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Forage yield, nutritive value, and ensilability of sweet pearl millet and sweet sorghum in five Canadian ecozones

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Abstract: Sweet pearl millet [Pennisetum glaucum (L.) R. Br.] and sweet sorghum [Sorghum bicolor (L.) Moench], previously tested for ethanol production, were evaluated as high sugar crops for animal feeds to possibly replace silage corn (Zea mays L.). We compared the forage yield, nutritive value, and ensilability of one hybrid of sweet pearl millet and two of sweet sorghum to a locally-adapted silage corn hybrid in five Canadian ecozones. Forage yields of sweet pearl millet and sorghum were similar to that of silage corn in Boreal Shield, Mixedwood Plain, and Atlantic Maritime ecozones, greater in the Prairies and lower in the Pacific Maritime ecozone. Across sites, forage DM concentration was less for sweet pearl millet (289 g kg⁻¹) and sweet sorghum (245 g kg⁻¹) than for silage corn (331 g kg⁻¹). Sweet pearl millet had lower total digestible nutrient (TDN) concentration (452 g kg⁻¹ DM) and NDFd than sweet sorghum and silage corn along with greater aNDF and WSC concentrations than silage corn. Sweet sorghum had greater neutral detergent fibre (aNDF) and water soluble carbohydrate (WSC), lower starch, and similar TDN (534 g kg⁻¹ DM) concentrations but greater aNDF digestibility (NDFd) as compared with silage corn. Sweet pearl millet and sorghum fermented as well as silage corn, reaching low pH values and acceptable concentrations of lactic and volatile fatty acids. Sweet sorghum is therefore a viable alternative to silage corn in Canada except in the Pacific Maritime ecozone, but early-maturing hybrids with acceptable DM concentration at harvest are required.

Key words: Sweet sorghum, sweet pearl millet, silage corn, forage, nutrients.

INTRODUCTION

Silage corn is widely used by dairy farmers because of its high yield and energy value in feed rations. In Canada, 75% of silage corn is produced in Quebec, Ontario, British Columbia, Alberta, and Nova Scotia (Statistics Canada 2016), five provinces that together account for approximately 90% of Canada’s dairy production (Canadian Dairy Information Centre 2016).
Because of its high N requirement and low N utilization efficiency, production of silage corn presents a risk of N losses to the environment (Drury et al. 2014). Also corn is increasingly more susceptible to dry conditions (Lobell et al. 2014). Alternative crops are needed for dairy feed that are more drought tolerant and sustainable than silage corn. Because of the likely increase in the frequency of drought events with global warming, and because of the public interest in environmental protection, it seems appropriate to find potential alternatives to silage corn.

Pearl millet and sorghum are annual forage grasses known for their greater resistance to drought and their tolerance to soils with low organic matter (Andrews and Kumar 1992; Bidinger and Hash 2004) as well as for their high N and water use efficiencies (Singh and Singh 1995; Schittenhelm and Schroetter 2014; Thivierge et al. 2015b). These two species have, therefore, valuable characteristics that could be helpful in dealing with certain consequences of global warming, such as increased average temperatures and the heterogeneous distribution of annual precipitations (do Nascimento et al. 2005; Thivierge et al. 2015b).

Sweet pearl millet and sweet sorghum are hybrids developed to contain more fermentable sugars than standard forage types for use in ethanol production. These hybrids can have dual purpose since the press residues (bagasse) from the ethanol industry are suitable as animal feed (dos Passos Bernardes et al. 2016). Whole plants of sweet pearl millet and sweet sorghum could also be used as animal feed because their high sugar concentration contributes to high levels of total digestible nutrients (TDN), that are beneficial in dairy production (do Nascimento et al. 2005; Amer et al. 2012).

Recent studies conducted in Quebec reported forage dry matter (DM) yields for both sweet pearl millet (10 to 20 Mg ha\(^{-1}\); Bouchard et al. 2011; Leblanc et al. 2012; dos Passos Bernardes et al. 2016) and sweet sorghum (16 to 19 Mg ha\(^{-1}\); Thivierge et al. 2015a; dos Passos Bernardes et
al. 2016) that are comparable to the average DM yields of silage corn in Québec (12.9 to 18.9 Mg ha\(^{-1}\); La Financière agricole 2018). The nutritive value of sweet pearl millet and sweet sorghum has not been widely studied. Recent studies conducted in eastern Canada (Bouchard et al. 2011; Amer et al. 2012; Bélanger et al. 2018) reported greater fibre and lower total N concentrations for sweet pearl millet and sweet sorghum when compared with recommended average concentrations for a silage corn hybrid (National Research Council 2001), suggesting a lower potential for milk production. In contrast, the same studies indicated greater \textit{in vitro} neutral detergent fibre digestibility (NDFd) in sweet pearl millet and sweet sorghum, indicating greater fibre digestibility than in silage corn. However, no studies have compared the yield and nutritive value of sweet pearl millet, sweet sorghum, and silage corn under the same growing conditions in Canada. The objective of this study was, therefore, to determine whether sweet pearl millet and sweet sorghum are viable alternatives to silage corn, in terms of yield, nutritive value, and ensilability for feeding dairy cows in five contrasting Canadian ecozones.

**MATERIALS AND METHODS**

**Description of sites and treatments**

This study was carried out at five experimental sites located in Canadian ecozones where silage corn is grown for dairy feed: 1) Agassiz, BC, Pacific Maritime (lat. 49°14′N, long. 121°45′W); 2) Lethbridge, AB, Prairies (lat. 49°42′N, long. 112°45′W); 3) Saint-Augustin-de-Desmaures (referred to hereafter as St-Augustin), QC, Boreal Shield (lat. 46°43′N, long. 71°31′W); 4) Sainte-Anne-de-Bellevue (referred to hereafter as Ste-Anne), QC, Mixedwood Plain (lat. 45°25′N, long. 73°55′W); and 5) Kentville, NS, Atlantic Maritime (lat. 45°04′N, long. 64°28′W).
The experiment was conducted over two growing seasons (2015 and 2016) on different plot areas each year; year was considered as a random factor. The treatments were replicated four times in a randomized complete block design. The treatments consisted of a locally-adapted silage corn hybrid as control, a sweet pearl millet hybrid, and two sweet sorghum hybrids with the BMR (“brown midrib”) genetic mutation from two different regions (Europe and North America) grown under rain-fed conditions.

The sweet pearl millet hybrid (CSSPM7) was developed by AERC Inc. (Delhi, ON). One of the sweet sorghum hybrids (BMR1) was developed in France as X15-06 and the second (BMR2) was developed in the USA as SM#1 (sterile male, catalogue number 327 X 36; Richardson Seeds, Vega, TX). At Lethbridge, only the European BMR sweet sorghum hybrid (BMR1) was tested. Standard, non-BMR, locally-adapted silage corn hybrids were seeded at each site. The seeding dates are reported in Table 1. Silage corn was planted earlier than the other species due to its lower soil temperature tolerance. Minimum soil temperatures for planting and germination are 6 °C for silage corn and 10 to 12 °C for sweet pearl millet and sweet sorghum. In 2016, the silage corn had to be reseeded in Kentville 12 d after sweet pearl millet and sweet sorghum. Silage corn was seeded at an average depth of about 5 cm and a row spacing of 76 cm, for a plant density of 75 000 to 105 000 plants ha\(^{-1}\). Sweet pearl millet and sweet sorghum were seeded at a rate of 15 kg ha\(^{-1}\) and 10 kg ha\(^{-1}\), respectively, at a seeding depth of 1.5 to 2.0 cm, and at a row spacing of 18 cm.

At four sites, part of the N requirements were met with cattle slurry applied in the fall preceding seeding (2014 and 2015) in order to supply about 50 kg available N ha\(^{-1}\) to the crops in the next growing season. At Agassiz, however, cattle slurry was applied 2 to 3 wks before seeding in the spring of 2015 and 2016 according to local practices. The manure was incorporated by ploughing or disk ing to a depth of 15-20 cm at all sites. In 2015 and 2016, silage corn received an
additional 35 to 100 kg N ha\(^{-1}\) as mineral fertilizer in accordance with local recommendations, taking into account the 50 kg of available N provided by the cattle slurry and assuming no losses. Sweet pearl millet and sweet sorghum received 65-75\% of the amount of mineral N fertilizer applied to silage corn. At Agassiz for example, sweet pearl millet and sorghum received 80 kg mineral N ha\(^{-1}\) which represented 65\% of the amount of mineral N fertilizer applied to silage corn. Half of the mineral N fertilizer was applied at seeding, and the rest at the five-to-six-leaf stage of corn and at tillering of sweet sorghum and sweet pearl millet. At Kentville, mineral N was only applied at seeding because of the low mineral N application rate (35 kg N ha\(^{-1}\)). Phosphorus and potassium requirements were met in accordance with soil analyses and current recommendations for corn at each site. At all sites, the plots were tilled with a vibocultivator or a disc harrow before seeding. For controlling broadleaf weeds, sweet pearl millet and sweet sorghum were treated with the herbicide Basagran Forte (active ingredient: bentazon; isopropyl-3 1 H,3 H-benzothiadiazin-2,1,3 one-4 dioxide-2,2) at a rate of 1.08 kg active ingredient ha\(^{-1}\) at the three- to six-leaf crop stage. The corn hybrids at all sites were Roundup Ready\(^{\circledR}\) and were treated by hand with glyphosate [N-(phosphonomethyl)glycine] at a rate that varied depending on the site and the weed development stage. Additional weeding was performed by hand when required, especially for the sweet pearl millet and sweet sorghum.

**Data collection and laboratory analyses**

**Environmental conditions**

Soil characteristics were determined at the beginning of the study. At each site, soil cores were randomly taken prior to seeding to a depth of 15 cm and pooled to make three composite samples. Soil samples were air-dried and sieved to 2 mm prior to analysis. Soil pH was measured
in a 1:1 soil:water ratio (Hendershot et al. 1993). The total organic carbon concentration was determined by dry combustion (Model TruMac, Leco Corp., Loveland, CO). Soil phosphorus and potassium were extracted following the Mehlich III method (Tran and Simard, 1993) and determined by inductively coupled plasma optical emission spectrometry (Optima 4300 DV, PerkinElmer Corp., Norwalk, CT). The characteristics of the soils at each site are presented in Table 1. The long-term average precipitation, cumulative growing degree-days, and corn heat units (CHU) are presented in Table 2.

**Forage sampling and yield determination**

Each treatment (crop) was replicated four times in a randomized complete block design. The plot size varied among sites but was a minimum of 9.72 m$^2$. Crop samples were taken on five occasions during crop growth on a minimum surface area of 0.36 m$^2$ to document the phenology of all crops at each site for crop growth modelling purposes (data not shown). A last forage sampling of all crops was made when silage corn reached a DM concentration of approximately 350 g kg$^{-1}$. At that time, because of the four previous forage sampling times in each plot and to avoid any edge effect, the sampling area comprised one central row of 1 to 2 m in length, excluding 1 to 2 m from the plot edges. At this harvest, silage corn was at the R5-R6 stage (dent-black layer; Ritchie et al. 1993), sweet pearl millet at stage 7-8 (milk-dough; Maiti and Bidinger 1981), and sweet sorghum at stage 7 (soft dough; Vanderlip 1993). Developing grains were observed on the sterile BMR sorghum hybrid (BMR2). Harvesting was performed manually by cutting the plants at a 5-cm height. All the harvested plants from each plot were weighed to determine yield and then chopped with shears or a corn chopper. A 500-g sample was then collected and dried for 72 h at 55°C for determination of DM concentration. After drying, the sample was ground to 1 mm in a
Wiley mill (Standard Model 4; Arthur H. Thomas Co., Philadelphia, PA) for subsequent laboratory analysis.

**Forage nutritive value**

All forage samples from the first sampling year of the study (2015) were scanned by visible and near-infrared reflectance spectroscopy (VNIRS) using a VNIRS DS2500 monochromator instrument (Foss NIRSystems Inc., Silver Spring, MD) in a wavelength interval from 400 to 2500 nm. By means of the WinISI 4 software program (version 4.5.0.14017; Infrasoft International LLC, State College, PA), a group of calibration samples (n = 60) and a group of validation samples (n = 15), as well as certain outlier samples with a spectrum too different from the average spectrum of the overall population (n = 6), were identified. Forage samples collected in the following year (2016) were also scanned with the VNIRS spectrometer. The 2016 spectrum population was then compared with the 2015 sample population, and the two sample populations were deemed comparable. To obtain robust VNIRS prediction equations, a calibration set (n = 7) and a validation set (n = 15) of samples, plus 2 outlier samples were selected from the 2016 population using the WinISI 4 software program and added to the 2015 calibration and validation sets of samples.

A total of 105 forage samples (81 from 2015 plus 24 from 2016) were therefore chemically analyzed for concentrations of neutral detergent fibre assayed with a heat stable α-amylase and sodium sulfite (aNDF; Mertens, 2002) and ADF (method 973.18; AOAC, 1990) using an ANKOM220 Fibre Analyzer (ANKOM Technology 05/03, Macedon, NY) with F57 filter bags (25-μm porosity). The *in vitro* true digestibility of DM (IVTD) was determined using the Goering and Van Soest (1970) method with a 48-h incubation in buffered rumen fluid. This analysis was
followed with the determination of aNDF concentration of the post-digestion residues. The incubation was done with an ANKOM Daisy II incubator, using the F57 filter bags and the batch incubation procedures of ANKOM Technology Corp. The rumen fluid was taken from two ruminally fistulated dairy cows fed the same diet constituted of 37% grass silage, 15% corn silage, 8% hay, 30% corn grain, and 10% concentrate mix. This diet was formulated to meet the nutritional requirements of a lactating dairy cow expected to produce 10,200 kg milk yr⁻¹, according to NRC (2001). Each sample was analyzed in duplicate, with a 5% maximum coefficient of variation between duplicates. The IVTD (g kg⁻¹ DM) and the NDFd (g kg⁻¹ aNDF) were calculated as follows:

\[
\text{IVTD (g kg}^{-1}\text{ DM)} = \left[1 - \left(\frac{W3 - (W1 \times C1)}{W2 \times DM}\right)\right] \times 1000
\]

\[
\text{NDFd (g kg}^{-1}\text{ aNDF)} = \left[1 - \left(\frac{W3 - (W1 \times C1)}{W2 \times DM \times \left(\frac{\text{aNDF}}{100}\right)}\right)\right] \times 1000
\]

where \(W1\) = weight of the empty bag; \(W2\) = weight of the sample; \(W3\) = weight of the bag after NDF digestion; \(C1\) = blank bag correction; \(DM\) = dry matter concentration of the sample.

To determine total N concentration, 0.1 g of each sample was mineralized using a block digester (Digestor 2520; FOSS, Hillerød, Denmark) in accordance with the method of Isaac and Johnson (1976). The solution obtained was then analyzed for total N concentration by a continuous-flow analyzer with automatic injection (QuikChem 8500 Series 2 FIA System, Lachat Zellweger Analytics, Milwaukee, WI) in accordance with method 13-107-06-02-E (Lachat Instruments 2016).

To extract water soluble carbohydrates (WSC), 0.1 g of forage sample was soaked in 25 mL of distilled water for 60 min and the solution was filtered through a Whatman No. 2 filter paper. The final volume of the liquid fraction was adjusted to 45 mL and five mL of 1 N sulfuric acid (\(H_2SO_4\)) was added to the filtrate; the mixture was heated in a water bath at 100 °C for 15 min.
(Suzuki 1971). The WSC were then measured with a spectrophotometer at 415 nm and using a \( p \)-hydroxybenzoic acid hydrazide (PABAH) solution (Blakeney and Mutton 1980).

Starch concentration was determined using 0.25 g of ground material. The material was washed three times with ethanol 80%, heated to 60 °C, and centrifuged at 2000 g, and the resulting pellet was then left to air dry overnight. The next day, the samples were diluted in distilled water and heated to 100 °C in order to gelatinize the starch. The starch was hydrolyzed in an alkaline solution (acetate buffer) containing amylglucosidase (75.12%). The starch concentration of the samples were then measured by a spectrophotometer at 415 nm and using a PABAH solution (Blakeney and Mutton 1980). Crude fat (ether extract) was determined using the Ankom xt15 extractor technology method (American Oil Chemists’ Society, 2003). Dry matter and ash concentrations were determined by thermogravimetry (Leco Corporation, 2009) using an auto-analyser (model TGA701, Leco Corporation, St. Joseph, MI, USA).

Using total N, aNDF, NDFd, starch, and crude fat chemically determined values, and the Excel spreadsheet MILK2006 produced by the University of Wisconsin (Shaver et al. 2006), forage concentration of total digestible nutrients (TDN) was calculated based on NRC (2001) for all chemically analyzed forage samples. Total digestible nutrients are a summation of four nutritive attributes, namely, non-fibre carbohydrates, crude protein (total N \( \times 6.25 \)), fatty acids, and aNDF, multiplied by their respective digestibility.

The modified partial least squares regression method of the WinISI IV software was used to develop a VNIRS calibration equation for each forage nutritive attribute. These equations were then validated using the validation set that includes some 2015 and 2016 samples (\( n = 30 \)). Statistics on the performance of VNIRS equations to predict concentrations of various nutritive attributes in forage samples of the validation set are presented in Table 3. The ratio of prediction
to deviation (RPD), equals to the standard deviation of samples in the validation set (SD) divided by the standard error of prediction corrected for the bias [SEP(C)], was greater than 3 for all nutritive attributes, and thus the prediction equations can be considered valid (Malley et al. 2004).

**Ensilability**

The ensilability of sweet pearl millet, sweet sorghum, and silage corn at harvest time was determined in 2016 at the St-Augustin and Ste-Anne sites as per the method described by Tremblay et al. (2014). Briefly, after the forage from the harvest zone had been ground with a corn chopper, a sufficient quantity of representative material from each plot was used to fill one PVC mini-silo per plot. The mini-silos were 25 cm long with an inner diameter of 7.5 cm. To compact the material, 1200 kPa of pressure was applied to the forage with a hydraulic press. The mini-silos were closed and kept at room temperature (20-23 °C) for 90 d. After this fermentation period, the mini-silos were opened and a silage sample (1/3 of the silo) was stored at −20 °C until analyzed for pH, lactic acid, and volatile fatty acids according to Tremblay et al. (2014).

The pH was measured using an Accumet AR25 pH meter (Fisher Scientific, Fair Lawn, NJ) on 20 g of fresh silage mixed with 200 mL of distilled water. The mixture was then allowed to stand for 24 h at 4 °C, with occasional agitation, for the measurement of lactic acid and volatile fatty acids by ion chromatography using a Dionex ICS-2000 system equipped with an IonPac AS11-HC/AG11-HC column (Dionex Inc., Sunnyvale, CA).

**Statistical analyses**

The data were analyzed using the PROC MIXED procedure of the SAS software package (SAS Institute Inc., Cary, NC) with sites and treatments (crops) as fixed factors, and years as a
random factor. The homogeneity of variance of the residuals was checked visually using the graphs obtained with PROC GPLOT, and the normality of the residuals was checked using the kurtosis, skewness, and Shapiro-Wilk statistical tests, obtained with PROC UNIVARIATE. The raw data did not need any transformations, and the type I error was set at 0.05. The site × treatment (crops) interaction was significant ($P < 0.001$) for each of the attributes, with the exception of NDFd and WSC (Table 4). The data were therefore reanalyzed by site.

RESULTS AND DISCUSSION

Forage yields

The DM yield of silage corn (17.1 Mg DM ha$^{-1}$) was greater than those of sweet pearl millet and the two sweet sorghum hybrids (average of 11.7 Mg DM ha$^{-1}$) at Agassiz, whereas at Kentville, the DM yield of silage corn (15.5 Mg DM ha$^{-1}$) was greater than that of the BMR1 sweet sorghum hybrid (10.6 Mg DM ha$^{-1}$) but not of the sweet pearl millet and BMR2 sweet sorghum hybrids (Fig. 1A). At Lethbridge, however, the DM yield of silage corn was the lowest (15.8 Mg DM ha$^{-1}$), while that of sweet pearl millet was the highest (34.3 Mg DM ha$^{-1}$). The high DM yields of sweet pearl millet and sweet sorghum at Lethbridge compared to that of silage corn can be partly explained by the observations made by Singh and Singh (1995) as well as by Farré and Faci (2006), who concluded that the greater the water stress, the greater the decrease in corn yield in comparison with the yields of forage pearl millet and forage sorghum. Precipitations between seeding and harvesting at Lethbridge were just over half the amount received at the other sites for sweet pearl millet and sweet sorghum (168 vs. 284 mm on average for 2015 and 2016), and for silage corn (197 vs. 328 mm on average for 2015 and 2016) (Table 2).
Sweet pearl millet, the two sweet sorghum hybrids, and silage corn had similar DM yields within sites at St-Augustin and Ste-Anne. At those two sites, the DM yields of sweet pearl millet (Fig. 1A) were within the range of those reported in previous studies (13.6 to 20.4 Mg DM ha\(^{-1}\)) conducted at the same sites and with the same hybrid (Bouchard et al. 2011; Leblanc et al. 2012; Thivierge et al. 2015\(^a\); dos Passos Bernardes et al. 2015). In some of those studies, however, the DM yield of sweet pearl millet was greater than that of sweet sorghum (Thivierge et al. 2015\(^a\); dos Passos Bernardes et al. 2015). Climate variations as well as soil conditions specific to each site may have contributed to the variation in DM yield among sites. These results from five sites across Canada indicate that, in terms of DM yield, sweet pearl millet and sweet sorghum are promising alternatives to silage corn, except at Agassiz.

**Forage dry matter concentration**

Silage corn DM concentration at harvest varied from 260 to 380 g kg\(^{-1}\) depending on the site with an average across sites of 330 g kg\(^{-1}\) (Fig. 1B; Supplementary Table S1), which is close to our objective of harvesting all crops when silage corn reached a DM concentration of approximately 350 g kg\(^{-1}\). Within sites at Lethbridge, St-Augustin, and Ste-Anne, the DM concentrations of sweet pearl millet, sweet sorghum, and silage corn differed significantly but there was no difference between the sweet sorghum hybrids at the two latter sites (Fig. 1B). Average DM concentration across those three sites were 331 g kg\(^{-1}\) for silage corn, 289 g kg\(^{-1}\) for sweet pearl millet, and 245 g kg\(^{-1}\) for the sweet sorghum hybrids. At Agassiz, the silage corn DM concentration (296 g kg\(^{-1}\)) was not statistically different from the sweet pearl millet DM concentration (264 g kg\(^{-1}\)), but significantly greater than the two sweet sorghum hybrids (average
of 222 g kg\(^{-1}\)). Kentville was the only site where sweet pearl millet had a greater DM concentration (300 g kg\(^{-1}\)) than silage corn (260 g kg\(^{-1}\)) which was seeded very late in one year (Table 1).

One of the conditions required for ensiling forage is that it must have a DM concentration of 280 to 350 g kg\(^{-1}\) for storage in a bunker silo (Salfer and Linn 1992; Valacta 2017) and 300 to 500 g kg\(^{-1}\) for an unsealed tower silo (Bagg 2013). Low DM concentrations promote fermentation by *Clostridia* and the occurrence of butyric acid that reduces the palatability of the forage along with increasing the risks of seepage, whereas high DM concentrations lead to the development of moulds (Bagg 2013). In previous studies in Quebec, average DM concentration was 269 g kg\(^{-1}\) for the same sweet pearl millet hybrid and 249 g kg\(^{-1}\) for different sweet sorghum hybrids (Amer and Mustafa 2010; Amer et al. 2012). Overall, sweet pearl millet had a DM concentration at the time of the silage corn harvest that was close to being suitable for storage in a bunker silo. Nevertheless, the silage potential for sweet sorghum was currently constrained by its low DM concentration across sites of 245 g kg\(^{-1}\).

**Forage fibre concentrations and digestibility**

The forage ADF (Fig. 1C) and aNDF (Fig. 1D) concentrations followed the same trends at all sites in terms of variations among crops. Sweet pearl millet had the highest fibre concentrations (average across sites of 392 g ADF kg\(^{-1}\) DM and 644 g aNDF kg\(^{-1}\) DM), the BMR sweet sorghum hybrids had intermediate values (average across sites of 347 g ADF kg\(^{-1}\) DM and 592 g aNDF kg\(^{-1}\) DM), and silage corn had the lowest concentrations with values across the five sites ranging from 217 to 299 g ADF kg\(^{-1}\) DM and from 395 to 578 g aNDF kg\(^{-1}\) DM (Supplementary Table S1). The two BMR sweet sorghum hybrids had similar ADF and aNDF concentrations except at Ste-Anne. At Lethbridge, the ADF and aNDF concentrations of silage corn and the BMR1 sweet
sorghum hybrid did not differ significantly (averages of 302 g ADF kg\(^{-1}\) DM and 570 g aNDF kg\(^{-1}\) DM).

The values measured in the present study are very similar to those reported by Bouchard et al. (2011) and Bélanger et al. (2018) in Quebec with the same sweet pearl millet hybrid (average of 399 g ADF kg\(^{-1}\) DM and 642 g aNDF kg\(^{-1}\) DM) and similar to values (368 g ADF kg\(^{-1}\) DM and 578 g aNDF kg\(^{-1}\) DM) obtained in Quebec by Amer et al. (2012) with a forage sorghum hybrid and by Bélanger et al. (2018) with a different sweet sorghum hybrid. Acid and neutral detergent fibre concentrations greater than those of silage corn could potentially reduce voluntary DM intake of the sweet sorghum hybrids and sweet pearl millet fed to dairy cattle.

Sweet pearl millet had the lowest IVTD (average of 703 g kg\(^{-1}\) DM) at all sites except at Lethbridge where it did not differ from that of silage corn. The sweet pearl millet IVTD was lower than the value (750 g kg\(^{-1}\) DM) reported by Bélanger et al. (2018), even though they used the same hybrid in St-Augustin and Ste-Anne under similar growing conditions. The earlier harvest date in Bélanger et al. (2018) (stage 6: 50%-75% tassel emergence) than in the present study (stage 7: milk) could explain the differences in IVTD.

Overall, the sweet sorghum hybrids had greater IVTD (average of 820 g kg\(^{-1}\) DM) than silage corn (average of 778 g kg\(^{-1}\) DM), except at St-Augustin where the IVTD of the sweet sorghum hybrids did not differ from that of the silage corn, and at Kentville where the IVTD of the BMR2 sweet sorghum hybrid and silage corn were similar (Fig. 1E). The IVTD values of sweet sorghum were greater than the average of 790 g kg\(^{-1}\) DM reported by Bélanger et al. (2018) in Quebec with another sweet sorghum hybrid. This generally greater DM digestibility (IVTD) of the two sweet sorghum hybrids could be explained by the presence of the BMR gene, which results in a lower lignification. At all sites where the two sorghum hybrids were studied, the BMR1 had a
significantly greater IVTD (average of 834 g kg\(^{-1}\) DM) than the BMR2 sweet sorghum hybrid (average of 803 g kg\(^{-1}\) DM). The BMR1 sweet sorghum is an European hybrid with an enhanced nutritive value, whereas the BMR2 sweet sorghum is an American hybrid that is supposedly sterile to limit lodging, although we observed the presence of some developing grains at the time of harvest. Our results indicate that the genetics of the BMR1 sweet sorghum hybrid differs positively from the genetics of the BMR2 sweet sorghum hybrid in terms of forage DM digestibility.

Silage corn had intermediate NDFd values with an average across sites of 589 g kg\(^{-1}\) aNDF that was significantly greater (Table 4, Fig. 1F) than sweet pearl millet at all sites (Fig. 1F) (average across sites of 529 g kg\(^{-1}\) aNDF). The sweet pearl millet NDFd was very close to results reported by Leblanc et al. (2012) (average of 556 g kg\(^{-1}\) aNDF) and Bouchard et al. (2011) (average of 591 g kg\(^{-1}\) aNDF) with the same sweet pearl millet hybrid grown at St-Augustin and Ste-Anne under similar conditions. Sweet sorghum had NDFd greater than both silage corn and sweet pearl millet at all sites (Fig. 1F), with an average of 706 g kg\(^{-1}\) aNDF across sites. The NDFd of BMR2 sweet sorghum hybrid was numerically lower than with BMR1 sweet sorghum hybrid at all sites where they were both studied but the difference was significant only at Ste-Anne (Fig. 1F). The average NDFd for the BMR1 and BMR2 sorghum hybrids (719 and 690 g kg\(^{-1}\) aNDF, respectively) was greater than the average value of 601 g kg\(^{-1}\) aNDF reported by Bélanger et al. (2018) for sweet sorghum. The difference could possibly be, as for IVTD, explained by the presence of the BMR gene in the sweet sorghum hybrids of the present study. Although it is not ideal to compare BMR sweet sorghum hybrids with non-BMR silage corn, our results suggest that BMR sweet sorghum forage could be as good as non-BMR silage corn or even more digestible for dairy cattle, despite greater ADF and aNDF concentrations.
Forage total N, WSC, and starch concentrations

Silage corn, sweet pearl millet, and the two sweet sorghum hybrids did not differ in total N concentration at Agassiz, St-Augustin, and Ste-Anne (Fig. 2A). At Kentville, silage corn had a significantly greater total N concentration (10 g kg\(^{-1}\) DM) than sweet pearl millet and the two sweet sorghum hybrids (average of 7 g kg\(^{-1}\) DM). At Lethbridge, sweet pearl millet and sweet sorghum had a similar total N concentration (average of 16 g kg\(^{-1}\) DM), which was significantly greater than that of silage corn (11 g kg\(^{-1}\) DM). Total N concentrations from 9 to 14 g kg\(^{-1}\) DM for sweet pearl millet (Bouchard et al. 2011; Leblanc et al. 2012; Bélanger et al. 2018) and from 10 to 19 g kg\(^{-1}\) DM for sorghum (Getachew et al. 2016) or sweet sorghum (Podkówka and Podkówka 2011; Amer et al. 2012; Atis et al. 2012; Bélanger et al. 2018) have been reported.

Considering that the recommended average concentrations for a silage corn hybrid are 280 g ADF kg\(^{-1}\) DM, 450 g aNDF kg\(^{-1}\) DM, and 14 g total N kg\(^{-1}\) DM, as well as a NDFd value of 560 g kg\(^{-1}\) aNDF (National Research Council 2001), our corn silage hybrid was in general considered of good maturity with average values across sites of 267 g ADF kg\(^{-1}\) DM, 500 g aNDF kg\(^{-1}\) DM, 10 g total N kg\(^{-1}\) DM, and a NDFd of 589 g kg\(^{-1}\) aNDF. With average values across sites of 392 g ADF kg\(^{-1}\) DM, 644 g aNDF kg\(^{-1}\) DM, 10 g total N kg\(^{-1}\) DM, and a NDFd of 529 g kg\(^{-1}\) aNDF, sweet pearl millet was considered to have greater fibre concentration, but less fibre digestibility than silage corn. And with average values across sites of 347 g ADF kg\(^{-1}\) DM, 592 g aNDF kg\(^{-1}\) DM, 9 g total N kg\(^{-1}\) DM, and a NDFd of 706 g kg\(^{-1}\) aNDF, sweet sorghum forage was considered to have greater fibre concentration and greater fibre digestibility than silage corn.

The sweet pearl millet WSC concentrations were greater than those of the silage corn at Agassiz, St-Augustin, and Ste-Anne but they were similar at Lethbridge and Kentville (Fig. 2B). The WSC concentrations in sweet pearl millet varied from 100 to 145 g kg\(^{-1}\) DM, in keeping with
those reported in the literature (132 to 195 g kg\(^{-1}\) DM) (Leblanc et al. 2012; Bouchard et al. 2011; Thivierge et al. 2015\(a\)). The WSC concentrations in the BMR sweet sorghum hybrids were greater than in sweet pearl millet and silage corn at all sites (Fig. 2B), and the BMR1 sweet sorghum hybrid had a greater WSC concentration (average across sites of 209 g kg\(^{-1}\) DM) than the BMR2 sweet sorghum hybrid (average of 189 g kg\(^{-1}\) DM). The sweet sorghum WSC concentrations reported in the literature vary from 129 to 281 g kg\(^{-1}\) DM (Thivierge et al. 2015\(a\); dos Passos Bernardes et al. 2016; Saïed et al. 2017). In ruminants, the intake of forage with a high WSC concentration can cause digestive disorders due to the excessive production of volatile fatty acids in the rumen (Owens et al. 1998). On the other hand, a high WSC concentration can promote the fermentation of forage into silage and thus help preserve it (Davies et al. 1998). Sweet sorghum thus has the potential to make good silage.

Silage corn had a much greater starch concentration (110 to 260 g kg\(^{-1}\) DM) than sweet pearl millet and sweet sorghum hybrids (Fig. 2C). The starch concentration of sweet pearl millet hybrids varied from 9 to 62 g kg\(^{-1}\) DM, which was greater than the concentrations in the sorghum hybrids at Kentville and St-Augustin and equal to the concentrations in the sorghum hybrids at the other sites. Amer and Mustafa (2010) also reported a low starch concentration (22 g kg\(^{-1}\) DM) for forage pearl millet grown in Quebec. The starch concentration was lower in the BMR1 (average of 12 g kg\(^{-1}\) DM) than the BMR2 sweet sorghum hybrid (average of 26 g kg\(^{-1}\) DM) at Agassiz and Kentville, but similar in the two hybrids at St-Augustin and Ste-Anne. These starch concentrations in sweet sorghum are lower than those (51 g kg\(^{-1}\) DM) reported by Amer et al. (2012) in Quebec. Our values of starch concentration are also lower than those reported by Getachew et al. (2016) in California (141 g kg\(^{-1}\) DM) and Zhang et al. (2015) in China (93 g kg\(^{-1}\) DM). Starch is known as the main source of rapidly fermentable energy in corn silage. These low starch concentrations in
sweet pearl millet and sweet sorghum could negatively affect the silage utilization by ruminant animals.

**Forage total digestible nutrient concentration**

At all sites, sweet pearl millet had the lowest TDN concentrations (429 to 474 g kg\(^{-1}\) DM) (Fig. 2D). The two sweet sorghum hybrids did not differ from each other and had TDN concentrations that were greater (569 g kg\(^{-1}\) DM) than silage corn (533 g kg\(^{-1}\) DM) at Agassiz, similar (525 g kg\(^{-1}\) DM) to silage corn (528 g kg\(^{-1}\) DM) at Lethbridge and Ste-Anne, and lower (525 g kg\(^{-1}\) DM) than silage corn (590 g kg\(^{-1}\) DM) at St-Augustin. At Kentville, the TDN concentration of only the BMR2 sweet sorghum hybrid (513 g kg\(^{-1}\) DM) was lower than that of silage corn (543 g kg\(^{-1}\) DM). The average TDN concentration of silage corn across sites was 544 g kg\(^{-1}\) DM, which is lower than the average value of 688 g kg\(^{-1}\) DM published by the National Research Council (2001). Total digestible nutrients are a summation of four nutritive attributes, namely, non-fibre carbohydrates, crude protein, fatty acids, and aNDF, multiplied by their respective digestibility. It is therefore a very valuable index for comparing the nutritive value of different species. Data on the TDN concentration of sweet pearl millet and sweet sorghum are only available for climates much warmer than those in our study, and that information cannot be used as a valid source of comparison. However, our TDN results suggest that sweet sorghum could be an alternative to silage corn for feeding ruminants but does not support the use of sweet pearl millet (Fig. 2D).
Forage ensilability

At ensiling in 2016 at St-Augustin and Ste-Anne, forage DM concentration was less for sweet pearl millet and sweet sorghum than for silage corn (Table 5). The two sweet sorghum hybrids had a similar DM concentration at St-Augustin, whereas at St-Anne, the DM concentration was less for the BMR2 hybrid than for the BRM1 sweet sorghum. After 90 days of fermentation, however, all silages of sweet pearl millet, sweet sorghum, and silage corn produced in the mini-silos were of excellent quality. The silage pH was less than 4.0 after 90 d of fermentation (Table 5), which is below the target pH of 4.3 (Lafrenière 2008) to ensure silage stability and avoid the development of butyric acid and bacteria spores. In other studies carried out in Quebec with the same sweet pearl millet hybrid but different sweet sorghum hybrids, pH values below 4.3 after fermentation were also observed (Amer and Mustafa 2010; Amer et al. 2012).

While the effects of forage species were statistically significant for concentrations of lactic, acetic, and propionic acids (Table 5), they were biologically negligible since all of these concentrations were within the range reported for excellent quality silages. Lactic acid is the main acid that lowers the pH during the forage fermentation process. To ensure good palatability of the silage, the lactic acid concentration should be four times greater than the acetic acid concentration (Lafrenière 2008), which should not exceed 20 g kg$^{-1}$ DM (Leduc and Fournier 1998). Sweet pearl millet and sweet sorghum silages at both sites had three to six times more lactic acid than acetic acid and an acetic acid concentration less than 20 g kg$^{-1}$ DM (Table 5). Moreover, the propionic and butyric acid concentrations were close to zero for both crop species, which are also indications of good quality and palatable silages. All fermentation parameters measured indicated that sweet pearl millet and sweet sorghum fermented as well as silage corn in mini-silos.
Agronomic and animal nutrition implications

Sweet pearl millet and sweet sorghum offer several agronomic advantages. They would allow a later harvest of winter cover crops or they could be used as a replacement where the planting season for silage corn was missed due to poor weather or other factors. Both species are also more efficient in utilizing fertilizer N as both species yielded as much if not more than silage corn with 65-75% of the amount of fertilizer N. This greater efficiency of N fertilizer utilization, also reported by Thivierge et al. (2015b), would reduce the cost of production, while decreasing the risks of N losses to the environment. Both species performed particularly well in terms of forage yield at Lethbridge, the site with the drier conditions. Hence, they offer interesting alternatives to silage corn in the context of the likely increase in the frequency of drought events in Canada with global warming.

Both species have a greater WSC concentration than silage corn. Forages with a high WSC concentration have the potential to increase N utilization in cows, fat content in milk, and milk yield. The low starch concentrations in sweet pearl millet and sweet sorghum, however, could negatively affect the silage utilization by ruminant animals. Sweet sorghum also has interesting characteristics in terms of digestibility and TDN concentration. The benefits of feeding those two species to dairy cows remain, however, to be demonstrated. Although both species have several advantages over silage corn, seed and hybrid availability remains a challenge.

Our results indicate that the potential of sweet pearl millet and sweet sorghum as silage crops is currently constrained by their low DM concentrations if they are harvested at the same time as corn. This problem could potentially be solved by harvesting them later in the fall or by wilting them in the field. The feasibility of both options, however, depends on the fall weather conditions in the different regions of Canada. Both sweet pearl millet and sweet sorghum could
also be managed as multi-cut forage crops but this option was not evaluated in our study. More research is needed to evaluate those potential options.

CONCLUSIONS

The sweet pearl millet and sweet sorghum hybrids were adapted to all Canadian regions where silage corn is also adapted, and their forage DM yields were generally similar to or greater than those of silage corn in all regions, except in the Pacific Maritime ecozone. Whereas greater fibre concentrations in sweet sorghum suggests a lower voluntary DM intake in dairy cattle compared to silage corn, this is mitigated by greater digestibility (IVTD and NDFd) and a similar TDN concentration compared to silage corn. By contrast, sweet pearl millet had greater fibre concentration, and lower digestibility (IVTD and NDFd) and TDN concentration than silage corn. Even though sweet pearl millet and sweet sorghum forages fermented as well as silage corn in laboratory silos, the DM concentrations of both sweet pearl millet (289 g kg\(^{-1}\)) and sweet sorghum (245 g kg\(^{-1}\)) were lower than that of silage corn (331 g kg\(^{-1}\)), suggesting possible problems such as seepage in farm silos. As a result, solely sweet sorghum appeared as a possible alternative to non-BMR silage corn in four of five regions. Early maturing hybrids with a greater DM concentration at harvest are required to ensure good ensilability in most commercial silo types.

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Table 1. Soil characteristics along with seeding and harvest dates for the two crop years at five sites in Canada.

| Site                  | Agassiz, BC | Lethbridge, AB | St-Augustin, QC | Ste-Anne, QC | Kentville, NS |
|-----------------------|-------------|----------------|-----------------|--------------|--------------|
| Ecozone               | Pacific Maritime | Prairies | Boreal Shield | Mixedwood Plains | Atlantic Maritime |
| Soil characteristics (depth of 15 cm) |             |               |                 |              |              |
| Soil series           | Monroe      | Lethbridge    | St-Antoine      | Chicot       | Debert       |
| Texture               | Silt loam   | Clay loam     | Sandy loam      | Fine sandy loam | Sandy loam  |
| pH                    | 5.9         | 8.4           | 7.0             | 6.1          | 5.7          |
| Organic matter (g kg\(^{-1}\)) | 42          | 17            | 37              | 30           | 34           |
| Phosphorus (kg ha\(^{-1}\)) | 66          | –             | 294             | 191          | 418          |
| Potassium (kg ha\(^{-1}\)) | 160         | –             | 324             | 189          | 204          |
| Seeding dates         |             |               |                 |              |              |
| 2015 (silage corn)    | 8 May       | 9 May         | 16 May          | 19 May       | 29 May       |
| 2015 (sweet pearl millet and sorghum) | 27 May | 26 May  | 4 June | 12 June | 5 June |
| 2016 (silage corn)    | 30 May      | 18 May        | 11 May          | 18 May       | 15 June      |
| 2016 (sweet pearl millet and sorghum) | 6 June | 27 May  | 1 June | 9 June | 3 June |
| Harvest dates (all crops) |             |               |                 |              |              |
| 2015                  | 25 Sept.    | 24 Sept.      | 1 Oct.          | 17 Sept.     | 28 Sept.     |
| 2016                  | 26 Sept.    | 7 Oct.        | 16 Sept.        | 13 Sept.     | 22 Sept.     |
Table 2. Cumulative growing degree-days, corn heat units, and precipitations from seeding to harvesting for two crop years at five sites in Canada.

| Site                | Agassiz, BC | Lethbridge, AB | St-Augustin, QC | Ste-Anne, QC | Kentville, NS |
|---------------------|-------------|----------------|-----------------|--------------|---------------|
| Cumulative growing degree-days > 5 °C for sweet pearl millet and sweet sorghum | | | | | |
| 2015                | 1698        | 1528           | 1524            | 1480         | 1515          |
| 2016                | 1337        | 1490           | 1420            | 1511         | 1527          |
| 1976-2005 average   | 2174        | 1775           | 1762            | 2114         | 1776          |
| Cumulative corn heat units for silage corn | | | | | |
| 2015                | 3001        | 2443           | 2674            | 3202         | 2353          |
| 2016                | 2518        | 2457           | 2581            | 2895         | 2615          |
| 1976-2005 average   | 3071        | 2403           | 2638            | 315400       | 2574          |
| Precipitation (mm) for sweet pearl millet and sweet sorghum | | | | | |
| 2015                | 310         | 147            | 246             | 324          | 359           |
| 2016                | 202         | 189            | 349             | 262          | 222           |
| Historical average  | 408         | 280            | 586             | 483          | 429           |
| Precipitation (mm) for silage corn | | | | | |
| 2015                | 332         | 163            | 308             | 422          | 414           |
| 2016                | 224         | 230            | 412             | 301          | 209           |
| Historical average  | 408         | 280            | 586             | 483          | 429           |

**Note:** Values of growing degree-days and precipitations are cumulative data between the seeding and harvesting dates for the different species, obtained from Environment Canada, AgWeather Québec, [www.farmwest.com](http://www.farmwest.com), and independent stations managed by Université Laval or Agriculture and Agri-Food Canada. The 1976-2005 average values of cumulative growing degree-days (base 5°C) and corn heat units were obtained from [https://climateatlas.ca/map/canada/chu_2060_85#](https://climateatlas.ca/map/canada/chu_2060_85#) for the municipalities of Chilliwack (24 km from Agassiz), Lethbridge, Donnacona (21 km from St-Augustin), Montréal (35 km from Ste-Anne), and Kentville.
Table 3. Statistics on the performance of the equations developed by visible and near infrared spectroscopy (VNIRS) used to predict concentrations of nutritive attributes in the validation samples (n = 30) of corn, sweet pearl millet, and sweet sorghum forages grown at five Canadian sites in 2015 and 2016.

| Nutritive attribute                                      | Statistics       |
|----------------------------------------------------------|------------------|
|                                                           | Mean  | Slope | SEP(C) | R^2  | RPD  |
| Acid detergent fibre (ADF, g kg\(^{-1}\) DM)              | 317   | 0.94  | 12.8   | 0.97 | 5.3  |
| Neutral detergent fibre (aNDF, g kg\(^{-1}\) DM)          | 557   | 0.98  | 18.9   | 0.95 | 4.5  |
| In vitro true digestibility of DM (IVTD, g kg\(^{-1}\) DM) | 796   | 0.99  | 24.9   | 0.92 | 3.5  |
| In vitro aNDF digestibility (NDFd, g kg\(^{-1}\) aNDF)    | 641   | 0.98  | 33.5   | 0.93 | 3.7  |
| Total N (g kg\(^{-1}\) DM)                               | 96    | 1.00  | 11.2   | 0.97 | 5.4  |
| Water soluble carbohydrates (WSC, g kg\(^{-1}\) DM)       | 108   | 1.01  | 12.6   | 0.96 | 4.8  |
| Starch (g kg\(^{-1}\) DM)                                | 44    | 0.98  | 13.4   | 0.97 | 5.5  |
| Total digestible nutrients (TDN, g kg\(^{-1}\) DM)        | 570   | 1.01  | 30.2   | 0.91 | 3.4  |

Note: SEP(C), bias-corrected standard error of prediction; \(R^2\), coefficient of determination; RPD, ratio of prediction to deviation equals to the standard deviation of samples in the validation set divided by the SEP(C); aNDF, neutral detergent fibre assayed with a heat-stable \(\alpha\)-amylase and sodium sulfite.
Table 4. Analysis of variance (ANOVA) with probabilities (P-values) of fixed effects and their interaction for forage attributes of silage corn, sweet pearl millet, and two hybrids (BMR1 and BMR2) of sweet sorghum grown at five sites in Canada and harvested when corn reached a dry matter (DM) concentration of approximately 350 g kg\(^{-1}\), in two consecutive years (2015 and 2016).

| Forage attributes                                      | Sources of variation |
|--------------------------------------------------------|----------------------|
|                                                        | Sites    | Crops    | Sites × Crops |
| Yield (Mg DM ha\(^{-1}\))                              | <0.001   | ns       | <0.001        |
| DM (g kg\(^{-1}\))                                     | <0.001   | <0.001   | <0.001        |
| Acid detergent fibre (ADF, g kg\(^{-1}\) DM)           | ns       | <0.001   | <0.001        |
| Neutral detergent fibre (aNDF, g kg\(^{-1}\) DM)       | 0.015    | <0.001   | <0.001        |
| In vitro true digestibility of DM (IVTD, g kg\(^{-1}\) DM) | ns       | <0.001   | <0.001        |
| In vitro aNDF digestibility (NDFd, g kg\(^{-1}\) aNDF) | ns       | <0.001   | ns            |
| Total N (g kg\(^{-1}\) DM)                             | <0.001   | ns       | <0.001        |
| Water soluble carbohydrates (WSC, g kg\(^{-1}\) DM)    | ns       | <0.001   | ns            |
| Starch (g kg\(^{-1}\) DM)                              | <0.001   | <0.001   | <0.001        |
| Total digestible nutrients (TDN, g kg\(^{-1}\) DM)     | 0.001    | <0.001   | <0.001        |

Note: ns, not significant (P > 0.05).
Table 5. Concentration of forage dry matter (DM) at ensiling, along with pH and concentrations of lactic, acetic, propionic, and butyric acids after 90 d of fermentation of silage corn, sweet pearl millet (SPM), and two hybrids (BMR1 and BMR2) of sweet sorghum (SS) grown at two sites in QC, Canada (St-Augustin and Ste-Anne) and harvested when the corn reached a dry matter (DM) concentration of around 350 g kg$^{-1}$ in 2016.

| Sites          | Crops       | DM (g kg$^{-1}$) | pH  | Lactic acid (g kg$^{-1}$ DM) | Acetic acid (g kg$^{-1}$ DM) | Propionic acid (g kg$^{-1}$ DM) | Butyric acid (g kg$^{-1}$ DM) |
|----------------|-------------|------------------|-----|-----------------------------|-----------------------------|--------------------------------|--------------------------------|
| St-Augustin, QC| Silage corn | 382$^a$          | 3.8 | 34$^b$                      | 12$^b$                      | 0.07$^d$                        | 0.00                          |
|                | SPM         | 291$^b$          | 3.8 | 55$^a$                      | 12$^b$                      | 0.47$^a$                        | 0.00                          |
|                | BMR1 SS     | 268$^{bc}$       | 3.8 | 49$^a$                      | 17$^a$                      | 0.28$^b$                        | 0.02                          |
|                | BMR2 SS     | 258$^c$          | 3.8 | 57$^a$                      | 16$^a$                      | 0.18$^c$                        | 0.00                          |
| Ste-Anne, QC   | Silage corn | 388$^a$          | 3.7 | 34$^c$                      | 8$^b$                       | 0.17$^b$                        | 0.00                          |
|                | SPM         | 281$^b$          | 3.8 | 60$^b$                      | 10$^b$                      | 0.33$^a$                        | 0.00                          |
|                | BMR1 SS     | 232$^c$          | 3.8 | 65$^{ab}$                   | 14$^a$                      | 0.38$^a$                        | 0.28                          |
|                | BMR2 SS     | 208$^d$          | 3.8 | 73$^a$                      | 16$^a$                      | 0.43$^a$                        | 0.12                          |

Sources of variation

| Sites          | <0.001      | ns$^a$           | <0.05 | <0.05 | <0.05 | –$^b$ |
| Crops          | <0.001      | ns              | <0.001 | <0.001 | <0.001 | –     |
| Sites × Crops  | <0.001      | ns              | <0.05 | ns    | <0.001 | –     |

Note: Within a column and at a given site, means not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

$^a$ns, not significant ($P > 0.05$).

$^b$–, No statistical analysis owing to the very low values.
FIGURE CAPTIONS

Fig. 1. Yield (A), dry matter (DM) concentration (B), acid detergent fibre (ADF) concentration (C), neutral detergent fibre (aNDF) concentration (D), *in vitro* true digestibility of DM (IVTD) (E), and *in vitro* aNDF digestibility (NDFd) (F) of silage corn, sweet pearl millet, and two hybrids (BMR1 and BMR2) of sweet sorghum grown at five sites in Canada and harvested when silage corn reached a DM concentration of approximately 350 g kg\(^{-1}\); average of 2 years (2015 and 2016). At a given site, means not sharing a lowercased letter differ significantly at the \(P < 0.05\) level.

Fig. 2. Total nitrogen (N) concentration (A), water soluble carbohydrate (WSC) concentration (B), starch concentration (C), and total digestible nutrient (TDN) concentration (D) of silage corn, sweet pearl millet, and two hybrids (BMR1 and BMR2) of sweet sorghum grown at five sites in Canada and harvested when the silage corn reached a dry matter (DM) concentration of approximately 350 g kg\(^{-1}\); average of 2 years (2015 and 2016). At a given site, means not sharing a lowercased letter differ significantly at the \(P < 0.05\) level.
Yield (A), dry matter (DM) concentration (B), acid detergent fibre (ADF) concentration (C), neutral detergent fibre (aNDF) concentration (D), *in vitro* true digestibility of DM (IVTD) (E), and *in vitro* aNDF digestibility (NDFd) (F) of silage corn, sweet pearl millet, and two hybrids (BMR1 and BMR2) of sweet sorghum grown at five sites in Canada and harvested when silage corn reached a DM concentration of approximately 350 g kg\(^{-1}\); average of 2 years (2015 and 2016). At a given site, means not sharing a lowercased letter differ significantly at the \(P < 0.05\) level.
Total nitrogen (N) concentration (A), water soluble carbohydrate (WSC) concentration (B), starch concentration (C), and total digestible nutrient (TDN) concentration (D) of silage corn, sweet pearl millet, and two hybrids (BMR1 and BMR2) of sweet sorghum grown at five sites in Canada and harvested when the silage corn reached a dry matter (DM) concentration of approximately 350 g kg\(^{-1}\); average of 2 years (2015 and 2016). At a given site, means not sharing a lowercased letter differ significantly at the \( P < 0.05 \) level.