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Concentration of pro-vitamin A carotenoids in common beef cattle feedstuffs¹

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Abstract

Quantification of the pro-vitamin A carotenoids in feedstuffs commonly fed to livestock has been ignored for many years. A greater dietary concentration of vitamin A has the potential to limit adipogenesis in cattle, thereby reducing carcass quality and value. A survey of 18 feedstuffs commonly fed to beef cattle was conducted for determination of vitamin A equivalents based on analysis of carotenoids. The pro-vitamin A carotenoids of interest were β -carotene, α -carotene, and β -cryptoxanthin. Collaborators in 5 states collected the feedstuffs and then shipped them to The Ohio State University for compilation and analysis. Carotenoids were extracted from the feedstuffs and then quantified using HPLC with photodiode array analysis. Fresh fescue pasture contained approximately 10 times more vitamin A equivalents than hay and 5 times more than corn silage (39,865, 2,750, and 6,900 IU of vitamin A/kg of DM for fresh pasture, hay, and corn silage, respectively). Beta-cryptoxanthin and α -carotene could not be detected in any forage samples. Hay and corn silage vitamin A equivalents decreased over extended periods of time from harvest to sample collection. Corn was the only feedstuff to have appreciable concentrations of all 3 pro-vitamin A carotenoids quantified. Corn processing had a minimal impact on the vitamin A equivalents. High-moisture corn contained 54% more vitamin A equivalents than whole shelled corn (378 and 174 IU of vitamin A/kg of DM, respectively). Pro-vitamin A carotenoids were more concentrated in corn coproducts than in whole shelled corn. The drying of distillers grains with solubles may significantly degrade β -carotene (800 and 480 IU/kg of DM for wet and dry distillers grains, respectively). Soybean-based feedstuffs contain a small concentration of pro-vitamin A carotenoids, at 55 and 45 IU of vitamin A/kg of DM for soybean meal and soybean hulls, respectively. Overall, there was considerable variation in the pro-vitamin A content of feedstuffs based on location and storage conditions. An extensive analysis of feedstuffs would need to be conducted for an accurate estimation of the vitamin A content of feedlot cattle diets.

Keywords

carotenoid; cattle; vitamin A

INTRODUCTION

Plant-based feed ingredients used in ruminant diets contain minute amounts of vitamin A; however, plants contain carotenoids (Nozière et al., 2006). The most common pro-vitamin A carotenoids in plant-based feedstuffs are β -carotene, α -carotene, and β -cryptoxanthin. The

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pro-vitamin A carotenoids in major feed ingredients used in livestock diets have not been assessed for almost 50 yr. Recent investigations have reported considerable differences between current analytical values and the vitamin A equivalents reported in the 2000 Beef NRC (NRC, 2000; Gorocica-Buenfil et al., 2007a; Pickworth et al., 2011, 2012). There is also substantial variation between the vitamin A equivalents reported in the Beef NRC (2000) and the Dairy NRC (2001).

Vitamin A in increased concentrations inhibits adipocyte differentiation in vitro (Kawada et al., 1996), and feeding finishing diets to feedlot beef cattle without supplemental vitamin A has been shown to improve carcass quality (Gorocica-Buenfil et al., 2007b,c; Arnett et al., 2008; Pickworth et al. 2011, 2012). Throughout the finishing phase, intramuscular adipocytes are undergoing hyperplasia, differentiation, and hypertrophy to increase marbling (May et al., 1994); therefore, these adipocytes may be sensitive to dietary vitamin A intake and storage. Vitamin A recommendations in the Beef NRC (2000) and Dairy NRC (2001) were written based on limited research that is now more than 50 yr old and without vitamin A equivalents for many common feedstuffs.

Therefore, the objective of this study was to collect a representative sample of feedstuffs fed to beef cattle to determine the pro-vitamin A carotenoid content. A better understanding of the content and variation of carotenoids in feedstuffs may improve the accuracy of dietary vitamin A formulation for beef cattle and other livestock.

MATERIALS AND METHODS

No animals were used in this study, therefore Animal Care and Use Committee approval was not obtained.

A survey of feedstuffs commonly fed to finishing beef cattle was compiled at The Ohio State University (Wooster) to determine the pro-vitamin A carotenoid content. Carotenoids of interest included β -cryptoxanthin, and α - and β -carotene. Feedstuff samples were compiled from 5 different locations across the United States, including The Ohio State University. Collaborators for sample collection included Alfredo DiCostanzo from the University of Minnesota (St. Paul), Matt Poore from North Carolina State University (Raleigh), Jon Schoonmaker from Iowa State University (Ames), and Tim Murphy from High Plains Consulting Inc. (Dodge City, KS). Requests were made to obtain 3 samples of each feedstuff to account for storage and sampling differences. As samples were collected by the collaborators, they were sealed in plastic bags and stored at -20°C in the dark until all samples were compiled. Samples were shipped on dry ice overnight to The Ohio State University in Wooster. Upon arrival, samples were stored at -20°C until all samples were collected from collaborators. Approximately 200 g of the feedstuffs were freeze-dried (Labconco Freeze Dryer 8, Kansas City, MO), and then transferred to a blender (Blend Master, Hamilton Beach, Washington, DC) and ground for 1 to 2 min. Ground feedstuff samples were also stored in sealed plastic bags, in the dark at -20°C , until all samples were prepared for extraction or proximate analysis.

Proximate analysis was conducted on all feedstuff samples. All samples were analyzed for DM, OM, N (macro Kjeldahl), and ether-extractable lipid (Ankom Technology, Fairport, NY; AOAC, 1997). Feed samples (100-g subsamples) were dried in a forced-air oven at 55°C , ground to pass through a 1-mm screen, and analyzed for DM (AOAC, 1997). Neutral detergent fiber and ADF were also determined on forage and coproduct samples using Ankom Technology methods 5 and 6, respectively (Ankom 200 Fiber Analyzer, Ankom Technology, Macedon NY).

Carotenoid analyses were conducted on ice under dim yellow lighting to prevent sample degradation. All chemicals used in the extraction and analysis procedures were analytical grade or better. Extraction of carotenoids from feedstuffs was based on a modified method of Gorocica-Buenfil et al. (2007a). Extraction procedures and analyses were conducted in duplicate. An aliquot of 1.5 to 2.0 g of each ground feedstuff was weighed into a 30-mL polypropylene tube, 10 mL of methanol was added, and the tubes were vortexed for 3 min. The tubes were then centrifuged for 5 min at $1,000 \times g$ at room temperature. All the supernatant was pipetted into a 50-mL polypropylene tube, and extraction of the residue was repeated 2 times with 10 mL of hexane:acetone (1:1, vol/ vol). To the combined extracts, 20 mL of 10% aqueous sodium chloride solution was added. The samples were shaken for 2 min and centrifuged to facilitate separation. The supernatant hexane phase was transferred into a 25-mL disposable glass tube; the lower watery phase was re-extracted with 10 mL of hexane and combined with the first extract. A 5-mL aliquot of the combined hexane extract was pipetted into a 10 $\times$ 130 mm screw-cap glass vial, evaporated to dryness under a stream of N₂ gas, and sealed. All extracts were stored dry at -80°C until analysis.

For HPLC analysis of carotenoid content of feedstuffs, samples were reconstituted in 200 μL of methyl *tert*-butyl ether (MTBE):methanol (1:1, vol/vol) and filtered through a 0.2- μm nylon filter. All samples were extracted in duplicate, and means are reported. Samples were analyzed using an HPLC system (Waters 996, Waters Corp., Milford, MA) interfaced with a photodiode array detector (Waters 2996, Waters Corp.) following the methods of Gorocica-Buenfil et al. (2007a) with slight modifications. Separation was achieved using a YMC C30 column (150 $\times$ 4.6 mm i.d., 5- μm particle size, Waters Corp., Milford, MA). A gradient elution method with methanol:water/2% aqueous ammonium acetate buffer:MTBE (88:5:2:5, by vol; solvent A) and MTBE:methanol:water:2% aqueous ammonium acetate buffer (79:16:3:2, by vol; solvent B) was used. The gradient was isocratic at 0% solvent B for 5 min, linear to 65% solvent B over 16 min, linear to 83% solvent B over 4 min, quickly increasing to 100% solvent B and holding for 1 min, and quickly returning to 0% solvent B and holding for 4 min. The flow rate was 1.3 mL/min, the column temperature was 30°C , and the injection volume was 5 to 20 μL (based on predicted concentration). Quantification was based on external calibration curves using authentic standards: β -carotene (Sigma Aldrich, St. Louis, MO), α -carotene (Chromadex, Irvine, CA), and β -cryptoxanthin (Indofine, Hillsborough, NJ). The limit of detection (defined as a signal-to-noise ratio of 3 to 1) for this assay for all 3 carotenoids was estimated as 0.35 $\mu\text{g}/100\text{ g}$ of dry weight. The assay CV was less than 5%, with an accuracy of greater than 95% for samples and standards. All solvents were purchased from Fisher Scientific (Pittsburgh, PA).

Mean concentrations and SEM of pro-vitamin A carotenoids and vitamin A equivalents, and the nutrient composition for each feedstuff were determined using the PROC MEANS procedure (SAS Inst. Inc., Cary, NC).

RESULTS AND DISCUSSION

A total of 18 common feedstuffs used in beef cattle diets were analyzed for the concentration of pro-vitamin A carotenoids. Tables 1, 2, 3, and 4 provide information on the pro-vitamin A carotenoids, vitamin A equivalents, and nutrient composition of the feedstuffs. The tables include a description of the feedstuff, all the values obtained, and the mean and SEM for each type of feedstuff. Samples with the same feedstuff identification number and different sample dates are replicates collected with different lengths of storage between harvest and sample collection for carotenoid analyses.

There was immense variation in the carotenoid content of some of the feedstuffs based on where the sample was collected and the length of the storage period from harvest to sample

collection (when the feedstuff typically would be fed to cattle). Aurand et al. (1947) identified genetic selection, environmental conditions, agronomic factors, and plant maturity as a few of the preharvest factors that affected the concentration of carotenoids in corn. Postharvest conditions also significantly alter the carotenoids of a feedstuff. Temperature, humidity, duration of storage, UV light exposure, and oxygenation conditions result in various rates of degradation of the carotenoids (Porter et al., 1946). It is unclear how these factors alter carotenoid stability and vitamin A potential of corn or any other feedstuff fed to cattle; however, it is clear that there is a great amount of within-feedstuff variability of carotenoids. The limited information on the vitamin A equivalents of feedstuffs reported in the Beef NRC (2000) and Dairy NRC (2001) were obtained by older methods, which can overestimate or underestimate pro-vitamin A content. In some of the early methods, carotenes were separated from xanthophylls first with saponification and then by solvent-solvent partitioning (Guilbert, 1934; Peterson et al., 1937). Later methods separated carotenes from xanthophylls by using open column chromatography (Martin et al., 1968). Once the carotenes were isolated, pro-vitamin A content was quantified using absorption coefficients for β -carotene. As highlighted by Simpson (1983), this method works well if β -carotene is the only pro-vitamin A carotenoid in the feedstuff. However, this method of analysis overestimates the pro-vitamin A contribution of α -carotene and γ -carotene by estimating their contributions to vitamin A equal to β -carotene, and would not assess β -cryptoxanthin at all.

Methods (i.e., HPLC) that separate pro-vitamin A carotenoids were first developed in the late 1970s and 1980s (Simpson, 1983) and have significantly improved the ability to accurately measure concentrations of pro-vitamin A carotenoids in feedstuffs. Thus, the concentrations of pro-vitamin A carotenoids of feedstuffs used in cattle diets after different storage and processing conditions warranted research using updated extraction and quantification methods.

The β -carotene content of dry forages varied considerably and was reduced with prolonged postharvest storage (Table 1). Alfalfa and fescue hay vitamin A equivalents declined in the same lot of hay after 4 mo of storage in a dry, roofed barn (1,781 to 1,366 and 3,622 to 1,974 IU of vitamin A/kg of DM for alfalfa and fescue hay, respectively). Alfalfa hay collected in North Carolina had more than twice the vitamin A equivalents as that collected in Ohio. These differences may be related to growing conditions, such as soil nutrient profile, heat units, and water. They may also be related to the drying conditions, such as the number of days between cutting the forage and baling. As a result of these potential differences, and the relatively small number of samples in this analysis, it should not be assumed that these relative differences in vitamin A equivalents are sustained regional differences. Plant maturity at harvest also greatly affects the β -carotene content of plants. However, this exact information was not available for these samples. The Beef NRC (2000) reports that alfalfa hay has 19,000 to 81,000 IU of vitamin A/kg of DM equivalents depending on the maturity state of alfalfa at harvest. Based on nutrient composition, alfalfa hay samples in this compilation are most similar to the "Alfalfa Hay, Early Bloom-N" described in the Beef NRC (2000), except for vitamin A equivalents (2,913 and 56,000 IU of vitamin A/kg of DM for the present study and Beef NRC, respectively). Fescue hay vitamin A equivalents were reduced by 45% during 4 mo of storage, even when stored indoors away from UV radiation and moisture. This reduction over time was similar to the variation in fescue hay by harvest location. The Beef NRC (2000) does not report vitamin A values for "Fescue K31, Hay" at any maturity. The concentration of β -carotene in orchardgrass hay was not as affected by storage as fescue hay and averaged 3,109 IU/kg of DM. Overall, the vitamin A equivalents of the hay samples analyzed in this study were approximately half those reported in the Beef NRC (2000).

The classification and description of forages presented in the Beef NRC (2000) is vague, making it difficult to compare hay and fresh forage samples. The vitamin A equivalents and proximate analysis of the late summer fescue-based pastures in Ohio were similar to those reported in the Beef NRC (2000) for range or meadow forages. The Beef NRC (2000) reports 37,200 IU of vitamin A/kg of DM for all maturity states of range, and the results observed in this study for fescue pasture were similar, with 39,000 IU of vitamin A/kg of DM. Although the fescue hay and the fescue pasture were not sampled from the same field, fescue pasture had more than 13 times the vitamin A equivalents compared with fescue hay (39,000 and 2,900 IU of vitamin A/kg of DM, respectively). Chauveau-Duriot et al. (2005) reported that 83% of carotenoids in grasses are lost or degraded during the hay-making process. The maturity of the forage at harvest, drying methods, and storage conditions could have a considerable impact on dry forage carotenoid concentration and must be considered when estimating vitamin A equivalents of a diet.

Corn silage is commonly used as a roughage source in feedlot cattle diets and is consequently the primary source of carotenoids in these diets. The vitamin A equivalents of corn silage ranged from 1,829 to 16,117 IU of vitamin A/kg of DM (Table 2). The greatest vitamin A equivalent for corn silage reported in this survey was only 36% of that reported in the Beef NRC (2000). The percentage of grain in the corn silage was not determined, to compare directly with the categories presented in the Beef NRC (2000) for nutrient analysis; however, vitamin A equivalents are reported as 58,100 IU of vitamin A/kg; thus, percentage of grain should not be a factor. Whereas Nozière et al. (2006) hypothesized that corn silage would have minute carotenoid concentrations, actual concentrations were not measured. We observed a 5-fold difference in vitamin A equivalents of corn silage samples collected from 4 feedlots in Kansas even though NDF, ADF, CP, and ether extract did not vary greatly. Silo types and storage periods were not clearly defined for these samples and could have resulted in the variation in β -carotene and vitamin A equivalent concentrations. No indications of frost damage, heating, or spoilage were present in any of the silage samples, as indicated by physical appearance and nutrient composition. Three months of storage resulted in a 6 to 39% variance in vitamin A equivalents of corn silage (corn silages 2, 3, 4, and 6 in Table 2). Corn silages used in the feedlot studies by Gorocica-Buenfil et al. (2007a, 2008) and Pickworth et al. (Pickworth et al., 2011, 2012) contained an average of 5,934 IU of vitamin A/kg of DM equivalents from carotenoids, which is similar to the mean corn silage vitamin A equivalents from carotenoids of the 19 samples analyzed. Even at the 5 to 10% dietary inclusion rate used in these 3 experiments, corn silage was the primary vitamin A source for steers fed diets without supplemental vitamin A. The vitamin A provided in the basal diet was sufficient to prevent deficiency symptoms in finishing cattle in each of those studies.

Corn is a primary ingredient in feedlot cattle diets and contains a trace concentration of carotenoids (Table 3). Among the major feed grains, corn is the only one that contains significant concentrations of β -carotene (Buckner et al., 1990). The pro-vitamin A carotenoid profile of corn was much different from those of forages because it contained β -cryptoxanthin and α -carotene in addition to β -carotene. Corn processing had little effect on the vitamin A equivalents, with carotenoids being similar for whole shelled corn, steam-flaked corn, and cracked corn (170, 137, and 150 IU of vitamin A/kg of DM, respectively). It is important to note, however, that these determinations of corn after processing were not made with a common source of corn. The drying process of whole shelled corn immediately after harvest had no effect on the vitamin A equivalents when a batch of corn was subsampled because it was placed in the grain dryer at harvest and again after a standard 24-h drying process (WS corn 3 in Table 3). The Beef NRC (2000) does not list vitamin A equivalents for dry or high-moisture corn; however, it does indicate that cracked corn grain contains 1,000 IU of vitamin A/kg of DM. Preliminary research at The Ohio State University determined the vitamin A equivalents of whole shelled corn to be 370 IU of

vitamin A/kg of DM (Gorocica-Buenfil et al., 2007a), which is approximately double the average in the present study (170 IU of vitamin A/kg of DM). The Beef NRC (2000) does not indicate the method of analysis used in the determination of vitamin A equivalents, nor does it give the number of data points used to determine the listed value. Egesel et al. (2003) reported that β -carotene ranges from 13 to 290 $\mu\text{g}/100\text{ g}$, depending on the corn variety in a collection of 200 samples. The β -cryptoxanthin content of corn in the present study (29.5 $\mu\text{g}/100\text{ g}$) was within the lesser range of that reported previously (Egesel et al., 2003). Differences in growing season, corn variety, growing conditions, and extraction procedures likely contributed to the variation in carotenoids quantified as previously identified by Porter et al. (1946) and Aurand et al. (1947).

The fermentation of high-moisture corn was expected to reduce the carotenoid content; however, Gorocica-Buenfil et al. (2007a) reported that high-moisture corn had 40% more vitamin A equivalents than whole shelled corn. In the present study, high-moisture corn averaged 359 IU of vitamin A/kg of DM, which was 200 IU of vitamin A/kg of DM greater than whole shelled corn. The differences in the concentration of carotenoids in high-moisture corn and whole shelled corn might be related to the carotenoid concentration in the corn kernel at harvest. High-moisture corn is harvested at a younger plant maturity and does not undergo a prolonged drying phase in the field before harvest as compared with whole shelled corn. Thus, carotenoids may actually be degrading in whole shelled corn as the plant matures, and the corn kernels dry before harvest occurs. The effects of storage time on the concentrations of pro-vitamin A carotenoids of high-moisture corn appear to be minimal. Because high-moisture corn was stored in a silo from harvest to feeding to cattle, the carotenoids concentrated or degraded, depending on the sample (high moisture corn 1 to 5 in Table 2). Even after approximately 2 yr of storage, the high moisture corn 6 (Table 2) yielded vitamin A equivalents similar to the mean for high-moisture corn in this study. Ensiled high-moisture corn is in a low-oxygen environment, which could also slow the degradation of carotenoids as compared with whole shelled corn. These differences may contribute to the lesser degradation over time for high-moisture corn and the greater total carotenoid concentration compared with whole shelled corn.

Corn coproducts had greater vitamin A equivalents than whole shelled corn (Table 4). Corn gluten meal contained the greatest concentration of pro-vitamin A carotenoids of all of the corn coproducts investigated, at 3,747 IU of vitamin A/kg of DM. Here again, the vitamin A equivalents of corn gluten meal analyzed in the present study were 86% less than the 29,800 IU of vitamin A/kg of DM reported in the Beef NRC (2000). The drying of distillers grains may have a considerable impact on their carotenoid concentration. Overheating of distillers grains, resulting in the Maillard reaction binding up protein, may also destroy pro-vitamin A carotenoids. Wet distillers grains contained 800 IU of vitamin A/kg of DM, whereas dry distillers grains contained 482 IU of vitamin A/kg of DM. These samples did not originate from the same corn, but rather were representative samples of wet and dry distillers grains being fed to beef cattle. Further investigation of the effects of drying on carotenoids in distillers grains is warranted because inclusion rates of distillers grains in livestock diets is increasing. The Beef NRC (2000) suggests that both wet and dry distillers grains contain 1,200 IU of vitamin A/kg of DM. The carotenoid content of the corn used and the processing and drying methods would greatly affect the carotenoid content of distillers grains.

Soybean-based coproduct feedstuffs contained very minimal concentrations of pro-vitamin A carotenoids compared with corn or forages (Table 4). Soybean meal and soybean hulls had similar pro-vitamin A carotenoid profiles, which resulted in equal vitamin A equivalents (43.8 and 54.9 IU of vitamin A/kg of DM, respectively). These vitamin A equivalents for soybean meal are approximately one-third those reported for whole soybeans in the Beef

NRC (2000; 1,600 IU of vitamin A/kg of DM). Soybean products provide minimal amounts of vitamin A for livestock.

Numerous factors can influence the carotenoid composition of a feedstuff, such as growing conditions, maturity at harvest, and postharvest storage conditions and processing. Discrepancies also exist between historical carotenoid quantifications and those determined using more accurate HPLC methods. To be able to accurately meet, but not exceed, vitamin A requirements of beef cattle through supplementation, diet analysis will be required because of extensive variation in the vitamin A equivalents of diet ingredients. A more comprehensive and accurate listing of the vitamin A equivalents of feedstuffs used in the beef industry would be helpful, or the carotenoid content of feedstuffs should be included in nutrient analyses. Having knowledge of the vitamin A equivalents of a diet could help nutritionists formulate rations to meet animal requirements for health while maximizing performance and carcass potential.

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Table 1

Pro-vitamin A carotenoid composition of dry or fresh forages

State	Feedstuff identification	Sample date	Pro-vitamin A carotenoids ^J				DM, %	OM, %	NDF, %	ADF, %	CP, %	Ether extract, %
			β-Carotene ⁴	β-Crypt ⁵	α-Carotene	Vitamin A equivalents ^{2,3}						
OH	Alfalfa hay 1 ⁶	October 18, 2007	445.1	ND ⁷	ND	1,780.5	83.7	90.5	38.2	35.6	17.8	2.39
OH	Alfalfa hay 1	February 10, 2008	341.5	ND	ND	1,366.1	84.3	90.7	40.7	36.8	16.7	2.13
NC	Alfalfa hay 2 ⁸	September 20, 2008	1,398.3	ND	ND	5,593.4	84.1	91.9	47.0	41.1	17.3	1.69
Mean			728.3	ND	ND	2,913.3	84.0	91.0	42.0	37.8	17.2	1.74
SEM			336.3	ND	ND	1,345.3	0.19	0.44	2.59	1.66	0.31	0.36
OH	Fescue hay 1 ⁹	October 18, 2007	905.6	ND	ND	3,622.4	83.8	93.6	57.2	33.8	9.3	2.75
OH	Fescue hay 1	February 10, 2008	493.4	ND	ND	1,973.7	85.8	90.1	62.3	38.0	10.8	2.26
NC	Fescue hay 2 ⁸	September 20, 2008	1,010.9	ND	ND	4,040.4	86.0	95.3	67.8	41.4	7.1	1.88
NC	Fescue hay 3 ¹⁰	September 20, 2008	513.6	ND	ND	2,054.3	85.2	94.5	75.2	47.7	6.1	1.31
Mean			730.7	ND	ND	2,922.7	85.2	93.4	65.6	40.2	8.3	2.05
SEM			132.9	ND	ND	531.7	0.51	1.15	4.24	3.26	1.05	0.38
OH	Orchardgrass hay 1 ⁹	October 18, 2007	972.3	ND	ND	3,889.3	86.1	93.4	63.6	37.6	8.7	1.72
OH	Orchardgrass hay 1	February 10, 2008	848.0	ND	ND	3,392.0	84.4	93.0	63.1	36.0	8.9	1.87
NC	Orchardgrass hay 2 ¹⁰	September 20, 2008	511.2	ND	ND	2,044.6	85.2	92.7	68.7	49.2	8.8	1.77
Mean			777.2	ND	ND	3,108.7	85.2	93.0	65.1	40.9	8.84	1.79
SEM			137.8	ND	ND	550.8	0.51	0.21	2.10	4.16	0.18	0.14
OH	Fescue pasture 1	August 3, 2007	20,897.1	ND	ND	43,588.6	33.6	97.2	66.0	47.1	10.9	2.34
OH	Fescue pasture 1	September 5, 2007	8,925.0	ND	ND	35,699.9	28.2	97.2	65.0	35.2	10.0	2.53
OH	Fescue pasture 2	August 6, 2007	8,708.0	ND	ND	34,952.0	34.2	97.1	71.3	40.8	11.8	2.65
OH	Fescue pasture 2	September 5, 2007	11,305.1	ND	ND	45,220.3	33.4	97.2	62.1	37.1	10.4	2.37
Mean			9,966.3	ND	ND	39,865.2	32.5	95.7	66.1	40.0	10.8	2.72
SEM			661.6	ND	ND	2,646.2	1.41	1.50	1.94	2.62	1.05	0.23
NC	Wheat × ryegrass hay ¹⁰	September 20, 2008	496.3	ND	ND	1,985.0	85.0	94.4	70.6	44.4	10.6	1.01
OH	Wheat straw ⁶	October 2, 2007	15.1	ND	ND	60.4	84.3	96.2	90.3	66.1	1.2	1.02

^JExpressed as micrograms per 100 g of DM.

² Expressed as international units per kilogram of DM.

³ Calculated as follows: 1 mg of β -carotene = 400 IU of vitamin A; 1 mg of β -cryptoxanthin = 200 IU of vitamin A; and 1 mg of α -carotene = 200 IU of vitamin A.

⁴ Includes *cis*-9 and all-*trans* β -carotene.

⁵ β -Crypt = β -cryptoxanthin.

⁶ Harvested in July 2007.

⁷ ND = not detected.

⁸ Harvested in June 2008.

⁹ Harvested in June 2007 (botanical mix of approximately 50% wheat and 50% ryegrass in hay bale).

¹⁰ Harvested in May 2008.

Table 2

Pro-vitamin A carotenoid composition of fermented forages

State	Feedstuff identification	Sample date	Pro-vitamin A carotenoids ¹					Vitamin A equivalents ^{2,3}	DM, %	OM, %	NDF, %	ADF, %	CP, %	Ether extract, %
			β-Carotene ⁴	β-Crypt ⁵	α-Carotene									
OH	Corn silage 1 ⁶	October 30, 2006	1,887.9	ND ⁷	ND		7,551.5	38.3	97.2	40.6	25.1	6.8		2.42
OH	Corn silage 1	January 28, 2007	1,999.8	ND	ND		7,999.3	34.8	97.1	40.0	24.3	6.3		2.83
OH	Corn silage 1	May 7, 2007	1,618.0	ND	ND		6,472.0	35.4	96.9	36.4	22.5	6.4		2.65
OH	Corn silage 2 ⁸	October 31, 2007	1,503.0	ND	ND		6,011.9	39.5	96.5	39.0	24.8	6.6		2.82
OH	Corn silage 2	January 20, 2008	1,367.0	ND	ND		5,468.1	36.1	96.2	37.8	24.8	6.7		2.78
OH	Corn silage 3 ⁸	November 15, 2007	496.9	ND	ND		3,987.5	39.9	96.6	42.7	23.9	7.4		3.35
OH	Corn silage 3	February 11, 2008	308.8	ND	ND		2,435.4	39.7	95.2	40.6	22.8	8.0		3.56
OH	Corn silage 4 ⁸	March 3, 2008	2,521.8	28.4	ND		10,143.9	37.0	96.8	39.2	23.3	6.8		2.99
OH	Corn silage 4	June 9, 2008	2,379.6	30.6	ND		9,579.5	37.1	96.7	43.7	24.0	6.9		3.12
MN	Corn silage 5 ⁹	November 15, 2007	3,339.8	ND	ND		13,359.1	35.2	96.2	50.5	31.7	9.6		2.39
MN	Corn silage 5	January 15, 2008	3,047.2	ND	ND		12,188.6	34.5	96.2	48.5	29.7	7.5		2.46
MN	Corn silage 5	May 15, 2008	2,039.5	ND	ND		8,157.9	31.6	95.5	49.1	31.3	7.8		2.10
MN	Corn silage 6 ⁹	March 28, 2007	637.5	ND	ND		2,549.9	39.6	96.3	41.8	31.5	6.2		2.58
MN	Corn silage 6	April 25, 2007	457.4	ND	ND		1,829.4	47.2	96.8	36.3	26.8	5.8		2.33
MN	Corn silage 6	June 6, 2007	496.8	ND	ND		1,987.1	40.0	96.7	39.5	28.7	5.8		2.36
KS	Corn silage 7 ⁸	August 29, 2008	807.8	ND	ND		3,231.3	34.4	91.5	47.6	33.4	6.9		2.39
KS	Corn silage 8 ⁸	August 29, 2008	1,365.3	ND	75.3		5,611.6	35.8	93.1	45.8	30.0	7.4		2.76
KS	Corn silage 9 ¹⁰	August 29, 2008	3,854.2	ND	ND		15,416.8	44.4	94.8	37.3	22.9	8.4		1.97
KS	Corn silage 10 ¹⁰	August 29, 2008	4,029.0	ND	ND		16,116.1	25.5	94.5	37.4	24.6	9.0		2.65
Mean			1,721.6	3.0	3.8		6,899.9	39.4	95.8	43.6	28.8	7.0		2.68
SEM			257.9	2.0	3.8		1,032.1	2.48	0.32	1.79	1.55	0.40		0.12

¹ Expressed as micrograms per 100 g of DM.

² Expressed as international units per kilogram of DM.

³ Calculated as follows: 1 mg of β-carotene = 400 IU of vitamin A; 1 mg of β-cryptoxanthin = 200 IU of vitamin A; and 1 mg of α-carotene = 200 IU of vitamin A.

- ⁴ Includes *cis*-9 and all-*trans* β -carotene.
- ⁵ β -Crypt = β -cryptoxanthin.
- ⁶ Harvested in 2006.
- ⁷ ND = not detected.
- ⁸ Harvested in 2007.
- ⁹ Harvest date not known.
- ¹⁰ Harvested in 2008.

Table 3

Pro-vitamin A carotenoid composition of corn

State	Feedstuff identification	Sample date	Pro-vitamin A carotenoids ^J				Vitamin A equivalents ^{2,3}	DM, %	OM, %	CP, %	Ether extract, %
			β-Carotene ⁴	β-Crypt ⁵	α-Carotene						
OH	WS corn ⁶ 1	October 30, 2006	27.6	26.6	8.2	180.1	88.7	99.0	8.3		3.96
OH	WS corn 1	May 29, 2007	25.6	25.1	7.4	167.2	89.1	98.7	8.1		3.84
OH	WS corn 2	October 23, 2007	30.7	42.4	25.2	258.2	87.6	98.7	7.1		3.75
OH	WS corn 2	January 20, 2008	29.9	40.3	18.5	237.4	89.0	98.5	7.9		3.21
OH	WS corn 2	April 14, 2008	29.1	33.2	21.6	225.8	87.6	98.6	7.4		3.46
OH	WS corn 3	October 24, 2007	24.2	1.0	3.2	105.1	88.7	98.6	9.1		2.02
OH	WS corn 3	October 25, 2007	25.1	1.0	3.1	108.5	85.3	98.8	9.3		2.16
IA	WS corn 4	October 12, 2007	23.5	2.0	10.8	119.3	87.6	98.8	7.6		3.30
KS	WS corn 5	August 29, 2008	26.1	1.0	5.0	116.5	88.0	99.0	7.7		2.12
KS	WS corn 6	August 29, 2008	29.5	1.2	5.8	132.0	86.7	98.8	8.8		2.03
Mean			29.5	16.1	9.9	170.0	87.8	98.7	8.1		1.29
SEM			2.5	5.3	2.5	17.3	0.94	0.04	0.18		0.03
KS	SF corn ⁷ 1	August 29, 2008	28.9	0.9	5.3	128.1	78.7	99.0	8.4		2.38
KS	SF corn 2	August 29, 2008	32.6	1.1	7.0	146.7	79.0	99.1	7.8		2.63
Mean			30.8	1.0	6.1	137.4	78.9	99.1	8.10		2.51
SEM			1.9	0.1	0.8	9.3	0.13	0.04	0.29		0.13
MN	Cracked corn 1	March 28, 2007	39.4	1.6	ND ⁸	160.7	86.5	99.0	9.0		2.11
MN	Cracked corn 1	April 25, 2007	36.0	1.5	ND	146.9	86.9	98.8	8.8		2.40
MN	Cracked corn 1	May 23, 2007	34.3	1.4	ND	139.9	87.1	98.6	8.2		2.33
KS	Cracked corn 2	August 29, 2008	34.7	1.1	5.4	151.9	83.4	98.7	9.0		3.36
Mean			36.1	1.4	1.4	149.8	86.0	98.8	8.8		2.55
SEM			1.2	0.1	1.4	21.3	0.85	0.09	0.28		0.34
OH	HM corn ⁹ 1/10	October 30, 2006	94.7	33.7	10.7	467.6	74.7	98.8	6.9		4.99
OH	HM corn 1	May 7, 2007	94.3	64.6	39.8	586.1	75.4	98.9	7.2		4.84
OH	HM corn 2/11	October 31, 2007	61.3	59.4	ND	363.7	70.3	98.8	7.1		3.64
OH	HM corn 2	January 20, 2008	62.4	67.5	ND	384.6	70.2	98.8	7.9		3.98

State	Feedstuff identification	Sample date	Pro-vitamin A carotenoids ¹				DM, %	OM, %	CP, %	Ether extract, %
			β-Carotene ⁴	β-Crypt ⁵	α-Carotene	Vitamin A equivalents ^{2,3}				
OH	HM corn 2	June 9, 2008	73.2	55.7	ND	404.3	73.0	98.8	8.4	3.80
OH	HM corn 3 ¹¹	November 7, 2007	83.1	2.3	10.1	357.4	73.7	98.7	8.3	3.53
OH	HM corn 3	March 21, 2008	57.0	1.4	12.2	255.3	74.4	98.9	7.9	3.13
MN	HM corn 4 ¹²	March 28, 2007	81.2	1.6	12.9	353.9	71.1	98.3	9.2	3.62
MN	HM corn 4	April 25, 2007	39.6	1.5	7.2	175.7	69.7	98.7	8.9	2.75
MN	HM corn 4	June 6, 2007	35.5	1.7	5.6	156.4	70.0	99.0	8.3	2.82
IA	HM corn 5 ¹¹	October 10, 2007	46.0	1.5	20.7	228.2	69.0	98.5	8.9	3.23
IA	HM corn 5	May 20, 2008	35.7	1.7	4.5	155.1	72.5	98.5	7.9	3.33
KS	HM corn 6 ¹⁰	April 2, 2008	78.3	3.0	14.8	348.7	70.3	98.6	7.9	2.91
KS	HM corn 7 ¹¹	April 4, 2008	134.9	3.6	29.9	606.5	71.3	98.5	7.9	2.05
KS	HM corn 8 ¹¹	August 29, 2008	153.5	3.1	21.5	663.2	67.4	98.7	8.6	1.73
KS	HM corn 9 ¹³	August 29, 2008	116.9	3.8	33.4	542.2	66.9	98.7	8.7	3.81
Mean			72.9	20.2	13.5	359.1	71.5	98.7	8.3	3.26
SEM			7.6	7.0	3.2	38.1	0.62	0.05	0.20	0.24

¹ Expressed as micrograms per 100 g of DM.

² Expressed as international units per kilogram of DM.

³ Calculated as follows: 1 mg of β-carotene = 400 IU of vitamin A; 1 mg of β-cryptoxanthin = 200 IU of vitamin A; 1 mg of α-carotene = 200 IU of vitamin A.

⁴ Includes *cis*-9 and all-*trans* β-carotene.

⁵ β-Crypt = β-cryptoxanthin.

⁶ WS corn = whole shelled corn.

⁷ SF corn = steam-flaked corn.

⁸ ND = not detected.

⁹ HM corn = high-moisture corn.

¹⁰ Harvested in 2006.

¹¹ Harvested in 2007.

¹² Harvest date not known.

¹³ Harvested in 2008.

Table 4

Pro-vitamin A carotenoid composition of coproducts

State	Feedstuff identification	Sample date	Pro-vitamin A carotenoids ^J					DM, %	OM, %	NDF, %	ADF, %	CP, %	Ether extract, %
			β-Carotene ⁴	β-Crypt ⁵	α-Carotene	Vitamin A equivalents ^{2,3}							
IA	Soybean meal 1	August 15, 2007	11.4	ND	ND	45.5	86.4	92.8	17.4	16.7	50.6	2.64	
OH	Soybean meal 2	October 24, 2007	15.3	ND ⁶	1.5	64.3	89.1	93.2	19.2	14.0	44.8	2.45	
Mean			13.3	ND	0.8	54.9	87.8	93.0	18.3	15.4	47.7	2.55	
SEM			2.0	ND	0.8	9.5	1.33	0.19	0.90	1.35	2.94	0.10	
OH	Soybean hulls 1	October 30, 2006	8.3	ND	ND	33.3	79.4	96.1	70.6	55.5	10.6	2.13	
OH	Soybean hulls 2	October 2, 2007	11.2	ND	6.0	56.8	84.3	96.2	71.6	55.2	12.3	1.21	
OH	Soybean hulls 3	October 24, 2007	12.6	ND	7.7	66.0	88.6	95.1	62.5	46.6	11.8	1.76	
OH	Soybean hulls 4	October 31, 2007	11.7	ND	5.1	57.2	79.6	95.3	71.0	54.6	11.3	1.24	
IA	Soybean hulls 5	August 15, 2007	4.0	ND	1.3	18.8	85.2	95.1	66.5	50.8	11.6	1.36	
Mean			9.2	ND	3.5	43.8	83.2	95.4	67.9	51.8	11.8	1.39	
SEM			1.9	ND	1.8	10.8	2.24	0.26	2.13	1.99	0.21	0.13	
IA	Wet DGS ⁷ 1	October 12, 2007	140.5	5.4	88.1	748.8	31.3	95.1	32.8	13.7	30.1	13.06	
MN	Wet DGS 2	May 15, 2008	147.8	6.7	61.0	726.6	30.9	95.1	34.2	18.6	30.9	11.12	
KS	Wet DGS 3	August 29, 2008	211.2	5.6	34.3	924.5	35.4	95.2	30.1	16.3	25.1	13.34	
Mean			166.5	5.9	61.1	800.0	32.6	95.2	32.5	16.2	28.7	12.5	
SEM			22.4	0.4	15.5	62.3	1.44	0.04	1.31	1.66	1.82	0.70	
IA	Dry DGS ⁸ 1	October 12, 2007	141.5	4.0	87.7	749.5	89.3	95.6	31.0	18.9	27.9	10.29	
OH	Dry DGS 2	October 24, 2007	85.7	4.6	21.8	395.6	89.0	95.7	35.3	18.5	25.1	9.77	
MN	Dry DGS 3	May 15, 2008	84.8	3.1	40.2	425.8	89.0	94.7	29.9	18.8	27.1	12.11	
KS	Dry DGS 4	August 29, 2008	46.3	2.9	41.1	273.2	88.1	95.6	37.7	22.1	19.9	10.98	
KS	Dry DGS 5	August 29, 2008	55.1	3.1	49.9	326.4	90.5	95.0	32.7	18.0	23.1	10.07	
KS	Dry DGS 6	August 29, 2008	163.4	3.9	29.5	720.4	88.4	95.4	39.8	18.9	31.1	11.22	
Mean			96.1	3.6	45.0	481.8	89.0	95.3	34.4	19.2	25.7	10.7	
SEM			19.1	0.3	9.4	83.0	0.34	0.17	1.59	1.21	1.59	0.35	
MN	Corn syrup	May 15, 2008	137.7	9.7	114.6	799.3	27.5	91.0	—	—	20.2	18.46	
OH	Corn gluten meal	October 24, 2007	824.8	15.2	208.7	3,747.0	91.4	97.9	9.01	5.12	62.7	2.19	

^JExpressed as micrograms per 100 g of DM.

² Expressed as international units per kilogram of DM.

³ Calculated as follows: 1 mg of β -carotene = 400 IU of vitamin A; 1 mg β -cryptoxanthin = 200 IU of vitamin A; and 1 mg of α -carotene = 200 IU of vitamin A.

⁴ Includes *cis*-9 and all-*trans* β -carotene.

⁵ β -Crypt = β -cryptoxanthin.

⁶ ND = not detected.

⁷ Wet DGS = wet distillers grains plus solubles.

⁸ Dry DGS = dry distillers grains plus solubles.