The value of forage quality when feeding dairy cows

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Introduction

Dairy farms are looking for cost-effective feeding strategies to find opportunities to increase profitability. In this sense, feedstuffs correspond to about 40 to 60% of the total milk production cost. Thus, nutritional programs start with adequate forages programs. In the United States, corn silage is the most common ensiled crop used to feed dairy cows (Ferraretto et al., 2018). Corn silage provides a large amount of energy per kilo of dry matter than other traditional forages (Grant and Adesogan, 2018). Starch and fiber are the primary sources of energy for dairy cows fed corn silage-based diets and, therefore, understanding these components and how they change their digestibility is essential to improve milk production or reduce feed costs through enhanced feed efficiency.

It is important to highlight that corn silage has higher starch than other common cereal grains such as barley, oats, sorghum, and wheat compared (Table 1). The total energy available to the cow is usually a function of the dietary starch and its total tract starch digestibility. The starch digestibility changes according to the differences in cereals, as described in Table 1.

Table 1. Starch composition and digestibility of different cereal grains.

Cereal grain	Starch, % of DM	Ruminal Starch Digestibility, % of starch intake	Total Tract Starch Digestibility, % of starch intake
Barley	57.8	70.8 (46.1 - 91.0)	94.3 (76.1 - 99.5)
Corn	70.4	53.2 (9.7 - 80.2)	91.7 (69.5 - 99.4)
Oats	44.6	NA	NA
Sorghum	72.3	48.1 (NA)	83.5
Wheat	67.6	78.9 (59.1 - 95.1)	93.9 (86.3 - 99.1)

Starch

Dairy farmers are seeking silage-specific hybrids to address the high energy requirements of high-producing dairy cows. In this sense, starch is the most significant energy source in the corn silage, ranging from 26.8 to 36.8 % of DM in the last year (Cumberland lab; Figure 1). The high starch on current hybrids is linked to specialized selection programs in the last decades (Ferraretto and Shaver, 2015).

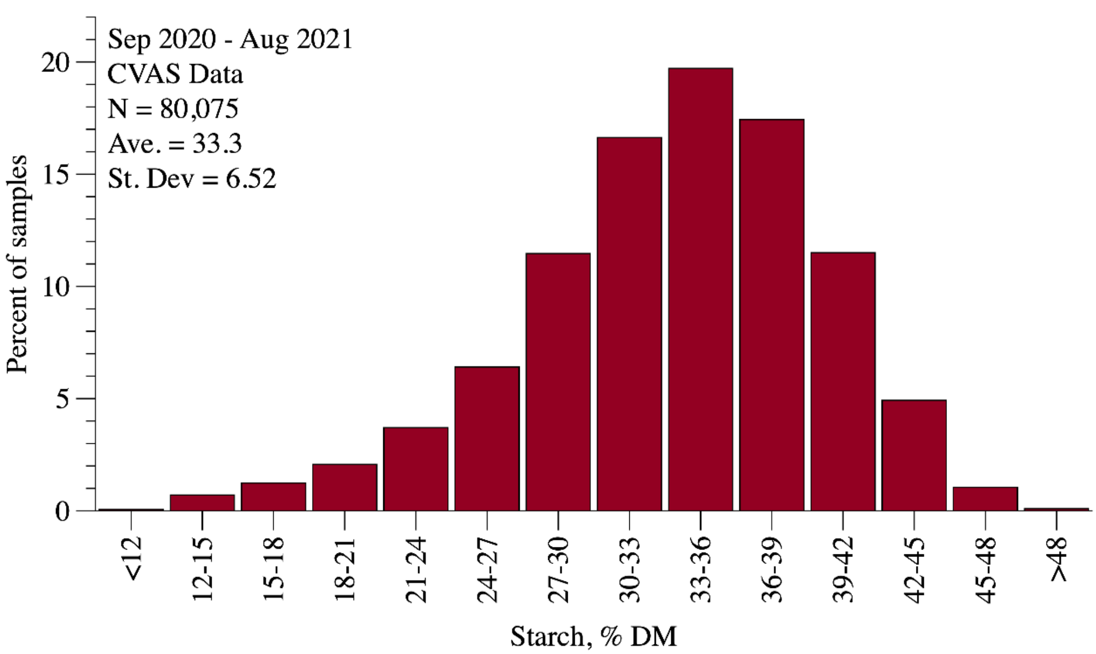

Figure 1. *Distribution of starch content (% DM) in corn silage samples analyzed in the Cumberland Valley analytical services.Source: Web page Hoard's Dairyman Sept. 13, 2021.*

The proportion of starch is an important consideration for choosing a hybrid that allows higher milk production per ton of DM. Furthermore, the starch digestibility will determine how much of that starch will be available for cow utilization. Thus, improvements in corn silage nutritional quality and components digestibility are reached by changes in kernel and stalk characteristics. For instance, hybrids with a greater proportion of floury endosperm are preferred over those with a greater proportion of vitreous endosperm. This is because floury endosperm has a greater starch digestibility than vitreous (Giuberti et al., 2014). The starch molecule in the vitreous endosperm is most involved with prolamins, which are hydrophobic proteins that confer resistance to digestion (Figure 2).

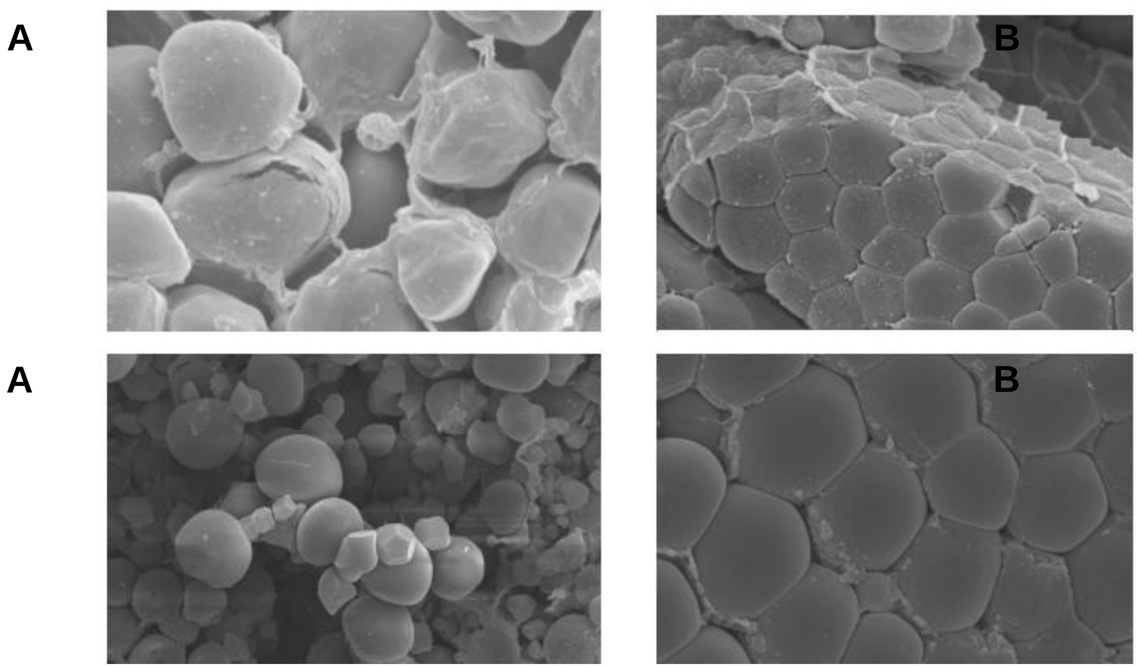

Figure 2. *Representation of floury (A) and vitreous (B) endosperm. Adapted from Davide et al., (2009). Thesis, UFLA repository. Federal University of Lavras, Lavras, MG, Brazil.*

The vitreousness is a laboratory parameter used to evaluate the percentage of vitreous to floury endosperm; hence, starch digestibility decreases as hybrid vitreousness increases. This relationship can be observed in the previous publication by Correa et al. (2002) (Figure 3).

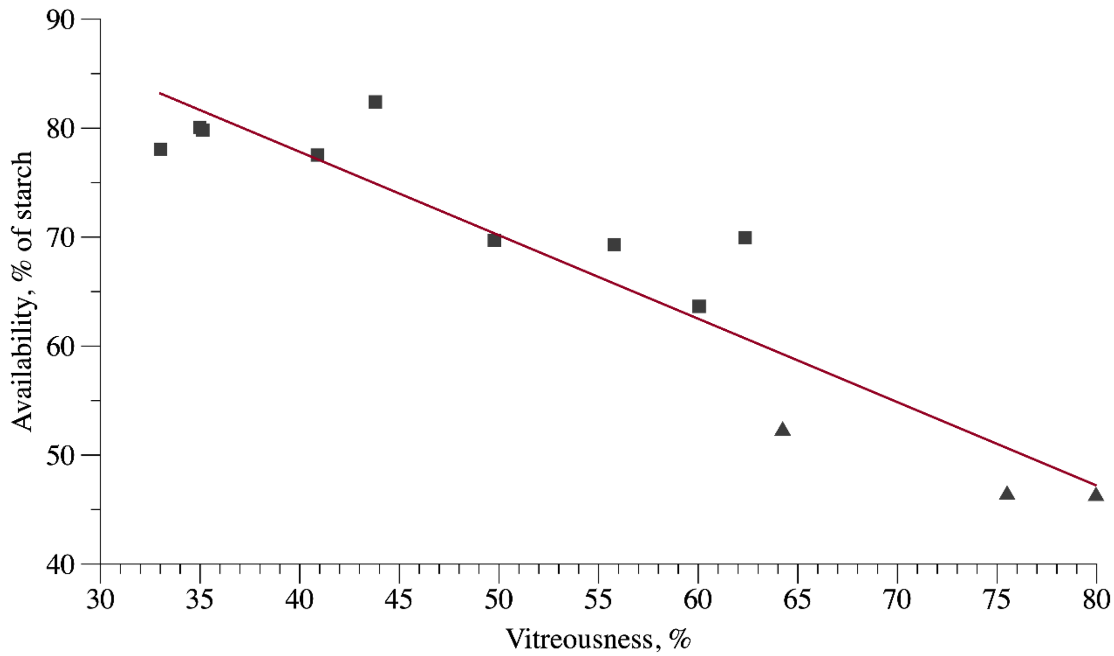

Figure 3. *Relationship between corn kernel vitreousness and ruminal in situ starch availability measured in three U.S. dent (■) and Brazilian flint (▲) hybrids harvested at the matured stage of maturity and two U.S. dent (■) hybrids harvested at half milk line, black layer, and maturity stages of maturity. Adapted from* Correa et al. (2002)

The combination of starch content and digestibility would affect the diet's energy density, affecting milk yield and/or feed efficiency. The starch digestibility of corn silage is influenced not only by the hybrid starch content and endosperm type but also by parameters defined at harvest. For instance, stage of maturity, particle size, and silage stocking time are recognized parameters used to manipulate starch digestibility (Ferraretto et al., 2013).

Maturity

The literature extensively documented that starch content increases with advances in the maturity stage (Ferraretto et al., 2014). Furthermore, a meta-analysis by Ferraretto et al. (2018) has demonstrated that not only starch increased with maturity but also kernel vitreousness. In that study, vitreousness increases as the kernel DM concentration increases (Figure 4), suggesting that high maturity at harvest would negatively impact starch digestibility.

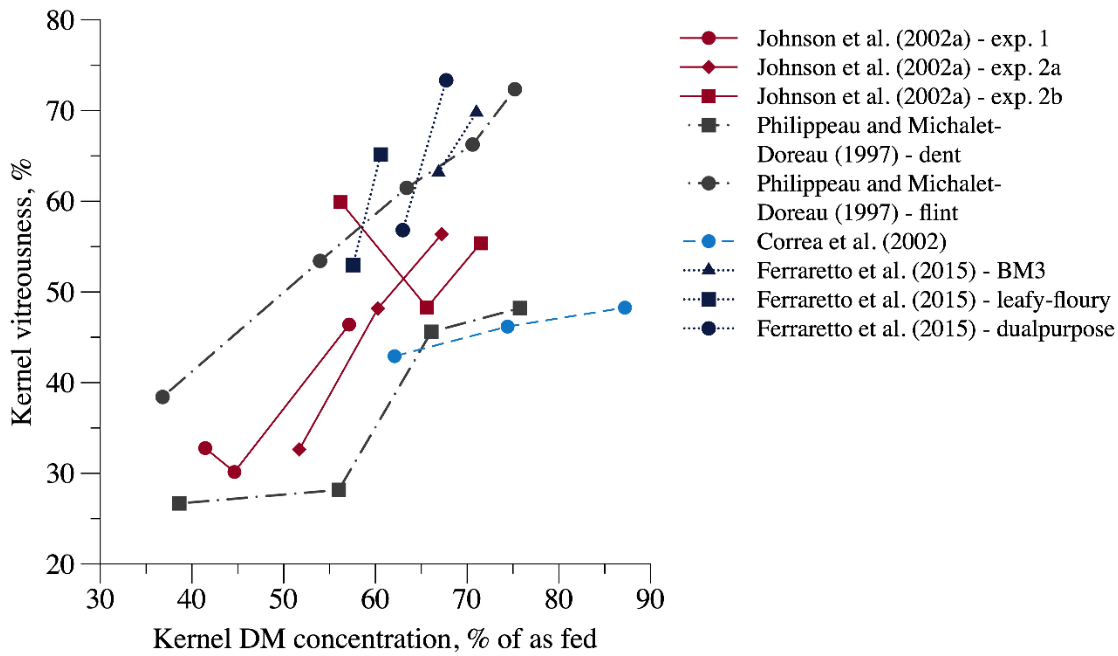

Figure 4. *Relationship between DM concentration and vitreousness in corn kernels. (adapted from Ferraretto et al., 2018)*

In addition, Ferraretto and Shaver (2012) observed an interaction between maturity and particle size on total-tract starch digestibility (TTSD). In this meta-analysis, the TTSD was increased by the mechanical process of corn silage diets containing 32 to 40% of DM. In the same study, TTSD was 5.9 and 2.8% units greater for silage processed using 1 to 3 mm roll gap settings than processed or unprocessed corn silage with 4 to 8 mm (Figure 5). Additionally, cows fed with processed corn silage produced 1.8 kg more than cows fed with unprocessed corn silage.

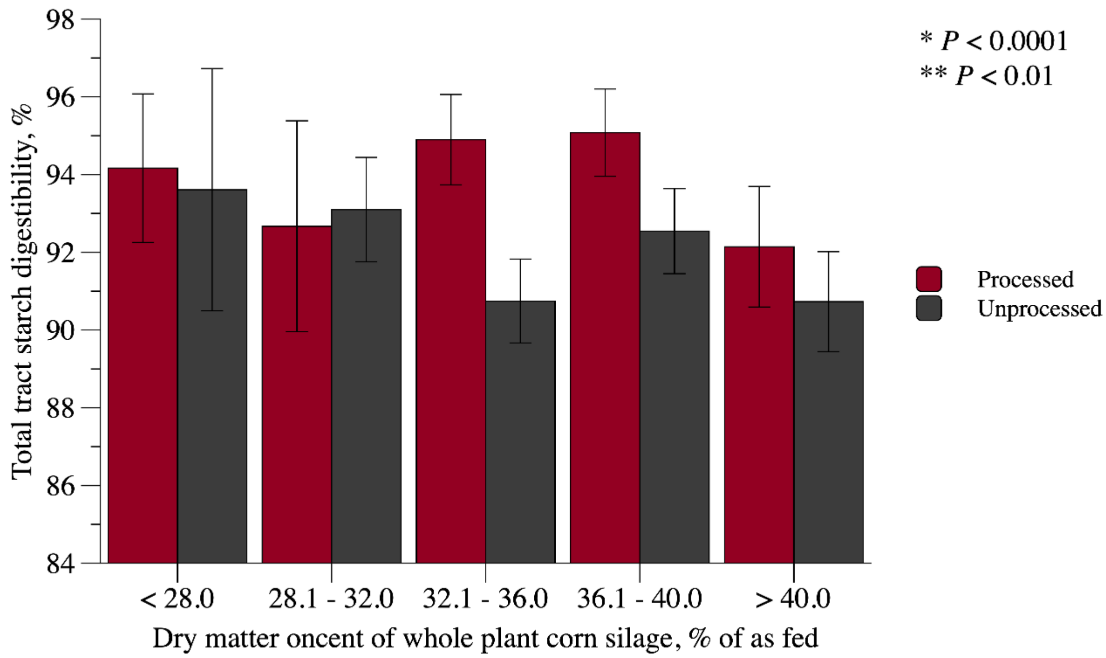

Figure 5. Effect of kernel processing and DM content of whole-plant corn silage on total-tract digestibility of dietary starch. Adapted from Ferraretto and Shaver, (2012)

Particle size

The Kernel processing score (KPS) is used to assess the level of kernel damage after harvest (Ferreira and Mertens, 2005). In this essay, the amount of starch passing through a 4.75 mm screen indicates a score for the kernel corn processing. Samples with more than 70% pass-through 4.75 mm indicate a good kernel process, which is associated with high starch digestibility. Meanwhile, samples retained above the 4.75 mm sieve suggest poor processing, linked to low starch digestibility. Dias Junior et al. (2016) observed an increase in *in situ* starch digestibility when unfermented kernels were split from two to third-six pieces. In that study, 60% of the kernels broken in one-fourth were retained at 4.75 mm sieve, suggesting that broken kernels in four parts were not enough to reach a good KPS score.

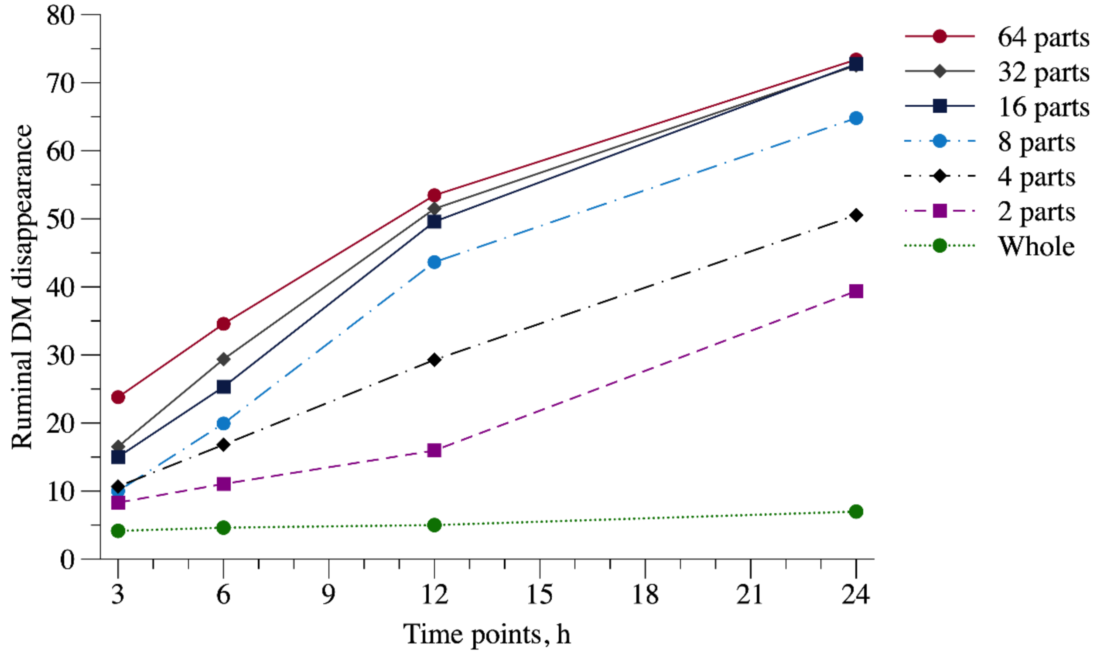

Figure 6. *Ruminal in situ DM disappearance (% of DM) of unfermented kernels. Adapted from Dias Junior et al., (2016)*

For practical formulation use, the NASEM (2021) has adopted TTSD digestible coefficients based on corn silage DM (Table 2). However, it's important to highlight that starch digestibility can be changed by mean particle size and length of fermentation. The effect of particle size on TTSD can be illustrated for dry ground corn, whereas TTSD increase as the particle size decrease (Table 2). Thus, nutritionists must consider adjustments in the digestibility coefficient to account for these missing values for corn silage. Rémond et al. (2004) and Weiss (2021) demonstrated how to modify starch digestibility for particle size in semi-flint or dent corn. In summary, TTSD in dent and semi-flint corn would decrease by 2.6% and 7.5% units per 1 mm increase in mean particle size, respectively.

Table 2. Total tract starch digestibility of dairy diets containing selected corn grain sources.

Feeds	Total-tract starch digestibility (% starch)
Corn silage, less than 30% DM	91
Corn silage, 32 o 37% DM	89
Corn silage, more than 40% DM	85
Dry ground corn, fine grind (< 1,250 um)	91
Dry ground corn, medium grind (1,500 to 3,250)	89
Dry ground corn, coarse grind (> 3,500 um)	77
High-moisture corn, fine grind (< 2,000 um)	96
High-moisture corn, coarse grind (> 2,000 um)	94
Steam flaked corn	94

Adapted from (Ferraretto, 2021a)

As mentioned, the storage length of corn silage is also associated with a change in starch digestibility. For instance, Kung et al. (2018) summarized the effects of prolonged silage storage on the in vitro TTSD. In that review, starch digestibility has widely increased from 0 to 90 days of fermentation, whereas starch digestibility slightly increases after 120 days of storage (Figure 7). Thus, research supports that new silage would be fed only between 90 to 120 days after ensilage to maximize starch digestibility.

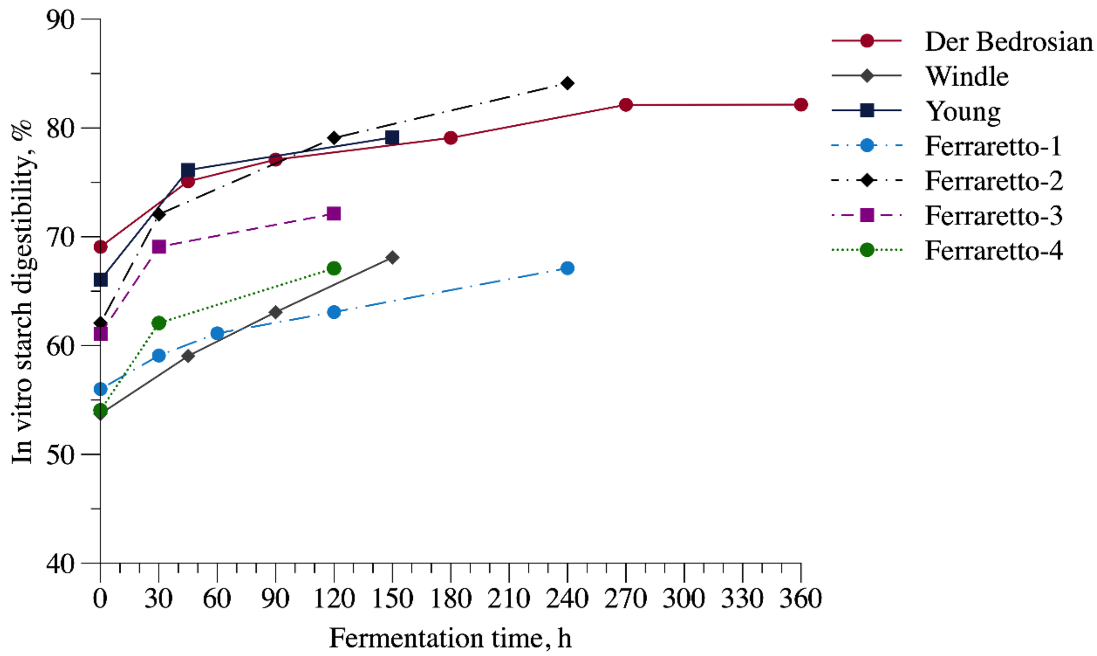

Figure 7. *Effect of days of ensiling on ruminal in vitro starch digestibility. Adapted from* Kung et al. (2018)

Thus, dairy producers have frequently increased the corn silage storage time aimed to increase starch digestibility. Therefore, commercial feed analysis laboratories have adopted assays to report the rate of disappearance data (%/h) calculated using *in vitro* or *in situ* starch digestibility. Predicted values of ruminal starch and whole tract starch digestibility can be calculated using these disappearance rates. Ferraretto (2021) has exemplified the effect of corn silage storage time on the TTSD, TDN, NEL, and milk per ton (Table 3).

Table 3. *Effect storage length on the nutritional parameters of corn silage.*

Storage length, days	0	30	120	240
ivSD, % of starch	58.9	65.2	71.2	75.6
Starch kd, %/h	14.5	17.5	21.8	23.4
Predicted total tract starch digestibility, % of starch	93.6	94.5	95.3	95.6
TDN, % of DM	72.4	72.7	73.0	73.1
NEL, Mcal/kg	1.62	1.63	1.64	1.64
Milk per ton, kg	1765	1776	1789	1793

In this simulation, the predictions of TTSD have increased as the corn silage storage time increased. In addition to the greater TTSD, the prediction of energy supply (NEL) and milk per ton have also increased with the advanced storage time. Therefore, inventory planning would be set up cautiously to guarantee corn silage availability. One important aspect is that ensiling time does not attenuate differences in starch digestibility caused by hybrids or maturity. Moreover, hybrid choices and harvest time decisions are also important for the total energy available from corn silage.

Stover fraction

Milk production is primarily limited by energy intake on high-production dairy cows. Especially cows in early lactation are normally consuming less than their demand. Limitations in intake are frequently caused by low forages NDF digestibility, which is associated with greater rumen fill and hence, reduced milk production. According to Oba and Allen (1999), each 1% improvement in NDF digestibility corresponds to increases in DMI and 4% fat-correct milk of 0.40 and 0.55 lb/d, respectively. The reduced digestibility of NDF is mainly caused by lignin, an indigestible component of the NDF fraction. Thus, an increase in forage digestibility is often accomplished by reducing lignin NDF concentration (Grant and Ferraretto, 2018).

Most corn stover fraction improvements are relative to fiber digestibility (Sattler et al., 2010). For instance, the brown midrib (BMR) mutant hybrid has a reduced proportion of lignin compared to conventional hybrids (Sattler et al., 2010). Therefore, it is frequently associated with a greater NDF digestibility compared to conventional hybrids. In a meta-analysis, Ferraretto and Shaver (2015) have demonstrated greater ruminal and total-tract NDF digestibility for BMR hybrids (Table 4). Cows fed BMR hybrids produced, on average, 1.5 and 1.0 kg/d more milk and

3.5% fat-corrected milk, respectively, compared to cows fed conventional hybrids. However, it is important to point out that not all BMR hybrids have greater yield than conventional hybrids (Adesogan et al., 2019). Thus, we should use caution when choosing a BMR hybrid and correctly manage the forage inventory.

Table 4. *Effect of corn silage hybrids with different stalk characteristics on adjusted least square means for ruminal and total NDF digestibility as well as for lactating performance by lactating cows*

Item	CONS[1]	BMR[2]	*P*-value
NDF ruminal digestibility, % of intake	37.0	40.8	0.16
NDF total-tract digestibility, % of intake	42.3	44.8	0.001
Milk yield, kg/d	37.2	38.7	0.001
3.5 FCM	37.6	38.6	0.01

[1]CONS = conventional, dual-purpose, isogenic, or low to normal fiber digestibility hybrids; [2]BMR = brown midrib hybrid; Adapted from (Ferraretto and Shaver, 2015).

Another factor that is related to improving corn silage fiber digestibility is increasing the harvesting height. This practice is not only associated with increasing the silage energy content but also decreasing the NDF and lignin content on the ensiled material. It is typically adopted by producers that meet or exceed their forage plan. Consequently, producers that harvest corn at a higher height would need less concentrate per unit of milk. Ferraretto (2021b) demonstrated that silage NDF decreased 2.5 and 5.0 % units when harvest height was increased to 10 and 20 inches, respectively, compared to standard harvest height at 6 in (Table 5). In that simulation, the silage starch increased 2.2 and 4.1% units for harvesting whole-plant corn silage at 16 and 26 inches, respectively, compared to harvest at 6 inches. Increased in vitro NDF digestibility was also predicted as harvest height was increased. In contrast, the yield has decreased by 0.4 and 1.0 ton/acre as the harvesting height was increased.

__Table 5__. Predicted effects of chop height on whole-plant corn silage nutrient composition, digestibility, and yield.

Item	Normal chop height[1]	Simulation[2]	Simulation[2]
Cutting height, inches	6	16	26
NDF, % of DM	37.7	35.2	32.7
Starch, % of DM	37.5	39.6	41.6
ivNDFD[3], % of NDF	49.6	52.6	53.6
Yield, ton/acre	8.9	8.4	7.9

[1]Data from Ferraretto et al. (2017); [2]Predicted using equations from Paula et al. (2009); [3]Ruminal in vitro NDF digestibility.

Alfalfa

Alfalfa is one of the most common forages used to feed cows among US dairies (Ghelich Khan et al., 2016), and most of it is fed as alfalfa hay. In 2020, the harvested area and production of alfalfa hay were estimated at 16 million acres and 53.1 million tons, respectively (USDA, 2020). This production represents about 18% of the total forage harvested in that same year. According to nutritional attributes, alfalfa hay is quality-classified as supreme, premium, good, fair, and low (Table 4; USDA, 2021). The attributes are related to energy availability and crude protein content (Table 3). In November 2021, alfalfa hay prices in the Pacific Northwest averaged $260, $238, $221 to premium, good, and fair alfalfa hay, respectively (USDSA Hay Markets). As a standard forage, alfalfa is considered a compliment forage to corn silage due to its nutritional attributes. As a high-protein forage, it helps to support the requirements of protein of high-production cows. Despite its high soluble protein, alfalfa also has a high amount of protein escaping ruminal degradation, which decreases the necessity of supplementing undegradable nitrogen.

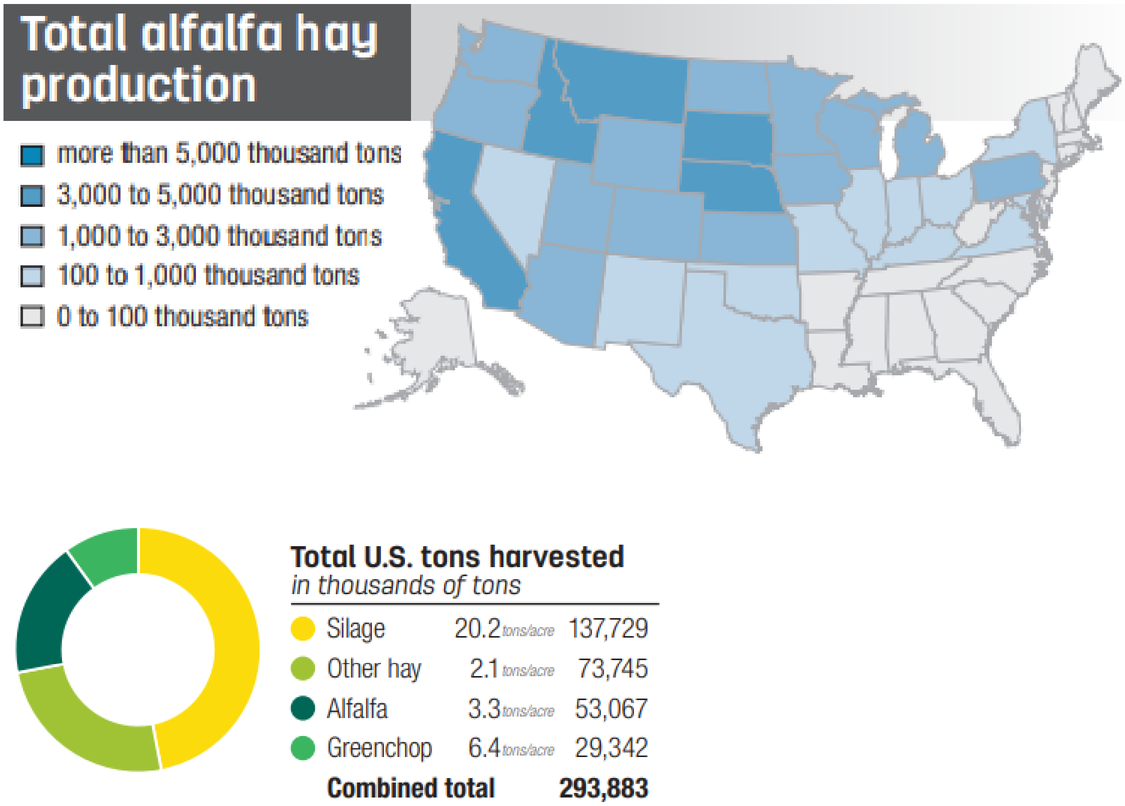

Figure 8. *Total alfalfa hay production in 2020. Source: National forage review (2020 U.S. forage statistics)*

Table 6. *Alfalfa hay quality designation guidelines.*

Quality	ADF[1]	NDF[2]	RFV[3]	TND-100%[4]	TDN-90%[4]	CP[5]
Supreme	< 27	< 34	> 185	> 62	> 55.9	> 22
Premium	27 -29	34 - 36	170 - 185	60.5 - 62	54.5 - 55.9	20 - 22
Good	29 - 32	36 - 40	150 - 170	58 - 60	52.5 - 54.5	18 - 20
Fair	32 - 35	40 - 44	130 - 150	56 - 58	50.5 - 2.5	16 - 18
Utility	> 35	> 44	< 130	< 56	< 50.5	< 16

[1]Acid detergent fiber; [2]Neutral detergent fiber; [3]Relative feed value (An index for ranking cool-season grass and legume forages based on combining digestibility and intake potential. Calculated from ADF and NDF); [4]Total digestible nutrients.

The provision of physically effective fiber is another beneficial factor of feeding alfalfa. Fiber stimulates cows' rumination and salivation, which results in rumen buffering. Besides lower NDF content, alfalfa has a higher content of lignin than traditional forages, an indigestible fiber component. The lignin content increases according to the different alfalfa growth stages, reducing the fiber digestibility and affecting energy supply (Figure 9).

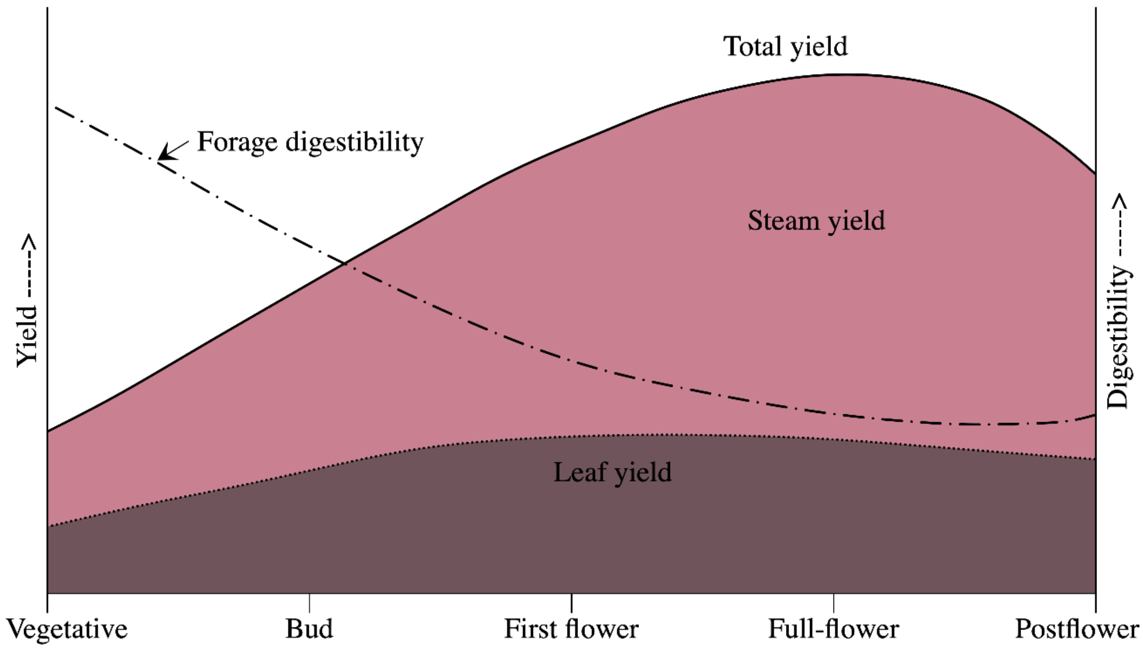

Figure 9. *Table 5. Relative forage yield and quality at different alfalfa growth stages. Adapted from Orloff and Putnam (2004).*

Thus, new selections technologies such as reduced lignin and condensed tannins are used to improve the nutritional attributes. Reduced alfalfa lignin directly increases fiber digestibility and consequently the energy supply. Reduced lignin had a 10 to 15% decrease in lignin content, which increased 10 to 15% in the relative forage quality (RFV) (Adesogan et al., 2019). As lignin in the plant increase as the advance of maturity, the reduced lignin allows a greater harvest window compared to conventional alfalfa. Weakley et al. (2008) has evaluated the effects of feeding two transgenic alfalfa down reduced lignin (COMT and CCOMT) to dairy cows. In that study, fiber digestibility was greater in the two reduced lignin alfalfa hay than conventional alfalfa (Table 7). In addition, cows fed with the COMT gene down-regulated produced 2.6 lb/d compared to cows fed conventional alfalfa.

Table 7. *Effect of feed alfalfa reduced lignin on the fiber digestibility and milk yield.*

Alfalfa hay type[1]	CP (% DM)	NDF (% DM)	NDFD (% NDF)	Milk, lb/d
COMT Inactive	18.1	31.1	53.5**	84.7*
COMT Active (control)	18.4	29.3	42.5	82.1
CCOMT Inactive	18.1	42.5	48.6**	84.5
CCOMT Active (control)	18.3	31.1	44.5	86.7

[1]TMR diets - 50% alfalfa hay, 10% corn silage, 40% concentrate; *Significant, P<0.10; **Significant P< 0.01; Source: Weakley et al. 2008 J. Dairy Sci. Supple. 1

Alfalfa is also commonly fed as silage. Hoffman et al. (1998) reported greater milk production (+1.6 kg/d) for cows fed with alfalfa silage than cows fed perennial ryegrass silage. Broderick (1985) has evaluated the effects of feeding alfalfa silage to corn silage as sole forage in the diet of lactating cows. In the two trials, cows fed about 60% of alfalfa silage as forage had similar milk production and 4% fat corrected milk that cows fed primally corn silage (Table 8). Furthermore, cows had the same milk performance when fed alfalfa silage or alfalfa hay. Broderick (1985) concluded that high-quality alfalfa silage is essentially equal to corn silage for milk production, reducing the problem from milk fat depression (trial 1).

Table 8. *Production and milk components of cows fed with alfalfa silage, corn silage, and alfalfa hay.*

	Dietary forage (Trial 1)[1]			Dietary forage (Trial 2)[1]		
Item	60% AS	60% CS	79% CS	63% AS	60% AH	60% CS
Milk, kg/d	26.4[a]	26.1[a]	23.9	29.8[a]	29.4[ab]	30.3[a]
4% FCM[3]	25.1[a]	24.1[a]	22.9[b]	28.3[a]	28.0[ab]	29.2[a]
Fat, %	3.72[a]	3.50[b]	3.74[a]	3.68	3.70	3.86
Protein, %	3.16	3.18	3.21	3.11[b]	3.11[b]	3.32[a]

[ab]Means in row within each trial different superscript differ (P<0.05); [1]Proportion of dietary dry matter from alfalfa silage (AS), alfalfa hay (AH), or corn silage (CS); [2]Far corrected milk.

In summary, alfalfa has been the most common forage used to feed dairy cows. The combination of the high energy and protein content accounts for more of this choice. In addition, improvements in fiber digestibility thought of technologies such as reduced lignin increase the potential to use alfalfa in dairy diets, which might be associated with lower feed costs or greater animal performance.

Alternative forages for the Pacific Northwest

Due to climate changes and predictions for drier conditions (lower rainfall and less water for irrigation), there is a search for alternative feeds in dairy operations that require less water usage, fit the production system that integrates forage production, promoting sustainability and regenerative agriculture (Rockström et al., 2017).

Considering the water availability situation, the current scenario is that 40% of the U.S is in a drought; much of the Western half of the United States is in the grip of a severe drought of historic proportions (Table 10). When it comes to the Pacific Northwest, 100% of this region is experiencing abnormally dry conditions, with more than a fifth of the region enveloped in exceptional drought — the most severe category outlined by the U.S. Drought Monitor (NIDIS, 2021).

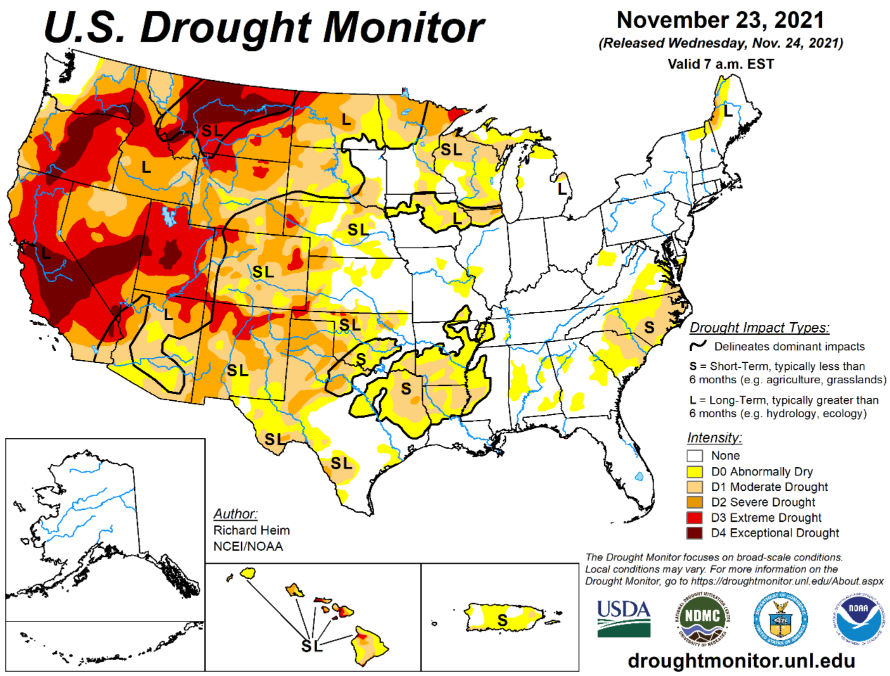

Figure 10 – Current drought situation in the U.S. according to categories. Source: Heim (2021).

The primary direct economic impact of drought in the agricultural sector is crop failure and pasture losses. These costs are often passed on to consumers through increased prices and/or they may be offset through government disaster assistance programs.

The instability of livestock feed prices has forced farmers from integrated agriculture systems to search for alternative feed resources to replace traditional grains without compromising the feed quality or animal performance. This would improve the relationship between crop and livestock production; thus, increasing the stability of feed prices and the ability of producers to cope with climate changes, water shortage, and soil depletion (Condon et al., 2015).

Wheat (*Triticum aestivum*)

Wheat (*Triticum aestivum*) is gaining acceptance as an alternative for more sustainable silage production due to its productivity, nutritional quality (Meinerz et al., 2011), and smaller water requirement (McKenzie and Woods, 2011). This crop has a world annual production of over 735 million tons, being among the largest crop cultivated globally and an essential source of carbohydrates for millions of people (FAO, 2015). Wheat ranks third among U.S. field crops in planted acreage, production, and gross farm receipts, behind corn and soybeans. In 2020/21, U.S.

farmers produced a total of 1.8 billion bushels of winter, durum, and other spring wheat from a harvested area of 36.7 million acres (USDA, 2021b). Washington's Whitman County produces more wheat than any other county in the United States (WGA, 2021)

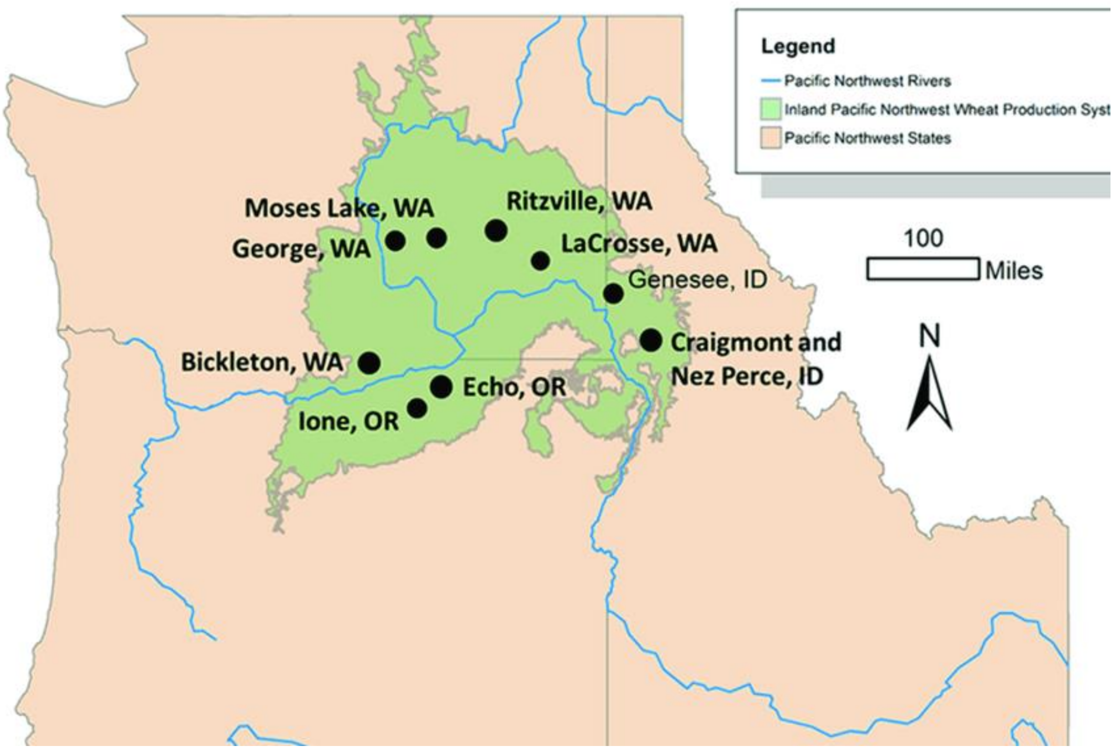

Figure 11. The major wheat-producing area of the inland Pacific Northwest. Source: REACCH (2020).

Despite its potential, wheat has predominantly been a minor forage for livestock in the United States, even with available data supporting its use. When alternative forages, such as wheat silage, fully replace corn silage in a ration, starch content decreases and fiber increases. Thus, normally, energy density of the diet is reduced, potentially impacting MY (Sutton et al., 1998). Therefore, a full substitution was not recommended in the past. However, no study has been done evaluating the replacement of corn silage with WS while maintaining standardized dietary starch levels; thus, standardizing energy levels (Table 9).

Table 9. Current experimental levels of replacement testing wheat as a feed alternative.

Product	Treatment	Main results	Reference
Long wheat hay (HL), short wheat hay (HS) or wheat silage (SI)	30% of TMR DM	Concentrated TMR containing only 30% to 32% wheat forages, HS is better than HL or SI at preventing feed sorting and increasing intake. Replacing HL with SI (containing 20% spikes mass) increased DM digestibility and intake of digestible DM, and resulted in higher yields of milk, 4% FCM and ECM by lactating cows.	(Shaani et al., 2017)
Wheat (*Triticum aestivum*) silage (WS)	10% of the diet DM	Apparent total-tract digestibility of DM and OM was decreased. The diet resulted in higher urinary urea excretion, higher milk urea N, and lower milk N efficiency than the CS diet. WS decreased CO_2 emission, but MY may decrease slightly (3%). At MY of around 42 kg/d, WS can partially replace CS DM and not affect DM intake.	(Harper et al., 2017)
Untreated wheat straw (UWS) or WS silage (treated with sodium hydroxide, molasses and wheat grain; TWSS)	1) control (20% alfalfa hay (AH) and 20% corn silage (CS); 2) UWS (13% AH, 13% CS, and 13% UWS) and 3) TWSS (13% AH, 13% CS, and 14.3% TWSS)	The yield of 4 % FCM did not differ between the cows offered the control or TWSS diets ($P>0.05$). Milk fat contents by cows fed TWSS diet were higher than those fed control diet ($P<0.05$). Overall, partly substitution of the diet forage by the TWSS (13% of diet DM) had no effects on the digestibility and FCM yield compared with the cows offered control diet, but led to improvement of these traits than the cows offered UWS diet.	(Ghasemi et al., 2016)

Canola (*Brassica spp.*)

Canola is grown in 29 states in the U.S., ranging from just a few hundred acres in some states to 1.7 million acres in North Dakota. According to the latest report from the U.S. Department of Agriculture's Farm Services Agency, there were 2.2 million acres of canola planted in the United States in 2021 (Figure 12). Major production regions in the U.S. include the Northern Plains, Pacific Northwest (PNW), and Southern Great Plains. Montana, Washington, and Idaho are the top producing states after North Dakota (U.S. Canola Association, 2021).

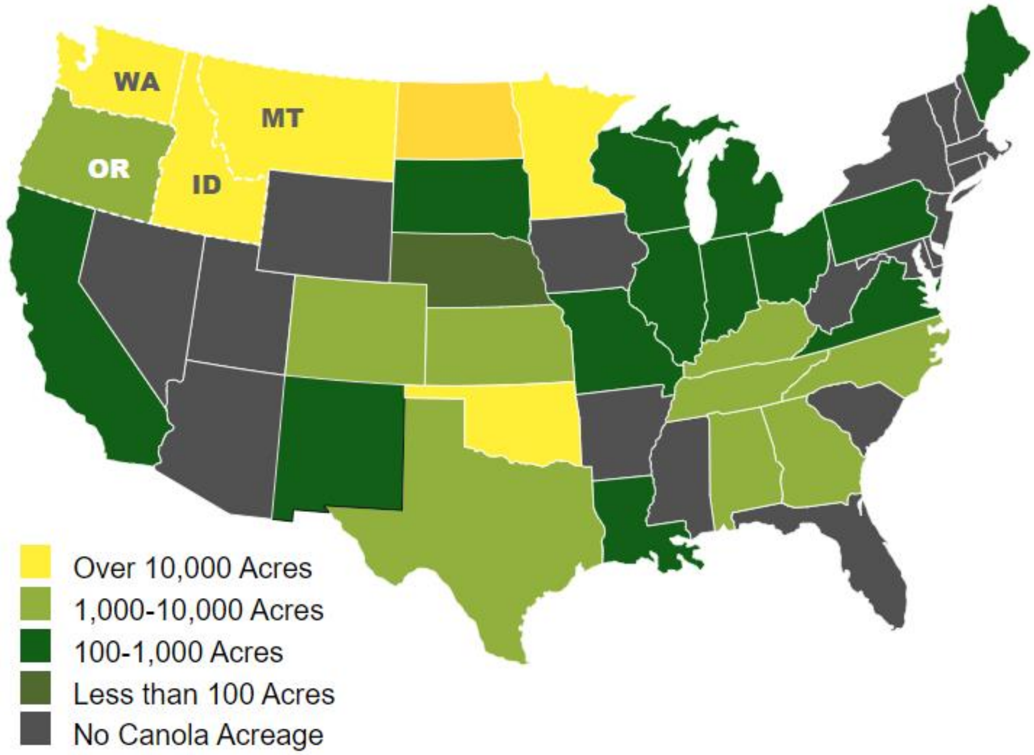

Figure 12. Main Canola cultivation places in Pacific Northwest in 2021. Source: PNW Canola Association (2021).

Brassica plants are frost, heat, and drought-resistant, making them an excellent choice as an alternative crop. Forage rape produces high yields of DM (8–15 t of DM/ha) in a relatively short period (60–120 d), has low establishment costs, uses water and nitrogen efficiently, and has high concentrations of digestible DM and CP. Further, is highly digestible (75–85% DOM), with 10–20% of CP, 18–20% of NDF and high concentrations of readily fermentable carbohydrates such as starch (6–11%), sugars (10–15%), and pectin (9%).(Keim et al., 2020).

Brassicas have long been used as forage for livestock, mainly in temperate grazing systems (Chakwizira et al., 2014). However, significant variations in animal response occurred among experiments testing Brassica forages (Barry, 2013; Table 10).

Table 10. Response data observed in experiments testing Brassica forages in dairy animals.

Product	Treatment	Main results	Reference
Forage rape silage	(1) control, (2) 30% FRS, and (3) 45% FRS	Including FRS to dairy cow diets, up to 45% of diet DM, improved MY due to changes in VFA and predicted microbial N flow, and had no negative impact on dairy cow health or sensory characteristics of milk.	(Keim et al., 2020)
Brassica forages	Control, turnip, or rape silage	Supplementation with turnip or rape modified the profile of FA in blood plasma and milk, increasing the saturated fraction, mainly short- and medium-chain FA, and decreasing the mono- and polyunsaturated FA. Cheeses made with milk from animals fed turnip and rape were differentiated by increased odor, flavor, spiciness, bitterness, and acidity.	(Seguel et al., 2020)

Triticale (*X Triticosecale*)

Triticale is an intergeneric hybrid of wheat (*Triticum* sp.) × rye (*Secale cereale* L.) (Kavanagh et al., 2010). The latest U.S. agricultural census conducted in 2017 reported that triticale grain was harvested from 33,000 ha with 3,700 ha of the total from the state of Washington (USDA-NASS, 2017)

The original goal for producing triticale was to produce a new cereal crop that combined the superior agronomic performance and the end-use qualities of wheat with the stress tolerance (both biotic and abiotic) and adaptability of rye, making it more suitable for the production in marginal areas (acidic, saline, or soils with heavy metal toxicity). Further, possible effects of climate change in terms of reduced rainfall or a change in the pattern of rains (IPCC 2014) call for the need to research alternative forage sources better adapted to those scenarios (Thornton et al., 2009). However, despite having many advantages over wheat, global triticale production is still very low (Colín-Navarro et al., 2021).

The low adoption of triticale is due to factors including production concerns, availability of end-use markets, production economics, policy, and competition from wheat. However, new triticale cultivars often have a significantly higher grain yield than wheat cultivars, with plumper more uniform kernels (Meale and McAllister, 2015) that possess desirable nutritional characteristics for inclusion in lactating cows (Mikulła et al., 2011). Besides, triticale has been used to prevent soil erosion during bare soil periods. Preserving the soil is critically important for continued crop productivity, and therefore has long-term benefits.

Triticale has been evaluated as forage for dairy cattle since the 1970s with good results in terms of yield and nutritive value (Fisher, 1972). Thus, it represents a viable alternative for feeding livestock, given its high DM production and multi-purpose utilization (Table 11). It can be grazed, made into hay, or ensiled, and has the additional advantage of a slow decrease in nutritive value as the plants progress through their growth stages (Mendoza-Elos et al., 2011; Salcedo et al., 2014).

Table 11. Experimental results found testing triticale in different levels as an alternative for feeding dairy animals.

Product	Treatment	Main results	Reference
Triticale silage (TS)	10% of the diet DM	Digestibilities of NDF and ADF were increased in the TS diet compared to the control diet (CS). The diet resulted in higher urinary urea excretion, higher milk urea N, and lower milk N efficiency than the CS diet. Enteric CH_4 emission/kg of ECM was highest in the TS diet, but MY may decrease slightly (3.51%). At milk production of around 42 kg/d, TS can partially replace CS DM and not affect DM intake.	(Harper et al., 2017)
Triticale hay (TH)	0% TH, 9.0% AH and 7.4% TH	No effect was observed on ECM production because of a compensatory linear effect of increasing milk fat concentration with the incorporation of TH in the diet. Total-tract NDF digestibility tended to increase linearly by 18.5%, but no differences were detected for urinary urea-N excretion and N utilization estimated as milk N	(Santana et al., 2019)
Triticale silage (TS)	5.0 and 7.5 kg DM/d	Providing TS to grazing dairy cows in small-scale dairy farms during the dry season, when herbage growth is limited, was a viable option to sustain moderate MY of 12 kg/cow/d. There was no benefit in providing 7.5 kg DM/cow/day of TS over 5.0 kg DM/cow/day as there were no differences in MY, milk composition, body condition score or live weight.	(González-Alcántara et al., 2020)

Barley (*Hordeum vulgare*)

Barley is one of the first crops domesticated by humans and remains a popular food source. It is a short-season, early maturing crop and is likely the world's oldest cultivated grain. It is produced in a variety of climates in both irrigated and dry-land production areas. In terms of harvested area, barley is second only to corn, at 47 million hectares worldwide in 2017. Barley competes with corn and sorghum as a feed grain. It has higher protein contents than corn, which reduces the need for protein supplements in feed rations. However, it lacks some of the other nutritional elements present in corn. In general, feed barley prices are approximately 85% of corn prices on a per bushel basis (AgMRC, 2021).

Barley grows well in cool and dry conditions. As a result, U.S. barley production is concentrated in the Northern Plain states and the Pacific Northwest (WGC, 2021; Figure 13). U.S. producers harvested 2.2 million acres of barley in 2020 with an average yield of 77.2 bushels/acre.

Total production in 2020 was 170.8 million bushels. From that, in 2020, Idaho was the leading U.S. state in terms of barley production. That year, some 55 million bushels of barley were produced in Idaho. Montana was another major producer of barley in the United States, at 45.67 million bushels (Shahbandeh, 2021).

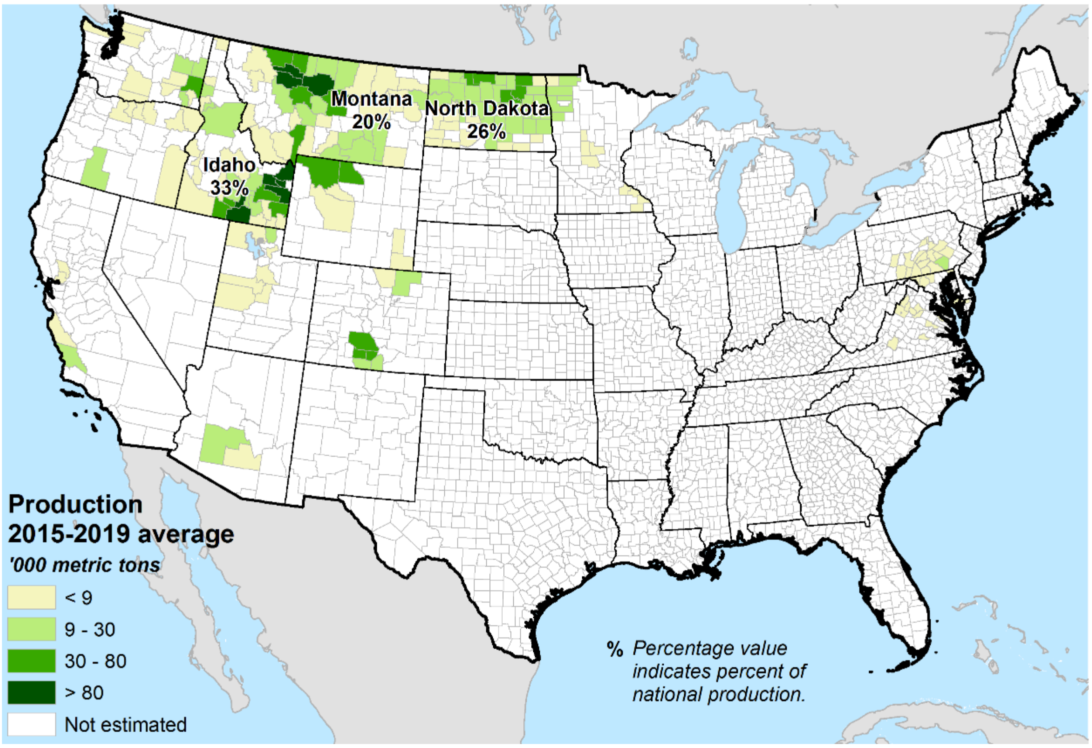

Figure 13. United States: Barlley Production Map. Source: USDA (2021c).

However, because of ongoing drought conditions and an unusually long heatwave that has gripped much of the state, Idaho barley yields and total production are expected to decrease considerably this year compared with 2020 (Sean Ellis, 2021). A similar drop in production is expected for other states, such as Washington. According to the USDA, while Washington farmers planted around 70,000 acres in 2021 — down 90,000 in 2020 — to 2021 harvest and yield plummeted to 2.6 million bushels at 38 bushels-per-acre from 6.4 million bushels at 90 bushels-per-acre in 2020 (Featherstone, 2021).

Barley grain is a valuable feedstuff for several different classes of ruminants. When properly processed, mixed, and fed, barley is an excellent feed grain. It can be used as a supplement in forage rations for replacement heifers and as an energy and protein source (Table 12).

Table 12. Experimental data of barley in different levels of substitution in dairy animal diets.

Product	Treatment	Main results	Reference
Hulled or hull-less barley	(1) 45% forage and hulled barley as the sole grain source, (2) 65% forage and hulled barley as the sole grain source, (3) 45% forage and hull-less barley as the sole grain source, and (4) 65% forage and hull-less barley as the sole grain source.	DMI tended to be lower for the diet with 65% forage and hulled barley than for the rest of the diets (24.4 vs. 26.6 kg/d). Neither the type of barley nor the F:C ratio affected MY (41.7 kg/d). Barley type did not affect milk fat or protein concentrations. Feeding LF diets decreased milk fat concentration from 3.91% to 3.50%.	(Yang et al., 2018)
Barley silage (BS)	Barley varieties with different digestible fiber concentrations	Cows fed BS with relatively higher ruminal ivNDFD did not show significant difference from the cows fed other BS varieties with lower ruminal ivNDFD in MY and total chewing activity.	(Refat et al., 2017)
Barley silage (BS)	(1) 0% CS and 54.4% BS in the TMR (0% CS), (2) 27.2% CS and 27.2% BS in the TMR (27% CS), and (3) 54.4% CS and 0% BS in the TMR (54% CS)	CH_4 production adjusted for DM or gross energy intake increased as the amount of CS decreased in the diet. Decreasing the CS proportion in the diet reduced N utilization.	(Benchaar et al., 2014)

Conclusion

Globally, atmospheric greenhouse gases continue to rise, and it is becoming increasingly apparent that adaptation may be the only viable option to ensure the future food needs of humanity. Furthermore, due to climate changes, the search and adoption of alternative crops that are capable of producing high grain yields on marginal lands under arid conditions with minimal inputs (i.e., fertilizer, pesticide, water) as compared to other cereal grains are becoming more and more necessary as demands for sustainable livestock continue to rise.

Based on the information, these alternatives can be successfully included in the diets of dairy cows, taking into account some specific limitations of each crop (Table 13). Therefore, they represent a way to reduce costs, without considerable changes in milk production and composition, especially in places where the use of corn silage is limited by economic, environmental, or logistical factors. Thus, the main recommendations that can be used are present in Table 13.

Table 13. Recommendation for alternative crops in the Pacific Northwest

Crop	Amount	Effect	Reference
Wheat silage	10 to 13 % of the diet DM	No effect on DMI and digestibility; higher milk fat and no effects on the FCM and ECM yields.	(Ghasemi et al., 2016; Harper et al., 2017)
Canola silage	Up to 45% of diet DM	Improved MY due to changes in VFA and predicted microbial N flow, modification in the profile of FA in blood plasma and milk and had no negative impact on dairy cow health	(Keim et al., 2020; Seguel et al., 2020)
Triticale silage	10% of the diet DM or up to 5.0 kg DM/day	Digestibilities of NDF, ADF, urinary urea excretion and milk urea N were increased, while milk N efficiency was reduced. Enteric CH_4 emission/kg of ECM was highest in the TS diet, but MY may decrease slightly (3.51%), depending on the animal milk yield and composition, body condition score, and weight.	(Harper et al., 2017; González-Alcántara et al., 2020)e
Barley silage	Up to 65% in diet DM	No effect in MY, milk fat or protein concentrations. Diets with low forage (45%) had milk fat decreased from 3.91% to 3.50%. Diets with high barley showed CH_4 production adjusted for DM or gross energy intake increased and reduced N utilization	(Benchaar et al., 2014; Yang et al., 2018)

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