240 and 360	No	ND	NM	NM	NM	NM	↑	↑	NM	NM	Emrah et al. (2016)
Wheat*	1100	0, 15, 30, 45 and 60	No	↑	NM	↑	↑	ND	NM	NM	NM	NM	*Appendix 8.2
Faba bean *			No	↑	NM	↑	↑	↑	NM	NM	NM	NM	

CP crude protein, Non-fiber CHO non-fiber carbohydrate (starch, sugar, etc.), NDF neutral detergent fiber, ADF acid detergent fiber, DM dry matter, DMD dry matter digestibility, OMD organic matter digestibility, LWG live weight gain, NM not measured or mentioned, " increasing; # decreasing, ND no difference. *Data was presented orally in 55 International Microwave Power Institute. The data will be published as proceeding

↑ increasing.

↓ decreasing,

=, no significant difference.

Microwave Treatment Effect on Roughage Feed Nutritive Value

For ruminants, roughage feeding is a significant portion of the total ration. Fresh forage is the most common form of roughage, where ruminant animals directly graze pastures and grasslands. However, due to seasonal variation, year-round fresh forage feeding is not always possible. As a result, alternative forms of roughage feed resources, such as hay or straw, are used by the farmers to fill feed gaps. Considering the fact that, hay and straw normally have low to moderate quality compared with fresh forage, farmers have been urged for decades to develop alternative processing techniques to improve low-quality roughages. Over time, researchers have studied different processing techniques (chemical, physical, or biological) to improve dry roughage quality (Ajila et al., 2012; Ghasemi et al., 2013; Hartley, 1981; Viola et al., 2008). However, despite quality improvements, most of the efficient methods are not sustainable for commercial use due to their high processing cost, being hazardous to humans and the environment, their longer operating time, and/or their higher energy consumption/cost. Several studies suggested that MW treatment of forage hay has potential to improve feed quality. Dong et al. (2005) suggested that MW treatment can improve the ruminal organic matter degradability of wheat straw by 20% vs. control. This was found in an in sacco degradability experiment with yak-fed wheat straw that was MW treated in a 750 W power oven, operating with a frequency of 2.45 GHz, for up to 480 s. Another interesting finding of this study was that acid detergent fiber digestibility improved by 62% without creating any negative effect on other chemical components of the treated wheat straw. In a small-scale pepsin cellulase *in vitro* study, Brodie et al. (2012) found that dry matter digestibility (DMD) of lucerne hay increased by 15% when it was MW treated for up to 80 s using a 750 W MW oven, operating at a frequency 2.45 GHz. Brodie et al. (2012) treated lucerne hay in larger quantity (25 kg bags) with a 6 kW, 2.45 GHz, MW chamber for 450, 900, 1350, and 1800 s in a larger scale experiment. This experiment also found an improvement in DMD %; however, the level of DMD increase (i.e. 6%) was less than the aforementioned small-scale pepsin cellulase study. In a follow-up sheep growth trial, Brodie et al. (2012) found that this 6% improvement of DMD in the 25 kg bags of MW-treated lucerne hay led to an 8.1% increase in liveweight gain in the sheep fed the MW-treated lucerne hay in comparison with the sheep being fed the untreated lucerne hay. After calculating energy efficiency, Brodie et al. (2012) found that the bulk treatment of lucerne hay samples (25 kg bag for 900 s with 6 kW power) consumed approximately 216 kJ kg^{-1} of equivalent energy to achieve a 6% increase in pepsin-cellulase DMD, compared with the control, which provided an extra 540 kJ kg^{-1} of metabolizable energy (ME) to the sheep during the growth trial (considering that lucerne hay contained approximately 9.16 MJ kg^{-1} ME according to El-Meccawi et al. (2008). Furthermore, in simple economic analysis, Brodie et al. (2012) demonstrate that providing the extra 540 kJ kg^{-1} of ME to the sheep led to an additional AU$6.50 per head for the sheep that were fed with the MW-treated lucerne hay over the 5 weeks, considering all the treatment and other costs. Recently in a multi-forage hay pepsin cellulase *in vitro* study, Shishir et al. (2020) treated five forage hays (lucerne, canola, wheat, pasture, and oat) for five treatment times of 0, 20, 40, 60, and 80 s with MW power of 1.1 kW in an oven operating at 2.45 GHz. He found that lucerne, canola, and wheat hay digestibility of organic matter in the dry matter (DOMD) was increased by 14, 12, and 8%, respectively. However, the improvement occurred in the forage hays after different MW treatment times (lucerne 60 s, canola 20 s, and wheat 40 seconds). Shishir et al. (2020) also found a strong positive relationship ($r2$ = 0.79; $p < 0.001$) between crude protein (CP) content of the untreated forage hays and the MW energy requirement for their optimal DMD improvement. This finding provides an approach to calculating the MW energy requirement for hay treatment to achieve increased DMD when the CP content of the selected forage is known. The review of these studies demonstrates that MW treatment has the potential to improve the quality of low-quality roughage for better ruminant production. However, the limited number of studies is a major drawback. More research is required to understand the effects of MW treatment of hay under different conditions to develop MW processing method further.

MW Treatment Effect on Concentrate Feed Nutritive Value

Feeding concentrate to the animals is considerably more complicated in comparison with roughage feeding. Certain criteria need to be considered while feeding concentrate feed resources, including the type of animal (ruminant vs. nonruminants), the availability and price of the feed resource, and the presence of anti-nutritional factors (e.g., trypsin inhibitor in soybean meal, gossypol in cottonseed meal, etc.). Therefore, the effect of MW treatment application on concentrate feed resources' nutritive value needs to be considered for both ruminant and nonruminant animals.

Microwave Treatment on Concentrate Feed's Ruminal Degradation and Fermentation Characteristics

Rumen degradability of feed nutrients is used to describe the supply of available nutrients to the anaerobic microbes and body tissues of ruminant animals . The MW heat treatment effect on effective rumen degradability of dry matter (DM) and CP of different grains were measured in several studies (Table 1). All the studies found that DM and CP's ruminal degradability were decreased significantly ($P < 0.05$) when treated with MW compared with the control. However, the level of reduction on DM and CP degradability was not the same across different grain types. A previous study showed soybean meal treated with MW reduced both *in vitro* DM and CP degradability by 40% compared with untreated soybean meal (Sadeghi et al., 2005). On the other hand, barley grain showed only a 4.4 and 17% reduction in *in vitro* DM and CP degradability, respectively. The magnitude of changes can be attributed to the variation in the nutrients present and the morphological structure of the feed type. For example, the lower degradability of DM in

MW-treated grain was attributed to the reduction in effective protein degradation. This may link to the MW heat treatment of feed increased the feed protein's enzyme resistance (Englard & Seifter, 1990). Besides, (Banik et al., 2003) suggested that there may be some non-thermal effect of MW heat treatment on protein alteration and transformation.

It is a well-established fact that the protein's denaturation and unfolding due to heating could break the bond that stabilizes the protein's tertiary structure. As a result, hydrophobic groups of proteins get exposed to enzymes, which reduces the protein solubility (Voragen, 1995) and ruminal protein degradability. This statement is also supported by Prestløkken (Prestløkken, 1999) with an in sacco study, where pelleted and expander-treated barley were suspended in three non-lactating dairy cows. Prestløkken (1999) reported that hydrophobic amino acids degraded less in the rumen than hydrophilic amino acids.

One of the important concentrate feeds used in animal production is sorghum; however, a major limitation to the use of sorghum is that its starch digestibility is comparatively lower than other cereal grains. This is due to peripheral endosperm layer resistance that encloses the starch granule (Rooney & Pflugfelder, 1986). The MW heating can help to disrupt the complex protein–starch bond by migrating and liberating hygroscopically bound water within the organic complexes (Brodie et al., 2019). In an *in vitro* rumen fermentation study, (Bootes et al., 2012) treated three-grain sorghums, maize, and wheat grains in a 900 W, 2.45 GHz MW oven for 180 and 300 s. The results showed that the maximum amount of ruminal gas production was increased by 6.9% in sorghum and 5.5% in maize, but not in wheat when treated for 180 s. The gas production indicated the microbial fermentation characteristics due to feeding various types of feed resources. It also helped predict the range and rate of digestion of different feed resources (Getachew et al., 2004). However, no changes occurred beyond 180 s of MW treatment. This result demonstrated that MW treatment could improve rumen *in vitro* gas production of sorghum and maize when correct treatment time was applied. In another study, sorghum and broom sorghum were treated with MW. The MW heat treatment significantly increased *in vitro* gas production. The maximum gas production with 3, 5, and 7 min treatment time for sorghum increased by 10, 13, and 8%, respectively, in MW-treated sorghum (Parnian & Taghizadeh, 2009).

MW-Treatment Effect on Concentrate Intestinal Crude Protein Digestibility in Ruminant

In case of ruminant production systems, by-pass protein plays an important role. By-pass protein is a portion of dietary proteins that by-pass or escape the rumen degradation process and are made available for intestinal digestion (Kempton et al., 1977). In addition, there are other different protein sources available for intestinal digestion, such as microbial protein synthesized in the rumen and endogenous proteins from the animal's body. Over the last century, animal researchers have tried to develop some physical or chemical techniques that can manipulate the degradable nature of CP to prevent the degradation of protein in the rumen (Kempton et al., 1977). Table 1 showed that, physical techniques like MW treatment have been proven to decrease CP's degradability in the rumen and increase CP digestibility in the intestine at the same time. In addition to that, Fig. 2 demonstrated that, MW studies with canola seed (Ebrahimi et al., 2010), canola meal (Sadeghi & Shawrang, 2006), cottonseed meal (Sadeghi & Shawrang, 2007), and soybean meal (Sadeghi et al., 2005) increased intestinal CP digestibility by 7–25%, with some differences between feed sources and MW treatment times. The mechanism for MW heat treatment to increase intestinal CP digestibility may be due to enhance the protein denaturation and unfolding of the tertiary structure, which exposes hydrophobic amino acid with positional group active sites for enzymes like pepsin and trypsin present in the small intestine (Negi et al., 2001).(Chen et al., 2010)

Microwave Treatment Effect on Anti-Nutritional Factors Present in Feed

Anti-nutritional factors are the chemical compounds, or their secondary metabolites, found in feedstuff, which intervene in feed utilization, digestive processes, or metabolic utilization of feed (Emrah et al., 2016). There are different types and levels of antinutritional factors in feeds that can cause problems during feed ingestion and Fig. 2 Graphical presentation of the effect of MW heat treatment on ruminal DM degradability and intestinal CP digestibility of concentrate feeds (canola seed, canola meal, soybean meal, and cottonseed meal) (Shishir et al., unpublished)

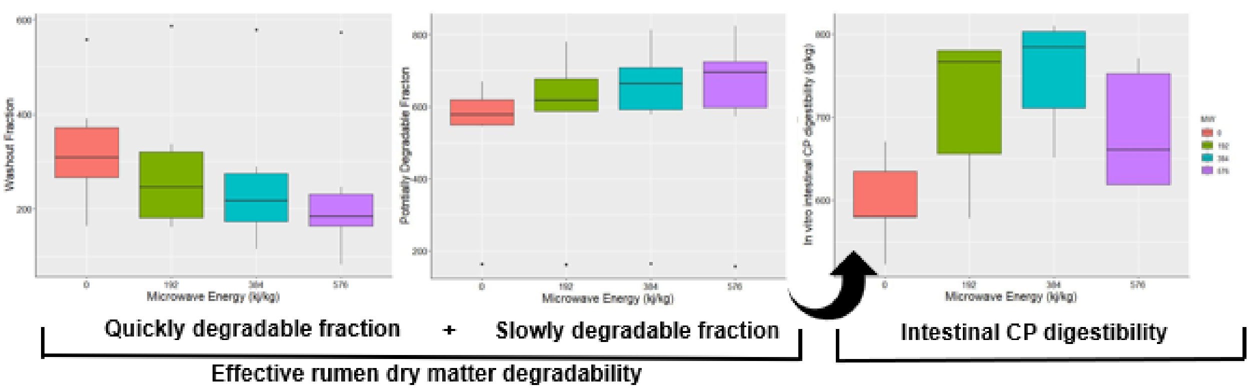

Fig. 2. Graphical presentation of the effect of MW heat treatment on ruminal DM degradability and intestinal CP digestibility of concentrate feeds (canola seed, canola meal, soybean meal, and cottonseed meal)

utilization in animals. As a result, many physical and chemical methods have been applied to reduce the harmful effects of anti-nutritional factors of plant feed components on animals (e.g., heating, chemical treatment, extraction, etc.) (Mubarak, 2005; Yacout, 2016). Physical treatments, like MW heat treatment, have been effective in completely removing trypsin inhibitors from legume seed (Khattab et al., 2009). In addition, other anti-nutritional factors like tannins and phytic acid in legume seeds are also significantly reduced by MW treatment (Khattab et al., 2009). The reduction in these anti-nutritional factors due to MW treatment may be partly due to their heat-labile nature and the formation of insoluble chemical complexes (Rakić et al., 2007; Udensi et al., 2007). Increased animal performance by reducing anti-nutritional factors in feed by MW treatment was demonstrated in nonruminant animals by Xian and Farrell (1991). In this study, MW-treated raw soya bean had reduced trypsin inhibitor and urease activity after 330 s of MW treatment with 14.1 kW conveyor-type MW oven. When fed to chickens, the apparent digestibility for MW-processed raw soybean was significantly higher, except for nitrogen retention. On the other hand, feed intake (DM and CP intake) was lower in the MW-processed soybean diet than the raw diet. The growth rate of chicken fed MW-processed soybean diet was 76% higher than the control group. In a rat feeding trial, significant increases in growth rate were observed due to being fed a MW-processed soybean diet, which led to higher efficiency in feed conversion ratio (FCR). But, no effect was observed in feed intake. In the case of rabbits, no significant effect was found in performance whatsoever. The results demonstrated that positive responses can be achieved for nonruminant animals, like poultry, due to the reduction of anti-nutrition factors. However, more extensive research is needed to understand the MW treatment's effect on a broader range of anti-nutritional factors in feed resources.

Microwave-Treated Concentrate Feed Effect on Ruminant Animal Performance

In regard to ruminant animal feeding trials with MW treatment concentrate feed resources, only the *in vivo* study conducted by Khajehdizaj et al. (2014) on sheep fed on MW-treated sorghum observed the effect on sheep nutrient utilization, blood metabolites, and fermentation characteristics. The apparent digestibility of DM, organic matter, and starch increased linearly when treated with 900 W of MW power, operating at 2.45 GHz, for 300 s. In the rumen fermentation characteristics, the concentration of volatile fatty acid in the rumen fluid was significantly higher in the MW-treated sorghum. On the other hand, ammonia nitrogen was linearly reduced with increasing MW treatment time, from 0 to 300 s. However, no significant effect was observed on the blood parameters due to feeding MW-treated sorghum. The lack of *in vivo* studies of MW-treated feed highlights an important knowledge gap.

Microwave Drying

There is a wide range of drying applications that have been used in processing animal feed and animal origin food products (e.g., meat and egg). Many studies have investigated MW drying applications to various feed resources. Irrespective of the purpose of drying, MW heating showed some favorable aspects in each case. To preserve quality during storage and avoid spontaneous combustion, drying of forage or concentrate feeds with MW can be useful (Brodie et al., 2019). The MW drying proved to be more convenient due to its high energy efficiency and quick-drying and less effect on the product quality than conventional hot air drying (Vadivambal & Jayas, 2007). In many cases, MW drying even improved the products' quality because rapid energy absorption in the material during MW heating, due to dielectric properties, led to quick evaporation of moisture (Brodie, 2007), which causes less damage to the product quality. The MW drying has also been extensively used for moisture determination in the lab (Altan, 2014; Nirmaan et al., 2020) and to help preserve the sample for further chemical analysis (Goossen et al., 2018; Higgins & Spooner, 1986) since it has been found in research that MW heating has minimal effects on the nutrient composition of the material (Lenaerts et al., 2018; Pradeep et al., 2013).

Microwave Soil Treatment Effect on Crop Growth and Yield

Wheat and rice can be utilized as a grazing crop for animal production. Previous studies suggested that soil MW treatment increased wheat and rice biomass yield by 33% and 22%, respectively (Khan et al., 2019b; Khan et al., 2019c). This indicates that there is a potential to offer more feed to the grazing animal in the form of grazed forage by considering MW heat-treated paddocks vs. non-treated paddocks, which may lead to increased animal production performance. On the other hand, a recent paper published by Khan et al. (2019a) showed that MW soil treatment did not alter rice crop (plant and grain) nutritive value. However, an increase in total nitrogen and DM accumulation in the rice crop was observed under field conditions. The higher DM production of MW-treated soil may support higher stocking rates and animal production if it is grazed by livestock; however, experimental work with grazing animals on the MW-heat-treated paddocks or small plots is required to validate this hypothesis. Further work in pastures and grasslands is required to examine if yield increases also occur in those systems to increase animal performance.

Prospect of MW Technology in Animal Production System

It is plausible to predict that the future advancement of any technology must consider three points to become useful and sustainable at the same time. These points are time efficiency, energy efficiency, and being relatively risk-free. The MW technology potentially fulfills all these criteria and has already been proven in many fields, like the technical, agriculture, medical industries, etc. (Ayappa et al., 1991). The MW techniques may be a prospective technique that can possibly replace existing drying techniques in the feed milling industry worldwide. Furthermore, the potentiality of MW techniques regarding the removal or reduction of anti-nutritional factors will help develop techniques that can increase the storage life of animal feed and animal products. Moreover, improving the nutritive value of feed may lead to lower energy losses in the form of methane from ruminant animals

(Eckard et al., 2010). This will reduce the enteric greenhouse gas contribution from the ruminants. However, MW treatment's possible effect on the conversion rate of methane has not yet been studied. Future work needs to determine the optimal MW treatment energy level (kW), time, frequency to improve feed quality, yield and animal performance. Mathematical model need to build to support the decision making process of optimal MW treatment selection.

Conclusion

In a sustainable animal production system, the feed will always be the most important input. The MW treatment is a processing technique that may help to achieve maximum nutritional benefits from the animal feed from the intake and utilization point of view. In order to gain more comprehensive knowledge on how MW heat treatment may impact on feed quality parameters in forage/conserved forage, further research needs to be conducted. In addition, the exploration of the mechanisms that underpin previously observed feed quality changes in grain/meals is also needed. The level of MW power used, application duration (time), feed physical/chemical structure, and their interactive effects on feed quality and animal performance are the key areas to be understood. While *in vivo* animal study is essential to validate the use of MW application in the animal industry, the *in vitro* study will continue to be a time/cost-effective approach to conduct a preliminary analysis to recognize the usefulness of MW heat treatment in animal production.

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