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Prediction models of silage fermentation products on crop composition under strict anaerobic conditions: A meta-analysis

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ABSTRACT

A meta-analysis was conducted to establish linkages between crop and fermentation variables. Data from well-controlled mini silage studies were used in which no additives had been used and no ingress of air had occurred. The silage set consisted of data on crop chemical composition and epiphytic lactic acid bacteria count, and fermentation products (organic acids, alcohols, and ammonia-N) from 118 silages made from 30 grass, 7 legume, 15 grass and legume mixtures, and 66 whole-crop maize samples. The prediction models for fermentation products on crop variables were obtained by stepwise multiple regression analysis. Perennial forage and maize silages were analyzed separately. The best models were obtained for acetic acid in perennial forage silages, with a coefficient of determination of 0.63, and for lactic acid and ethanol in whole-crop maize silages, with coefficients of determination of 0.84 and 0.61, respectively. Fermentation products of perennial forage and maize silages were best related to dry matter and crude protein contents, respectively. Overall, the prediction equations were weak.
Key words: fermentation product, meta-analysis, prediction model, silage

INTRODUCTION

In countries where forage production is limited to a short period during the year, conservation as silage is vital to provide feeds for ruminants throughout the year. Silage production has increasingly become the dominant form of forage conservation in many parts of the world, mainly because of its lower dependency on dry weather compared with hay making.

End products of fermentation largely determine the hygienic and nutritive value of silage, affecting animal performance, milk composition, and milk product quality. High concentrations of ammonia and organic acids have been shown to decrease silage intake (Huhtanen et al., 2007). Increased levels of lactic acid or total acid also decrease milk fat and protein concentrations (Huhtanen et al., 2003). High levels of ethanol in silages can decrease milk yield but increase milk fat and protein concentrations and also induce milk off-flavor (Randby et al., 1999).

The composition of fermentation products can vary extensively and often unpredictably. Some attempts have been made to predict ensiling results of green silage crops from pre-ensiled composition (Wilkinson et al., 1983; Pitt et al., 1985; Leibensperger and Pitt, 1987). However, these studies either provided approximate estimations of silage quality or did not take into account formation of end-products such as alcohols. To what extent formation of individual end-products relates to initial composition of silage crops remains unclear.

The aim of this study was to obtain prediction models for fermentation products. We hypothesized that crop composition and field flora could explain fermentation product concentrations under strict anaerobic conditions.

MATERIALS AND METHODS

Silage Database

A silage database was constructed from laboratory studies performed at the Department of Animal Nutrition and Management of the Swedish University of Agricultural Sciences (Uppsala) between 1994 and 2011. The database contained 118 observations (30 grasses, 7 legumes, 15 grass and legume mixtures, and 66 whole-crop maize). All crops were grown in Sweden at latitudes of 58 to 60°N. Perennial forages varied in stage of maturity and cut number. Similarly, data on whole-crop maize covered a wide range of maturity stages, including early-harvest observations. Ensiling length and silo type varied from 90 to 151 d and from 1.5-L glass silos to 25-L stainless steel silos. All silos were airtight and kept at 20 ± 2°C during the ensiling

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Table 1. Arithmetical mean, range, and standard deviation (SD) of crop and fermentation variables of perennial forages (grass, legume, and mixture of grass and legume) and whole-crop maize (g/kg of DM unless otherwise stated)

	Perennial forages				Maize			
Item[1]	Mean	Range	SD	No.	Mean	Range	SD	No.
Crop variable								
DM (g/kg)	346	131–623	139.9	52	291	200–406	56.4	65
CP	152	61–220	33.4	52	83	58–103	9.5	66
WSC	119	27–333	58.7	52	108	10–235	59.4	66
Starch	—	—		—	208	13–400	113	65
aNDFom	—	—		—	447	351–553	56.2	65
Ash	—	—		—	45	36–58	5.7	65
BC (g of LA/100 g of DM)	5.6	3.8–10.7	1.4	34	—	—		—
LAB (log cfu/g of FM)	3.4	1.2–5.5	1.2	39	4.9	2.5–7.6	1.5	50
Fermentation variable								
Ammonia-N (g/kg of total N)	96.6	0.2–414.5	87.1	50	84.5	56.8–139.7	18.4	66
Lactic acid	34.5	0.1–133	34.7	52	50	11.8–95.2	20.8	66
Acetic acid	13.7	0.3–82.8	16.6	52	18.5	4.3–55.8	11.6	66
Butyric acid	16.4	0.1–105.9	26.5	42	0.7	0.1–11.7	1.9	63
Propionic acid	5.6	0.1–57.5	9.9	36	1.6	0.1–14.3	2.8	63
2,3-Butanediol	8.7	0.1–90	15.9	46	4.2	0.1–18.5	3.6	63
Ethanol	16.6	2.5–131.6	18.7	48	11.5	0.9–34.7	7.6	66

[1]WSC = water-soluble carbohydrates; aNDFom = amylase-treated ash-free NDF; BC = buffering capacity; LA = lactic acid; LAB = lactic acid bacteria; FM = fresh matter.

period. No additive treatments were included in the database. Crop variables included DM, water-soluble carbohydrates (**WSC**), buffering capacity (**BC**), CP, amylase-treated ash-free NDF, ash, starch, and lactic acid bacteria (**LAB**). Silage composition included organic acids (lactic, acetic, propionic, and butyric acids), alcohols (ethanol and 2,3-butanediol), and ammonia-N. Arithmetical mean, range, and standard deviation of crop and fermentation variables are given in Table 1.

Laboratory Analyses

Crop samples were dried at 60°C overnight and milled to pass a 1-mm sieve before being subjected to chemical analyses. The DM concentration was measured after drying at 103°C and before ashing at 550°C for 3 h. Concentration of CP was estimated by multiplying N concentration measured by the Kjeldahl technique to 6.25. Starch and WSC were measured by using an enzymatic method described by Udén (2006, 2010). The method described by Van Soest et al. (1991) and modified by Chai and Udén (1998) was used for determination of amylase-treated ash-free NDF. Crop BC was measured according to McDonald and Henderson (1962). Culture-dependent microbial analysis was used to quantify LAB with Rogosa agar as the culturing medium (Seale et al., 1986).

Organic acids and alcohols were measured on extracted silage juice by HPLC (Andersson and Hedlund, 1983). The method described by Broderick and Kang (1980) was used to measure ammonia-N.

Statistical Analyses

All statistical analyses were carried out using SAS software (version 9.2; SAS Institute Inc., Cary, NC). Relationships within crop and fermentation variables were studied by correlation analysis, and significance was declared at $P < 0.05$. The prediction models for fermentation products were obtained using the REG procedure, in which multiple regression models were fitted by the STEPWISE model-selection method. Variables were entered and retained in the model at $P < 0.15$. The Univariate procedure was used to test the normality of residuals, and logarithmic transformation of response variables was applied if not normally distributed. Perennial forage and maize silages were analyzed separately. The effect of study was not included in the statistical model because the data set included only one observation per study.

RESULTS

Correlation Analysis of Fermentation Products

Pearson correlation coefficients between fermentation products of perennial forage and whole-crop maize silages are presented in Tables 2 and 3, respectively. In both silage categories, ammonia-N was positively correlated with butyric acid and 2,3-butanediol. Several discrepancies, however, were found between perennial forage and maize silages regarding correlation results. For instance, ammonia-N and acetic acid were positively correlated in perennial forage silages but uncor-