Digestion of whole-crop grain silage starch in ruminants

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ABSTRACT

The effect of cereal species (oat, triticale, rye and barley) and stage of maturity of plants at harvest (heading – H, milk – M, and milk-dough – MD) on starch digestion was studied. An in vivo digestibility trial was conducted on 12 wethers. Starch ruminal degradability was determined in situ and postruminal digestibility by the mobile nylon bag technique. Starch from whole-crop cereal silages was nearly completely digested in the digestive tract. Its digestibility significantly increased as plants matured from H to M stage (P<0.05) and then was stable. With the exception of triticale, starch from silages made at H or M stages of maturity was entirely digested within 16 h of incubation in the rumen. In stage MD the highest contents of fraction A (94.6 %) and starch ERD (98.1 %) were found for oat silage (P<0.05), and the lowest ERD for barley and rye silages (87.1 and 82.8%, respectively).

It can be concluded that regardless of cereal species, silages made at stages H and M of maturity contain starch that is quickly and completely digested in the rumen. In older plants (MD or later stages), differences in the site of digestion and its extent may occur.

KEY WORDS: whole-crop grain silage, stage of maturity, starch, rumen degradability, intestinal digestibility

INTRODUCTION

The importance of whole-crop grain silages is steadily increasing in Poland. The nutritive value of these forages depends on the cereal species and stage of growth of plants at harvest. Optimum harvesting time is usually a compromise between the highest yield and nutrient availability, which is influenced by the progressing maturity of plants (Mannerkorpi and Brandt, 1995). The lack of effect of maturity stage on organic matter digestibility in silages made from milk or later
stages is mainly caused by a fast increase in starch content (Mannerkorpi and Taube, 1995). The starch content in whole-crop wheat or barley silages can range from nil for crops harvested at the vegetative stage of growth, to over 250 g kg\(^{-1}\) DM for mature crops (Leaver, 1996). Numerous studies have compared the site and extent of starch digestion from cereal grains (Herrera-Saldana et al., 1990; Żebrowska et al., 1997), but little information on digestion of starch in cereal crops from different species is available, especially for silages. This information can be useful in the choice of cereal species for silage production.

The aim of the present study was to determine the effect of cereal species and stage of plant maturity at harvest on starch digestion in the rumen, small intestine and in the whole digestive tract of ruminants.

**MATERIAL AND METHODS**

Whole-crop grain silages were made of oat, triticale, rye and barley, cut at three stages of maturity: heading (H), milk (M), and milk-dough (MD). Plants were harvested, chopped and ensiled with a microbial inoculant additive (Microsil, 10 g T\(^{-1}\) fresh forage) in 100 L\(^{-1}\) plastic containers. The dry matter content of silages was determined by the toluene method (Dewar and McDonald, 1961). Chemical composition was determined on dried (45°C, 48 h) and ground samples using standard methods (AOAC, 1995). Starch content was determined by the method of Faisant et al. (1995) and NDF, ADF and ADL by the method of Goering and Van Soest (1970).

*In vivo* digestibility (IVD) was determined on 12 wethers randomly divided into 3 groups of 4 animals and fed twice a day with silages supplemented with vitamin-mineral premix. *In situ* starch ruminal degradability was determined by the method of Michalet-Doreau et al. (1987), using 3 rumen fistulated steers fed standard diets. Approximately 3 g of samples (ground to pass through a 1.5 mm screen) were placed in nylon bags that were then put in the rumen of steers just before the morning feeding. Incubations were carried out at 2, 4, 8, 16, 24, 48 and 72 h. Nine measurements (three repetitions and three steers) were made for each incubation time. The effective rumen digestibility (ERD) of starch and digestibility rate constants (A, B, C) were calculated according to Ørskov and McDonald (1979). Postruminal digestibility of starch escaping rumen fermentation was evaluated on 3 steers, about 370 kg body weight, fitted with rumen and duodenal cannula, using the mobile nylon bag technique (MNB) by Peyraud et al. (1988), as modified by Kowalski et al. (1995). Bags filled with oven-dried (45°C, 48 h) and ground (1.5 mm) silages were incubated in the rumen for 16 h and then in HCl-pepsin for 2.5 h (pH 2.0, 39.5°C). After inserting into the duodenum, the bags were collected from faeces within 24 h, rinsed and washed.
The data were subjected to two-way analysis of variance using the GLM procedure of SAS (1995). The individual means were separated by the Student-Newman-Keuls test (SAS, 1995). Differences were considered to be significant at P<0.05.

RESULTS AND DISCUSSION

Dry matter and starch increased as the maturity of plants progressed (P<0.05), which was accompanied by a decrease in protein content (Table 1). Mannerkorpi and Brandt (1995) observed the same tendencies in relation to the stage of maturity of barley plants. The highest proportion of starch was in silages prepared at stage MD, especially barley and triticale (210 and 147 g kg\(^{-1}\) DM, respectively). According to Edmisten et al. (1998), due to the "dilution" effect of starch, the NDF, ADF and ADL contents increased rapidly between stages H and M and then slightly decreased between stages M and MD.

*In vivo* digestibility of starch of all silages was high (over 87%) (Table 2). Irrespective of species, starch digestion significantly increased (P<0.05) between H (93.4 %) and M (99%) stages of maturity. However, there were no significant differences (P>0.05) between stages M and MW (99%). In stage H, silages made of rye and barley had the highest *in vivo* starch digestibility, triticale and oat silage starch was less but still highly digestible. Regardless of species, starch in silages M and MD was nearly entirely digested (Table 2).

Due to the high rate and extent of starch digestion, it was difficult to establish the effect of maturity on rumen and intestinal digestibility of starch. Regardless of species, starch in silages H and M was entirely digested in the rumen within 16 h. Probably the higher starch content and hardiness of grain caused a decrease in ruminal starch degradability of MD silages. In this stage, a higher starch ERD (98.1) and A parameter (94.6%) were shown for oat silage (Table 2). The lowest ERD was observed for barley and rye silages (87.1 and 82.8, respectively). These silages also had a lower content of rapidly degradable starch fraction A (65.8 and 63.8, respectively), which was accompanied by a high content of slowly degradable fraction B. The lowest ERD of triticale in stages H and M is noteworthy. However, ERD of triticale silage made in the MD stage was higher than for barley or rye silage. According to Żebrowska et al. (1997), the ERD of starch from cereal grains was also the highest for oat and the lowest for barley (winter variety). Based on these findings, it can be concluded that in more mature stages of growth (MD or later) starch digestibility and degradability in the rumen of whole-crop grain silages may be closely connected with the potential availability of starch from cereal grains (Table 2). This was particularly true for MD silages of all species. It is important to point out that except for rye silages, the *in vivo* total digestive tract starch digestibility was slightly but apparently lower than that determined by the MNB method.
### Chemical composition of whole-crop grain silages

<table>
<thead>
<tr>
<th>Species</th>
<th>Stage of growth$^1$</th>
<th>Dry matter g kg$^{-1}$</th>
<th>Organic crude</th>
<th>Crude protein</th>
<th>N-free extractives</th>
<th>Ether extract g kg$^{-1}$ DM</th>
<th>Starch</th>
<th>NDF</th>
<th>ADF</th>
<th>ADL</th>
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<tbody>
<tr>
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<td>198</td>
<td>916</td>
<td>95</td>
<td>504</td>
<td>73</td>
<td>13</td>
<td>471</td>
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<tr>
<td></td>
<td>M</td>
<td>265</td>
<td>928</td>
<td>98</td>
<td>532</td>
<td>63</td>
<td>110</td>
<td>506</td>
<td>336</td>
<td>47.9</td>
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<tr>
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<td>296</td>
<td>927</td>
<td>70</td>
<td>542</td>
<td>52</td>
<td>130</td>
<td>483</td>
<td>312</td>
<td>47.1</td>
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<tr>
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<td>918</td>
<td>94</td>
<td>492</td>
<td>49</td>
<td>7</td>
<td>517</td>
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<td>75</td>
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<td>78</td>
<td>551</td>
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<td>937</td>
<td>60</td>
<td>572</td>
<td>27</td>
<td>147</td>
<td>499</td>
<td>342</td>
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<td>H</td>
<td>194</td>
<td>926</td>
<td>121</td>
<td>477</td>
<td>29</td>
<td>9</td>
<td>549</td>
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<tr>
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<td>M</td>
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<td>82</td>
<td>474</td>
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<td>616</td>
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<td>91</td>
<td>551</td>
<td>24</td>
<td>83</td>
<td>534</td>
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<td>Barley</td>
<td>H</td>
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<td>98</td>
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<td>24</td>
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<td>562</td>
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<td>942</td>
<td>57</td>
<td>592</td>
<td>38</td>
<td>210</td>
<td>474</td>
<td>292</td>
<td>54.4</td>
</tr>
</tbody>
</table>

$^1$ H – heading; M – milk stage; MD – milk-dough stage
### TABLE 2
Starch digestibility of whole-crop cereal silages

<table>
<thead>
<tr>
<th>Species</th>
<th>Stage of growth</th>
<th>in vivo</th>
<th>in situ parameters</th>
<th>MNB</th>
<th>ISD</th>
<th>TTSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oat</td>
<td>H</td>
<td>89.3</td>
<td>100</td>
<td>0.0</td>
<td>0.000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>99.1</td>
<td>100</td>
<td>0.0</td>
<td>0.000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>MD</td>
<td>98.8</td>
<td>94.6</td>
<td>5.5</td>
<td>0.115</td>
<td>98.1</td>
</tr>
<tr>
<td>Triticale</td>
<td>H</td>
<td>87.5</td>
<td>58.1</td>
<td>43.0</td>
<td>0.120</td>
<td>84.3</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>98.7</td>
<td>93.5</td>
<td>6.6</td>
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<td>97.6</td>
</tr>
<tr>
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<td>98.1</td>
<td>91.4</td>
<td>8.8</td>
<td>0.086</td>
<td>96.6</td>
</tr>
<tr>
<td>Rye</td>
<td>H</td>
<td>100</td>
<td>100</td>
<td>0.0</td>
<td>0.000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>100</td>
<td>100</td>
<td>0.0</td>
<td>0.000</td>
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</tr>
<tr>
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<td>100</td>
<td>63.8</td>
<td>37.2</td>
<td>0.063</td>
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<tr>
<td>Barley</td>
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<td>100</td>
<td>0.0</td>
<td>0.000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>97.6</td>
<td>100</td>
<td>0.0</td>
<td>0.000</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>MD</td>
<td>99.6</td>
<td>65.8</td>
<td>34.3</td>
<td>0.100</td>
<td>87.1</td>
</tr>
</tbody>
</table>

**Effect species**

- Oat: 95.8\(^c\), 97.8\(^a\), 2.2\(^b\), 0.046\(^a\), 99.2\(^a\)
- Triticale: 94.8\(^c\), 81.0\(^b\), 19.5\(^a\), 0.102\(^a\), 92.8\(^b\)
- Rye: 100\(^a\), 87.9\(^c\), 12.4\(^b\), 0.021\(^c\), 94.3\(^c\)
- Barley: 97.9\(^b\), 88.6\(^b\), 11.4\(^c\), 0.033\(^bc\), 95.7\(^b\)

**Effect stage of growth**

- H: 93.4\(^b\), 89.5\(^b\), 10.7\(^b\), 0.030\(^b\), 96.1\(^b\)
- M: 98.9\(^a\), 98.4\(^a\), 1.7\(^c\), 0.025\(^a\), 99.4\(^a\)
- MD: 99.1\(^a\), 80.1\(^c\), 20.2\(^a\), 0.093\(^b\), 91.7\(^c\)

**Interaction**

- S: 0.65, 2.57, 2.62, 0.01, 1.06

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1. H – heading, M – milk stage, MD – milk-dough stage
2. means with the same letter are not significantly different (\(^a\), \(^b\), \(^c\) P>0.05; \(^a\), \(^b\), \(^c\) P>0.01)
3. S – significant differences (P<0.05)
4. SEM – standard error of the means
5. MNB – post-ruminal starch digestibility determined by mobile nylon bag technique (16 h incubation in rumen)
6. ISD – intestinal starch digestibility
7. TTSD – total tract starch digestibility
CONCLUSIONS

Starch from whole-crop grain silages is nearly entirely digested in the digestive tract of ruminants. *In vivo* starch digestibility increases with maturity of plants between heading and milk stage. Starch from such silages is very susceptible to rumen fermentation since it was entirely digested within 16 h of incubation in the rumen (for heading and milk stages). In MD silages, the highest starch ERD was shown for oat, the lowest for barley and rye silages.

REFERENCES


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STRESZCZENIE

Strawność skrobi kiszonek z całych roślin zbożowych przez przeżuwacze

Oznaczono zawartość i strawność skrobi w kiszonkach sporządzonych z całych roślin owsa, pszenicy, żyta i jęczmienia, zbieranych w okresie klośnięcia (H), dojrzalości mlecznej (M) i mleczno-woskowej ziarna (MD). Strawność in vivo oznaczono na 12 tryczkach, strawność w zwaczu oznaczono metodą in situ, a strawność jelitowa metodą woreczków mobilnych. W miarę dojrzewania roślin zmniejszała się zawartość białka ogólnego, a wzrastała skrobia. Skrobia z kiszonek zbożowych była prawie całkowicie trawiona w przewodzie pokarmowym owiec. Jej strawność wzrastała wraz z dojrzalością roślin pomiędzy fazą H i M (P<0,05), a następnie utrzymywała się na tym samym poziomie w fazach M i MD. W fazach H i M skrobia była całkowicie trawiona w ciągu 16 godzin inkubacji woreczków w zwaczu. W fazie MD najwyższy ERD skrobi (98,1) oraz udział frakcji A (94,6%) stwierdzono w kiszonce z owsa (P<0,05), najniższy w kiszonkach z jęczmienia i żyta (87,1 i 82,8, odpowiednio; P<0,05). Skrobia, która uniknęła rozkładu w zwaczu, była w całości trawiona w jelitach.

Bez względu na gatunek zboża kiszonki sporządzone z roślin zbieranych w okresie klośnienia i dojrzalości mlecznej ziarna zawierają skrobię całkowicie i szybko trawioną w zwaczu. Kiszonki sporządzone z roślin zbieranych w okresie mleczno-woskowej dojrzalości ziarna mogą różnić się tempem oraz miejscem trawienia skrobi w zależności od gatunku zboża.