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Strategies to increase the digestibility of corn and sorghum starch and NDF in dairy cattle nutrition

Student: Matheus Rebouças Pupo, **n°USP**: 9394066
Advisor: Luiz Gustavo Nussio
Collaboration: Luiz Felipe Ferraretto, University of Florida, Gainesville, FL, EUA.

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Matheus Rebouças Pupo
Bachelor’s degree in Agronomic Engineering

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Summary

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Abstract

The objective was to evaluate the yield and chemical composition, as well as neutral detergent fiber digestibility of corn and sorghum during both spring and summer seasons. This trial was performed to evaluate hybrids to use in North Central Florida. The best cultivars were classified according to Milk2006 inputs and then combined to find out a season's average. A completely randomized block design was used for this test, and data were analyzed using the PROC MIXED of SAS 9.3. Spring corn showed higher levels for the parameters aforementioned than those seeded on summer. On the other hand, summer sorghum although presents lower dry matter yield than those in the spring demonstrated similar quality values to both seasons. There were season's effects on either yield or chemical composition, while for NDF digestibility it was found only for corn. Future studies in different regions are required to validate this finding before their recommendation.

Key words:chemical composition, hybrids, season, yield

Introduction

Feeding represents the largest cost in animal production. The main diet component of ruminants diets is usually forage (Armentano et. al, 1997), and its chemical composition and nutritive value are variable. Several factors like plant species, variety, type and degree of processing, storage, climate, maturity, and other factors contribute to this variation. Although chemical analysis of feedstuffs can be expensive, it offers important information that avoid limited animal performance. (Cherney, 2000).

As nutrient content, their digestibility is one of the most important parameters in this evaluation. Usually, there is a high correlation between carbohydrates digestibility and animal performance (Ferraretto et. al, 2015), so factors that affect these parameters directly, should be evaluated.

Different aspects can affect carbohydrates availability and utilization by ruminants, such as physical and chemical properties of starch along with the degree of processing of corn grain (Giuberti et al., 2014) or sorghum particle size correlated to dry matter disappearance (Galyan et. al, 1981).

In addition, a huge difference on chemical composition between hybrids was observed (Johnson et al., 1991; Schwab, 2003), which also contributed to a wide chemical variation among feeds. According to their features, specific hybrids are developed for each season, so a significative difference in chemical composition among cultivars within the same location or the same cultivar grown in different stations should be expected.

General Objectives

The objective was to evaluate and compare the yield and chemical composition, as well as neutral detergent fiber digestibility of corn and sorghum hybrids during both spring and summer seasons and rank them according to performance.

Specific Objectives

- To evaluate chemical composition and NDF digestibility among 36 (thirty-six) corn hybrids and 34 (thirty-four) sorghum hybrids from different companies in US;
- To estimate milk production potential using the Milk2006 software based on the chemical composition and digestibility of the hybrids;

- To provide information from our studies that connect academia and producers, providing resources to develop producer's business.

Literature Review

Overview

Corn (*Zea mays* L.), a cereal grain of the *Poaceae* family (Vincent, 2001), is the most produced grain worldwide with over 1 billion metric tons of corn grain produced from 197 million hectares harvested in 2017 (FAOSTAT, 2017). The US is the largest producer of corn in the world with 36.5 million hectare planted in 2017, producing 370 million metric tons of corn grain while, 2.6 million hectares or approximately 7% were harvested for corn silage production (USDA-NASS, 2017). Corn grain is an integral component of human nutrition across the globe and its importance as animal feed is well established (Hasjim et al., 2009). The total consumption of corn grain in the US in 2017 was 318.7 million metric tons with 37.8% destined to ethanol production, 36.9% used as livestock feed (8.5% fed as dried distillers grain), 3.2 % for high-fructose corn syrup, 2.6% for sweetener production, 1.6% for starch, 1.4% for cereal/other, 1% for beverages/alcohol, and 0.2% for seed production (USDA-NASS, 2017). Among livestock feed, about 40% of corn grain was used for ruminants (beef and dairy cattle) while the remaining portion was diverted towards monogastric animals including swine and poultry (ProExporter Network, 2018).

Sorghum (*Sorghum bicolor* L. Moench.), a cereal grain of the *Poaceae* family, had approximately 58 million metric tons produced in 2017). The US is the largest producer with 12 million metric tons. Many dairy producers consider silage-type sorghums as a viable alternative crop, increasing harvested area in the world, reaching 41 million metric tons in 2017 (FAOSTAT, 2017). Sorghum is better suited to semi-arid conditions than corn for several reasons including lower transpiration ratios, slower leaf and stalk wilting, recovery after drought (Martin, 1930), and lower irrigation requirements (Lamm et al., 2007). Additionally, sorghum may drain less water from the soil than corn (Marsalis et al., 2010)

Physical and Chemical Attributes

Structure

The physical structure of grains determines their features. Sorghum grain is composed of three main components: the pericarp, endosperm, and germ (Rooney and

Miller, 1982, Evers and Millar, 2002). Naturally, the amounts of these components will be different, but a general composition of a sorghum grain has been reported to be 3 to 6% pericarp, 84 to 90% endosperm, and 5 to 10% germ (Hubbard et al., 1950; Rooney and Miller, 1982; Rooney and Serna-Saldivar, 2000). The composition of these tissues differs substantially.

The pericarp consists of multiple layers, including the epicarp, mesocarp, and endocarp (Waniska and Rooney, 2000). Sorghum is unique in that it is the only cereal to have starch granules present in the pericarp (Rooney and Miller, 1982; Zeleznak and Varriano-Marston, 1982; Evers and Millar, 2002). Pericarp thickness is variable, is not of uniform thickness within a single grain, and is related to the amount of starch in the mesocarp (Earp et al., 2004). The outer layer of the pericarp is covered with wax. (Bean et. al, 2016). The structure of sorghum grain is shown in Figure 1.

The endosperm consists of an outer translucent area and an inner white area. The outer endosperm is corneous and the inner endosperm soft. The proportions of the two areas can vary from cultivar to cultivar. Such variation in the proportion of the two types of endosperm is also seen in corn. Axtell and Hamaker (pers. comm.) have identified progeny of crosses of a mutant cultivar of sorghum previously identified as high in lysine with normal kernels in which an island of corneous endosperm is formed surrounded by a floury sea.

Corn kernels, are the reproductive seeds of the plant, represented by Figure 2. They can be anatomically divided into 4 structures: tip cap, germ, pericarp and endosperm. The tip cap is a structure that firmly attaches the kernel to the cob and allows the movement of nutrients from the plant to the kernel until there is enough nutrients to nourish the embryo.

The germ, which is the reproductive part of the grain, is composed of enzymes, nutrients such as lipids and proteins, and genetic material that would originate the new plant. The pericarp is the structure that surrounds the whole kernel, except for the tip cap area, and is formed mainly from dead cells, rich in cellulose and hemicellulose. The epidermis constitutes the outer layer of the pericarp cells covered by cutin, a lipid layer that restricts water and gas passage in and out of the kernel.

Finally, the endosperm, which comprises the majority of the kernel dry matter (DM; up to 70%) and its high starch content is of particular interest from feed energy standpoint. Approximately 86% of the whole endosperm DM is composed of starch while the remaining 13% comprise primarily of proteins (9%), lipids, sugars, and ash (Eckhoff and Paulsen, 1996, Ferraretto et al., 2018). The endosperm and germ are the major parts of the corn kernel, containing most of the starch and oil, respectively (Shukla and Cheryan, 2001).

Carbohydrates

Neutral Detergent Fiber

Van Soest e Moore (1966) described that NDF is comprised by hemicellulose, cellulose and lignin. Nutritionally, fiber is the indigestible or slowly digesting fraction of a feed or diet that occupies space in the gastrointestinal (GI) tract, being the best technique to estimate insoluble fiber (Mertens, 2015).

Dietary carbohydrates can be divided into two basic fractions: fiber and nonfiber carbohydrates (NFC). According to Mirzaei-Aghsaghali (2011), fiber demonstrated that the amount and physical form of dietary fiber are important factors in lactating dairy cows ration in order to maintain proper ruminal function, animal health status and milk composition.

Biologically NDF have been related to intake, feed density, chewing activity, digestibility, rate of digestion, and depression of digestibility associated with high levels of intake. However, an increasing content is not desirable unless digestible NDF (dNDF) makes up a large fraction of NDF, once indigestible NDF (iNDF) limits the dry matter (DM) intake (DMI) (Jensen, 2005).

Starch

Starch is a highly versatile compound being used for multiple purposes, from more simple ones, like energy source as food and feed to more complex industrial processes, such as ethanol and synthetic polymer production (Carvalho, 2008).

Your composition includes two types of macromolecules, amylose, which is essentially linear and mostly distributed in the amorphous growth ring with small amounts associated with the semi-crystalline growth ring (Montgomery & Senti, 1958), and amylopectin, which is highly branched and constitutes the crystalline lamellae.

Starch is an important nutrient for high-producing dairy cows, and it is generally assumed that starch digested in the small intestine is more efficiently used to support milk production than starch digested in the rumen (McDonald et al., 1995). In a review of production data from cattle fed on corn or sorghum based diets, Owens et al. (1986) concluded that starch digested in the small intestine provided 42% more energy than ruminally digested starch.

The ability to digest starch varies among domestic animals. In ruminants, amylolytic organisms degrade a large, but variable amount of starch in the rumen (Mills et al., 1999). Alpha-amylase is probably more limiting than intestinal oligosaccharidase activity in the degradation of starch to glucose (Mills et al., 1999).

Reducing starch concentrations in diets by lowering the proportion of corn fed may decrease animal performance (Ferraretto, 2017). While some studies have shown that feeding reduced-starch diets by replacing corn with byproducts did not change milk yield by dairy cows (Batajoo and Shaver, 1994, Ipharraguerre and Clark, 2003, Gencoglu et al., 2010), others have reported lower milk production in mid-lactation dairy cows (Fredin et al., 2015). Nevertheless, it is paramount to find novel strategies for increasing starch digestibility to overcome issues related with lower milk production by cows fed reduced-starch diets.

Chemical Comparison

Corn and sorghum are potential energy sources for dairy cattle. Depending on climatic conditions, one of them may be chosen over another. The farmers usually use corn. However, some climatic conditions can limit its productivity. Nutrient composition comparing both is informed in Table 1.

Sorghum grain contains more crude protein than corn. Fiber measured by acid detergent fiber (ADF), is lower for corn and higher for sorghum. The ADF values for sorghum are variable and may be a reflection of an increased proportion of seed coat to endosperm and germ as compared to corn. This also likely contributes to the overall greater level of ADF found in the sorghum. While differences exist, these are small and would not have a large negative effect on ruminant digestion. Energy values are expressed in terms of net energy for maintenance (NEm), gain (NEg) and lactation (NEl). These are a reflection of how an animal would utilize energy from the feedstuffs. Comparing the NRC value to the more recent laboratory studies, it appears that the levels of energy have increased.

This is due to plant genetics and agronomic practices improvement, which yield greater levels of starch nowadays than in the past. Sorghum and corn are very comparable in terms of energy. Values above indicate a trivial advantage for corn over sorghum, but the difference is relatively small and may not be detected in animal trials. Considering the influence of climate, agricultural practices and genetics, both grain sources should be analyzed and the resulting nutrient profiles used to formulate animal diets rather than utilizing the tabular values.

However, even considering this small difference in general, since 2000 researchers have conducted variety tests and other designed trials with normal, BMR, PS, and PS-BMR forage sorghums and sorghum-sudangrasses at the Texas AgriLife Research facilities near Bushland, Texas. In the hybrids trial the entries are determined by the companies that submit the materials for testing. Five years of information focusing primarily on forage sorghums were summarized by McCollum et al. (2005). Another four year series of data for sorghum-sudangrasses and forage sorghums was compiled by Bean and McCollum (2006), presented in Table 2.

There is a huge variation within a type of plant (i.e. sorghum-sudangrass, forage sorghum or BMR). Although an average value for one type may be different from or similar to another type, there are many exceptions when the varieties within types are observed. The recommendation is to take decisions based on varietal comparisons rather than general characteristics of the type of forage.

Varieties of corn and sorghum

A selection pressure by both humans and nature has resulted in various corn genotypes, hybrids and cultivars, but generally, they could be classified into six common types depending on starch structure and composition, generally classified by properties of their grain endosperm, depending on quality and quantity: flint, flour, dent, popping, sweet and waxy (Knott et al., 1995).

Waxy corn is characterized by starch composed only of amylopectin while conventional corn is composed of starch formed by 75% amylopectin and 25% amylose (Yu et al., 2015). Starch from high amylose corn is characterized by presence of 70% amylose, while sugary corn contains lower starch and greater sucrose accumulation (Yu et al., 2015). Conventional corn can be further classified into dent and flint corn. Both dent and flint corn contain a hard (vitreous) and a soft (floury) endosperm; however, flint corn has mostly hard, glassy endosperm with smooth, hard seed coats (pericarps). Flint corn is used most commonly in South American countries, including Brazil, while dent corn is commonly used in the US (Correa et al., 2002).

As aforementioned, vitreous endosperm differs from floury endosperm due to starch granules presented on the former being more densely packed and surrounded by a thicker protein matrix, while the floury endosperm is formed by larger round granules and a thinner protein matrix layer (Dombrink-Kurtzman and Bietz, 1993). During in-field drying, due to the kernel losses moisture and due to the thinner structure of the protein matrix on the floury endosperm, greater fraction in dent corn grain, soft starch collapses and crown region is pulled inward, as the kernel shrinks, the dented aspect is observed (Eckhoff and Paulsen, 1996).

Forage sorghum is an important annual forage source in the Midwestern and plains regions of the U.S and can be planted later than corn (*Zea mays* L.). It presents more efficiency using water, yields greater biomass, and provides an acceptable yield when exposed to drought (Sanderson et al., 1992). Breeding improvements in the past 10 to 15 years have resulted in new varieties of BMR forage sorghum with the brachytic dwarf trait (Oliver et al., 2005) that can compete in yield with conventional varieties, but energy supplements might be needed for forage sorghum-based rations. (Lyons et. al, 2019)

Chemical and genetic approaches have been active to increase forage fiber digestibility focus on reducing the amount of lignin or the extent of lignin cross-linking with cell wall carbohydrates. Brown midrib (BMR) forage genotypes usually contain less lignin and have altered lignin chemical composition (Bucholtz et al., 1980; Cherney et al., 1991; Vogel and Jung, 2001). According Gerhardt et. al (1994), genetic control of the lignification process through manipulation has offered the most direct and productive approach to solve this issue.

Besides this hybrid, another known variety is Sorghum-Sudangrass. It is produced from crossing inter-specific *Sorghum sudanensis* Piper Stapf hybrids with *Sorghum bicolor* genotypes (Raupp & Brancão, 2000). There is an opportunity to harvest between 2 and 3 times that is compatible with many forage programs and that allows manure application during summer and well-suited with grazing (Kilcer et al., 2001). However, the nutrient digestibility amount contained is lower levels than corn hybrids.

Factors Affecting Carbohydrates Utilization by Ruminants

Effects of heat and moisture on carbohydrates properties

Increasing pressure, moisture, and temperature gelatinizes starch and are important components of the steam flaking process (Theurer et al., 1999). Steam-flaking is characterized by steaming whole corn kernels at low pressure for 20 to 90 min in vertical, stainless steel steam chamber to increase grain moisture to achieve 18-20%. Steamed corn is later flaked by passing between preheated larger rollers to a specific flaking density (309-386 g/L or 24-30 lb/bushel); (Theurer et al., 1999). Lower flake density is associated with extensive processing.

Steam-flaking breaks crystalline structure of starch and the starch-protein matrix, therefore, making starch more susceptible for amylolytic degradation resulting in greater ruminal and total-tract starch digestibility compared to ground corn (Kishida et al., 2001, Armbruster, 2006). Lactation studies have shown consistent improvement in milk and milk protein yield with steam-flaked corn compared to dry rolled corn (Theurer et al., 1999). This method can also develops energetic efficiency of corn and it is comproved to have advantages on the net energy for maintenance and gain principally, due to the increase in starch digestibility but also possibly to the greater digestibility of other kernel components and reduction of methane energy loss (Council, 1996, Owens et al., 1997, Zinn et al., 2002, National Academies of Sciences, 2016).

At excess water content, the gelatinization usually occurs between 50 and 70 ◦C. Swelling causes nearly all amylose in the starch granule to leach out (Han and Hamaker, 2001). Viscosity increases during gelatinization, and is caused by swollen granules and gels consisting of solubilized amylose (Hermansson and Kidman, 1995). In addition to the importance for starch digestion, the increase in viscosity during gelatinization may also affect physical quality of processed feeds positively through increased binding between feed particles. (Svihus et al., 2005)

Feed processing

Recent methods of feed processing include grinding, steam flaking, pelleting, extrusion and expander processing. During steam conditioning and pelleting, only between 10 and 200 g starch/kg is usually gelatinized (Svihus et al., 2005). This low extent of gelatinization implies that steam conditioning and pelleting will not have a marked effect on neither starch digestibility nor physical quality of the feeds.

Wood (1987) found that pellet quality improved substantially as gelatinized starch replaced ungelatinized starch. This gives indirect evidence that starch is not gelatinized and it indicates that starch has a potential to perform as a binder if gelatinized. The effect of steam flaking on starch gelatinization and subsequent availability will be dependent on amount of steam added and treatment time. Medel et al. (2004) cooked with steam for 90 min followed by flaking of barley and corn to result in between 0.4 and 0.5 starch gelatinization, related to energy digestibility. (Svihus et al.,2005)

During expander processing of feeds, up to 80 g water/kg is added and the diet is exposed to high temperatures, above 100 ◦C under pressure. Expander processing has resulted in an extent of gelatinization between 220 and 350 g starch/kg, excluding effects in nutrients availability. (Goelema et al., 1999; Cramer et al., 2003).(Svihus et. al, 2005).

Steam-flaked corn is highly digestible in the rumen because of the degradation of the protein matrix of starch granule during processing. Degradation of the matrix increases surface area and allows for greater microbial attachment and digestion of the starch granule, increasing the energy available for microbial protein synthesis and increased utilization of recycled and dietary nitrogen (Cooke et. al, 2009)

Effects of ensiling, harvesting and chop length

The biochemistry of ensiling is essentially a simple process of preserving high moisture forage in lack of oxygen and in presence of organic acid produced during bacterial fermentation (Wilkinson et al., 2003). During ensiling, the desired effect is to ferment water-soluble carbohydrates such glucose and fructose and convert them into organic acids by anaerobic bacteria. The most appropriate organic acids are lactic and acetic acid, as lactic acid reduces pH to levels below 3.8 and control spoilage microorganisms during ensiling while acetic acid inhibit aerobic spoilage microorganisms at the feed-out thereby promoting greater aerobic stability (Muck et al., 2018).

When sufficient amount of lactic acid has been produced, all microbial activity is inhibited, primarily through the effect of undissociated lactic acid, and the silage can then be stored anaerobically until required for feeding, minimizing nutrient loss.

Plant maturity at harvest is one of the most important factors influencing forage quality and digestibility; as plants age, their digestibility tend to decrease (Buxton and O'Kiely, 2003). Even though starch accumulation is greater with advanced maturity (Bal et al., 1997), but starch digestibility decreases with maturation possibly due to increase in the proportion of vitreous endosperm which more strongly packed by a thicker protein matrix than floury endosperm (Philippeau and Michalet-Doreau, 1997). Ngonyamo-Majee et al. (2009) observed lower ruminal *in vitro* starch digestibility and increased proportion of vitreous endosperm when corn kernels were harvested at black layer stage compared with one-half of milk line stage. In the same way, Bal et al. (1997) observed lower *in vivo* starch digestibility and lower (0.4 kg/d) intake of digestible starch for lactating cows fed silage from corn harvested at the black layer stage.

Planting date is more critical in corn than sorghum (Cummins, 1972). Double cropping, even three in some countries, of sorghum is possible and may be considered an advantage over corn, which does not reach its highest nutritive value until the grain reaches maturity. The maturing process is highly complex and involves numerous changes in plant composition and structure which, in turn, influence the fermentation process (Goering et al., 1972). (Smith et. al, 1983)

The increasing amylose content also corresponds to a decrease in the crystallinity of the starch as well as the reduction in the lamellar periodicity peak intensity. The increase of amylose content in the amorphous region of the starch appears to mess up the lamellar periodicity altering the structure of the starch granule.

The gelatinization attributes for the mature (harvestable moisture content) sorghum can be compared with previous studies. Beta and Corke (2001) reported gelatinization temperatures and enthalpies on ten sorghum starches. The Tp ranged from 68.0 C to 71.0C and DH ranged from 7.5 J/g to 9.8 J/g. The increased DH values along with the greater amount of crystallinity associated in samples early in development suggests that the starch structure is closer to a perfect crystal then degrades over the course of maturation either by physical (dehydration) or enzymatic processes. This phenomenon has also been demonstrated in potato starches throughout development (Protserov et al., 2000).

The best time of harvest for corn silage was considered when grain is denting or milk line is 1/2 - 2/3rd way down the kernel. However, harvest time based on these parameters is not truthful due to the presence of new characteristics in modern corn hybrids such as stay-green. Hence, decision on harvest time should be based on DM content and number of days, so being harvested when the DM concentration is between 30-35%, reaching 100 – 115 days as average.

Chop length is one of the most important factors affecting starch digestibility. Theoretical length of cut (TLOC), and cutting height are well-established management tools for improving physical and chemical characteristics and therefore nutrient digestibility of WPCS (Johnson et al., 1999; Allen et al., 2003; Buxton and O'Kiely, 2003; Ferraretto and Shaver, 2012).

Research in North America has shown that processing whole-plant corn silage (WPCS) improves total-tract starch digestion in dairy cows (Bal et. al,1998) and beef steers (Rojas et al., 1987) and milk production by dairy cows (Johnson et. al, 1999). Satter et al. (1999) summarized WPCS processing trials for response in milk production, and found 0.5 kg/d higher milk production for processed compared with unprocessed WPCS. In two studies, total-tract starch digestion was increased 5 percentage units for processed compared with unprocessed WPCS diets.

Choppers set between 0.93 and 2.86 cm have presented greater starch digestibility due to kernel breakdown by cutting knives on the shorter theoretical length while on the longer settings corn stover passes through without proper cutting (Ferraretto and Shaver, 2012). However, chop length had no effects on digestibility of NDF, DMI, and milk production (Ferraretto and Shaver, 2012).

Material and Methods

Both corn and sorghum trials were conducted at Plant Science Research and Education Unit, Citra, Florida (29°24’18.0”N 82°10’28.9”W). Experimental design was randomized blocks for each one. The corn was planted in March 2018 for spring and August for summer. It was used 38 hybrids (Table 3) considered as treatments, from 10 different companies.

The planting rate was approximately 75.680 plants/hectare for corn and 247.105 plants/hectare for sorghum, and the distance between lines was 75 centimeters (30 inches) in 4 (four) lines, being two rows used as protection and two more center rows to harvest during approximately 105-120 days for corn and 80-130 days for sorghum. Plants were placed side by side, found out in 4 different blocks.

During whole crop, it was applied nitrogen, phosphorus, and potassium in a rate of 106 kg/ha of nitrogen, 124,5 kg/ha of phosphorus and 202 kg/ha of potassium, divided in six different moments: before planting, during planting, and four more applications, under effect of irrigation. The insecticide used was Bifenthrin 2EC, which its active ingredient is Bifenthrin to control pest population, mainly armyworm (*Spodoptera frugiperda*).

During observing dry matter (DM) levels, the plants were tested at 60° C oven weekly after stage R1, targeting 32% DM. At harvest, the first two plants of the center lines were discarded and then harvested plants along three meters, calculating DM yield following the next formula: ((Yield 1 + Yield 2) * 2,20462)* 871,2)/2000.

Later, the plants were processed in a processor connected to the tractor, with individual weight for the plants processed of each line and the sampling by blocking method. Samples were placed in a 60° C oven for 48 hours and ground to 4 mm in a Willey mill. Samples were sent to a commercial laboratory for nutrient analysis and NDF digestibility. Milk yield data by area was calculated using Milk2006 from the University of Wisconsin.

The multi-component summative equation of Weiss (1996) was used to estimate the NEL value of feedstuffs based on the concentration and true digestibility of CP, fatty acids (FA), NFC, and NDF. Each nutrient fraction is multiplied by its respective digestibility coefficient to determine the amount of digestible nutrients contributed by each fraction, the digestible nutrient components are summed, and the total is corrected for the energy from metabolic fecal matter

The performance of the hybrids was defined calculating indices of milk/ton of silage DM and milk/ha, being used to compare cultivars (Undersander et al., 1993). Milk/ton of silage DM was predicted using starch digestibility and milk/ha is the product of milk/ton of silage DM and DM yield/ha of the plant.

Furthermore, sorghum was planted two weeks after corn for spring and in September for summer. It was used 34 hybrids (Table 4), being 25 forage sorghum. During its conduction, it was applied 55 kg/ha of nitrogen, 124,5 kg/ha of phosphorus and 269 kg/ha of potassium. Sorghum was harvested and processed as previously described for corn.

Samples ground to 4 mm sieve in a Willey mill were sent to a commercial laboratory for nutrient analysis and NDF digestibility. Milk yield data by area was calculated using Milk2006 from the University of Wisconsin, such as corn.

Data were analyzed using the PROC MIXED of SAS 9.3 (SAS Inst. Inc. Cary, NC) considering hybrids as fixed effects. Means were compared by Tukey test and significance was declared at $P \leq 0.05$.

Results and Discussion

Sorghum Hybrids

As shown in Figures 3 and 4, during the summer 4 hybrids presented high performance, however for the period of spring 5 hybrids achieved high levels of milk/ton silage DM and yield DM (tons per hectare) between 36 hybrids. The inclusion of BMR sorghum silage (BMRSS) in diets of dairy cows may result in increased fiber digestion, which can improve energy consumption and animal performance. (Sanchez-Duarte et. al, 2019)

The chemical composition that defined best hybrids for both seasons are described in Table 5. Forage sorghums are used largely as silage for livestock and ensiling of forage sorghum demonstrated to be a successful method of conservation (Black et al., 1980; De Brouwer et al., 1991). Forage yield, ensilage losses and silage nutritive quality of sorghum varieties may also be affected by relations between the genotype, stage of maturity at harvest, and re-growth ability. Therefore, any examination of new sorghum varieties should consider these aspects. (Miron et.al, 2006)

The NDF (spring) was lower than the values found by Amer et. al (2012), Grant et. al (1995), and Ward et. al (2001) (67%, 59%, and 63,60%, respectively). These variations reveal a possible significant error on the accurate formulation of dairy diets if used chemical composition withouth chemical composition evaluation, leading to inefficient utilization of feed resources and impaired utilization of the nonfiber components of the ration.

Crude Protein (spring) was higher, on average, than found by Thomas et. al (2013) and Oliver et. al (6,30% and 7,30 %, respectively). This is a consequence of high levels of fiber found out in these studies, decreasing CP percentage, due to accumulation of fiber components instead of protein. According Wilson et. al (1991), increasing temperature estimulates NDF increases, as a result of a cell wall growth.

Typically, conventional forage sorghum varieties outperforms BMR sorghum varieties in yield (Oliver et al., 2005; Marsalis et al., 2009, 2010). For example, Marsalis et al. (2010) reported a 13% lower yield for BMR forage sorghum compared with a conventional variety (21.1 vs. 24.4 tons of DM/ha, respectively), which is higher than 11,07 tons of DM/ha, as a result of damage caused by sugarcane aphids.

The BMR has been developed a lower lignin content and increased NDF digestibility (NDFD) compared with traditional varieties (Grant et al., 1995; Oliver et al., 2004). Harper et. al (2017) found out 47,3% and Oliver et al. (2005) 54,4% for BMR and 40,8% for conventional sorghum, similar to our data.

Starch was lower, on average, compared to Harper et. al (2017) and Oliver et. al (2005) for BMR (20,9% and 19,5 %, respectively vs 18,4%). For conventional varieties, Oliver et. al (2005) and Colombini et. al (2012) found highest levels (17,4% and 20,8%, respectively vs 16,9%). This difference is due to harvest time, obtaining a lower proportion of grain in the total mass and then elucidating the lower concentration of starch in sorghum plants. Moreover having less starch, sorghum has lower starch digestibility than corn.

Historically a comparison between seasons demonstrates some chemical composition differences. A collaborative study presented by Virginia Tech and

University of Florida with sorghum grown in Florida, 2008 to 2014 (Table 7), describes components and shows in general higher quality for spring than summer. These variations are due the way forages grown at cooler temperatures, depositing less lignin and, consequently increased *in vitro* NDFD compared with the same forages grown at higher temperatures (Buxton, 1996). However, these differences were not declared at this trial (Figure 5).

Corn Hybrids

During the summer, 8 hybrids presented high performance (Figure 7), however in spring 12 hybrids achieved high levels of milk/ton silage DM and yield DM (tons per hectare) (Figure 8). Their chemical composition were described (Table 7).

Marsalis et. al (2010) and Darby et. al (2002) found out higher yield DM produced (25,5 and 24,8 tons of DM/ha, respectively). Miron (2007) presented a lower value (17,4 tons of DM/ha).

These variations can be caused by temperature and precipitation, once corn requires large amounts of water (up to 770 mm year^{-1}; Al-Kaisi and Yin, 2003, Howell et al., 1995, Howell et al., 1997, Howell et. al, 2008) in order to be high yielding and of adequate nutritional value.

Crude Protein levels, on average, was similar to Kung Jr (2015) and Miron (2007) (7,4% and 5,92%, respectively). The starch concentration was similar to Kung Jr (2015) and Kehoe (2019) and Ballard (2001) (32,8% and 34,4% and 32,5%, respectively).

The NDF was similar to Ballard (2001) and Kung Jr and Colombini et. al (2012) (43,8 % and 40,6% and 39,5%, respectively). For NDFD, Kehoe (2019) found similar levels, as well as Kung Jr. (2015) (56,71% and 60%, respectively).

Corn plants usually have less neutral detergent fiber (NDF) and lignin concentration than sorghum plants and increased ruminal *in vitro* NDF digestibility (ivNDFD) 30h. Besides, chemical composition variations in literature are not so large compared to sorghum.

In general, key aspects present small differences between them. The DM yield variation was essential to corroborate the importance of the weather (Figure 6) and its effects. Our summer-crop was damaged by southern leaf blight, due to a suitable environment for their growth, obtaining lower quality than spring-crop (Figure 9).

Conclusion

Sorghum did not present chemical composition differences between seasons, while corn showed better results in the spring. In general, related to yield DM, crops performed better during the spring than summer crop.

Percentually, there were more hybrids with high performance for corn than sorghum, regardless of the season evaluated.

Sorghum is a viable alternative crop to corn for silage production; its benefits are improved in areas with potentially delayed planting due to wet soil, elevated summer temperatures, and mainly drought.

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Table 1.Comparison among three different sources. Adapted from Brouk and Bean (2011).

Item	Grain	Beef NRC[1]	Dairy NRC[2]	Dairy One[3]
Crude Protein (%)	Sorghum	12.60	11.60	10.53
	Corn	9.80	9.40	9.20
Acid Detergent Fiber	Sorghum	6.38	5.90	7.90
	Corn	3.30	3.40	3.63
NEm[4], Mcal/lb	Sorghum	0.91	0.88	0.96
	Corn	1.02	0.93	1.00
NEg[5] , Mcal/lb	Sorghum	0.61	0.59	0.65
	Corn	0.70	0.63	0.69
NEl[6], Mcal/lb	Sorghum	---	0.82	0.91
	Corn	---	0.87	0.94
Ash, %	Sorghum	1.87	2.00	1.92
	Corn	1.46	1.50	1.55

[1] Nutrient Requirements of Beef Cattle, 1996

[2] Nutrient Requirements of Dairy Cattle, 2001

[3] Dairy One Forage Laboratory, 2010

[4] Net Energy of Maintenance

[5] Net Energy of Gain

[6] Net Energy of Lactation

Table 2. Quality parameters of BMR and non-BMR sorghums and corn grown in Bushland (Bean et al. 2001).

Type	CP (%)	ADF (%)	NDF (%)	Lignin (%)	IVTD (%)
BMR	9.2	27.6	45.9	3.6	81.3
Range	6.9-10.5	24.3-35.0	40.7-60.1	2.8-4.5	75.1-84.2
Non-BMR	8.3	29.9	49.1	4.4	75.5
Range	6.3-10.8	21.3-41.7	33.9-67.5	2.7-6.4	60.9-83.6
Corn	9.0	23.9	41.2	3.5	82.7

Table 3.List of corn hybrids.

Variety #	Company	Variety ID
1	Augusta Seed	A1165VT2PRORIB
2	Augusta Seed	A7768GT3110
3	Augusta Seed	A1367GT3220
4	Augusta Seed	A7668GT3110
5	Augusta Seed	TMF17W95
6	Augusta Seed	TMF14L46
7	Augusta Seed	TMF14R77
8	Augusta Seed	TMF15H86
9	Augusta Seed	Not described
11	AgraTech	998VIP
12	AgraTech	909VIP
13	AgraTech	1778VIP
14	AgraTech	1024VIP
15	AgraTech	749VT29
16	AgraTech	85VT2P4
17	AgraTech	608VIP
18	Pioneer	P1662YHR
19	Pioneer	P1847AML
20	Pioneer	1870YHR
21	Masterchoice	MCT6552
22	Masterchoice	MCT6653
23	Masterchoice	MCT6733
24	Croplan Genetics	5700VT2P
25	Croplan Genetics	55900VT2P
26	Dynagro	D58QC72
27	Dynagro	D55QC73
28	Dynagro	D585565
29	Dynagro	D55VC45
30	Terral Seed	REV25BHR26
31	Terral Seed	REV28BHR18
32	Terral Seed	REV25BHR89

33	Terral Seed	REV27BHR79
34	Monsanto	DKC67-99
35	Monsanto	DKC66-29
36	Monsanto	DKC68-69
37	Syngenta	NK1694-3111
38	Syngenta	NK1808-3111

Table 4. List of sorghum hybrids.

Variety #	Company	Variety ID	Type
1	Moss Seed	4EverGreen	Forage
2	Moss Seed	MeganGreen	Sudangrass
3	Moss Seed	MeganGreenBMR	Sudangrass
4	Sorghum Partners	SP45555 BMR	Sudangrass
5	Sorghum Partners	NK300	Forage
6	Sorghum Partners	SS304	Forage
7	Sorghum Partners	SPx56216BMR	Forage
8	Sorghum Partners	SP2876BMR	Forage
9	Sorghum Partners	SP38085B BMR	Forage
10	Advanta Seed	Alta AF7401	Forage
11	Advanta Seed	Alta AF8301	Forage
12	Advanta Seed	Alta XF372	Forage
13	Advanta Seed	Alta XF033	Forage
14	Advanta Seed	F 6504	Forage
15	Dynagro	FX 18311	Forage
16	Dynagro	FX18340	Forage
17	Dynagro	FX18130	Forage
18	Dynagro	F76FS77BMR	Forage
19	Dynagro	705F	Forage
20	Dynagro	FX18878	Forage
21	Dynagro	FX18851	Forage
22	Dynagro	F74FS23BMR	Forage
23	Dynagro	FX18317	Forage
24	Dynagro	FX18811	Forage
25	Dynagro	SuperSilo30	Forage
26	Dynagro	SuperSilo20	Forage
27	Dynagro	F73FS10	Forage
28	Dynagro	Danny BoyBMR	Sudangrass
29	Dynagro	FX1884	Sudangrass
30	Dynagro	Fmllgraze BMR	Sudangrass
31	Dynagro	FX 18835	Sudangrass

32	Dynagro	Dual ForageSCA	Both purpose
33	Dynagro	6X 16921	Both purpose
34	Dynagro	FX18152	Forage

Table 5. Spring and summer forage sorghum chemical composition from 2018

Hybrid	Dry Tons/hectare	CP %	NDF %	NDF digestibility %	Starch %
SPRING					
SS304	23,87	8,09	44,66	37,09	22,55
SP38085BMR	17,09	8,83	54,74	52,92	9,95
Alta AF7401	18,75	9,33	50,29	47,41	15,91
Alta XF372	17,86	9,99	48,22	44,43	18,55
F73FS10	18,05	10,62	38,51	23,75	32,37
SUMMER					
SS304	15,92	9,18	50,03	41,05	15,03
SP2876BMR	10,15	10,15	46,09	40,16	18,68
FX 18311	10,95	9,36	47,87	40,09	17,89
F76FS77BMR	10,09	11,56	49,09	48,74	17,91

Table 6. Yield and nutritive value of sorghum. Hay&Forage Grower (2017)

Item	**Forage Sorghum**	
	Spring	**Summer**
DM yield, ton/ hc	21,45	14,85
NDF, % of DM	55,9	56,3
NDFD, % of DM	52,9	48,5
Starch, % of DM	17,3	14,1

Table 7. Spring and summer corn chemical composition from 2018

SPRING					
Hybrid	Dry tons/ha	CP %	NDF %	NDFD %	Starch %
A1165VT2PRORIB	23,1	8,2	36,4	59,6	40,7
A7768GT3110	23,3	7,8	39,9	57,3	36,5
A1367GT3220	22,8	8,3	39,7	60,3	34,9
A7668GT3110	23,9	7,7	39,1	58,9	38,1
749VT29	23,3	8,5	40,1	59,1	35,7
85VT2P4	25,3	7,7	38,3	55,8	39,4
608VIP	22,2	8,3	39,1	58,5	36,8
55900VT2P	25,3	8,2	40,5	53,2	34,7
D58QC72	24,4	7,6	40,0	55,9	36,8
D585565	22,5	7,6	38,3	55,8	39,6
DKC66-29	22,8	7,3	38,0	56,0	40,5
DKC68-69	23,3	7,9	39,8	59,7	37,5
SUMMER					
A1367GT3220	17,0	9,0	37,4	52,5	37,6
1024VIP	17,0	9,7	44,7	48,5	27,0
749VT29	17,8	8,3	37,3	52,0	39,0
MCT6733	17,0	8,8	41,0	50,6	34,5
REV25BHR26	18,1	10,1	40,1	49,8	31,7
REV25BHR89	17,0	10,4	43,4	51,3	26,7
DKC66-29	17,8	8,7	42,9	51,6	31,6
NK1808-3111	17,0	9,0	42,1	51,4	32,5

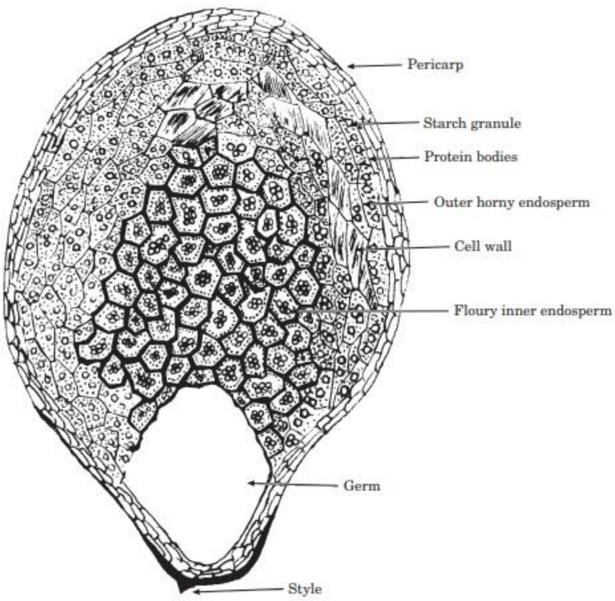


Figure 1.Cross-section of sorghum grain. (Chandrashekar et al.,1999).

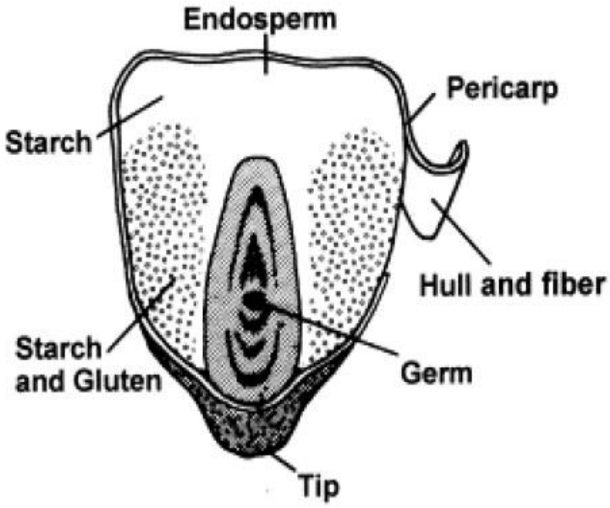


Figure 2. Cross-section of corn kernel. (Shukla and Cheryan, 2001).

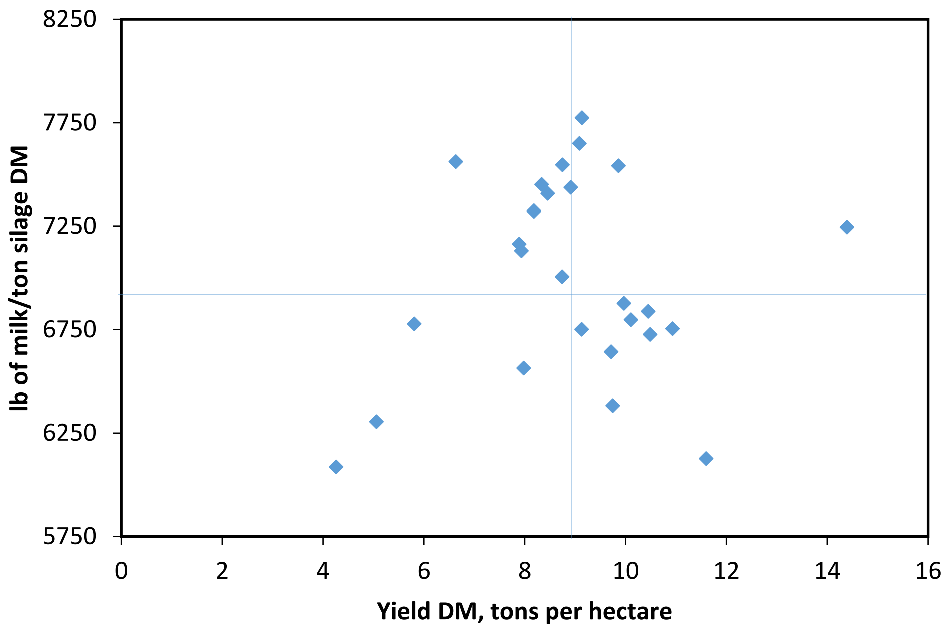


Figure 3.High-Performance Summer Sorghum Hybrids

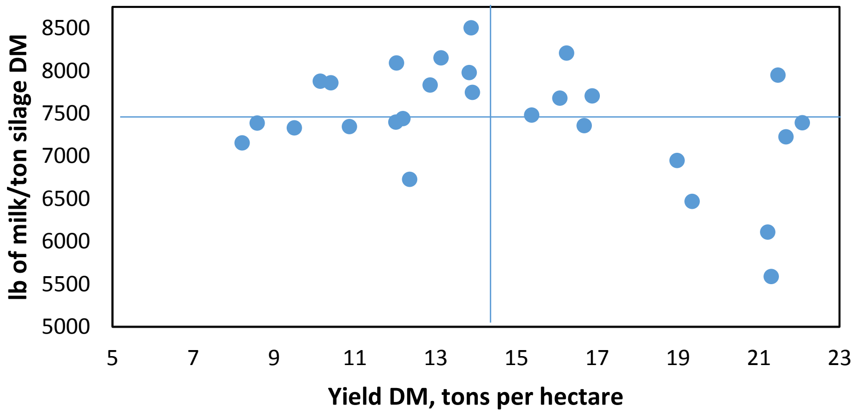
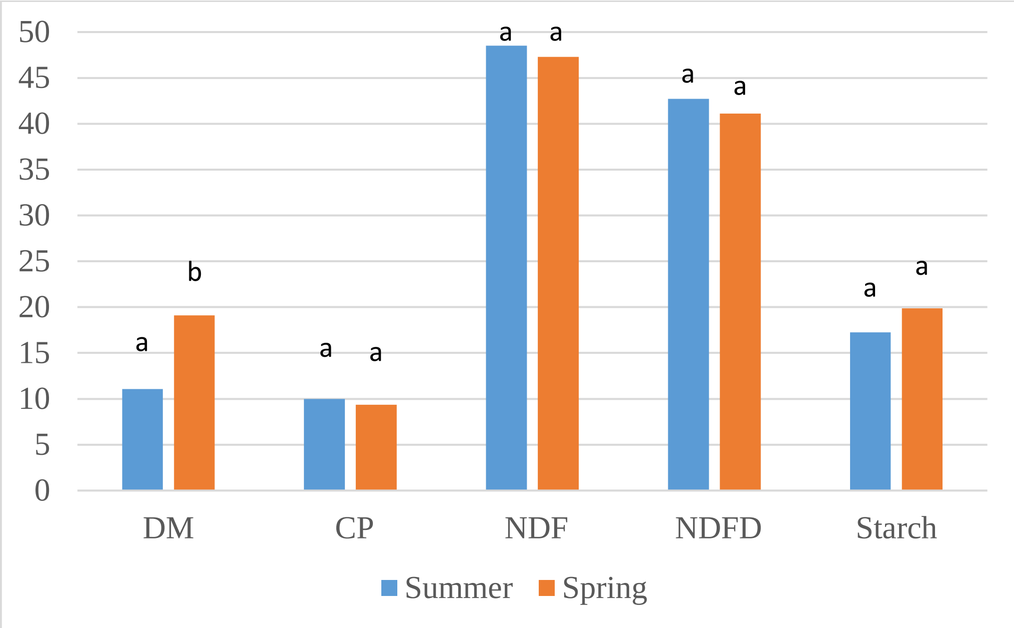


Figure 4 High-Performance Spring Sorghum Hybrids



DM: P value < 0.001; CP: P value = 0.107; NDF: P value = 0.521; NDFD: P value = 0.829 and Starch: P value = 0.139

Figure 5. Yield (tons/hectare) and Chemical composition (%) for sorghum

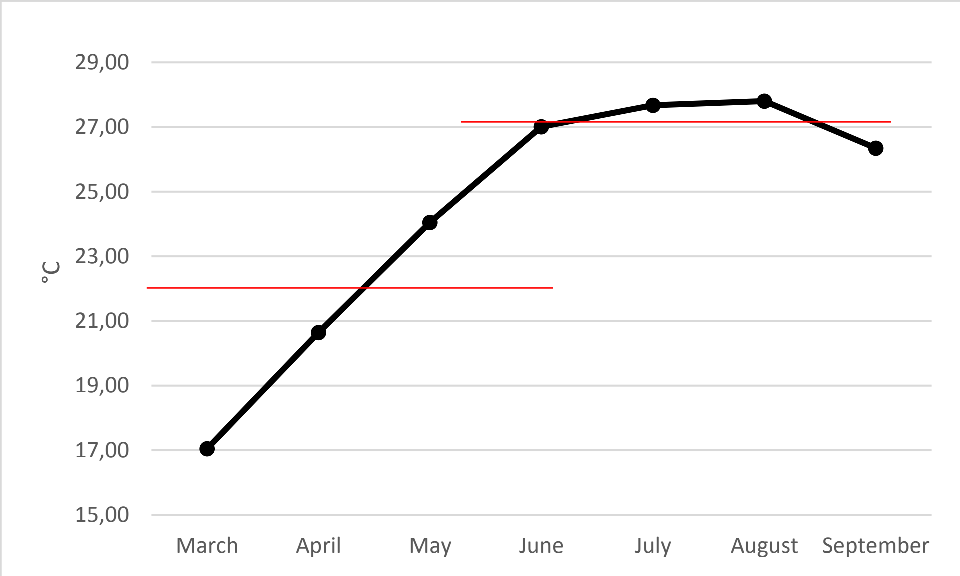


Figure 6. Weather History Citra, 2007 to 2018. U.S climate data (2019)

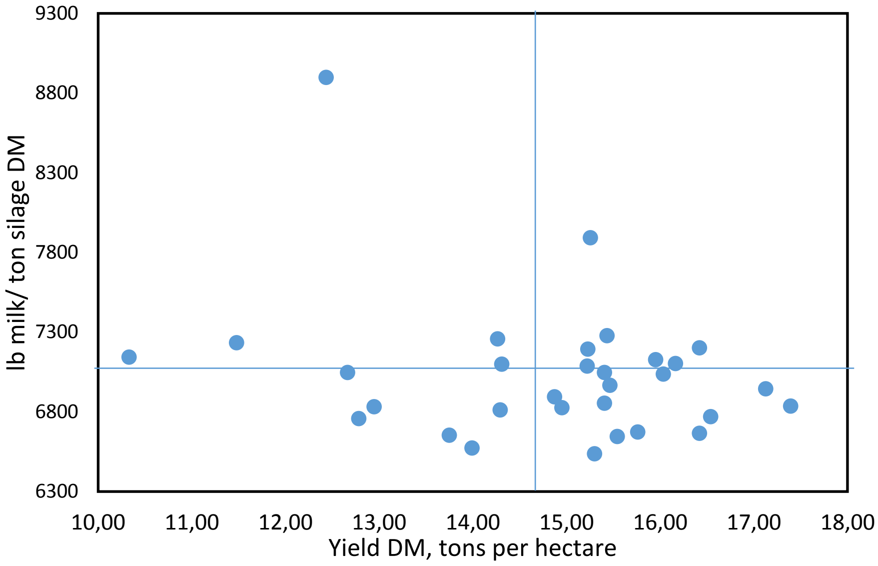


Figure 7. High-Performance Summer Corn Hybrids

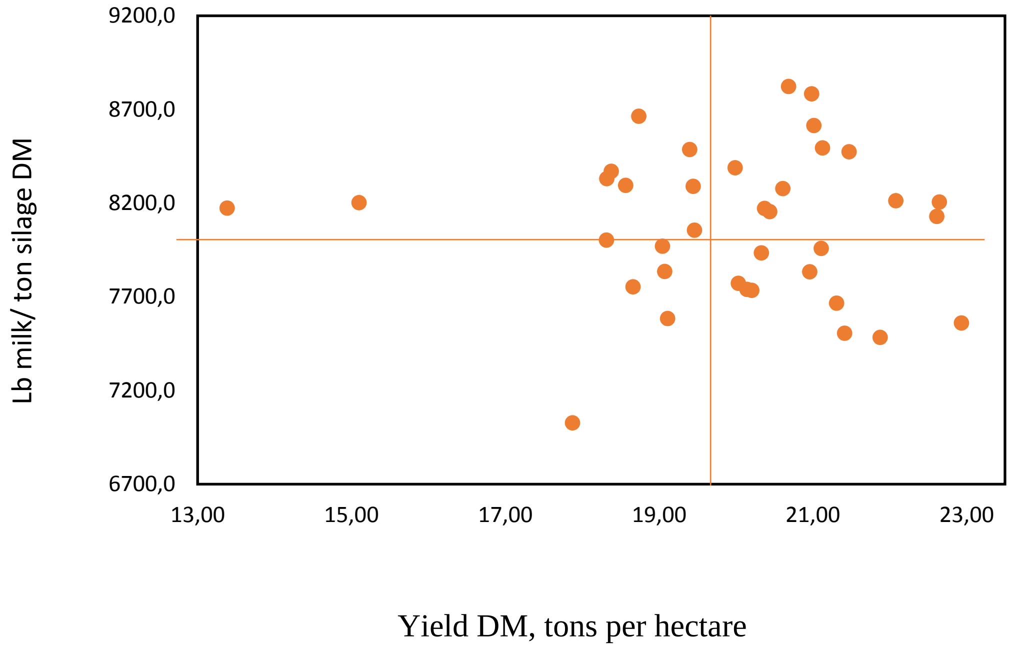
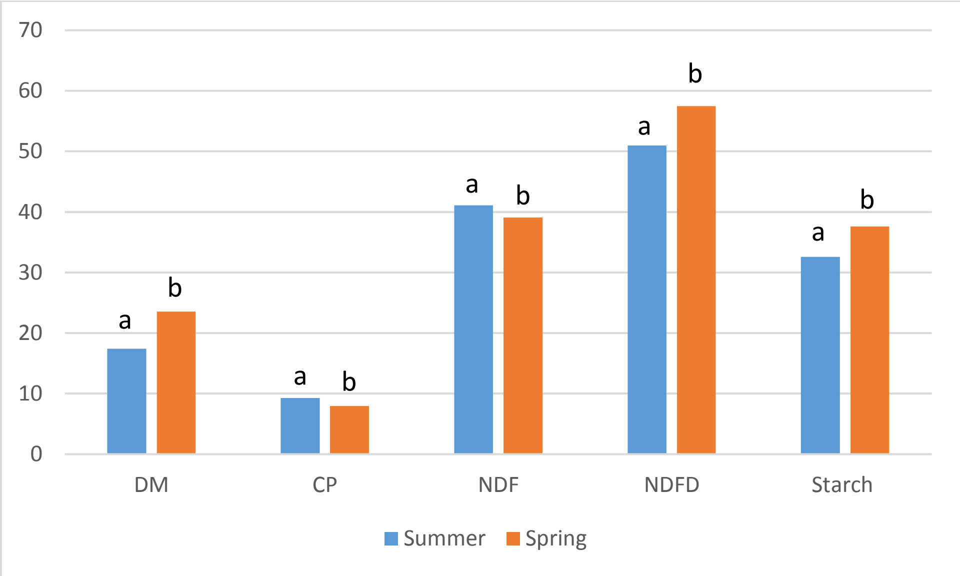


Figure 8. High-Performance Spring Corn Hybrids



DM: P value < 0.001; CP: P value < 0.001; NDF: P value = 0.023; NDFD: P value < 0.001 and Starch: P value < 0.001

Figure 9. Yield (tons/hectare) and Chemical composition (%) for corn