

## TAPPING INTO THE UNSUNG POTENTIAL OF MAIZE (*ZEA MAYS L.*) BASED SILAGE IN ANIMAL FEED INDUSTRY

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**Abstract:** Feed is widely recognized as the most crucial component of livestock production systems, accounting for up to 70% of production costs. The existing gap between the supply and demand of fodder is a matter of significant concern. To minimize wastage and enhance animal production, fodder crops can be preserved as silage, haylage, or hay for feeding purposes. Maize silage stands out as a favored option due to its higher yield, acceptable nutritional content, and the presence of water-soluble carbohydrates that can be fermented into lactic acid. Additionally, it provides an economical source of fiber and starch that complements grazing for a substantial part of the year. When incorporating high levels of maize silage supplementation, optimizing milk solids output requires addressing dietary deficiencies in protein, minerals, and occasionally fiber. Although certain losses naturally occur during fermentation and storage, improving management techniques can help reduce them. Over the years, the in-situ approach has been widely employed to assess the expected digestibility of feed components in ruminants. This approach is a valuable tool for predicting the rumen degradability of organic matter derived from the diet. To address these challenges, it is imperative to identify non-conventional feed sources or encourage farmers to cultivate more nutritious fodder varieties.

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### Introduction

The largest agricultural subsector, livestock accounts for 11.5% of the GDP and 60.1% of the value added to agriculture. There are 213.1 million heads of livestock in the country. Moreover, More than 8 million families in rural areas raise livestock, accounting for more than 35 to 40 percent of their income (GOP, 2021). In developing countries, population growth, globalization, sustainable growth, and shifting consumer preferences are all causing increased need for livestock products (Delgado *et al.*, 2001). Livestock population in Pakistan depends upon fodder and crop residues 51%, rangelands 38%, cereal by-product 6%, post-harvest feeding 3%, and agro-industrial by-product 2% (Hanjra *et al.*, 1995). Up to 70% of the cost of production for livestock production systems are attributed to feed, with the remainder going towards health and other management-related expenses (Buza *et al.*, 2014; Makkar, 2013). Only 2.1 million hectares or 6.5% of Pakistan's agricultural land is typically used for raising fodder (Habib *et al.*,

2016). Due to their significance as the most affordable source of nutrients for cattle, fodder crops are essential to the agricultural economies of developing nations (Iqbal and Iqbal, 2015). Fodder crops in Pakistan are the only source of nourishment for livestock producers, especially in irrigated regions. They supply ruminants with between 85% and 90% of their nutritional needs (Gill, 1998). One of the main obstacles to completing the required level of livestock output is the shortage of feed and fodder because animal productivity is directly related to their nutrition (Meena *et al.*, 2018). The amount of fodder available in Pakistan barely meets the 40% nutritional requirements of the livestock population. When it comes to metabolizable energy (ME) and crude protein (CP), there is a shortfall between supply and demand which is 38 percent and 37.2 percent, respectively (Habib *et al.*, 2016).

The current scenario of livestock population witnessed an increase of 3 % (GOP, 2021), and there

is a massive increase in the demand for feed, particularly during the lean season when fresh feed is scarce. There are two scarcity periods in our country firstly in the summer months (June-July) and the second in the winter months (October-November) (Sarwar *et al.*, 2002). Compared to other crops, the fodder crop situation is unique in diversity, geographical distinctiveness, and seasonality. Additionally, due to fodder crops' poor commercial value, farmers are typically not attracted to them (Iqbal *et al.*, 2015). Low cost of feed, insects, pests, and substandard seeds. The lack of high-quality fodder seed is a significant issue for developing nations worldwide (Biemond *et al.*, 2012). Depriving animals of the nutrients they require to perform to their full potential. In the spring, fodder is usually more easily accessible. Therefore, fodder can be stockpiled as hay or silage for feeding during times of scarcity throughout the year to minimize waste and maximize animal output. These facts necessitated immediate action to alleviate the nation's feed shortage to enhance livestock productivity. To ensure balanced livestock output in Pakistan, it is essential to explore alternative animal feeding methods, as the conventional resources are expected to degrade in the future, given the rapidly growing livestock population. This growing disparity between nutritional supply and demand poses a serious hazard. In this context, it is critical to evaluate several non-traditional feed sources. Some of these substitute resources include molasses, sugar beet pulp, filter press mud (a byproduct of the sugar milling process), hulls, maize bran, rice gluten, slaughterhouse by-products, and bakery by-products. Among these options, silage-based animal feeding is the most suitable, reliable, and sustainable approach to meet livestock nutrition requirements (Horst *et al.*, 2020; Peyrat *et al.*, 2014; Blasel *et al.*, 2006).

#### **Silage production: a thriving vitality in livestock sustainability**

Silage is created from forages, crop by-products, and agricultural by-products preserved by acidity, either naturally occurring or artificial. It is an efficient method for forage storage during periods of scarcity in ruminant feeding systems. Dairy farms favor silage as a feed option because it minimizes nutrient loss from harvest to storage, simplifies feeding processes, improves efficiency, reduces reliance on weather conditions, allows for multiple harvests per year, and enables timely feed mixing (Mahanna and Chase, 2003). Silage serves as a substitute source of fodder, effectively addressing the shortage of conventional feed without negatively impacting intake and digestibility. By inhibiting the growth of undesirable microbes, silage ensures that the fodder is suitable for animal consumption. There is a common misconception that silage with a fruity and sweet odor indicates good quality. However, this odor is primarily attributed to high levels of ethanol produced by yeast or bacteria. Since lactic acid which

is the main organic acid at the end of fermentation and is odorless is the primary organic acid, well-fermented, high-quality silage shouldn't have a strong or recognizable smell. Another organic acid commonly found in silage is acetic acid, which has a vinegar-like odor. It often appears in the bottom layers of silos due to compaction and higher moisture levels (McDonald *et al.*, 1991). Hafner *et al.* (2013) researched corn silage and identified ethanol as the most significant volatile organic compound in the silage. The alcohol produced through yeast fermentation can react with acids in silage, resulting in a fruity aroma in corn silage. Silages that are drier and well-ensiled tend to spoil at a faster rate compared to wetter silages. This is primarily because drier silages become more porous within the silo and contain lower levels of organic acids, which play a crucial role in inhibiting the growth of lactate assimilating yeast that can lead to aerobic putrefaction. Consequently, silage quality is enhanced through decreased pH in drier silages (Muck *et al.*, 2018).

Good quality silage is attained by maintaining anaerobic conditions within the silos and by attaining a low silage Ph by fermentation of water-soluble carbohydrates. Quality of silage is determined by pH like good silage 3.8-4.2, medium silage 4.2-4.5, poor silage more than 4.6 pH. After ensiling rapid decline in pH play a major role in decreasing the clostridia and also pH values of ensiled crops play a major role in determining its quality. Lactic acid bacteria produced lactic acid during fermentation of water-soluble carbohydrates in forages which is found in silages in higher concentrations and responsible for a decline in silage pH because it is approximately 10-12 times stronger than acetic acid and propionic acid present in silages. It reduces its pH up to 3.2-4.2. In rumen lactic acid in silage is converted into propionic acid. Silage fermentation stabilized by lowering pH due to higher lactic acid concentration in the silage (Ogunade *et al.*, 2016). Whiter and Kung (2001) reported that as the DM increased in the diet, water availability for growth of lactic acid bacteria decreased so pH of silage increased that cause a significantly negative effect on silage quality. The accomplishment of a low pH, which is attributable to the buildup of organic acids, facilitates the retention of the nutritional content of ensiled forage. The overall quality of the ensiled forage is preserved due to the low pH, which also restricts harmful bacteria's growth and prevents spoiling (Ogunade *et al.*, 2016). Inoculating ensiled forages with homo or hetero and facultative bacteria is a popular procedure to increase lactic acid fermentation (Arriola *et al.*, 2015; Silva *et al.*, 2016). Ward *et al.* (2001) researched to determine the silage characteristics of different forages like sorghum, tropical corn and pearl millet. Sorghum ensiled well in 4.09, tropical corn in 3.96 and pearl millet in 4.50 pH. This is because pearl millet had lower water-soluble carbohydrates than corn silage due to low

concentration of lactic acid and low pH. Good quality preserved silage has pH less than 4.2 and silage with pH greater than 4.2 have a greater chance of clostridial fermentation and harmful effect on silage quality. The second-most prevalent organic acid in silage is acetic acid (AA). The amount of dry matter (DM) in the silage is inverse to the AA concentration. Ruminants consume and absorb AA in the rumen, utilizing it for milk production and body fat synthesis. The presence of AA in silage contributes to improved aerobic stability due to its strong antifungal properties, effectively inhibiting fungal growth (Kung *et al.*, 2000). Silage with moisture content exceeding 70% tends to have higher levels of AA, possibly due to the presence of clostridia, enterobacteria, and heterolactic acid bacteria, as Webster (1992) reported. On the other hand, propionic acid concentration is typically low in high-quality silage. Propionic bacteria convert water-soluble carbohydrates into propionic acid and AA within the silage. *Clostridium propionicum*, specifically, increases the concentration of propionic acid from 0.3% to 0.5% in silage. To enhance the aerobic stability of silage, the addition of propionic acid at a rate of 0.15% to 0.30% on a DM basis has been suggested (Krooneman *et al.*, 2002).

#### **Improve fermentation while reducing storage losses**

While natural losses are inevitable during the fermentation and storage of silage, some strategies can be employed to reduce them (Borreani *et al.*, 2018). According to Pahlow *et al.* (2003), the ensiling procedure is classified into four stages: the initial aerobic phase, the primary fermentation phase, the stable phase, and the feed-out period.

#### **Initial aerobic phase**

Biological and chemical reactions occur during the first aerobic phase, which lasts until the forage is stored with oxygen, using nutrients and producing heat as a byproduct (Borreani *et al.*, 2018). Higher temperatures and prolonged exposure to heat increase dry matter losses and protein damage. To minimize oxygen exposure and the duration of the aerobic phase, it is beneficial to fill silos rapidly and promptly cover bunkers or piles (Bruning *et al.*, 2018).

#### **Primary fermentation phase**

After harvest, when the oxygen supply is depleted, the major fermentation period begins. The fermentation process is best carried out by lactic acid bacteria (LAB), which turn water-soluble carbohydrates into lactic acid (Mahanna *et al.*, 2017).

#### **Stable phase**

During the steady time of ensiling, the pH of the silage decreases, but as long as the silo is shut and oxygen-free, there aren't many changes (Pahlow *et al.*, 2003). However, other microbial species competing with lactic acid bacteria (LAB) in the silage might lead to the generation of less favoured fermentation end products (Mahanna *et al.*, 2017). Yeast numbers may rise if the silo isn't sealed right away or the filling procedure takes too long, which will cause more dry

matter loss and less aerobic stability (Pahlow *et al.*, 2003). The production of butyrate and the development of foul-smelling silage by clostridial species, which are connected to overly moist forage or contamination from soil, might have a detrimental influence on the palatability and intake of dry matter (Mahanna *et al.*, 2017). For that purpose, silage inoculants containing LAB improve silage quality by inhibiting the growth of unwanted microorganisms (Mahanna *et al.*, 2017).

#### **Feed-out period**

The conclusion of the stable phase transitions into the feed-out period, representing the final ensiling phase. The silo is now opened for feeding, exposing the silage to oxygen, and there is a greater chance that nutrients will be lost by aerobic oxidation. A considerable amount of the dry matter losses, up to 50%, happen during the feed-out phase (Mahanna *et al.*, 2017).

#### **Crop suitability for silage production**

Several crucial aspects, including the dry matter or sugar content, and buffering capability of the crops being considered for silage production, should be considered. Due to its high DM content, diminishing buffering ability with maturation, and enough water-soluble carbohydrates when completely ripe, corn is ideally suited for the formation of silage (Mannetje, 2016). In addition to its many benefits, corn silage has a high nutritional output per unit of land, is simple to include into total mixed rations, and contains a sizable amount of starch, which gives ruminant animals fermentable energy (Allen *et al.*, 2003; Blasel *et al.*, 2006). Alfalfa may be challenging to store as silage due to its high buffering capacity, low DM content, and few water-soluble carbohydrates. Grass often contains more water-soluble carbohydrates than legumes but is less acidification resistant (Mannetje, 2016). Silage production is commonly practiced in developed countries, with crops like maize, oats, and sorghum being particularly suitable. Maize, in particular, is a major forage source for ruminants worldwide, offering high genetic potential and efficient photosynthesis as a C4 plant (Wei *et al.*, 2018; Tariq *et al.*, 2010). Maize fodder is widely utilized as animal feed, and its cultivation spans temperate to tropical regions. In Pakistan, for example, maize is grown extensively to fulfill farm animals' forage and silage requirements (FAOSTAT, 2017). However, drought stress, dry seasons, late sowing, poor nutritional management, and weed infestation can significantly reduce forage maize production.

Maize is highly favored for silage production in the livestock industry due to its superior nutritional quality. It contains 8.33% crude protein (CP), 35.84% DM, 23.28% crude fiber (CF), 5.9% ash, and 60% total degradable nutrients (TDN) (Azim *et al.*, 2000). Additionally, it has 52.46% NDF and 32.5% ADF (Patel, 2012). Maize cultivation is widespread globally and is called "king of grain crops" (Hunje *et*

al., 2011). In Pakistan, it ranks as the 3<sup>rd</sup> most cultivated crop after wheat and rice, with a cultivation area of 1418 thousand hectares and productivity of 8.465 million tonnes (GOP, 2021). The upsurge in maize production may be due to expanded cultivation areas, availability of improved seed varieties, and better economic returns. Researchers have focused on developing maize varieties specifically suited for silage production to ensure sustainable animal feed utilization. The selection of corn hybrids can influence factors such as yield, grain content, and digestibility of corn silage (Schroeder, 2013). Given that the finest forage types are also the best grain varieties, plant breeders frequently choose hybrids based on grain output (Lee *et al.*, 2005). When used for silage, leafy corn hybrids have been demonstrated in certain studies to improve animal performance (Ferraretto *et al.*, 2015), however other research has revealed no differences across hybrids in terms of feed, silage, and stover output (Darby and Lauer, 2002). Each year, new types of maize are introduced to the market due to ongoing breeding efforts. Therefore, it is essential to regularly analyze the nutritional content of the available maize types when creating cow feeds.

#### **In-situ digestibility**

To meet the dietary needs of animals, it is crucial to accurately analyse the bioavailability of dietary components in animal feed or feed ingredients. Several techniques have been developed in recent decades, including in-situ, in vivo, and in vitro methods, to evaluate nutrient digestibility. Extensive research has been conducted to determine the nutritional value of essential forages and concentrate ingredients commonly used in the nutrition of dairy cows. The in-situ technique, which involves the utilization of animals with rumen cannulas, has been widely employed to estimate the degradability feed. This method is particularly useful for predicting the rumen degradability of organic matter in the diet (Mohamed and Chaudhry, 2008). Many researches have focused on investigating the digestive kinetics of feed components in various animal species, including buffalo (Sarwar *et al.*, 2004), cows (Di Marco *et al.*, 2002), sheep (Zagorakis *et al.*, 2015), and goats (Ghavipanje *et al.*, 2016).

#### **Dry matter degradation kinetics**

In a study employing the in-situ method, Peyrat *et al.* (2014) determined the impact of ensiling and fresh samples on the deterioration of maize fodder. The findings showed that corn silage had a larger degradable percentage than fresh corn, contributing to its higher dry matter (DM) degradability. The ensiling procedure had no impact on the DM content. Because there is a greater percentage of quickly degradable fraction in the coarsely ground 1mm samples, the effective degradability of DM was higher for 1mm samples than for 4mm ground samples. However, according to Dulphy *et al.* (1999), utilizing finely-ground samples caused an overestimation of DM's

ruminal degradability because insoluble particles were lost through the bag's pores and confused with the soluble and quickly degradable fractions.

Due to variances in grain yield and stover quality among hybrid corn plants, corn silage's composition and quality might change upon harvest (Wolf *et al.*, 1993). The impacts of hybrid corn silage (Pioneer 3489 and Pioneer 3335), maturity and digestibility in beef cattle were examined in research by Andrae *et al.* The diets comprised 40% chopped alfalfa hay and 60% corn silage (on a dry matter basis). The results showed that Hybrid 3489 had high stover neutral detergent fibre (NDF) content throughout maturity and generated silage with a high grain content. Hybrid 3335 displayed minimal stover and whole-plant NDF content, and as maturity increased, its grain growth was quick. The ruminal degradability of whole-plant dry matter for hybrid 3335 remained constant across maturities in the preliminary investigation, but it declined for hybrid 3489 as maturities increased. As plant maturity rose, the total tract digestibility of dry matter dropped; processing had no impact on the digestibility of dry matter. The effect of maize silage maturity on ruminal dry matter elimination was also studied by Bal *et al.* in 2000. As maize silage matured, the ruminal loss of dry matter was reduced. They also evaluated the ruminal nutrient loss of hybrid brown-midrib (BMR) corn collected as whole-plant maize silage to a standard grain hybrid. Because of their increased leaf content and reduced lignin concentration, BMR hybrids had higher ruminal dry matter disappearance (Oba and Allen, 1999). Compared to non-BMR hybrids, BMR maize silages showed better in-situ or in-vitro NDF digestibility and contained 34% less lignin, according to Eastridge (1999). For hybrid selection, dry matter yield and grain content are crucial variables (Kruse *et al.*, 2008; Filho *et al.*, 2011). Horst *et al.* (2020) noted the effect on ruminal fermentation kinetics, digestibility of maize plant components, and degradability of the resulting silage of harvesting three maize hybrids (Maximus VIP3, Defender VIP, and Feroz VIP) at various stages of maturity. Compared to the other two hybrids, the Maximus maize forage showed greater in-situ degradable DM and fibre potential digestibility. In addition, the Maximus hybrid had a larger propensity for neutral detergent fibre degradation than the Defender hybrid. Other findings, such as fermentation kinetics, gas generation, and volatile fatty acid synthesis, confirmed the Maximus hybrid's superiority over the other hybrids examined. This hybrid is recognised for having a strong stay-green characteristic. It follows that the vegetative portion of the Maximus hybrid should be easier to digest than those of the other hybrids. Conclusion: The Maximus VIP3 hybrid seems to be the greatest choice for creating silage when harvested between the dough and dent grain stages of maturity.

According to Bartle *et al.*, late-harvested maize plants showed decreased dry matter digestibility than early-

cut corn (1984). This can be due to the stem's loss of glucose and the plant's maturation-related increase in fibre components. The comparatively high lignin content in the stover may cause the extended lag time seen. The in-situ degradability of DM of 6 maize types collected at 2 maturation stages was assessed by Akbar *et al.* in 2002. Compared to Boss, Carlos and Bezemara types showed greater DMD, whereas the other kinds had moderate levels of degradability. With maturing, the DMD of all kinds is reduced. Stouter's potential degradability and rate of degradation did not significantly vary amongst the types. Overall, maize types varied in yield and in the capacity to degrade stover and cob, but potential degradability and degradation rate remained mostly constant.

Genotype, maturity stage, and processing often impact how digestible the nutrients are in maize silage. Processed maize silages frequently show higher in-vitro and in-situ nutrient digestibility than unprocessed silages because the physical barrier for microbial attachment and nutritional breakdown is lower in processed silages (Johnson *et al.*, 1999). Roughani and Zamiri (2009) investigated the chemical makeup, ruminal degradability of DM, and nutritional digestibility of maize silage concerning microbial inoculant (containing propionic and lactic acid bacteria) and formic acid. Control (no additive), *Propionibacterium acidipropionici* + *Lactobacillus plantarum*, and formic acid were the three treatments that were compared. Chemical analysis, DM degradability, and nutritional digestibility in sheep were performed on the silages. Formic acid was added to Treatment 3, which resulted in more effective dry matter degradation. In conclusion, formic acid has been observed to improve fermentation when added to silage material. Dehghani *et al.* (2012) looked at solubilizing readily digested portions of cell wall carbohydrates during ensiling fodder to provide substrates for lactate fermentation. Ensiling with the study's chosen enzymes did not enhance the in-vitro organic matter digestibility. However, an improvement in dry matter digestibility may be anticipated in high-producing dairy cattle with a short rumen retention period due to the reduced concentration of NDF. According to Russell *et al.* (1992), the dry matter's in-vitro digestibility in maize silage declined with increasing maturity and was strongly linked with the amounts of lignin and ADF.

#### **Neutral detergent fiber degradation kinetics**

Improving the digestibility of cell walls is vital to enhance the feeding value of forage. Overall enhanced digestibility and indigestibility are influenced by higher cell wall digestibility. Instead of concentrating just on lignin concentration, breeders should concentrate qualities directly associated with cell wall digestibility, such as in vitro NDF degradability. The digestibility of cell walls plays a significant role in feedstuffs containing dietary fiber, comprising hemicellulose, cellulose, and lignin. For hemicellulose and cellulose to be effectively broken

down for ruminant animals, who live in harmony with rumen bacteria, their digestibility must be sufficient. Maize, a commonly grown forage crop, demonstrates that both lignin content and structure affect the digestibility of cell walls. Traditionally, the lignin fraction has been considered the main obstacle to microbial fermentation of fiber, as higher lignin content negatively correlates with the degradability of maize stover's cell walls.

Due to its ability to quantify the components of cell walls that encourage rumination and fill the rumen, the NDF system has become more popular in the dairy sector. NDF digestibility in maize silage is indirectly influenced by using different maize hybrids or harvesting at various maturity stages. It has been observed that NDF digestibility decreases as the whole plant dry matter increases. Higher NDF digestibility leads to increased energy intake for cattle, regardless of dry matter intake. Improving NDF digestibility is crucial for genetic advancements in feeding value, both in forages with and without grain. NDF does not, however, fully account for the variation in dairy cattle's consumption and milk output. For ruminants, NDF is a significant source of energy. Greater microbial protein production in the rumen has been linked to feeding maize silage hybrids with higher NDF digestibility, which might lead to higher milk protein concentration. NDF digestibility shows a significantly positive effect on DM and organic matter digestibility. Grain content and stover digestibility both have an impact on the feed maize's digestion. The feeding value of maize can be increased by introducing brown midrib (BMR) genes or by making genetic changes. BMR hybrids have less lignin and more in vitro digestible NDF. Practices that improve NDF digestibility and dry matter intake benefit dairy cows, whose intake is constrained by rumen fill. In contrast, feedlot cattle diets high in starch cause ruminal pH to drop and NDF digestion to increase. Rumen fill may be a limiting issue for developing cattle fed diets with increasing roughage concentrations, although it often does not restrict intake in cattle on high-concentrate feedlot diets.

Research has shown that feeding lactating dairy cows corn silage made from various maize hybrids impacts their nutritional intake, digestibility, and milk output. Due to higher NDF and ADF digestibility, BMR corn silage-supplemented diets have demonstrated better milk output. The overall tract digestibility of NDF falls as maize silage ages. The NDF concentration and digestibility of silage are influenced by the maturity stage owing to physiological changes in the plants, such as cell wall lignification. The ensiling process enhances ruminal degradation of maize but may also lead to decreased NDF degradation compared to fresh plants due to partial hemicellulose hydrolysis. Harvesting maize at a later stage of maturity or with a higher dry matter content has a considerable negative influence on the performance and feed efficiency of growing calves fed significant amounts of corn silage.

Compared to early ripening hybrids with higher kernel content and NDF digestibility, which have larger dry matter yields but inferior animal performance, maize hybrids have different nutritional and agronomic traits. It is critical to consider maturation effects when assessing the functionality and nutritional value of maize hybrids. Techniques for producing in vitro gas offer chances to evaluate the nutritional qualities of fodder maize as it develops.

#### **Acid detergent fiber degradation kinetics**

The impact of harvest date on the quality and quantity of corn that used to produce fodder or silage was examined in a research by Darby and Lauer in 2002. They found that the ideal range for gathering fodder was between 65 and 70 percent moisture. This moisture range produced the highest in vitro true degradability levels and the lowest quantities of NDF and ADF. Silage contrasted with fresh forage in having greater ADF concentrations, poorer cell wall's digestibility, lower CP, and lower NDF and IVTD concentrations. The study also found that 95 percent of the optimum yield and milk production could still be maintained while harvesting at up to 58 percent moisture. The nutritional benefits of whole crop maize silage (WCMS) from 9 different maize types were investigated by Gruber *et al.* (2018). They discovered that the acid detergent fibre (ADF) content varied significantly depending on the maize variety, with ADF concentrations declining as maturity increased. Various maize types vary in the nutrients' ruminal degradability. According to Andrae *et al.* (2001), plant maturity and the total tract digestibility of ADF have an inverse relationship. Processing techniques were also observed to decrease ADF digestibility. Adams (1995) also found that the ADF content in WCMS declined in the early dough to the 2/3 milk line stage of maturity, but there was no change from the 2/3 milk line to the black layer stage. Johnson *et al.* (2001) discovered that when maturation progressed from the milk and early dough to the black line stage, NDF and ADF contents in WCMS dropped. In WCMS collected at the 2/3 milk line maturity stage, these results show a drop in ADF concentration with increasing maturity, probably due to decline in NDF and ADF contents, leading to greater DM and OM degradability.

Wolfrum *et al.* (2009) looked at the relationships between detergent fibre components (NDF and ADF) and dietary fibre constituents in maize whole-stover samples. Instead of estimating the amount of hemicellulose and cellulose, they recommended utilizing NDF and ADF as predictors of structural carbohydrate content. The amounts of NDF and ADF in whole crop maize were reduced in the ensiled maize because hemicellulose is sensitive to lower pH levels and partially hydrolyzes under acidic conditions. Acid detergent lignin (ADL) and crude protein (CP) concentrations increased with maturity, indicating a decline in the nutritional value of NDF components. NDF and ADF concentrations were

highest at the early dough stage and lowest at the black line stage, respectively, depending on the maturity of the plants. However, lignification will probably be higher in more mature plants, even if harvesting silage at more advanced stages results in higher biomass production and lower NDF concentration.

#### **Crude protein degradation kinetics**

Animals need protein to thrive because it is essential for tissue growth and repair. A study was done by Oney *et al.* (2019) to look at the protein content of corn silage that hasn't been rumen-degraded. According to their research, rumen undegraded protein makes up around 13 percent of corn silage's crude protein (CP), with about half of it being digestible. Despite being a frequent feed ingredient in developing calf diets, maize silage has little digestible, rumen-undegraded protein. To satisfy the needs for metabolizable protein in corn silage-based developing calf diets, rumen undegraded protein must be supplemented. This is since the energy content of diets based on silage is greater than the supply of protein from microbial protein and rumen undegraded protein. In particular, there is not enough metabolizable protein (MP) in corn silage to meet animal needs, which also include microbial crude protein (MCP) and rumen undegradable protein (RUP) (Nasem, 2016). In order to assess the whole-tract CP degradability of 20 maize silages with various chemical compositions, Ali *et al.* (2012) used the mobile Nylon bag approach. According to their research, the rumen degrades CP on average by 555 g per kg, with the post-ruminal tract contributing an extra 353 g per kg. There was, however, a large range of post-rumen (250-503 g per kg) and rumen (420-672 g per kg) degradation.

Four stages of maturity were evaluated in a research by Filya (2004) utilising the in-situ rumen degradability technique, and variables such the water-soluble carbohydrate and CP content in the silages were studied. According to the study, CP concentration reduced in the black line stage compared to the early dent and one-third milk line phases, while water-soluble carbs decreased with increasing maturity. Based on dry matter (DM), the CP content reduced from 80 to 58 g/kg. Similarly, Johnson *et al.* (2001) showed that whole crop maize's ability to assimilate nutrients decreased as maturity increased. In conclusion, the amount of DM and starch increased with increasing maturity, whereas the amount of water-soluble carbohydrates, neutral detergent fibre (NDF), acid detergent fibre (ADF), and CP tended to decrease. Eittle and Schwarz (2003) found variations in CP and starch content as new maize cultivars matured. However, the variations had no impact on the variation in fiber-containing carbs. The majority of investigations found no appreciable variations in NDF levels between types. As a result, it appears that there is little chance of increasing the nutritional value of whole corn maize silage (WCMS)

by changing the NDF concentration through variety selection, while there may be a modest drop in fibre carbs as a result of the NDF content's declining with maturation. These findings suggest that despite the development of new maize varieties, the amount of fibre carbs in WCMS has not altered in recent years. The researchers looked at several types of maize silage and found that the CP and CF concentrations declined as the maturity level increased. Additionally, as maturity increased, less NDF and ADF content was present. In contrast, according to Gruber *et al.* (2007), maturity did not affect the amount of CP, CF, NDF, ADF, and acid detergent lignin (ADL) in WCMS. Ebling and Kung (2004) looked at the impact of mechanical processing and hybrid type (P-BMR, U-BMR, and a conventionally processed P-7511 corn silage) on the nutritional content for nursing cows. P-7511 had a lower CP content than the BMR corn silages (8.29 percent on average on a DM basis) (6.19 percent). Compared to cows fed U-BMR diets, those fed diets with processed silages P-7511 exhibited a greater CP digestibility (64.2 percent) (58.2 percent). However, Cows given P-BMR demonstrated higher CP digestibility (65.7%) than cows fed P-7511 or P-7511. Therefore, compared to cows given the BMR silages, those fed P-7511 had a total mixed ration (TMR) with a somewhat lower protein level.

In a research on the nutritional value of four distinct maize cultivars (SNK 2950, CRN 5412, PAN 6364, and CRN 4502), Kriek *et al.* (2000) found that CRN 5412 had considerably greater crude protein (CP) content in feed samples than CRN 4502 in the first month. The CP content of CRN 5412 also tended to be greater than that of other cultivars during the grazing period. As previously noted by Adiaanse, the increased CP content in CRN 4502 may be explained by the negative correlation between the nitrogen concentration in leaves and grains (1990). There may be a genetic connection between these ties and procreation. Compared to other cultivars, CRN 4512's greater acid detergent fibre (ADF) content did not negatively impact animal performance. Significant variances and interactions between several characteristics were discovered in a research by Nazli *et al.* (2019), demonstrating that different maize varieties respond differently at various harvest phases. Due to its high dry matter (DM) production, digestible nutritional and calorie content, and low fibre component, sweet corn was determined to be best harvested at the dough stage. Sweet Corn often has a greater CP level and a lower lignin concentration when compared to grain corn types. The Susan variety was advised to be harvested at the dent stage. It had the most DM yield, the best digestible nutrition and energy content, low acid detergent fibre, and the highest DM output. Because there were no discernible variations in crude protein, crude fibre, DM yield, DM content, digestible nutrition, or energy at any stage, BTL 1 and BTL 2 types may be collected at either the dough or dent phases. The results of the financial

study showed that only the production of Sweet Corn was not economically viable, with Suwan having the highest financial evaluation values of all the grain kinds.

Amaranth (*Amaranthus* sp.) is a C4 plant that thrives in poor soils, areas with little rainfall, and hot climates, according to Karimi *et al.* (2015). It is distinguished by a high concentration of CP, which can reach up to 28.5 percent on a dry matter (DM) basis, and DM digestibility ranging from 59 to 79 percent, depending on the species and variety. The potential of this plant as a feed source for ruminants hasn't been properly investigated, though. Their research aimed to evaluate the nutritional content of silages prepared from three different plant materials: maize (*Zea mays*), two types of amaranth (*Amaranthus hypochondriacus*) - var. Kharkovskiy and var. Sem, and corn and amaranth combined. The assessment included looking at the assessment's chemical composition, silage fermentation characteristics, in vivo digestibility, and in-situ DM degradability. The treatments that were looked at were ensiled maize variety SC 704 (EC), ensiled amaranth variations Kharkovskiy (EK), Sem (ES), and combinations of ensiled maize and amaranth variants Kharkovskiy and Sem. EK and ES had a greater in vivo DM digestibility than EC. Compared to the other silages, EK and ES had a reduced effective degradability of DM. As a result, amaranth has the potential to be a helpful addition to ruminant diets alongside corn by improving the CP concentration and digestibility of the combined corn-amaranth silages.

#### Starch degradation kinetics

Increasing the energy density of the meal with the addition of starch is one method for dairy cow nutrition to maximize energy intake for the best milk output. To sustain microbial activity in the rumen, starch, the main source of stored carbohydrates in plants, is an essential source of fermentable energy in maize silages. The digestibility of starch present in ensiled maize grains is remarkably high, undergoing nearly complete digestion in the digestive tract. Maize starch is composed of the two distinct glucose polymers amylose and amylopectin. Amylose is a tightly packed, linear chain molecule as opposed to amylopectin, which is a loosely packed, highly branched chain molecule. Both amylose and amylopectin have -(1-4) bonds to join the glucose units, with the latter having extra -(1-6) connections that provide branch points. Normal maize starch has an amylose content of 20–30% and an amylopectin content of 70–80%; nevertheless, genetic diversity results in cultivars with a range of starch compositions, from waxy to high-amylose cultivars. Amylose maize, or amylo maize, is a term used to describe maize cultivars with an amylose content of more than 50%. Waxy maize refers to starch variations with nearly 100% amylopectin. In comparison to amylopectin, amylose is more resistant

to enzymatic hydrolysis because of its densely packed structure.

According to Peyrat *et al.* (2014), ensiled maize undergoes starch breakdown more quickly than fresh maize. Silage has a greater degradability because of the partial breakdown of the protein matrix around the starch granules during fermentation in ensiling. Coarse-grinding of maize also enhances starch degradability by increasing the subsequent degradation rate. Because dried samples may suffer protein matrix coagulation, restricting the accessibility of starch to microbial enzymes and so slowing starch breakdown, the faster degradation rate shown in coarse-ground samples can be explained by the lack of drying. It was discovered that the total tract digestibility of starch changed depending on the maturation stage of maize silage in research by Bal *et al.* (1997) and Fernandez *et al.* (2004). Cows fed silage from the black layer stage of the corn crop displayed less apparent total tract digestion of starch than cows fed silage from corn harvested at the two-thirds milking stage. Additionally, compared to early maturity stage silage, late maturity stage silage had a reduced total tract digestibility of starch. Generally speaking, ruminal starch digestion was high, particularly in diets that contained equal quantities of starch from maize grain. Starch digestion in the rumen varied according to food, with some starch escaping and being digested in the small intestine. The digestion of starch in the hindgut was unaffected by the treatments. A different investigation by Di Marco *et al.* (2002) revealed that silage's starch concentration rose according to plant maturity.

In whole-plant corn silage, Bal *et al.* (2000) examined the effects of maturation, hybridization, and processing on ruminal nutrient loss (WPCS). They noticed that ruminal starch loss reduced as silage matured, with black-layer stage silage displaying lower disappearance than earlier stages of maturity. Mechanical processing positively affected ruminal starch disappearance for both early and late stages of WPCS, with the leafy hybrid exhibiting higher rates of starch disappearance. While mechanical processing enhanced ruminal starch disappearance in WPCS due to higher ruminal starch disappearance, delaying silage harvest until the black-layer stage lowered ruminal nutrient loss. In research on the nutritional value of corn silage for nursing cows, Ebling and Kung (2004) investigated the effects of mechanical processing and hybrid type. Processing did not affect fiber digestion but improved early starch digestion. Cows fed processed corn silage digested organic matter, crude protein, and carbohydrate more efficiently than cows fed unprocessed silage. Der-Bedrosian *et al.* (2012) looked at how long maize silage was stored for regarding its nutritional content and composition. Longer storage duration generally led to increase in vitro starch digestion, possibly due to proteolysis. Kramer-Schmid *et al.* (2016) discovered a connection between NDF, starch, and

dry matter digestibility in whole-crop maize silage. Reduced starch content and higher crude protein concentration were linked to improved NDF digestibility.

When Andrae *et al.* (2001) looked at how starch digestibility affected hybrids, they found that one hybrid had a more significant decline in starch digestibility as it matured. Hybrid characteristics, such as kernel hardness and density, may contribute to this variation. Vitreousness rose with maturity and varied between genotypes, indicating the crystallinity and porosity of maize endosperm. The rate of starch breakdown and the proportion of quickly degradable starch were adversely linked with higher vitreousness. Enogen Feed Corn from Syngenta Seeds, LLC is one of the corn hybrids with higher expression of the alpha-amylase enzyme that have been created to improve starch digestibility. Feeding experiments with finishing cattle have shown positive results, including consistent improvements in weight gain when Enogen Feed Corn is combined with corn gluten feed. Additionally, silage from Enogen Feed Corn exhibited improved pH decrease and aerobic stability in experimental silos, suggesting preservation benefits for silage due to alpha-amylase expression (Baker and Drouillard, 2018).

#### **Ether extract degradation kinetics**

Johnson *et al.* (2002) investigated how the maturation and automated processes of whole-plant corn hybrids impact the digestibility of starch, fibre, and ether extract and the energy content of nursing Holstein cows' total mixed ration (TMR). With a theoretical cut of 6.4 mm, they collected Hybrid 3845 whole-plant corn at three distinct phases of maturity (hard dough, one-third milkline, and two-thirds milkline). Both methods of evaluating each development level involved mechanical processing. Reduced digestibility of total tract neutral detergent fibre (NDF), ether extract, and crude protein (CP) in cows given processed corn silage diets was shown to be the cause of the lower energy content seen in the TMR. The processing technique similarly influenced the total tract digestibility of ether extract. The total tract digestibility of ether extract was much greater in cows fed unprocessed corn silage diets (92 percent) than in cows fed processed corn silage diets (90.8 percent). The authors hypothesized that the discrepancy was partly caused by the shorter particle size of the corn silages, which increased the passing rate and lowered digestibility. Weiss and Wyatt (2000) discovered high oil silages had greater fatty acid contents (5.5 percent vs. 3.4 percent of dry matter) than typical hybrids. The increase in fatty acids came at the expense of other non-fiber carbohydrate compounds rather than starch. The digestibility of high oil silages (unprocessed 77%, processed 76%) was compared to conventional silage (unprocessed 78.7%, processed 82.5%). In comparison to cows given traditional corn silage, those fed high oil silage typically had lower levels of fatty acid digestibility. The effects of high oil maize



and corn silage on breastfeeding cows were examined by Atwell et al. in 1988, and their reactions were contrasted with those of animals fed control corn and corn silage. Animals fed high oil corn silage appeared to absorb ether extract less readily than those fed control corn silage (82.2 percent vs. 85.9 percent). Although diets including high oil corn or corn silage had decreased milk production efficiency, cows are given high oil corn recovered their body weight more quickly, indicating a more favorable energy status for milk production and body tissue deposition. In contrast, according to Drackley et al. (1996), high oil corn silage has a greater rate of fatty acid digestibility than standard corn silage (77.2 percent vs. 73.2 percent). The causes of the differences between this research are still a mystery.

### Conclusion

Researchers should focus on developing maize varieties suitable for silage production to ensure the availability of adequate genetic materials for long-term animal feed utilization.

### Conflict of interest

Authors declared no conflict of interest.

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