



Degree of starch access: An enzymatic method to determine starch degradation potential of corn grain and corn silage

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Abstract

Starch supplied from corn grain or corn silage is an important source of dietary energy for lactating dairy cows and other ruminants, but few laboratory methods are available to determine starch digestion potential. A laboratory method, degree of starch gelatinization (DSG), commonly used by the food industry to assess relative differences in starch characteristics of human foods was modified for application to corn grain and corn silage. The modified assay, degree of starch access (DSA, g/kg starch), was used to evaluate starch recovery by enzymatic hydrolysis in gelatinized undried, unground corn grains and corn silages, which differed in particle size, dry matter content and endosperm type. Effects of particle size (370, 500, 640, 1100, 3140 and 4000 μm) of corn grains, which are known to influence starch digestion in ruminants, were evaluated. For each 100 μm increase in particle size, DSA decreased ($P < 0.001$) 26.8 g/kg starch. In high-moisture corn grain, for each 10 g/kg fresh matter increase in DM content, DSA decreased 20.0 g/kg starch ($r^2 = 0.76$). In corn grain of differing endosperm vitreousness (0 g/100 g versus 100 g/100 g endosperm) DSA values were approximately 200 g/kg starch higher for corn grain with no vitreous endosperm as compared to corn grain with highly vitreous (100 g/100 g) endosperm. For corn silage, DSA was positively correlated to latent starch and starch retained on screens < 2.38 mm. While no comparisons between DSA and *in vivo*

Abbreviations: DSA, degree of starch access; DSG, degree of starch gelatinization; FM, fresh matter; PAF, processing adjustment factors

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starch digestibility exist, the DSA assay may be useful as an index for evaluating differences in starch digestion potential of corn and corn silage fed to ruminants.

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1. Introduction

Starch supplied from corn and corn silage is an important source of dietary energy for lactating dairy cows and other ruminants. However, various sources of corn starch have highly variable ruminal and total tract digestibilities (Ørskov, 1986; Theurer, 1986). Factors, such as particle size (Remond et al., 2004), partial gelatinization by heat processing (Callison et al., 2001), conservation method (Oba and Allen, 2003) and type of corn endosperm (Correa et al., 2002), can influence ruminal and or total tract digestion of corn starch by lactating dairy cows. In an attempt to address some of these sources of variation, NRC (2001) suggested empirical processing adjustment factors (PAF) to adjust non-fiber carbohydrate digestion coefficients for high-starch feeds. However, there is no system to measure or estimate PAF on feedstuffs, and so, it is a subjective value that can be difficult to apply in practice.

The food processing industry (Varriano-Marston et al., 1980; Marconi et al., 2004) employs a relatively simple laboratory method entitled degree of cook or degree of starch gelatinization (DSG) to assess physiochemical properties of high-starch human foods that relate to their digestibility. This laboratory approach, to determine DSG, is quantifiable and can be represented by the formula:

$$\text{DSG (g/kg starch)} = \frac{[\text{recovered starch} : \text{cooked}]}{\text{total starch}} \times 1000$$

The advantage of using a system, such as DSG, rather than PAF to adjust non-fiber carbohydrate digestion coefficients is that DSG is a defined and quantifiable laboratory procedure, while PAF is subjective and empirical.

The objective of this study was to evaluate whether a methodology, such as DSG could serve as an index to evaluate relative starch digestion potentials for corn or corn silage.

2. Materials and methods

2.1. Pre-trial

Upon reviewing DSG methods (Chiang and Johnson, 1977, Varriano-Marston et al., 1980, Marconi et al., 2004), we determined that changes in the assay would be required to adapt DSG for livestock feeds as the DSG procedure was principally designed to measure the effect of cooking on degree of starch gelatinization. Thus, DSG is typically determined

on finely ground material (i.e., 1 mm grind), which eliminates effects of physical form on DSG. Because physical form and DM content of starch are of critical importance in ruminants (Oba and Allen, 2003; Remond et al., 2004), the volume of the assay was increased to accommodate a larger sample, which is required to obtain a representative sample of feeds that are not ground nor dried. Because corn silage and high-moisture corn grain are fermented products with pH values often less than 5.0 and amylase or amyloglucosidase used in the DSG procedure are pH specific (McCleary et al., 1997), additional buffer control within the assay was required.

Therefore, the basic concept of DSG was redefined as degree of starch access (DSA) as:

$$\text{DSG (g/kg starch)} = \frac{[\text{recovered starch : undried/unground}]}{\text{total starch}} \times 1000$$

The term DSG was renamed DSA to define the assay in terms of the degree of enzyme access to starch after gelatinization of undried and unground feeds.

2.2. Recovered starch procedure

The procedure developed to determine recovered starch on undried and unground corn-based feed used 20 g of undried and unground corn silage (approximately 7 g of DM) transferred to a 1000 ml Berzelius beaker. Alternatively, 4 g of dry or high-moisture corn grain (2.8–3.6 g of DM), was weighed and transferred to a 1000 ml Erlenmeyer flask. A reference sample of 2.5 g corn starch (Sigma, S-4126, St. Louis, MO, USA) was included with each assay run to measure starch recovery potential and also used to correct recovered starch determinations for the test samples (Ehrman, 1996). A 150 ml volume of distilled water was added to each flask or beaker and swirled vigorously to ensure sample dispersion. A 200 ml volume of phosphate buffer containing 14.0 g $\text{NaH}_2\text{PO}_4 \cdot \text{H}_2\text{O}$ /986 ml H_2O and brought to pH 6.5 using 2N NaOH was added, flasks were fit with a loose fitting rubber stopper or beakers were covered, placed on a heating unit, swirled frequently and heated for approximately 25 min to 90 °C. Samples were removed from heat, 100 ml of distilled water added and when temperatures reached 80 °C, 3 ml of a heat stable amylase (Sigma A-3306) working solution containing 7200 units/ml was added. Sample solutions were continuously stirred and allowed to cool to 50 °C. All stirring procedures were performed on magnetic stir plates. When samples reached 50 °C, 100 ml of pH 4.2 acetate buffer (Ehrman, 1996) and 50 ml of amyloglucosidase (Sigma A-3042) working solution containing 60 units/ml were added. Sample flasks were stirred for 60 min, at which point 6 ml of hydrolysate was transferred via pipette into a 10 ml test tube containing 0.5 ml of a solution containing 50 g of trichloroacetic acid mixed with 200 ml of distilled water, which terminated the enzymatic reaction. Samples were stabilized by adding a 3.5 ml of pH 6.5 phosphate buffer (Ehrman, 1996), vortexed and free glucose determined with a YSI-2000 (YSI Incorporated, Yellow Springs, OH, USA). Starch, expressed as recovered starch g/kg DM, from glucose determination was calculated by the equations of Ehrman (1996) with recovered starch adjusted based on recovery potential of the reference corn starch. Mean recovery potential for pure corn starch was 950 g/kg DM with a S.D. of 9.0 g/kg DM.

2.3. Total starch

Samples of corn-based feeds were dried for 48 h at 55 °C in a forced air oven, weighed, determined for initial DM and ground through a Udy mill (Udy Corp., Boulder, CO, USA) fit with a 1 mm screen. Final DM was determined by drying 1 g of 1 mm grind sample at 105 °C for 3 h. Total starch was determined by methods of Ehrman (1996), where gelatinization is aided by sodium hydroxide and final glucose concentration is determined with an YSI-2700 fit with a dextrose detection probe.

2.4. Corn grain and corn silage

To evaluate the DSA assay, samples of corn grain and corn silage were prepared to evaluate assay sensitivity to particle size, DM content, corn endosperm type and utility in a heterogeneous feed (i.e., corn silage). To evaluate potential influences of particle size on DSA, a single lot of dry shelled corn grain was ground through a Wiley mill (Arthur A. Thomas Co., Philadelphia, PA, USA) fit with 1, 2, 4 or 8 mm screens. Additionally, two samples of dry shelled corn grain were prepared by grinding through a Wiley mill without a screen or left unground (whole dry shelled corn grain). All ground and whole corn grain samples were dry sieved (sieve apertures: 4000, 2000, 841, 420, 177 μm and bottom pan) using U.S. Standard sieves (E.H. Sargent Co., Chicago, IL, USA) and mean particle size was calculated according to ASAE (1968).

To evaluate effects of corn grain DM content on DSA, 18 samples of high-moisture shelled corn grain were obtained from routine submissions to the Marshfield Soil and Forage Analysis Laboratory (Marshfield, WI, USA). Samples were evaluated for DM, DSA and particle size as described previously. To evaluate effects of corn endosperm type on DSA, 17 dried corn samples of varying endosperm types were ground through a Wiley mill fit with an 8 mm screen and analyzed for DM, DSA and particle size as described previously. Corn grain vitreousness was determined by manual dissection of kernels (Dombrink-Kurtzman and Bietz, 1993) using the kernel selection and preparation scheme of Correa et al. (2002). Kernel vitreousness was chosen as the criterion to compare with DSA values, because corn grains with a greater proportion of vitreous endosperm have been shown to have decreased ruminal starch degradation (Correa et al., 2002; Philippeau and Michalet-Doreau, 1997).

To evaluate the utility of DSA in a heterogeneous feed, 44 corn silage samples were obtained from routine submissions to the Marshfield Soil and Forage Analysis Laboratory (Marshfield, WI, USA). Corn silages were analyzed for DM and DSA as previously described with a 20 g of undried and unground samples used for the DSA determination. Corn silage samples were ranked by DSA with every other ($n=22$) sample selected for subsequent particle size determination. Pre-screening a larger population ($n=44$) of corn silages and subsequent re-selection ($n=22$) assured a robust set of corn silage samples for evaluation. Particle size of starch in corn silages was determined by drying approximately 200 g of each corn silage sample for 48 h at 55 °C in a forced air oven. Dried corn silage samples were placed into a vertical shaker (W.S. Tyler Incorporated, Mentor, OH, USA) with nominal square apertures of 13.20, 9.50, 6.70, 4.75, 3.35, 2.36, 1.18, 0.60 and 0.30 mm and shaken for 20 min. After shaking material remaining on each screen was weighed,

ground through an Udy mill fit with a 1 mm screen and analyzed for residual DM by drying for 3 h in a 105 °C oven and starch by the methods of Ehrman (1996). Mean particle size of starch was calculated as described by ANSI (1993) by using the amount of starch remaining on each screen and the nominal dimension of the square aperture instead of the diagonal dimension.

Recovered starch and total starch and the corresponding DSA were determined in quadruplicate for corn grains of differing endosperm type, particle size (dry corn grains) and high-moisture corn grains. Duplicate evaluations of recovered and total starch and the corresponding DSA were conducted for corn silage. Mean DSA was calculated and expressed as g/kg starch for all samples. The effect of particle size on DSA for dry corn grain was evaluated using ANOVA with particle size as the independent variable. The effect of corn DM content on DSA in high-moisture corn was evaluated using the GLM procedure of SAS (1999) with DSA covariately adjusted for particle size with DM set as a random independent variable. For corns of differing endosperm type, DSA values were adjusted for unavoidable particle size differences created due to differences in grinding characteristics of corn grain samples using a slope coefficient developed from the particle size evaluation and particle size adjusted DSA values were compared to kernel vitreousness using the REG procedures of SAS (1999) exploring first-, second- and third-order relationships. For corn silage correlations between DSA and starch particle size, DM and total starch were explored using the CORR procedures of SAS (1999).

3. Results

3.1. Corn grain

Particle size influenced ($P < 0.0001$) DSA and ranged from 1068 to 15 g/kg starch for corn grains ranging from 370 to 4000 μm , respectively, indicating DSA is sensitive to corn grain particle size of corn (Fig. 1). The DSA of 1068 g/kg starch for 370 μm corn grain is not possible because recovered starch should never be higher than total starch, indicating that the value observed was affected by some error associated with total and recovered starch determinations. A DSA value near 1000 g/kg starch for 370 μm corn, is reasonable and was expected because recovered starch and total starch were determined on the same corn grain after grinding through a 1 mm screen. This suggests that recovered starch and total starch procedures, although different, have similar starch hydrolysis potential. When dry shelled corn grain samples were ground through screens of larger diameter ($>370 \mu\text{m}$) or unground ($>4000 \mu\text{m}$), recovered starch decreased as proportion of total starch resulting in declining DSA values. While we did not attempt to invoke linear particle size differences in the corn grain samples, we did explore (SAS, 1999) first- and second-order relationships of the data and observed that particle size effects on DSA were linear ($r^2 = 0.98$). For each 100 μm increase in particle size, DSA was reduced to 26.8 g/kg starch. Consistent with observations of Ehrman (1996), where enzymatic hydrolysis of starch to glucose in corn decreased as particle size increased. The DSA value observed for $>4000 \mu\text{m}$ (whole) corn grain was 15 g/kg starch indicating that the seed coat of dry shelled corn grain is a barrier to enzymatic hydrolysis of intact kernel starch. Based on these observations, the DSA assay

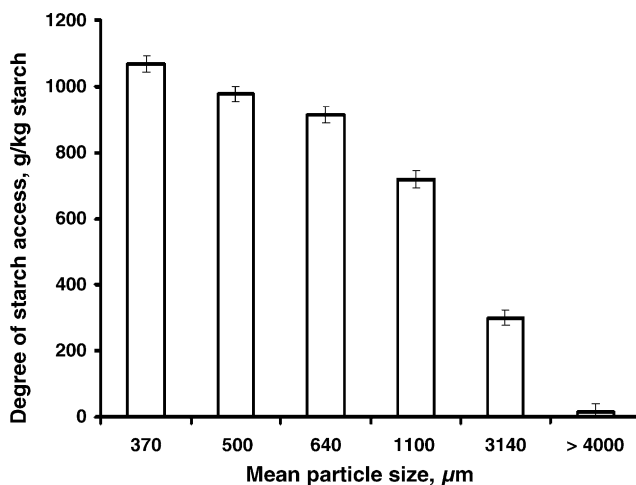


Fig. 1. Effect of particle size on degree of starch access (g/kg starch). Error bars (I) denote standard error ($P < 0.001$).

may be useful for assessing starch digestion potential in corn grain samples that differ in particle size.

Because particle size influenced DSA and particle size of high-moisture corn grain samples procured from a commercial testing laboratory used in the evaluation could not be controlled, least square means (adjusted for particle size) of DSA are presented (Fig. 2) and discussed. The DM content of corn influenced ($P < 0.0001$) DSA, with DSA decreasing 20 g/kg starch for each 10 g/kg fresh matter (FM) increase in DM content ($r^2 = 0.76$). Consistent with *in vivo* data of Oba and Allen (2003) and Knowlton et al. (1998), where

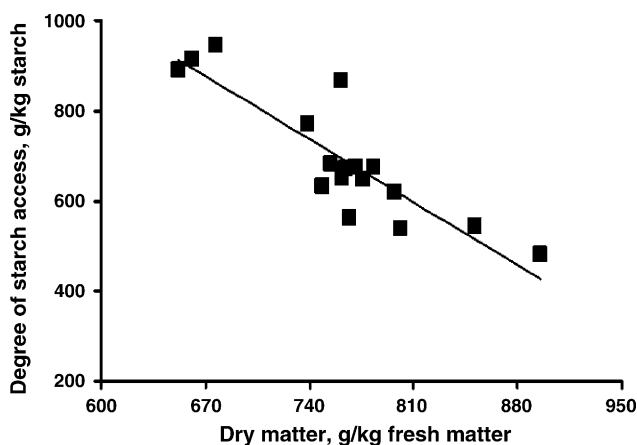


Fig. 2. Relationship between corn grain dry matter content and degree of starch access (DSA; g/kg starch). $DSA = -1.997 (DM) + 2214.8$, $R^2 = 0.76$ ($P < 0.001$).

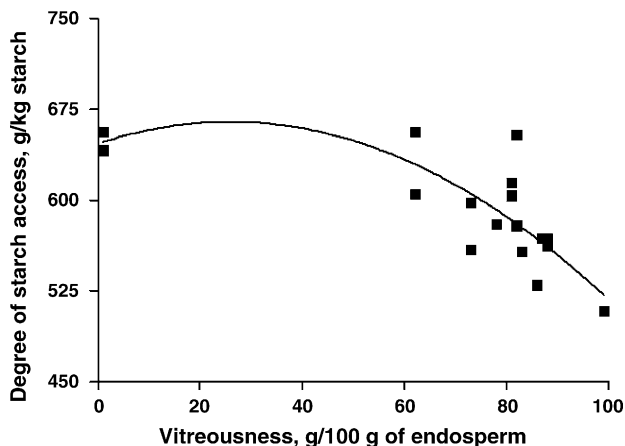


Fig. 3. Degree of starch access (DSA; g/kg starch) in corn grains with varying proportions of vitreous (V) endosperm. $DSA = 1.385(V) + -0.0267(V^2) + 646.5$, $R^2 = 0.59$ ($P < 0.01$).

ruminal starch digestion was higher in high-moisture corn *versus* dry corn grain. Other researchers (Philippeau and Michalet-Doreau, 1997; Correa et al., 2002) reported that the proportion of vitreous endosperm in corn grain increases with increasing DM content (i.e., advancing maturity) with a corresponding decrease in ruminal starch degradation. As the proportion of vitreous endosperm increases, secondary intermolecular bonding (Beery and Ladisch, 2001) occurs in starch decreasing water absorption and potential for enzymatic hydrolysis. These data (Philippeau and Michalet-Doreau, 1997; Beery and Ladisch, 2001) provide inference to our observations, which suggest that the higher DSA observed for corn with lower DM contents is likely because corn grains of lower DM content contains less vitreous endosperm, which made the endosperm more conducive to enzymatic hydrolysis.

This observation is further supported by DSA evaluation of corn samples differing in endosperm type (Fig. 3). We evaluated two opaque or floury corn grains (0 g/100 g vitreous endosperm), one flint (100 g/100 g vitreous endosperm) and 14 normal dent corn samples of 62–88 g/100 g vitreous endosperm. Vitreousness and particle size (data not shown) as affected by grinding through an 8 mm screen were moderately correlated ($r = 0.43$; $P < 0.05$), which was expected, because corn samples with greater vitreous endosperm have higher kernel density (Correa et al., 2002), which could influence post-grinding particle size even when ground through a similar size screen. Even though all corn grain samples in our evaluation were ground through an 8 mm Wiley mill screen, observed particle size of floury corn grain samples were approximately 200 μm less than flint or other highly vitreous corn grain samples. Because a 200 μm difference in particle size was found to impact DSA, we adjusted the DSA values to a standard 1250 μm particle size using the slope presented previously ($DSA, \text{g/kg starch} = 26.8 \text{ g}/(\text{kg starch } 100 \mu\text{m})$). The ability of DSA to differentiate corn grains of varying endosperm type is in Fig. 3, where the DSA assay accounted for approximately 60% of the variation in endosperm type. The relationship between DSA and vitreousness may over-fit because of two floury corns (0 g/100 g vitreous endosperm) but the objective was to explore the potential of the DSA assay to differentiate differences in

corn endosperm type rather than define theoretical population dynamics. The mechanism by which DSA differentiated endosperm type should be similar to mechanisms, which differentiate corn grains of differing DM content, because the principles of intermolecular bonding of starch, water absorption capacity and capacity for enzyme hydrolysis are similar (Beery and Ladisch, 2001). As for corn particle size and DM content, the DSA assay yielded values that were consistent with previous data regarding endosperm type (Correa et al., 2002; Philippeau and Michalet-Doreau, 1997), which suggests that corn grains with less vitreous endosperm have increased ruminal starch degradation.

3.2. *Corn silage*

If feeds high in starch were all homologous, such as dry ground shelled corn grain, the practical need for the DSA assay would be limited because particle size could simply be evaluated and related to animal response. However, corn silage is heterogeneous making determination of particle size of starch difficult because the starch fraction cannot be readily separated from the forage fraction. Therefore, we evaluated DSA on a robust set of corn silages to determine whether the DSA assay could determine relative differences in starch access between corn silages of differing moisture contents and particle size of starch as determined by the dry vertical shaking methods of Ferreira (2002).

Correlation coefficients for DSA and starch particle size characteristics of corn silage are in Table 1. The DSA of corn silage ranged from 552 to 1043 g/kg starch with a mean of 834. The mean DM and starch content of corn silages were 345 g/kg FM and 277 g/kg DM, respectively, with a range of 283 g/kg FM for DM and 385 g/kg DM for starch indicating a robust data set was developed. Both DM and starch content of corn silage were negatively related to DSA, but the DM correlation to DSA was not significant ($P=0.19$). A negative relationship of DM and starch to DSA would be expected because both are practical, but not total, indicators of maturity (Bal et al., 1997). Similar to high-moisture corn grains, advancing maturity increases silage DM, starch content and subsequent vitreousness of the starch (Philippeau and Michalet-Doreau, 1997; Correa et al., 2002), which have been shown in Figs. 2 and 3 to have a negative effect on DSA. Lack of a relationship between DSA and DM is somewhat surprising, but particle size of starch in corn silages (Table 1) was extremely variable, which could negate effects of moisture content on DSA (Fig. 1). Starch retained on the 13.2 and 9.5 mm screens was positively related ($P<0.08$) to DSA. The recovered starch procedure probably hydrolyzed fine starch particles or latent starch, still adhered to a predominantly forage fraction remaining on these screens because whole kernels of corn should not be retained on a 13.2 and 9.5 mm screens (Ferreira, 2002) after dry vertical shaking. This hypothesis is further supported by a stronger negative relationship ($r=-0.70$; $P<0.001$) between DM content of the corn silages and starch remaining on 13.2 and 9.5 mm screens (data not shown). This relationship suggests more starch was retained on 13.2 and 9.5 mm screens for wet immature corn silages compared to drier more mature corn silages. This relationship is logical because low DM silages harvested at immature stages are likely to contain physiologically immature grain with 0.0 g/100 g vitreousness starch (Philippeau and Michalet-Doreau, 1997), which could adhere to long forage particles and subsequently be retained on 13.2 and 9.5 mm screens after dry vertical shaking. These data suggest possible limitations of our method to evaluate particle size of starch in corn

Table 1

Correlation coefficients for degree of starch access and starch characteristics of corn silage ($n=22$)

Item	Mean	S.D.	Minimum	Maximum	DSA ^a correlation	
					<i>r</i>	<i>P</i>
Nutrient						
Degree of starch access (g/kg starch)	834	131	552	1043	1.00	–
DM (g/kg FM ^b)	345	62	166	449	–0.28	<0.19
Starch (g/kg DM)	277	84	82	467	–0.38	<0.07
Starch retained (screen size) (g/kg starch)						
13.2 mm	39	62	2.3	268	0.38	<0.08
9.5 mm	35	29	6.3	131	0.40	<0.07
6.7 mm	119	37	68	188	–0.28	<0.21
4.75 mm	223	63	104	349	–0.51	<0.01
3.35 mm	147	27	107	207	–0.57	<0.01
2.36 mm	115	26	77	178	–0.25	<0.26
1.18 mm	145	38	67	211	0.18	<0.41
.6 mm	91	31	39	149	0.38	<0.08
.3 mm	86	37	30	175	0.30	<0.14
<4.75 mm	583	101	359	755	0.08	<0.74
<2.36 mm + >6.7 mm	396	97	218	555	0.67	<0.001
Starch particle size (mm)						
Mean particle size	3.72	0.91	2.66	6.91	0.16	<0.47
Adjusted mean particle size ^c	2.87	0.45	2.13	3.71	–0.60	<0.003

^a DSA, degree of starch access.^b FM, fresh matter.^c A value of 0.30 mm was used in lieu of the nominal screen aperture for starch retained on 13.2 and 9.5 mm screens.

silage using dry vertical shaking methods (Ferreira, 2002). In contrast to starch retained on 13.2 and 9.5 mm screens, starch retained on 6.70, 4.75, 3.35 and 2.36 mm screens was negatively related to DSA. The strongest negative ($r = -0.51, -0.57$) significant ($P < 0.01$) relationships were observed for starch retained on 4.75 and 3.35 mm screens, respectively, and DSA. These observations are supported by the data of Ferreira (2002) who observed decreased *in vitro* starch digestibility on whole kernels and large kernel fragments in corn silage, which were retained on screens with nominal apertures of 4.75 mm. Because screens of 4.75 and 3.35 mm would retain whole kernels or larger kernel fragments and DSA of whole kernels or large kernel fragments is low (Fig. 1), a negative relationship between DSA and starch retained on screens of 4.75 and 3.35 mm would be expected. The DSA of corn silages were positively related to the amount of starch retained on screen sizes smaller than 2.36 mm with correlations ($P < 0.10$) occurring between DSA and starch retained on screen sizes of 0.60 and 0.30 mm. Starch retained on these screens would be defined as fine starch (Ferreira, 2002) and DSA increases as particle size is reduced (Fig. 1). As a result, higher amounts of fine starch retained on 0.60 and 0.30 mm screens sizes should increase DSA values. Finally, mean particle size as calculated by ANSI (1993) was not correlated to DSA but, as previously explained, starch retained on 13.2 and 9.5 mm screens was likely latent starch and improperly categorized for particle size. We recalculated mean particle size (i.e., adjusted mean particle size) considering starch retained on 13.2 and 9.5 mm screens

Table 2

Laboratory error associated with total starch, recovered starch and degree of starch access determinations

Evaluation set	Total starch (g/kg DM)	Recovered starch (g/kg DM)	DSA ^a (g/kg starch)
Mean			
Corn (particle size)	711	458	645
Corn (high-moisture)	725	509	702
Corn (endosperm type)	697	398	571
Corn silage	277	231	834
Repeatability S.D.			
Corn (particle size)	18.1	22.0	30.9
Corn (high-moisture)	20.0	24.1	33.1
Corn (endosperm type)	11.2	13.7	19.9
Corn silage	12.4	18.1	67.1

^a DSA, degree of starch access.

was latent starch of fine particle size (0.3 mm) as compared to using the actual nominal apertures in the mean particle length calculations. As a result, estimated mean particle size of starch in corn silage was reduced by approximately 1 mm and was negatively ($P < 0.003$) correlated ($r = -0.67$) with DSA, which suggests that as particle size of starch decreases in corn silage, the DSA increases. Data support our particle size evaluation (Fig. 1) and hypothesis that DSA should discriminate particle size of starch within a heterogeneous feed, such as corn silage. Results however, may indicate shortcomings of our starch particle size of separation technique (Ferreira, 2002) for corn silages. Therefore, results may not represent all idiosyncrasies between DSA and starch characteristics of corn silage.

4. Discussion

Repeatability is an important aspect of any new or proposed laboratory procedure. Repeatability S.D.s were calculated (Kragten, 1994) for total starch, recovered starch and DSA for the corn particle size, high-moisture corn and corn grain endosperm data by accessing all combinations of duplicate error in the quadruplicate runs (Table 2). In the case of the corn silage data, traditional duplicate laboratory errors were used to calculate the repeatability S.D. The repeatability S.D. for total starch determination were 18.1, 20.0, 11.2 and 12.4 g/kg DM for the aforementioned data, respectively. The precision of total starch determination by these enzymatic methods was similar to precision reported by McCleary et al. (1997) but determinations of recovered starch and DSA were less precise compared to total starch determinations. Because the recovered starch procedure developed is an alpha assay, no comparisons of laboratory error can be made to other published data. Some loss of precision would however be expected for the recovered starch assay because obtaining a representative sample of undried and unground material is likely more difficult than obtaining a representative sample of 1 mm ground material, which is generally used for total starch determination. For DSA, precision would be decreased simply because the repeatability S.D. is the product of the repeatability standard deviations of total starch and recovered starch. However, repeatability of the DSA assay appears to be reasonable, especially in

comparison to empirical PAF factors as a way to adjust non-fiber carbohydrate digestion coefficients for feeds containing high levels of starch.

Adaptation of the DSG assay used in the food industry to a livestock application had predictable advantages and disadvantages. The primary advantage is the assay is relatively simple with a minimum of laboratory equipment and is sensitive to factors in corn grains and corn silage, such as particle size, DM content and endosperm type, all known to influence corn starch digestion. The DSA assay also appears to determine relative starch digestion potential in the heterogeneous feed corn silage, which to date has been difficult to quantify by laboratory procedures.

Our DSA procedure is quantifiable with acceptable repeatability as compared to 'PAF' defined in NRC (2001), which is both subjective and empirical.

Despite these advantages, the DSA procedure has limitations. At present, there are no data available to establish a relationship between a measured DSA value and *in vivo* starch digestion. Also, the DSA assay may not have the capability to distinguish nuances of starch digestion, such as the interactions between ruminal and post-ruminal starch digestion that have been described (Oba and Allen, 2003). The DSA assay may also be prone to background interferences of mono- and oligosaccharides, which could result in over-estimation of DSA.

5. Conclusions

The DSA assay has potential for defining starch digestion potentials of corn grains and corn silages, but the DSA assay should be integrated into controlled research studies evaluating *in vivo* starch digestion to fully assess its potential.

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