ТЕХНОЛОГІЯ ВИРОБНИЦТВА І ПЕРЕРОБКИ ПРОДУКЦІЇ ТВАРИННИЦТВА

UDK 633.15:631.3:636.085

Corn Silage, Managing the Manageable

Mahanna B.[1], Zahorodnii A.[2], Chernyuk S.[3]

[1] *Ph.D., Dipl. ACAN, Pioneer Global Nutritional Sciences, Johnston, Iowa*

[2] *Corteva Agriscience Ukraine*

[3] *Bila Tserkva national agrarian university*

E-mail: silverest07@ukr.net

Маханна Б., Загородній А.П., Чернюк С.В. Кукурудзяний силос, управління керованими факторами. Збірник наукових праць «Технологія виробництва і переробки продукції тваринництва», 2025. № 1. С. 72–80.

Mahanna B., Zahorodnii A., Chernyuk S. Corn Silage, Managing the Manageable. «Animal Husbandry Products Production and Processing», 2025. № 1. PP. 72–80.

Рукопис отримано: 30.01.2025 р.
Прийнято: 13.02.2025 р.
Затверджено до друку: 22.05.2025 р.

doi: 10.33245/2310-9289-2025-194-1-72-80

This paper reviews key factors in corn silage production that affect quality, yield, starch content, and fiber digestibility–elements that directly influence feed costs and animal performance. Notably, improved management practices have the potential to enhance profits by as much as $30 per ton of silage. In the United States, over six million acres of corn silage are grown annually with an average yield of approximately 20 tons per acre at 30 % dry matter (DM), while premier production regions such as Washington, Idaho, and Oregon routinely achieve statewide yields near 30 tons per acre and even 35–45 tons per acre in optimal conditions. Advances in agronomic practices have also allowed plant populations to increase from around 24,000 plants per acre in the early 1980s to over 40,000 plants per acre today, driving further yield improvements.

The research highlights that kernel processing is a critical tool, demonstrated by a study where on-board processing increased 24-hour starch digestibility from 73,4 % to 85,8 %. Additionally, adjusting chop height–from 7 inches to 20 inches–improved fiber digestibility by 6,7 % and increased starch concentration by 6 %, although every 4–6 inches of increased chop height was associated with a reduction in yield of roughly 1 ton per acre (at 30 % DM). The paper further discusses the influence of hybrid selection (including the use of brown midrib [BMR] genetics), harvest maturity, and environmental factors on silage composition. It also emphasizes proper harvest and storage management practices, such as maintaining a moisture content of 63–68 % at harvest and achieving a silage density of over 16 lbs/ft^3, to minimize dry matter losses during fermentation and feed-out.

Key words: corn silage, inoculants, starch digestibility, forage, milk strains, milk acid bacteria, *Enterococcus Faecium*, *Lactobacillus Plantarum*, *Lactobacillus Buchneri*, fiber digestibility, storage management, silage producing.

Problem statement and analysis of recent research. Why should we carefully review management tools when producing corn silage? The management considerations discussed in this paper have significant impact on feed costs and animal performance. In a paper presented at this conference [13] stated improvements in silage management could improve profits by as much as $30,00 per ton. While many silage producers have implemented better management practices, most silage growers could likely find additional management improvements to increase profits [2].

Each year, over six million acres of corn silage are grown in the United States. Corn silage is often referred to as “The King of Forages”, even though more than 13 million acres of alfalfa are produced in the country. However, about 4,5 million acres of alfalfa are harvested as haylage or green chop. Corn silage is the forage that occupies the most acreage and produces the highest volume of fermented livestock feed [15]. The average yield for corn silage in the United States is about 20 tons per acre at 30 percent dry matter. The Northwest states of Washington, Idaho and Oregon are all in the top five states for corn silage yield producing closer to 30 tons per acre state wide. Areas in the three northwest states consistency produce 35–45 tons of corn silage per acre. Two factors allowing higher yields are:

1) Irrigated acres, usually with center pivot systems, which allow precise feeding of nutrients to the crop during the growing season, and

2) High-intensity sunlight with few cloudy days during the growing season.

These two factors allow higher plant density to be utilized allowing silage hybrids to grow taller and produce optimum grain and stover yields compared to growing the same hybrids in other areas of the country [10, 11].

Reasons why corn silage is the preferred fermented forage for many producers include [21]:

1) It produces high yields compared to other forage options.

2) It is a very palatable feed for livestock.

3) It contains adequate non-structural carbohydrates to ensure good fermentation.

4) If managed properly, it produces very high-energy forage.

5) It results in a consistent yearlong forage option.

6) It can be harvested directly, not requiring dry down prior to storage.

In recent years, there has been a trend among dairy producers in specific cropping programs to feed higher amounts of corn silage in their diets. This is generally done to reduce feed costs. The shift is possible because corn silage genetics have improved, resulting in higher crop yields and greater energy density [6]. Over the past two decades, silage producers have implemented significantly better management practices. A recent study published in the Journal of Dairy Science reported that between 1982 and 2017, alfalfa hay, hay crop silage, and green chop decreased by 32 %, while corn silage acreage remained constant, and corn silage production increased by 33 % [17].

This paper aims to review corn silage production factors that impact the quality, yield, starch content, starch digestibility, and fiber digestibility which are under the control of the silage producer.

Production practices where the producer has control include hybrid selection, agronomic practices (e.g. planting date, population, fertility, irrigation, fungicide use), harvest timing, chop height, degree of kernel processing, storage/feed-out management, and nutritional analysis. Factors where the silage producer lacks control will also be discussed and include growing environment (e.g. rainfall, heat units), disease/pest pressure, and within-field variability [28].

Material and methods of research. This study evaluated the key management practices influencing the quality and yield of corn silage production. The research involved both field experiments and a review of existing literature related to agronomic practices, hybrid selection, and post-harvest management techniques. Field trials were established in selected corn-growing regions with varying environmental conditions to assess differences in yield, starch content, fiber digestibility, and overall silage quality.

The field experiments were conducted in multiple locations across the Northwestern United States, including Washington, Idaho, and Oregon, which are known for high corn silage yields. The study sites were selected based on their differences in irrigation systems, climatic conditions, and soil fertility. Each site represented a different combination of soil type, temperature, and precipitation levels to analyze the impact of growing conditions on silage production.

Several commercial corn hybrids were selected for evaluation, focusing on their agronomic traits, starch yield, and fiber digestibility. The selection criteria included maturity groups, drought tolerance, plant height, and kernel characteristics. Special attention was given to hybrids with Brown Midrib (BMR) genetics and conventional hybrids to compare their fiber digestibility and overall feed value.

Harvest timing was determined based on kernel maturity stages, with samples collected at 1/3, 2/3, and full milk line maturity to assess starch accumulation and dry matter yield. Corn silage was chopped at varying heights (7 to 20 inches) to evaluate the effects on fiber digestibility and starch concentration. Kernel processing scores were recorded for each sample to determine the effectiveness of mechanical processing.

Silage samples were analyzed for dry matter (DM), neutral detergent fiber digestibility (NDFD), starch content, and undigested neutral detergent fiber (uNDF).

Research results and discussion. When one of the authors of this article began his career, little research had been conducted to explore the question: Are all hybrids equal in terms of nutrient quality or "bite for bite value"? Early work by Pioneer Hi-Bred Int. in conjunction with the University of Idaho produced a paper [11] showing significant differences between six hybrids grown at two locations, Idaho and California, harvested at three maturity points. Hunt et al., 1993 reported University of Idaho research showing significant differences in animal growth performance between two commercially available hybrids commonly used in the Northwest at that time [10].

Important genetic traits, that deserve selection consideration, include agronomic traits, which confer improved dry matter and energy yield. Key traits include heat unit accumulation to silking and maturity, stress emergence, drought tolerance, and disease resistance. Some of these traits are delivered via genetic modifications and some by natural genetic adaptability/resistance. Once proper maturity and agronomic traits are decided, the next trait that should be considered is dry matter (DM) yield. In silage, this is primarily determined by the amount of starch and height of the plant (biomass). Starch content is highly correlated with DM yield typically contributing 45–50 % of silage dry matter yield. The corn kernels in silage, because of starch and oil content, are responsible for 60–70 % of the plant's energy contribution followed by 25 % from cell walls (NDF) and 10 % from cell contents [4].

A trait of minimal importance during hybrid selection is fiber digestibility. The growing environment (e.g. amount of moisture the plant receives during vegetative growth stages) is three times more influential on fiber digestibility than hybrid genetics [30]. While fiber digestibility is highly heritable, variation among elite silage genetics is minimal. Despite years of academic research to improve fiber digestibility, limited success has been achieved. The more recent exception to this has been the discovery and plant breeding efforts using brown midrib (BMR) genetic hybrids which produce corn plants with reduced lignin content in the stalk and leaves which improves fiber digestibility.

Concurrent with continuous 1–2 bushel/acre/year yield increase in North American corn yield is parallel tonnage increases in silage yield. This is not surprising given the relationship between starch content and silage yield. Much of the increase in grain and silage yield in the last 15 years can be attributed to plant breeding efforts producing hybrids, which tolerate the stress of high plant populations. In the Northwest, plant populations in the early 1980s were about 24,000 plants per acre. Today, we see most silage growers successfully planting and harvesting high-quality corn silage at plant populations of greater than 40,000 plants per acre [8].

A summary of University of Wisconsin silage hybrid plot results from 1995–2007 showed that the top three drivers of silage DM yield were:

1) Kernel maturity at harvest.
2) Hybrid genetics, and.
3) Planting date.

If you ask animal nutritionists what amount of starch, they prefer to have in the corn silage they feed, they almost always say, "As much as I can get". If pressed for a more precise answer, it usually falls closer to 30 % or higher on a dry matter basis. Corn kernels are about 70 % starch so grain content in silage producing 30 % starch would be 42 % on a dry matter basis (30 / 7). Corn plants producing 35 % starch would contain 50 % grain on a dry basis (50 X 70). Kernel maturity at the time corn silage is harvested is a significant driver of silage DM yields. Harvesting when kernels are immature (e.g. 1/3rd milk/starch line) will result in lower DM yield compared to harvesting at later kernel maturities (e.g. ¾ milk/starch line). Research conducted by Pioneer Hi-Bred in conjunction with the University of Illinois reported kernels could increase in starch content by over 25 % from ½ milk/starch line to black layer maturity in the kernels [30]. Kezar, 2013 reported a starch increase of 22 % between 1/3 and 2/3 milk/starch line. Delaying harvest to allow kernels to more fully mature demands a plant, which maintains good late-season plant health. This is a constant goal of all corn breeders and is aided by fungicide use in those geographies prone to foliar diseases [16, 28].

Corn silage DM content of 30–32 % is often referenced as being the goal for silage stored in bunkers or drive-over piles. This traditional DM recommendation comes from two perspectives:

1) Ensuring enough moisture for adequate silage compaction, and.

2) Fearing delaying harvest will result in significant reductions in plant fiber digestibility.

However, technologies have advanced in both silage making and plant genetics allowing for targeting ¾ milk line (approximately 36–38 % whole plant DM) to capture more starch. A review by Pioneer of all published corn silage literature in the Journal of Animal Science and the Journal of Dairy Science found that in healthy plants, fiber digestibility declined only minimally (2–3 % points) from 1/3 milk line (~30–32 % DM) to ¾ milk line (36–38 % DM). Corn is a "modified grass", but generations of corn breeding efforts for improved late-season plant health have allowed corn plants to retain high fiber digestibility, even in later maturities, while the kernel is still depositing valuable starch.

Fiber digestibility is not recommended as an important silage hybrid selection trait, because recent research suggests that the growing environment the plant endures during the vegetative growth period is the primary determinant of whole plant fiber digestibility. Corn silage plots utilizing several hybrids grown in Michigan in a drought year followed by a normal precipitation year resulted in lower starch levels in the drought silage but a 20 % improvement in neutral detergent fiber digestibility (NDFD) along with lower lignin levels in the silage. By the tassel stage, plant stover growth has terminated. Under wetter than normal growing conditions during vegetative growth stages, plants have longer internodes and grow taller. Differences in lignin content are difficult to document but fiber digestibility as influenced by lignin cross-linkages to hemicellulose, is typically lower for these plants. This may be why corn silage grown under irrigation appears to have lower fiber digestibility than the same hybrids grown in dryland conditions. In drier than normal vegetative growth environments, internode length is shorter, and plants tend to display higher fiber digestibility [32]. While total DM yield may be lower due to a shorter plant, fiber digestibility is typically higher, and being a shorter plant, starch is further concentrated. Research at Cornell University suggests the moisture the plant receives is seven times more influential on fiber digestibility than the heat units the plant receives [29]. The growing environment post-tassel appears to have minimal effect on fiber digestibility but does exert a significant influence on ear development and silage starch content. It should be noted that, unlike starch digestibility, fiber digestibility would not change during fermented storage so the fiber digestibility at harvest will be the fiber digestibility for the entire feed-out [31].

While knowledge is abundant about how to irrigate corn for grain yield, there is a dearth of information about how to irrigate the corn plant for silage production. Granted, starch will drive yield and overall energy density, but what are of interest are vegetative stage irrigation regimes that might manipulate fiber digestibility. Agronomists are wary of reducing irrigation schedules with pivot irrigation given concerns about not being able to keep up with plant evapotranspiration needs. Producers using flood irrigation may be in a better situation to experiment with reducing irrigation during vegetative stages to increase fiber digestibility without reducing plant growth. These growers should then fully irrigate as the plant enters the reproductive stage to ensure high starch content [27]. This is an area in need of further research.

Another issue related to the growing environment is within-field variability. Corn silage fields do not possess the same soil profile, water-holding capacity, or fertility. There is unpublished data to suggest that field variability in fiber digestibility and starch content may be greater than the differences between hybrids. One of the ways for silage feeders to manage this variability is to "face" the entire bunker or pile and in this way, average out the variation that might exist in any one area of the bunker/pile.

While growers have limited control over the growing environment, they do have control over chop height as a method to manipulate fiber digestibility. A review of eleven published studies on high-chopping corn silage by researchers at Pennsylvania State University reports increasing chop height from 7 inches to 20 inches increased fiber digestibility by 6,7 % and concentrated starch by 6 % [32]. Research by Pioneer and the University of Idaho demonstrated that all hybrids do not respond to high chopping in the same way. There appears to be a strong genetic by-environment (G x E) interaction with high chopping. To predict what effect high-chopping might have on increasing fiber digestibility, it is necessary to chop plants at different heights and analyze them in order to see if increasing chop height is worth the loss in stover and effective fiber. Unpublished research by Pioneer indicates for every 4–6 inches of increased chop height, the average hybrid will be reduced in yield by about 1 ton (30 % DM) per acre.

One of the newest laboratory analytical measurements relating to forage fiber is undigested NDF (uNDF). The research is clear that NDF does not degrade in the rumen at a constant rate, but rather as three pools: fast, slow, and undigested NDF. Large slow and uNDF pools in the forage and diet cause greater rumination, and slower eating speeds but problematically, lower intake potential due to increased rumen fill. One of the advantages of corn silage as the primary forage ingredient is that it typically has the lowest uNDF of all forages and it is further diluted in the diet in corn silages possessing high starch content. Consulting nutritionists are starting to observe depressed DM intake and lower milk production when total uNDF240 intake/cow/day for forages (over 4mm in length) in the entire diet exceeds about 5,0–5,5 lbs (or about 0,35–0,40 % of body weight). uNDF is only appropriate for cows where DM intake is limited by rumen fill, which is typical of intakes during peak milk production. Exceeding these amounts may lower peak production, especially if cow persistency is high.

A discussion about fiber digestibility would be remiss without delving into the role of brown mid-rib (BMR) hybrids. The main nutritional advantage of BMR silage is higher fiber digestibility due to less lignin, which interferes with rumen bacteria degradation of cell walls [34]. Higher fiber digestibility impacts:

1) The amount of forage in the diet (typically more forage equates to a cheaper ration).

2) The energy obtained from the corn silage, and.

3) The amount of forage cows can consume per day.

BMR fiber appears to be more fragile and exits the rumen faster than fiber from non-BMR hybrids. While DM yields of BMR hybrids are behind non-BMR silage hybrids by 5–10 %, some silage growers and their nutritionists are adopting agronomically improved BMR hybrids and, are willing to sacrifice yield to obtain higher fiber digestibility, which then drives higher dry matter intake. This is not that different from alfalfa growers harvesting at late-bud stage rather than full-flower, sacrificing alfalfa yield to obtain forage with higher fiber digestibility and intake potential.

Silage producers who are considering BMR hybrids need to have realistic expectations including:

1) Potential for more agronomic risk, standability.

2) Reduced yields of 5–10 % depending upon growing conditions).

3) Extra inventory needed due to reduced yields and higher feed intake of BMR silage, and.

4) Possible need to segregate this silage given the biggest benefit will be in diets fed to transition and early lactation cows.

It should also be noted that high chopping while increasing fiber digestibility on lab reports, will not drive DM intakes as much as the fragile fiber found in BMR hybrids.

Starch Digestibility.

It is commonly understood today that starch digestibility in corn silage utilizes relatively immature kernels (pre-black layer) and is a moving target. Corn silage ruminal starch digestibility of new-crop silage is about 70 % and drifts upwards (about 2 % units/month) for about 6 months before plateauing [16, 22]. The University of Florida along with colleagues from Brazil have recently published a paper in the Journal of Dairy Science suggesting that bacterial activity, not acid load, appears to be the cause of solubilizing of the proteinaceous matrix surrounding corn starch granules that results in increased ruminal starch digestion over time in fermented storage.

The greatest silage improvement tool to evolve during the careers of the two authors of this paper was the development and adaption of on-board kernel processors, which proved to be a significant tool to improve starch digestibility [9]. One early study comparing two different hybrids showed kernel processing increased in situ 24-hour starch digestion from 73,4 % to 85,8 % [1]. Today, very little corn silage is harvested in the United States which has not been kernel processed at the time of harvest. The main factors influencing kernel damage at the chopper are:

1) Chop length (shorter chop length typically results in better kernel processing if effective fiber from corn silage is not an issue);

2) Synchronized timing between header and feed rolls;

3) Roller mill wear;

4) Roller mill gap setting (typically 1–3 mm);

5) Roller mill differential speed (many at 50 % or greater).

Many laboratories offer kernel-processing scores, which are helpful to nutritionists balancing diets. There is, however, a need for protocols to ensure corn silage is being evaluated for processing at the time it is being harvested. Pioneer developed a field test employing a 32-oz (1 liter) cup where the goal is to have less than 2 whole or half kernels in that volume of silage. Fecal starch analysis can be a good post-harvest indicator of the degree of kernel damage.

In a 2015 Pioneer field study of the high-production strings in 32 Wisconsin dairies, only two of the dairies showed more than the goal of <3 % fecal starch and those two dairies had poor corn silage processing scores [22, 25].

There have been discussions about the value of soft-floury (low vitreous, low prolamin) endosperm in corn silage kernels [23]. There does not seem to be a significant variation in the amount of hard, vitreous starch or starch digestibility at the immature kernel maturity (pre-black layer) at normal corn silage harvest. Pioneer field studies from side x side trials (in the same field receiving the same environment) show no difference in 7-hour ruminal starch digestibility between advertised “floury-kernel” and normal hybrids at silage (or high-moisture corn) kernel maturities. Ohio State University researchers concluded vitreousness (hard starch) of corn grain in corn silage is more digestible in contrast to the vitreousness of dry corn grain where it should be ground more finely [5]. This is consistent with research from France showing the negative effects of flint corn (very high vitreousness) on total tract starch digestion could be eliminated by grinding dry corn to 550 microns.

Harvest and Storage.

We cannot have any discussion about corn silage quality and potential profits, without covering management objectives once the corn plant is ready to be harvested and stored. The paper presented at this conference a few years ago discussed the economic significance of reducing silage losses as much as possible [13]. It must be understood; that the losses in silage dry matter during fermentation, storage, and when silage is exposed to oxygen are not a straight percentage of the total biomass. Microbial losses associated with initial respiration during and following placement of corn silage in storage units and again when silage is later exposed to oxygen utilize highly digestible soluble carbohydrates, primarily sugars, and produce carbon dioxide, heat, and water [24]. Thus, we are losing highly digestible nutrients and gaining nothing of value in return. For this reason, one percentage of loss we can reduce (ex: 18 % to 17 %) is as valuable as increasing corn silage starch by one percentage (ex: 31 % to 32 %) [19]. This paper will not discuss these specific management tools in detail, but it is important to understand that these tools are extremely important and should receive significant management consideration to reduce dry matter loss in corn silage. These tools include:

1) Correct moisture content of the corn silage at harvest (63–68 %);

2) Adequate packing of silage as it arrives at the storage unit to increase density in the silage (>16 lbs/ft3);

3) Correct cover placed on silage (ex; use of oxygen-barrier film);

4) Use of an effective combination inoculant, containing Lactobacillus buchneri strains, which inhibit silage loss on re-exposure to oxygen [3, 7, 14, 20, 26, 33]. Combination inoculants will reduce the loss on both ends of phases of fermentation, Figure 1;

5) Proper management of silage as it is being removed from the storage unit.

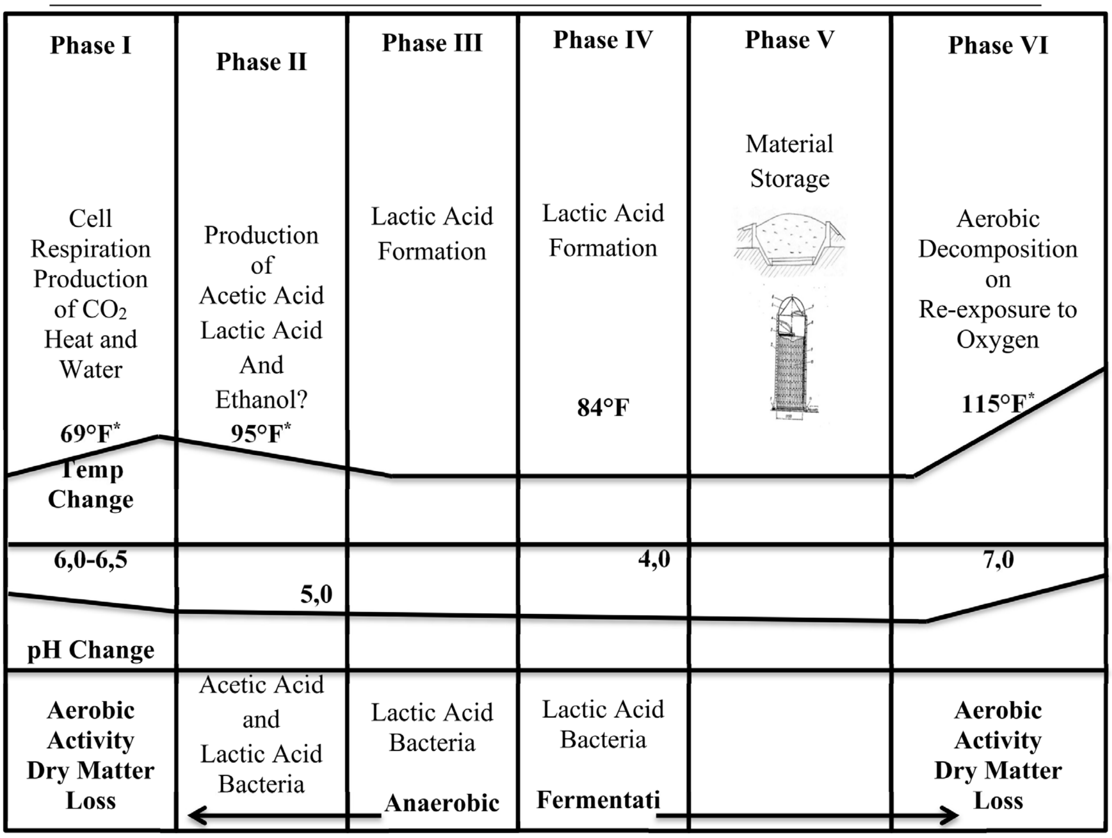

Fig. 1. **Phases of Silage Fermentation.**

Conclusions. Effective management of corn silage production plays a crucial role in optimizing feed costs and improving animal performance. Research has demonstrated that even small enhancements in silage management can significantly impact profitability. While advancements in genetics, agronomic practices, and harvesting techniques have led to increased yields and improved starch content, further opportunities remain for producers to refine their methods and maximize efficiency.

The study underscores the importance of selecting hybrids with superior agronomic traits, including drought tolerance, disease resistance, and optimal starch yield. Additionally, factors such as planting density, irrigation, and harvest timing directly influence silage digestibility and energy content. The ongoing evolution of silage hybrid genetics, including the introduction of brown midrib (BMR) hybrids, has contributed to increased fiber digestibility, albeit at the cost of reduced dry matter yields.

Another key finding is the role of environmental conditions in determining fiber digestibility. Moisture levels during the vegetative growth stage significantly impact fiber composition, with drier conditions generally promoting higher digestibility. Producers must also consider chop height as a management tool to manipulate fiber digestibility and starch concentration.

Starch digestibility remains a critical component in silage quality. Research indicates that kernel processing at harvest, along with appropriate chop length and roller mill settings, greatly enhances starch availability for digestion. Improvements in storage fermentation further increase starch digestibility over time, making proper silage management an essential aspect of dairy and livestock nutrition.

Ultimately, continued research and advancements in corn silage production practices will contribute to greater efficiency and sustainability in livestock feeding systems. By carefully evaluating hybrid selection, agronomic strategies, and harvest practices, silage producers can optimize both yield and nutritional value, ensuring long-term profitability and productivity.

REFERENCES

1. Andrae, J.G., Hunt, C.W., Pritchard, G.T., Harrison, J.H., Kezar, W., Mahanna, W. (2001). Effect of hybrid, maturity, and mechanical processing of corn silage on intake and digestibility by beef cattle. *Journal of Animal Science*, 79 (9), pp. 2268–2275. DOI:10.2527/2001.7992268x.

2. Da Silva, T.C., Smith, M.L., Barnard, A.M. (2015). The effect of a chemical additive on the fermentation and aerobic stability of high-moisture corn. Journal of Dairy Science, 98, pp. 8904–8912. DOI:10.3168/jds.2015-9640

3. Ferraretto, L.F., Fredin, S.M., Shaver, R.D. (2015). Influence of ensiling, exogenous protease addition, and bacterial inoculation on fermentation profile, nitrogen fractions, and ruminal *in vitro* starch digestibility in rehydrated and high-moisture corn. Journal of Dairy Science, 98, pp. 7318–7327. DOI:10.3168/jds.2015-9891

4. Ferraretto, L.F., Taysom, K., Taysom, D. (2014). Relationships between dry matter content, ensiling, ammonia-nitrogen, and ruminal *in vitro* starch digestibility in high-moisture corn samples. Journal of Dairy Science, 97, pp. 3221–3227. DOI:10.3168/jds.2013-7680

5. Firkins, J.L. (2006). Starch digestibility of corn – silage and grain, in proceedings of the Tri-State nutrition conference, Ft Wayne, Indiana. pp. 107–117. Available at: (Accessed: 25 April 2006).

6. Gallo, A., Fancello, F., Ghilardelli, F., Zara, S., Spanghero, M. (2022). Effects of several commercial or pure lactic acid bacteria inoculants on fermentation and mycotoxin levels in high-moisture corn silage. Animal Feed Science and Technology, 286, 115256 p. DOI:10.1016/j.anifeedsci. 2022.115256.

7. Guo, X., Guo, W., Yang, M., Sun, Y., Wang, Y., Yan, Y., Zhu, B. (2022). Effect of *Bacillus* additives on fermentation quality and bacterial community during the ensiling process of whole-plant corn silage. Processes, 10 (5), 978 p. DOI:10.3390/pr10050978

8. Heguy, J.M., Meyer, D., Silva-del-Río, N. (2016). A survey of silage management practices on California dairies. Journal of Dairy Science, 99 (3), pp. 1649–1654. DOI:10.3168/jds.2015-10058.

9. Hoffman, P.C., Esser, N.M., Shaver, R.D. (2011). Influence of ensiling time and inoculation on alteration of the starch-protein matrix in high-moisture corn. Journal of Dairy Science, 94, pp. 2465–2474. DOI:10.3168/jds.2010-3562

10. Hunt, C.W., Kezar, W., Hinman, D.D. (1993). Effects of hybrid and ensiling with and without a microbial inoculant on the nutritional characteristics of whole-plant corn. Journal of Animal Science, 71, pp. 38–43. DOI:10.2527/1993.71138x

11. Hunt, C.W., Kezar, W., Vinande, R. (1992). Yield, chemical composition, and ruminal fermentability of corn whole plant, ear, and stover as affected by hybrid. Journal of Production Agriculture, 5 (2), pp. 286–290. DOI:10.2134/jpa1992.0286.

12. Junges, D., Morais, G., Spoto, M.H.F., Santos, P.S., Adesogan, A.T., Nussio, L.G., Daniel, J.L.P. (2017). Short communication: Influence of various proteolytic sources during fermentation of reconstituted corn grain silages. Journal of Dairy Science, 100, pp. 9048–9051. DOI:10.3168/jds.2017-12943

13. Kennington, L.R., Hunt, C.W., Szasz, J.I., Grove, A.V., Kezar, W. (2005). Effect of cutting height and genetics on composition, intake, and digestibility of corn silage by beef heifers. Journal of Animal Science, 83 (6), pp. 1445–1454. DOI:10.2527/2005.8361445x

14. Kung, Jr. L., Schmidt, R.J., Ebling, T.E. (2007). The effect of *Lactobacillus buchneri* 40788 on the fermentation and aerobic stability of ground and whole high-moisture corn. Journal of Dairy Science, 90, pp. 2309–2314. DOI:10.3168/jds.2006-713.

15. Lynch, J.P., Baah, J., Beauchemin, K.A. (2015). Conservation, fiber digestibility, and nutritive value of corn harvested at 2 cutting heights and ensiled with fibrolytic enzymes, either alone or with a ferulic acid esterase-producing inoculant. Journal of Dairy Science, 98 (2), pp. 1214–1224. DOI:10.3168/jds.2014-8768

16. Mahanna, B. (2019). Starch digestibility analyses on the rise. Available at: (Accessed: 24 April 2019).

17. Martin, N.P., Russelle, M.P., Powell, J.M., Sniffen, C.W., Smith, S.I., Tricarico, J.M., Grant, R.J. (2017). Invited review: Sustainable forage and crop production for the US dairy industry. Journal of Dairy Science, 100, pp. 9479–9494. DOI:10.3168/jds.2017-13080

18. Morais, G., Daniel, J.L.P., Kleinshmitt, C. (2017). Additives for grain silages: A review. Slovak Journal of Animal Science, 50, pp. 42–54.

19. Muck, R.E., Nadeau, E.M.G., McAllister, T.A., Contreras-Govea, F.E., Santos, M.C., Kung, L.Jr. (2018). Silage review: Recent advances and future uses of silage additives. Journal of Dairy Science, 101, pp. 3980–4000. DOI:10.3168/jds.2017-13839

20. Naiara, C.S., Nascimento, C.F., Campos, V.M.A., Alves, M.A.P., Resende, F.D., Daniel, J.L.P., Siqueira, G.R. (2019). Influence of storage length and inoculation with *Lactobacillus buchneri* on the fermentation, aerobic stability, and ruminal degradability of high-moisture corn and rehydrated corn grain silage. Animal Feed Science and Technology, 251, pp. 124–133. DOI:10.1016/j.anifeedsci. 2019.03.003

21. Ogunade, I.M., Martinez-Tuppia, C., Queiroz, O.C.M., Jiang, Y., Drouin, P., Wu, F., Vyas, D., Adesogan, A.T. (2018). Silage review: Mycotoxins in silage: Occurrence, effects, prevention, and mitigation. Journal of Dairy Science, 101 (5), pp. 4034–4059. DOI:10.3168/jds.2017-13788

22. Powel-Smith, B., Nuzback, L., Mahanna, B., Owens, F. (2015). Starch and NDF digestibility in high producing cows: a field study. Journal of Dairy Science, 98 (Suppl. 2), Abstract T467. Available at: https://shaverlab.dysci.wisc.edu/wp-content/uploads/sites/204/2016/05/v3-shaver-penn-state-nutrition-conference-2015-starch-by-NDF-interactions.pdf

23. Raffrenato, E., Fievisohn, R., Cotanc, K.W., Grant, R.J., Chase, L.E., Van Amburgh, M.E. (2017). Effect of lignin linkages with other plant cell wall components on in vitro and *in vivo* neutral detergent fiber digestibility and rate of digestion of grass forages. Journal of Dairy Science, 100 (10), pp. 8119–8131. DOI:10.3168/jds.2016-12364

24. Revello-Chion, A., Borreani, G., Muck, R.E. (2012). Effects of various commercial inoculants on the fermentation, aerobic stability and nutritional quality of rolled and ground high moisture corn, in Proceedings of the XVI International Silage Conference. Hämeenlinna, Finland, 2–4 July. Hämeenlinna: MTT Agrifood Research Finland and University of Helsinki Press, pp. 280–281. Available at: https://hdl.handle.net/2318/123268

25. Saylor, B.A., Fernandes, T., Sultana, H., Gallo, A., Ferraretto, L.F. (2020). Influence of microbial inoculation and length of storage on fermentation profile, N fractions, and ruminal in situ starch disappearance of whole-plant corn silage. Animal Feed Science and Technology, September. Elsevier. DOI:10.1016/j.anifeedsci.2020.114557

26. Silva, N.C., Nascimento, C.F., Nascimento, F.A., de Resende, F.D., Daniel, J.L.P., Siqueira, G.R. (2018). Fermentation and aerobic stability of rehydrated corn grain silage treated with different doses of *Lactobacillus buchneri* or a combination of *Lactobacillus plantarum* and *Pediococcus acidilactici*. Journal of Dairy Science, 101, pp. 1–10. DOI:10.3168/jds.2017-13797

27. Shurcheh, A. (2024). Corn silage management: A review. Animal Science Department, University of Tehran, October. DOI:10.13140/RG.2.2.35833.28004 (Accessed: 28 October 2024).

28. Thomas, E., Mahanna, B. (2011). Corn silage: high-chop or traditional cut? Hoard's Dairyman. Available at: https://hoards.com/article-2943-corn-silage-high-chop-or-traditional-cut.html (Accessed: 10 August 2011).

29. VanAmburgh, M.E., Raffrenato, E., Ross, D.A. (2018). Development of an *in vitro* method to determine rumen undigested aNDFom for use in feed evaluation. Journal of Dairy Science, 101 (11), pp. 9888–9900. DOI:10.3168/jds.2018-15101

30. Weiss, W.P., Wyatt, D.J. (2006). Effect of corn silage hybrid and metabolizable protein supply on nitrogen metabolism of lactating dairy cows. Journal of Dairy Science, 89 (5), pp. 1644–1653. DOI:10.3168/jds.s0022-0302(06)72231-7

31. Weiss, K., Kroschewski, B., Auerbach, H. (2016). Effects of air exposure, temperature and additives on fermentation characteristics, yeast count, aerobic stability and volatile organic compounds in corn silage. Journal of Dairy Science, 99, pp. 1–17. DOI:10.3168/jds.2015-10323

32. Wu, Z., Roth, G. (2005). Considerations in managing cut height of corn silage. Extension publication DAS 03–72. Pennsylvania State University, College Park.

33. Guo, X., Xu, D., Li, F., Bai, J., Su, R. (2023). Current approaches on the roles of lactic acid bacteria in crop silage. Microbial Biotechnology, 16 (1), pp. 67–87. DOI:10.1111/1751-7915.14184

34. Yin, H., Zhao, M., Pan, G., Zhang, H., Yang, R., Sun, J., Yu, Z., Bai, C., Xue, Y. (2023). Effects of *Bacillus subtilis* or *Lentilactobacillus buchneri* on aerobic stability, and the microbial community in aerobic exposure of whole plant corn silage. Frontiers in Microbiology, 14, 1177031 p. DOI:10.3389/fmicb.2023.1177031

Кукурудзяний силос, управління керованими факторами

Маханна Б., Загородній А.П., Чернюк С.В.

У цій статті розглядаються ключові фактори виробництва кукурудзяного силосу, які впливають на якість, урожайність, вміст крохмалю та засвоюваність клітковини – елементи, що безпосередньо визначають вартість корму та продуктивність тварин. Зокрема, удосконалення методів управління може збільшити прибуток до 30 доларів на тонні силосу.

У Сполучених Штатах Америки щорічно вирощується понад шість мільйонів акрів кукурудзяного силосу, при цьому середня врожайність становить приблизно 20 тонн з акра за вмісту сухої речовини (СР) 30 %. Водночас у провідних регіонах виробництва, таких як Вашингтон, Айдахо та Орегон, врожайність на рівні штату часто досягає 30 тонн з акра і навіть 35–45 тонн за оптимальних умов. Покращення агрономічних заходів також дозволило збільшити густоту рослин із приблизно 24 000 на акр у 1980-х роках до понад 40 000 на акр сьогодні, що сприяє подальшому зростанню врожайності.

Дослідження підкреслює, що оброблення зерен є важливим інструментом: у межах одного експерименту використання силосу з обробленим зерном збільшило засвоюваність крохмалю упродовж 24-годин з 73,4 % до 85,8 %. Крім того, регулювання висоти зрізу – від 7 до 20 дюймів – покращило засвоюваність клітковини на 6,7 % і підвищило концентрацію крохмалю на 6 %, хоча кожні 4–6 дюймів збільшення висоти зрізу спричиняли зниження врожайності приблизно на 1 тонну з акра (при 30 % СР).

У статті також розглядається вплив вибору гібридів (зокрема, використання генетики бурої середньої жилки [BMR]), ступеня стиглості під час збирання та екологічних факторів на склад силосу. Окрему увагу приділено правильному управлінню збирання і зберігання, підтриманню вологості на рівні 63–68 % під час збирання та досягнення щільності силосу понад 16 фунтів / фут³, що дозволяє мінімізувати втрати сухої речовини під час ферментації та годівлі.

Ключові слова: кукурудзяний силос, інокулянти, перетравність крохмалю, корм, молочні штами, молочнокислі бактерії, *Enterococcus Faecium*, *Lactobacillus Plantarum*, *Lactobacillus Buchneri*, перетравність клітковини, зберігання, виробництво силосу.

ORCID iD:
Chernyuk S. https://orcid.org/0000-0003-0488-3624