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Oven-drying reduces ruminal starch degradation in maize kernels

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ABSTRACT

The degradation of starch largely determines the feeding value of maize (*Zea mays* L.) for dairy cows. Normally, maize kernels are dried and ground before chemical analysis and determining degradation characteristics, whereas cows eat and digest fresh material. Drying the moist maize kernels (consisting mainly of starch) at high temperatures can influence their physical properties and thus their degradation dynamics in the rumen. We compared the *in vitro* degradability of dried maize kernels with that of fresh kernels after incubation in rumen fluid. Maize kernels were obtained from genotypes diverse in starch structure, composition and type of endosperm. These genotypes were grown in greenhouses at different temperatures during starch accumulation, and harvested at different maturity stages, in two experiments. Starch content was assessed using the amyloglucosidase method. Fermentation in rumen fluid was measured using an *in vitro* gas production technique. Starch degradation of the kernels was calculated after 6, 12 and 20 h of incubation in rumen fluid. Oven-drying influenced ($P < 0.0001$) the *in vitro* degradation of starch in maize kernels at the different incubation times, with more starch being degraded in the fresh than in the oven-dried maize kernels, although the differences were small (11–15%). There was a consistent interaction ($P < 0.009$ to 0.0002) between oven-drying and genotype, with the high-amylose genotype showing larger effects of oven-drying than the other genotypes. The vitreous genotype showed a lower starch degradation than the non-vitreous type. At earlier maturity stages, the difference between oven-dried and fresh kernels was larger than at later maturity stages. The temperature during grain filling affected ($P < 0.0001$) starch degradation but did not affect the difference between fresh and oven-dried samples. Oven-drying reduced the *in vitro* rumen starch degradation of maize kernels regardless of growing conditions, genotype and maturity stage, but its effect depends on genotype and maturity.

1. Introduction

Maize (*Zea mays* L.) is a major component in the ration of dairy cows in many parts of the world. The feeding value of maize for ruminants largely depends on the starch content and its degradation characteristics (Canizares et al., 2011; Theurer, 1986). Maize starch degradability is mainly affected by its physical characteristics and can be altered through

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processing (Cone and Vlot, 1990; Yang et al., 2001) with post-harvest processing normally increasing the degradability of starch (Andrae et al., 2001; Yang et al., 2001). However, drying moist maize kernels (starch) at high temperatures can also cause changes to its physical properties by rearranging the amylose molecules (retro-gradation) and, thereby, decreasing its degradability (Rooney and Pflugfelder, 1986). Moreover, Maillard reactions and enzymatic browning may also occur during drying (Maillard, 1912) and can play an important role in the feeding quality of maize. The Maillard reaction is a non-enzymatic browning reaction between carbonyl and amino compounds, which occurs in foods containing protein and carbohydrates (Ong and Law, 2010).

Normally samples of feeds and feed ingredients are oven-dried before chemical analysis and determination of their degradation characteristics, either *in vitro* or *in sacco* (Deinum and Maassen, 1994). As the starch is not consumed by dairy cows in the form of dried material, the values for degradability obtained from dried material may not be truly representative for its feeding value (Wight, 2006). Maize genotypes differing in starch structure (*i.e.* amylose or amylopectin) and composition (*i.e.* amylose:amylopectin) may show different responses to oven-drying, and hence the estimation of their feeding values may be influenced differently by sample processing (Haros and Suarez, 1997).

The aim of the present study was to investigate the influence of forced oven-drying on the starch degradability of maize kernels *in vitro* using rumen fluid.

2. Materials and methods

2.1. Maize kernel samples

Maize kernels were collected from two greenhouse experiments conducted in 2008 and 2009 at the experimental greenhouse facilities of Wageningen University and Research Centre (UNIFARM) in Wageningen, The Netherlands. Each experiment was done with six different genotypes and three growing temperature regimes during grain filling (reproductive phase) in triplicate. The genotypes were selected on the basis of variation in their amylose contents and type of endosperm (*i.e.* vitreousness). Genotypes used in both experiments were: homozygous dent, homozygous flint, high amylose (50% amylose) and waxy (only amylopectin). Counterparts of high amylose and waxy were used only in Exp. 1, whereas a vitreous and a non-vitreous genotype were used only in Exp. 2. Both counterparts of high amylose and waxy had an amylose content of 20–30%, but were from different parental inbred lines. The day/night temperature treatments were 18/12, 24/18 and 30/24 °C with 12 h day and 12 h night in Exp. 1, and 22/12, 27/17 and 32/22 °C with 15 h day and 9 h night in Exp. 2. Cobs were harvested and kernels were manually removed from the cobs using a sharp knife. The samples were collected when starch content in the kernels was between 399 and 526 g/kg (350–500 °C d accumulated thermal time, *i.e.* 24–43 days after pollination) and between 566 and 643 g/kg OM (500–700 °C d accumulated thermal time, *i.e.* 34–63 days after pollination) in Exp. 1. In Exp. 2, the kernels were harvested at a starch content of 409–527 g/kg (300–400 °C d accumulated thermal time, *i.e.* 22–29 days after pollination) and 541–638 g/kg OM (550–750 °C d accumulated thermal time, *i.e.* 37–55 days after pollination) in Exp. 2. These samples were collected from one plant per replication in Exp. 1 and from two plants per replication in Exp. 2. Samples were divided into two sub-samples with one subsample immediately stored at −20 °C after harvest, whereas the second subsample was dried according to the standard procedures in our laboratory for feed samples (70 °C for 48 h in a forced ventilation oven) and then stored at room temperature. Both the fresh and dried samples were ground over a 1 mm sieve using a centrifugal mill (Retsch ZM 100, Haan, Germany). The fresh samples were ground frozen after freezing in liquid nitrogen.

The geometric mean diameter of ground maize kernels for five dried and corresponding fresh samples from five genotypes used in Exp. 2 grown at the medium temperature (27/17 °C) was analysed by laser diffraction (Mastersizer 2000, Malvern Instruments Ltd., Malvern, United Kingdom). Each sample was measured 5 times to provide a geometric mean value, with the mixing speed set at 1800 rpm.

2.2. Chemical analyses

Dry matter content was determined gravimetrically by drying for 4 h at 103 °C (ISO 6496, 1999), and ash was determined by incineration for 3 h at 550 °C (ISO 5984, 2002). Starch content was determined using the amyloglucosidase method described by Keppler and Decker (1970), after unsealing the starch in dimethyl sulfoxide (DMSO).

2.3. In vitro rumen fermentation and starch degradation

The *in vitro* fermentation of ground fresh and dry kernels was performed using a fully automated gas production technique as described by Cone et al. (1996). Rumen fluid was collected 2 h after the morning feeding from two lactating rumen-cannulated cows. The cows received grass (2/3) and maize silage (1/3) in the morning and afternoon and 7–8 kg of concentrate (160 g/kg DM starch, 300 g/kg CP, 38 g/kg DM Cfat and 80 g/kg DM ash) according to their requirements. Rumen fluid from both cows was combined and stored in warm insulated flasks filled with CO_2, filtered through two layers of cheesecloth, and mixed (1:2, v/v) with an anaerobic buffer/mineral solution as described by Cone et al. (1996). The dry matter content of ground kernels was determined before the *in vitro* incubations. Samples of 0.5 g DM (dry), or the equivalent of 0.5 g DM (fresh), were incubated in duplicate in 60 ml buffered rumen fluid in 250 ml bottles in a shaking water bath at 39 °C and gas