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Effect of maturity stage at harvest and kernel processing of whole crop wheat silage on digestibility by dairy cows

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ABSTRACT

The study aimed to explore whether digestibility by cows of whole crop wheat silage harvested at two different dough stages of maturity was impaired due to its content of whole kernels. Wheat was harvested at early (ED) and soft-to-hard (SHD) dough and preserved as roundbale silage. After five months of storage, half of silage from each maturity stage was processed using a roller mill. Early dough silages contained 334 g dry matter (DM)/kg and 110 g starch/kg DM whereas SHD silages contained 423 g DM/kg and 254 g starch/kg DM.

Total tract apparent digestibility and milk production by dairy cows was studied in a 2 × 2 factorial arrangement of silages harvested at the two maturity stages, either unprocessed or processed before feeding. Eight dairy cows were assigned to two Latin squares with four 3-week periods. Diets consisted of wheat silages offered ad libitum as the sole forage supplemented with 7.5 kg concentrates.

Cows consumed on average 14.1 kg DM of wheat silage, 0.6 kg DM more of SHD than of ED silage ($P < 0.001$), and 0.4 kg DM more of processed than of unprocessed silage ($P < 0.001$). Apparent organic matter digestibility of wheat silage, calculated by difference, was 0.62 and 0.60 ($P = 0.02$) for ED and SHD respectively, and the respective starch digestibility was 0.98 and 0.99 ($P = 0.02$). There was no main effect ($P > 0.20$) of processing on total tract digestibility for any nutrient, but a weak interaction ($P = 0.08$) suggesting that starch digestibility was slightly higher in unprocessed than in processed wheat silage from SHD with an opposite tendency for ED. Daily yields of protein and lactose were higher, and milk yield tended to be higher ($P = 0.07$), with processed than with unprocessed silage from ED, as expected due to higher forage intake, whereas no effect of processing was found in SHD silage, in spite of higher intake. Soft-to-hard dough diets contained a high load of starch plus sugar compared with fibre. This might have influenced the rate and extent of ruminal neutral detergent fibre digestion. It is concluded that starch in wheat kernels harvested at the soft-to-hard dough stage or earlier, at a DM

Abbreviations: AAT, amino acids absorbed in the intestine; ADF, acid detergent fibre; BW, body weight; CP, crude protein; DM, dry matter; DOMD, digestible organic matter in dry matter; ECM, energy corrected milk; ED, early dough; ME, metabolizable energy; NDF, neutral detergent fibre; NE, net energy; NE_L, net energy lactation; NH_3-N, ammonia-nitrogen; OMD, organic matter digestibility; PBV, protein balance in the rumen; SHD, soft-to-hard dough; std, standard deviation; VOS, in vitro rumen fluid organic matter digestibility; WCS, whole crop silage; WCW, whole crop wheat; WCWS, whole crop wheat silage; WSC, water soluble carbohydrates

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concentration in wheat silage up to 430 g/kg, is completely digested in dairy cows without processing.

1. Introduction

Whole crop silage (WCS) may give high dry matter (DM) yields from one single cut, and maximum DM yield is obtained at the dough stages of maturity, growth stages 80–89 (Zadoks et al., 1974), well before yellow ripening (Nadeau, 2007; Johansen, 2009). In Northern Europe, cereals are commonly sown as cover crops in the establishment year of perennial grass leys, and harvesting of the cover crop at dough stages instead of at ripening may be preferable for the development of the undersown ley. On farms where forage yields seem to be insufficient due to poor winter survival of meadows, drought or other problems, harvest of cereal crops as forage instead of grain is one way of providing more home-grown feed to the cattle.

Partly replacement of grass silage with whole crop wheat silage (WCWS) for cattle frequently increases total DM intake, however, increases in production are often low or absent (Phipps et al., 1995; Sutton et al., 1997, 1998, 2002, Sinclair et al., 2003; Beck et al., 2009). For high-yielding dairy cows offered early harvested, protein rich and highly digestible grass silage, dietary inclusion of WCS may be expected to improve protein utilization. However, inclusion of WCWS to constitute 0.4 of the dietary forage proportion increased total DM intake without any effect on milk yield, and resulted in similar or reduced utilization of energy and protein (Hameleers, 1998; Jaakkola et al., 2009).

When feeding urea-treated whole crop wheat (WCW) harvested at growth stage 87 with 603 g DM/kg, Abdalla et al. (1999) observed a large flow of whole grains into the duodenum that could explain very low DM and starch digestibility in the rumen. Jackson et al. (2004) observed increased starch digestibility by processing urea-treated WCW harvested at the hard dough stage (700 g DM/kg) using serrated steel rollers. Processing decreased DM intake, and no effect on milk yield was obtained.

In vitro and in situ techniques for digestibility determinations use dried and ground feed samples, and a possible escape of whole grain kernels from ruminal and intestinal digestion will not be detected. In the present study we aimed to isolate and reveal the potential effect of kernel processing on starch and organic matter digestibility (OMD) of WCW harvested at early and hard dough stages.

Our hypotheses were: 1. Total tract starch digestibility of WCWS by dairy cows is improved when kernels are processed. 2. This improvement in digestibility is more pronounced when WCWS is harvested at hard, compared with early dough.

2. Materials and methods

Legislations controlling experiments with live animals by the Norwegian University of Life Sciences Animal Care and Use Committee and the Norwegian Animal Research Authority were implemented in the experiment (Norwegian Ministry of Agriculture and Food, 2015).

2.1. Experimental design and animals

The study was conducted at the Animal Production Experimental Centre at the University of Life Sciences, Ås, Norway. Dietary treatments in a 2 × 2 factorial arrangement consisted of WCWS harvested at two maturity stages and offered unprocessed or processed. Eight Norwegian Red dairy cows in their second to fourth lactation were assigned to two squares according to days in milk. Cows were weighed twice during two weeks of adaptation to experimental diets and by the end of experiment. Each cow's average weight was used to calculate feed intake on body weight (BW) basis.

When experiment was initiated, average values with standard deviations in parenthesis for square 1 and 2, respectively were: days in milk 135 (6.8) and 175 (11.3), kg milk yield 22.6 (1.73) and 21.5 (0.92), and kg BW 648 (48.1) and 640 (37.2).

Each square constituted a 4 × 4 Latin square design with four 3-week periods. Cows were held in tie-stall with continuous access to water and feed. Feeds were provided at three daily meals, at 6:00, 13:00 and 19:00 h. Refusals, on average 4.8%, were collected before the morning meal.

2.2. Preparation of whole crop wheat silage

Spring wheat (*Triticum aestivum* L, cv Krabat) was sown on April 20, 2015, 240 kg/ha, and fertilized with 110 kg N, 15 kg P and 50 kg K per ha. The crop was treated with herbicide on June 15 (800 mL/ha Starane XL), and fertilized with another 50 kg N/ha on June 19.

The WCW was harvested at two maturity stages. The first one on July 27, at early dough (ED), growth stage 83 (Zadoks et al., 1974), after 339 mm precipitation and 646 day degrees above 5 °C. The second harvest was on August 14, after 414 mm precipitation and 819 day degrees above 5 °C, when wheat was evaluated to be at growth stage 86, soft-to-hard dough (SHD). This harvest was possibly 1–2 days prior to the intended growth stage 87, hard dough.

At both harvesting dates, the weather was sunny. The crop was mown as gently as possible aiming to avoid kernel loss, using Kverneland Taarup 5087 M (Kverneland Group, Klepp, Norway), with cutting height 11 cm. A rear-mounted mower aggregate without conditioner produced a 2-m wide swath that was picked up within 20 min using Orkel hiQ smartbaler (Orkel AS, Fannrem, Norway). No knives were used in the baler and no additive was applied to the forage. Kernel loss was observed at both growth stages but amounts were not measured. Bales were wrapped in inner plastic TrioBale Compressor Mantel film, 1.40 m wide, Triowrap (Trioplast, Smålandsstenar, Sweden) followed by 12 layers of 0.75 m wide and 0.025 mm thick white Triowrap 750 (Trioplast, Smålandsstenar, Sweden).

In January 2016, when the dairy cow experiment was initiated, round bales were opened every second week, weighed, and two bales containing WCWS from the same maturity were chopped together in Siloking Kverneland Duo 1840 TMR mixer (Kverneland Group, Klepp, Norway) for 40 min, to 30–40 mm median chop length. Half of the wheat silage from each maturity stage was processed using a Murska 350 S roller mill (Murska, Aimo Korteen Konepaja Oy, Ylivieska, Finland). The four forage qualities were stored at −18 °C until thawing and feeding, to avoid heating or moulding.

2.3. Diets

Whole crop wheat silage was offered for *ad libitum* consumption as the sole roughage. All cows received the same daily concentrate ration: 5.1 kg of a standard compound feed and 2.4 kg of a protein concentrate. The composition per kg feed of the standard compound feed was 314 g barley, 180 g rapeseed cake, 92 g wheat, 80 g molasses, 79 g extracted heat-treated soybean meal, 60 g beat pulp, 60 g oats, 33 g maize, 29 g SoyPass®, 28 g wheat bran, 18 g vegetable fat, 7.5 g $NaHCO_3$, 7.3 g urea, 5.0 g $CaCO_3$, 4.0 g NaCl, 2.4 g MgO, 2.0 g methionine analog, 1.4 g micro mineral premix, 1.3 g Na_2SO_4 and 0.9 g vitamin premix. The composition per kg feed of the protein concentrate was 401 g extracted heat-treated soybean meal, 187 g wheat, 150 g rapeseed cake, 80 g molasses, 45 g SoyPass®, 38 g $CaCO_3$, 31 g maize gluten meal, 14 g $Ca(H_2PO4)_2$, 11 g NaCl, 10 g MgO, 8.8 g urea, 6.1 g Na_2SO_4, 5.9 g micro mineral premix, 5.0 g vegetable fat, 4.4 g vitamin premix and 1.5 g methionine analog. Additionally, cows were provided with 50 g/d urea that was dissolved in warm water and sprayed into each cow's daily WCWS ration, and 200 g/d of a supplemental feed containing $NaHCO_3$, mineral premix, vegetable fat and live yeast (*Saccharomyces cerevisiae)*. The daily concentrate ration contained 243 g crude protein (CP)/kg DM, and the total diet, including urea, contained on average 154 g CP/kg DM at ED and 152 g CP/kg DM at SHD.

2.4. Sampling and analyses of feeds

At three occasions during each harvest, approximately 30 whole plants were cut by scissors and separated into spikes and straw + leaves. Core samples of fresh crop were taken from seven bales during ED harvesting and from nine bales during SHD harvesting, immediately before the bale was wrapped. Each core sample consisted of 3–4 single cores from the same bale. Separated samples and core samples were analyzed for DM, ash, CP, neutral detergent fiber (NDF), starch (not straw + leaves), and water soluble carbohydrates (WSC) using the same methods as described below for silage samples.

The four qualities of offered WCWS (ED unprocessed, ED processed, SHD unprocessed, SHD processed) were sampled daily Monday to Friday and stored at −18 °C. After thawing, pooled weekly samples were oven dried in duplicate at 59 °C to constant weight, corrected for volatiles according to NorFor – The Nordic feed evaluation system (Åkerlind et al., 2011), and used to calculate silage DM intake. A portion of pooled silage samples from week 3 in period 1 + 2, and period 3 + 4, respectively, were kept undried and analyzed for pH, NH_3-N, organic acids and ethanol as described previously (Randby et al., 2010). Another portion of the same, pooled silage samples were freeze dried, equilibrated to room humidity, and milled (Retsch SM200 cutting mill (Retsch GmbH, Haan, Germany)). For starch determination, samples were milled through a 0.5 mm screen, extracted with acetone and analyzed using an enzymatic method (heat stable α-amylase, and amyloglucosidase (Megazyme, Wicklow, Ireland)), with spectrophotometric quantification. For determination of ash, CP (Kjeldahl-N × 6.25), crude fat, NDF (assayed using sodium sulfite and with a heat stable alpha amylase, and expressed exclusive of residual ash (aNDFom)), acid detergent fibre (ADF; expressed exclusive of residual ash (ADFom)), and WSC, samples were milled through a 1.0-mm screen. Analyses of CP, crude fat, NDF and ADF were done as described by Randby et al. (2010), and analyses of WSC as described by Randby et al. (2015). Indigestible NDF (INDF) was determined in one pooled silage sample (period 1 + 2 + 3 + 4) from each of the four qualities. These were milled through a 1.5 mm screen and 2 g was incubated *in sacco* for 288 h according to Åkerlind et al. (2011) using polyester bags from Sefar Petex (Sefar AG, Heiden, Switzerland) with a pore size of 11 μm and a pore area equal to 5% of the total surface area. The sample size to surface area ratio was 10 mg/cm^2. One pooled silage sample from each silage quality was milled through a 1.0-mm screen and analyzed for *in vitro* rumen fluid digestible organic matter (VOS) as described by Åkerlind et al. (2011).

Eighty-gram samples from unprocessed and processed WCWS from ED and fifty-gram samples from unprocessed and processed WCWS from SHD was hand sorted into fractions (in mm) of: 0–25, 25–50, 50–75, 75–100, 100–150, and 150 − 250. The six fractions were dried and weighed, in order to determine median particle length of the feeds on DM basis. Additionally, wheat grains picked out from the four samples using a pair of tweezers were also weighed separately. Because the hand sorting was extremely laborious, only one small sample from each of the four feeds was sorted.

The two concentrates were sampled daily Monday to Friday. Pooled samples from period 1 + 2, and period 3 + 4, respectively, were dried at 103 °C to constant weight (16 h) and weighed warm for DM determination. Other pooled concentrate samples were freeze dried, equilibrated to room humidity, and milled through 0.5-mm screen for starch determination and a 1.0-mm screen for determination of ash, CP, crude fat, NDF, ADF and WSC as described for silage.

2.5. Sampling and analysis of feed residues

Feed residues were sampled from day 15–20 in each period, and pooled to one sample per cow and period. No concentrates were detected in the residues. Feed residues averaged 4.8% of offered WCWS. Initially, residues from the cow with the highest observed amount within each of the four diets (7.2–8.5%) were analyzed using the same procedures as for feed. For those four cows, digestibility calculated using chemical composition of feed residues was compared with digestibility calculations done by simply subtracting the amount of residue from the offered feed. Results were used to evaluate the need for feed analyses of all pooled samples of feed residuals.

2.6. Sampling and analyses of faeces and urine

Total collection of faeces to measure total tract apparent digestibility was conducted from Monday 08:00 h to Friday 08:00 h in week 3 in each period (day 17–20). Urine was separated from faeces using a funnel device, bonded around vulva, leading urine in a hose ending into a container. To prevent NH_3 volatilization, pH in the urine container was kept below 4.0, by daily addition of 1.5 L with 10% H_2SO_4 solution and control of pH. Liquid pooled urine samples were analyzed for Kjeldahl-N.

Pooled faeces samples from the four days were dried at 103 °C to constant weight and weighed warm for DM determination. Other faeces samples were freeze dried, equilibrated to room humidity, and milled through a 0.5-mm screen for starch determination and a 1.0-mm screen for determination of ash, CP, crude fat, NDF and WSC as described for silage.

Pooled 250-g undried faeces samples from the four days were soaked in cold tap water for 10 min prior to sieving with a Retsch AS200 wet sieve shaker (Retsch GmbH, Haan, Germany) operating with an amplitude of 2.5 mm for 10 min. The eight sieves had inner diameter 200 mm and pore sizes (mm) 4.0, 2.5, 2.0, 1.0, 0.50, 0.25, 0.20 and 0.10. Faeces particles retained in each sieve were dried at 59 °C for 24 h and weighed warm. Whole wheat grains retained on the three upper sieves were counted and weighed separately.

2.7. Milking and milk analyses

Milk yield was recorded during all milkings at 07:00 and 19:00 h using Delaval Milk meter MM6 (Tru-Test, Auckland, New Zealand). Milk samples were collected at six consecutive milkings from Monday evening to Thursday morning, conserved with Bronopol (2-bromo-2-nitropropane-1,3-diol) and stored at 4 °C. Pooled weekly samples from each cow were analyzed for fat, protein, lactose and urea with an infrared spectrophotometer (MilcoScan 6000, Foss Electric, Hillerød, Denmark). Energy corrected milk yield (ECM) was calculated from chemical composition (Sjaunja et al., 1991).

2.8. Calculations

Based on feed analyses, silage *in vivo* OMD was calculated according to Lindgren (1983), using the equation OMD% = -2.0 + 0.90 × VOS, where VOS is the *in vitro* rumen fluid % OMD. Silage concentrations of metabolizable energy (ME) and net energy lactation (NE_L) per kg DM were calculated according to Van Es (1978) using the equations MJ ME = 15.1 × DOMD, and MJ NE_L = 0.6 × (1 + 0.004 × ((Q × 100)-57)) × ME × 0.9752, where DOMD = digestible OM in DM, Q = ME/gross energy (GE), and GE = 18.4 MJ/kg DM.

Additionally, ME per kg DM was calculated based on the observed WCWS digestibility by the cows in the current study, using the equation: MJ ME = 14.02 × DOMD + 7.36 × DP, where DP is digestible CP, g/kg DM (Van Es, 1978). This ME-value was also further calculated into NE_L as described above.

Silage concentrations of metabolizable protein expressed as amino acids absorbed in the intestine (AAT), and protein balance in the rumen (PBV), were calculated according to Madsen et al. (1995) using analyzed CP values and the ME values based on feed analyses. Protein balance in the rumen is a measure of rumen degradable protein minus potential microbial consumption of degraded protein. Digestible carbohydrates in silages were calculated according to Spörndly (2003), where carbohydrates, g/kg DM = 922.0 × (1.46 × CP), and carbohydrate digestibility = (31.4 + (3.89 × ME))/100. Constant factors of 0.80 for rumen protein degradation and 0.82 for intestinal digestibility of undegradable amino acids in silages were used (Huhtanen et al., 2008). Concentrate contents of ME, NE_L, AAT and PBV were given by the producer (Felleskjøpet Agri, Lillestrøm, Norway).

Total diet digestibility was calculated as the digestible portion of nutrients in wheat silage and concentrates, including supplemental feed. For calculation of wheat silage digestibility by difference, nutrient digestibility of the concentrates was given by the producer. For the standard compound feed and protein concentrate, respectively, the given digestibilities were: 0.818 and 0.871 for OM, 0.783 and 0.899 for CP (N), 0.981 and 0.985 for starch, 0.551 and 0.624 for NDF, 0.833 and 0.838 for fat, 0.378 and 0.304 for ash, and 0.610 and 0.699 for residual compositions. Urea and $NaHCO_3$ in supplements were considered completely digestible OM.

Daily energy requirements, MJ of NE_L, for maintenance (0.29256 × $BW^{0.75}$; Van Es, 1978; Nielsen and Volden, 2011) and lactation (3.14 × ECM (kg); Nielsen and Volden, 2011) were calculated. Requirements for AAT (maintenance: AAT, g/d = 3.25 × $BW^{0.75}$, lactation: AAT, g/d = 40 × ECM (kg) + 0.2 × ECM^2) were calculated according to Madsen et al. (1995). Feed rations were composed to give a positive dietary PBV.

Nitrogen (N) use efficiency was calculated as grams of milk N (milk protein /6.38)/grams of total N intake. Nitrogen output (g) in urine and faeces, per kg ECM, was calculated as N in urine (g)/ECM (kg), and N in faeces (g)/ECM (kg), respectively. Feed conversion rate was calculated as ECM (kg)/DM intake (kg).

2.9. Statistical analyses

Feed intake data from day 8–20 in each period were analyzed using the PROC MIXED procedure of SAS (release 9.4, 2002–2012; SAS Institute inc., Cary, NC, USA), by the following model:

$$Y_{ijk} = \mu + c_i + P_l + H_m + K_n + H_m \times K_n + D_k + e_{ilmnk},$$

where μ = general mean, c_i = the random effect of cow i, P_l = the effect of period l, H_m = effect of harvest time m, K_n = effect of kernel processing n, $H_m \times K_n$ = the effect of interaction, D_k = the repeated effect of day k, and e_{ilmnk} is the random residual error. Square had minor effect, and was therefore not included in the model. Where interaction effects were significant, pair-wise

Table 1

Chemical composition, in vitro digestibility, and calculated energy and protein values of whole crop wheat silages harvested at two stages of maturity and either unprocessed or processed before feeding, and of concentrates. Mean values and standard deviations (std) of two pooled samples from each of the four silage qualities, and from each of the two concentrates.

	Wheat silage, early dough				Wheat silage, soft-to-hard dough				Concentrates			
	Unprocessed		Processed		Unprocessed		Processed		Standard compound feed		Protein concentrate	
	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std	Mean	std
DM[a], g/kg	335	4.8	332	2.9	422	25.4	423	20.3	875	1.3	881	4.0
pH	4.37	0.11	4.33	0.10	4.71	0.08	4.71	0.01				
NH_3-N, g/kg N	154	2.1	155	2.5	118	6.6	115	4.2				
Chemical composition, g/kg DM[b]												
OM[c]	949	2.8	945	8.6	957	1.3	957	1.0	936	1.2	869	9.5
CP[d]	104	1.8	102	3.5	100	0.8	105	11.2	199	1.6	336	5.9
Starch	110	3.2	109	6.9	266	17.3	241	5.9	359	10.0	174	3.2
WSC[e]	97	4.2	95	5.1	49	9.5	48	6.8	76.4	3.18	78.3	1.69
NDF[f]	480	12.6	484	1.6	454	9.1	458	25.8	181	5.5	128	15.2
INDF[g]	181	4.5	183	0.2	193	1.7	200	7.8				
ADF[h]	297	11.0	299	4.8	268	0.5	276	13.5	91.9	2.16	83.9	7.00
Fat	26	3.5	30	1.1	26	4.7	24	1.2	56.0	9.36	36.9	3.80
Lactic acid	50.8	0.76	51.1	8.10	29.7	2.79	28.4	0.75				
Acetic acid	14.6	1.47	14.9	3.50	5.9	0.56	7.6	2.64				
Propionic acid	7.9	3.71	9.2	4.54	7.8	1.05	9.3	0.25				
Ethanol	17.5	0.90	20.3	4.63	14.5	0.21	15.1	0.07				
NH_3-N	2.57	0.081	2.54	0.127	1.89	0.121	1.93	0.135				
Digestibility measures												
VOS[i]	0.676		0.672		0.659		0.657					
OMD[j]	0.588		0.585		0.573		0.571					
DOMD[k]	0.555		0.551		0.547		0.546					
Calculated nutritive values, per kg DM												
ME, MJ[l]	8.38		8.33		8.26		8.25					
NE_L, MJ[m]	4.68		4.64		4.60		4.59		7.86		7.09	
AAT_{RUP},[n] g	11.1		10.9		10.6		11.2					
AAT_{RMP},[o] g	52.2		52.2		52.3		51.7					
AAT[p], g	63.3		63.2		62.9		62.9		128		170	
PBV,[q] g	−4.8		−6.3		−8.5		−3.4		22.8		134	

[a] Dry matter.
[b] Formic and butyric acids were not detected in wheat silages (<0.01 g/kg DM).
[c] Organic matter.
[d] Crude protein.
[e] Water soluble carbohydrates.
[f] Netural detergent fibre.
[g] Indigestible NDF.
[h] Acid detergent fibre.
[i] In-vitro rumen fluid digestibility of OM.
[j] In vivo OM digestibility, OMD = -2.0 + 0.90 × VOS (Lindgren, 1983).
[k] Digestible OM in DM.
[l] Metabolizable energy, MJ/kg DM = 15.1 MJ × DOMD (Van Es, 1978).
[m] Net energy lactation = 0.6 × (1 + 0.004 × ((Q*100)-57)) × ME × 0.9752 (Van Es, 1978).
[n] Amino acids absorbed from the intestine, derived from rumen undegradable protein (Madsen et al., 1995) using constant factors of 0.80 for rumen protein degradability and 0.82 for intestinal digestibility of undegradable amino acids.
[o] Amino acids absorbed from the intestine, derived from rumen microbial protein (Madsen et al., 1995) using equations for digestible carbohydrates (Spörndly, 2003): Carbohydrates, g/kg DM = 922 - (1.46 × CP), and carbohydrate digestibility = (31.4 + (3.89 × ME))/100.
[p] Total Amino acids absorbed from the intestine.
[q] Protein balance in the rumen (Madsen et al., 1995).

comparisons between treatment means were performed using Tukey´s test.

Milk production data from week 2 (day 8–14) and 3 (day 15–20) in each period were analyzed using the same model, with day substituted by week.

Total tract apparent digestibility was analyzed using mean values of feed intake data from day 15–20 and faeces collection data from day 17–20. The same model was used, but without day or week.

The Chi-square test in the PROC FREQ procedure of SAS was used to evaluate the number of whole grains detected in wet sieved faeces samples, and the frequency of samples where whole grain was detected or not.

Results were considered statistically significant at $P < 0.05$, and P-values between 0.05 and 0.1 were considered to indicate trends. Values for $P \geq 0.1$ were considered nonsignificant.

3. Results

3.1. Yield and composition of wheat crop at harvest

Harvested yields were 7300 and 6780 kg DM/ha at ED and SHD, respectively. On DM basis, the separated fresh crop samples from ED and SHD constituted 0.41 and 0.59 of spikes, respectively. Separated spike samples from ED and SHD, respectively, contained per kg DM: 970 and 971 g OM, 113 and 116 g CP, 320 and 230 g NDF, 381 and 490 g starch, and 194 and 63 g WSC. Separated straw + leaves samples from ED and SHD, respectively, contained, per kg DM, 963 and 950 g OM, 58 and 55 g CP, 557 and 710 g NDF, and 263 and 75 g WSC.

Core samples from bales during harvest at ED and SHD, respectively, contained 334 and 430 g DM per kg, and per kg DM: 947 and 946 g OM, 99.4 and 94.9 g CP, 430 and 442 g NDF, 117 and 269 g starch, and 205 and 66 g WSC.

3.2. Ensiling quality and composition of wheat crop silages

No mould was detected in WCWS during bale opening. Numerical mean values of chemical composition, digestibility measures and calculated nutritive values of dairy cow feeds are presented in Table 1. Wheat silage bales were well preserved, with lower pH

Table 2
Effect of maturity stage and kernel processing of whole crop wheat silage on daily feed intake by cows.

	Early dough		Soft-to-hard dough			*P* value		
	Unprocessed	Processed	Unprocessed	Processed	SEM	Maturity	Processing	Interaction
Of whole crop wheat silage								
DM[a], kg	13.6	14.1	14.2	14.6	0.39	< 0.001	< 0.001	0.87
OM[b], kg	12.9	13.3	13.6	14.0	0.38	< 0.001	< 0.001	0.92
CP[c], kg	1.42[a]	1.44[a]	1.42[a]	1.54[b]	0.047	< 0.001	< 0.001	< 0.001
NDF[d], kg	6.54	6.80	6.46	6.69	0.175	0.07	< 0.001	0.76
ADF[e], kg	4.04	4.20	3.80	4.04	0.108	0.001	0.001	0.23
Starch, kg	1.50[a]	1.54[a]	3.78[c]	3.53[b]	0.085	< 0.001	< 0.001	< 0.001
WSC[f], kg	1.32	1.34	0.70	0.70	0.029	< 0.001	0.24	0.34
Fat, kg	0.351[a]	0.420[c]	0.377[b]	0.353[a]	0.014	< 0.001	< 0.001	< 0.001
Total acids, kg	1.24	1.34	0.82	0.88	0.029	< 0.001	< 0.001	0.01
Of total ration								
DM, kg	20.4	20.9	21.0	21.5	0.389	< 0.001	< 0.001	0.87
OM, kg	19.1	19.5	19.8	20.2	0.375	< 0.001	< 0.001	0.92
CP, kg	3.16[a]	3.19[a]	3.16[a]	3.29[b]	0.047	< 0.001	< 0.001	< 0.001
NDF, kg	7.61	7.87	7.54	7.77	0.175	0.07	< 0.001	0.76
ADF, kg	4.63	4.79	4.39	4.63	0.108	0.001	0.001	0.23
Starch, kg	3.47[a]	3.51[a]	5.75[c]	5.49[b]	0.085	< 0.001	< 0.001	< 0.001
WSC, kg	1.83	1.84	1.21	1.21	0.029	< 0.001	0.24	0.34
Fat, kg	0.679[a]	0.748[c]	0.705[b]	0.681[a]	0.014	< 0.001	< 0.001	< 0.001
(St + WSC)/NDF[g]	0.698[b]	0.683[a]	0.925[d]	0.865[c]	0.005	< 0.001	< 0.001	< 0.001
DM, g/kg BW[h]	31.2	31.9	32.1	32.7	0.96	< 0.001	< 0.001	0.75
OM, g/kg BW	29.1	29.8	30.2	30.8	0.92	< 0.001	< 0.001	0.95
NDF, g/kg BW	11.6	12.0	11.5	11.8	0.38	0.04	< 0.001	0.63

Least − square means with different superscripts differ significantly at P < 0.05.

[a] Dry matter.
[b] Organic matter.
[c] Crude protein.
[d] Netural detergent fibre.
[e] Acid detergent fibre.
[f] Water soluble carbohydrates.
[g] Rumen load index: Starch plus water soluble carbohydrates/netural detergent fibre.
[h] Body weight.

and higher concentrations of lactic acid, acetic acid, ethanol and NH_3-N in ED than in SHD silage, in line with lower DM concentration. Butyric acid and formic acid were not detected. Starch concentrations were highest in SHD silage, whereas WSC and NDF concentrations were highest in ED silage. Digestibility measures and calculated nutritive values were slightly higher in ED than in SHD silage.

Measured median particle length on dry weight basis was 35 and 21 mm for unprocessed and processed ED silage, respectively, and 25 and 19 mm for the corresponding SHD silages. Wheat grains detected in the same four samples, in the same order, constituted 18, 25, 89 and 84 g per kg sample DM.

3.3. Feed intake by dairy cows

Daily DM intake of SHD silage was higher than of ED silage, and higher of processed than of unprocessed silage (Table 2). Daily starch intake was higher from unprocessed than from processed SHD silage, because starch concentration was higher in unprocessed than in processed silage at that growth stage. Acid detergent fibre, WSC and fermentation acid intakes were higher from ED silage than from SHD silage, and a similar tendency was apparent for NDF intake. For all nutrients except starch and WSC, intake was somewhat higher of processed than of unprocessed wheat silage due to higher DM intake. The same differences were apparent for total ration intakes, because all cows received the same concentrate ration, and all cows consumed the complete concentrate allowance. Rumen load index, defined as dietary proportion of rapidly degradable (starch plus WSC) to slowly degradable (NDF) carbohydrates (Volden and Larsen, 2011) was higher in SHD than in ED diets, and higher with unprocessed than with processed silage, and reached 0.925 in the unprocessed SHD diet. Differences between silage treatments in daily intake of dietary DM, OM and NDF on BW basis were similar to corresponding differences on per cow basis.

3.4. Evaluation of feed residues

Compared with nutrient concentrations in offered WCWS, the four analyzed feed residues were higher in DM (+18 to +57 g/kg), lower in OM (-37 to -15 g/kg DM), higher in CP (6–15 g/kg DM), lower or equal in starch (-86 to 1 g/kg DM), lower or equal in WSC (-14 to -1 g/kg DM) and lower or higher in NDF (-28 to 61 g/kg DM). Total tract dietary apparent digestibility within cow was nearly identical when nutrient intake was calculated simply by subtracting the weight of residue from the weight of the offered feed, or by using the chemical composition of feed residues in intake calculation. The greatest observed difference within cow (without vs. with residue calculation) in OM digestibility was 0.704 vs. 0.702, in NDF digestibility 0.407 vs 0.401, and in starch digestibility 0.981 vs 0.982. Based on these results from observations of four cows with on average 7.8% feed residues, compared with total average of

Table 3
Effect of maturity stage and kernel processing of whole crop wheat silage on total tract apparent digestibility of wheat silage and total diet, and estimates of metabolizable energy and net energy lactation in wheat silage based on observed digestibility.

	Early dough		Soft-to-hard dough			*P* value		
	Unprocessed	Processed	Unprocessed	Processed	SEM	Maturity	Processing	Interaction
Whole crop wheat silage digestibility								
DM[a]	0.614	0.612	0.607	0.589	0.0077	0.07	0.21	0.31
OM[b]	0.618	0.619	0.608	0.591	0.0074	0.02	0.29	0.24
N	0.572	0.557	0.573	0.565	0.0164	0.80	0.49	0.83
NDF[c]	0.462	0.478	0.406	0.399	0.0108	<0.001	0.68	0.31
Starch	0.981	0.984	0.988	0.985	0.0019	0.02	0.98	0.08
Fat	0.755	0.757	0.736	0.697	0.0420	0.18	0.52	0.48
Ash	0.528	0.484	0.573	0.535	0.0339	0.15	0.22	0.94
DOMD[d]	0.587	0.585	0.582	0.566	0.0071	0.11	0.22	0.31
ME, MJ/kg DM[e]	8.66	8.62	8.58	8.37	0.109	0.14	0.26	0.44
NE_L, MJ/kg DM[f]	4.87	4.84	4.81	4.67	0.072	0.14	0.26	0.45
Total diet digestibility								
DM	0.673	0.671	0.665	0.655	0.0046	0.01	0.15	0.42
OM	0.690	0.689	0.678	0.669	0.0046	0.002	0.23	0.35
N	0.724	0.716	0.722	0.720	0.0057	0.87	0.35	0.58
NDF	0.477	0.490	0.428	0.424	0.0091	<0.001	0.66	0.35
Starch	0.981	0.982	0.986	0.984	0.0010	0.002	0.62	0.05
WSC	0.993	0.994	0.988	0.987	0.0009	<0.001	0.77	0.54
Fat	0.793	0.788	0.784	0.767	0.0214	0.27	0.42	0.63
Ash	0.439	0.421	0.458	0.438	0.0181	0.31	0.28	0.95

[a] Dry matter.
[b] Organic matter.
[c] Netural detergent fibre.
[d] Digestible OM in DM.
[e] ME, MJ/kg DM = 14.02 × DOM + 7.36 × DP, where DOM = digestible OM, g/kg DM and DP is digestible CP, g/kg DM (Van Es, 1978).
[f] NE_L = 0.6 × (1 + 0.004 × ((Q*100)-57)) × ME × 0.9752 (Van Es, 1978).

4.8% residues from all 32 observations (8 cows in 4 periods), it was decided that there was no need to analyze more feed residue samples.

3.5. Total tract apparent digestibility of wheat silage and total diet

Apparent digestibility of DM, OM, NDF, and WSC was higher in ED than in SHD diets, whereas digestibility of starch was highest in SHD diets (Table 3). There was no main effect of processing on digestibility for any nutrient. However, a weak interaction suggested that starch digestibility was slightly higher in diets with unprocessed than processed SHD silage, with no difference due to processing of ED silage.

Wheat silage digestibility determined by difference was numerically lower than total diet digestibility for DM, OM, N, NDF and fat, equal for starch, and higher for ash, however, the effect of maturity stage and processing was the same as for total diet digestibility. No significant effects of maturity stage or processing were found for DOMD, ME or NE_L when observed cow digestibility, and not VOS, was used in the calculations (Table 3).

3.6. Milk production, nutrient balance and feed utilization

When cows consumed ED silage, yields of protein and lactose were higher, and milk yield tended to be higher ($P = 0.07$) with processed than unprocessed silage whereas no differences due to processing were apparent when cows consumed SHD silage (Table 4). When cows consumed unprocessed silage, yields of milk, ECM, protein and lactose were higher with SHD silage than with ED silage whereas no yield differences were apparent when cows consumed processed silage. Milk protein concentration was higher and milk fat yield and concentration tended to be higher with SHD silage than with ED silage. Milk urea concentrations were similar for all diets and within the normal range, 3–6 mmol/L. When cows consumed ED silage, PBV was higher with unprocessed than with processed silage, whereas the opposite was true when cows consumed SHD silage. When ED silage was offered, nitrogen use efficiency tended to be higher with processed than unprocessed silage, whereas the opposite was true with SHD silage. When cows consumed SHD silage, more N tended to be lost in urine ($P = 0.08$) and faeces ($P = 0.08$) per kg of ECM with processed than with unprocessed silage, whereas no differences were apparent in lost N when cows consumed ED silage.

Table 4
Effect of maturity stage and kernel processing of whole crop wheat silage on daily milk yield and composition, and on calculated daily energy balance and feed nitrogen and energy utilization.

	Early dough		Soft-to-hard dough			*P* value		
	Unprocessed	Processed	Unprocessed	Processed	SEM	Maturity	Processing	Interaction
Milk yield								
Milk, kg	20.1[a]	20.9[ab]	20.9[b]	20.4[ab]	0.68	0.43	0.62	0.004
ECM[a], kg	22.8[a]	23.6[ab]	24.0[b]	23.5[ab]	0.79	0.048	0.62	0.01
Fat, g	965	992	1017	997	38.5	0.08	0.82	0.14
Protein, g	761[a]	792[b]	808[b]	789[ab]	19.6	0.005	0.43	0.002
Lactose, g	932[a]	978[c]	976[bc]	946[abc]	37.2	0.57	0.46	0.001
Milk composition								
Fat, g/kg	48.1	47.5	48.7	49.0	0.96	0.10	0.83	0.49
Protein, g/kg	38.1	38.0	38.7	38.9	0.63	<0.001	0.49	0.40
Lactose, g/kg	46.2[a]	46.8[a]	46.6[a]	46.3[a]	0.49	0.85	0.35	0.01
Urea, mmol/L	5.02	5.07	4.91	5.10	0.174	0.75	0.34	0.58
Nutrient balance and feed utilization								
EB, MJ NE_L[b]	5.50	4.22	4.63	6.25	3.409	0.72	0.92	0.37
AAT bal, g[c]	373	355	362	390	50.5	0.59	0.82	0.31
PBV intake, g[d]	319[c]	295[b]	259[a]	335[d]	2.54	<0.001	<0.001	<0.001
Milk N/Feed N[e]	0.233	0.242	0.246	0.237	0.0083	0.34	0.92	0.06
Urine N/ECM[f]	9.01[b]	8.55[ab]	8.01[a]	8.76[ab]	0.430	0.07	0.49	0.008
Faeces N/ECM[g]	6.36[a]	6.28[a]	5.97[a]	6.42[a]	0.329	0.34	0.15	0.04
ECM/DMI[h]	1.09	1.12	1.12	1.09	0.047	0.91	0.92	0.27

Least−square means with different superscripts differ significantly at $P < 0.05$.

[a] Energy corrected milk yield.
[b] Energy balance: Net energy lactation (NE_L) intake - NE_L requirements for maintenance and milk production.
[c] Metabolizable protein (AAT) balance: AAT intake - AAT requirements for maintenance and milk production.
[d] Total Protein balance in the rumen, intake.
[e] Nitrogen use efficiency: N in milk (milk protein /6.38)/total N intake.
[f] Nitrogen in urine (g) per kg energy corrected milk yield.
[g] Nitrogen in feces (g) per kg energy corrected milk yield.
[h] Feed conversion rate: Energy corrected milk yield (kg)/DM intake (kg).

3.7. Particle size distribution, and whole grains detected in faeces

Faeces from cows consuming SHD silage contained a higher proportion of particles > 4 mm than faeces from cows consuming ED silage (Table 5). Particles between 2 and 4 mm were found in highest proportion in faeces from cows consuming unprocessed WCWS. No effect of maturity stage or processing was found for particles between 0.1 and 2 mm. Faeces from cows consuming ED silage contained the highest proportion of the smallest particles (< 0.1 mm) that passed to the bottom pan and was considered soluble.

Of the total 32 faeces samples (250 g-samples) that were wet sieved, 22 samples contained no visible grains, 6 samples contained one grain, and 4 samples contained 2–8 grains. No significant differences between treatments were found in the number of grains detected in each faeces sample. No effect of processing, across maturity, was found in the frequency of faeces samples containing grains, however, a higher proportion of samples from SHD (8 of 16) than from ED diets (2 of 16) contained whole grains (P = 0.02). On average, less than one gram DM in whole grains was excreted daily per cow offered ED silage. For cows offered SHD silage, on average 11 and 4 g of grain DM were excreted daily per cow offered unprocessed and processed silage, respectively.

4. Discussion

4.1. Composition of whole crop wheat at harvest

Jaakkola et al. (2009) harvested WCWS at ED and SHD stages, and observed a profound increase in starch concentration and a reduction in WSC concentration during the 14 days longer growth time until SHD, whereas differences in protein and NDF were small. These observations were similar to results in the present study, as well as the increasing proportion of ear from 0.46 to 0.56 of the crop yield found by Jaakkola et al. (2009).

4.2. Ensiling quality and composition of wheat silage

Wheat silage bales from both growth stages were in general well preserved, however, 155 and 117 g NH_3-N/kg N in ED and SHD silage, respectively, similar to that found by Walsh et al. (2008), were higher than the maximum value recommended for grass silages (100 g NH_3-N/ kg N; Eurofins, 2019). Nadeau (2007) found even higher values (170 g/kg N) in untreated WCS from wheat, barley, triticale and oats at similar DM and growth stages. Those values were, however, clearly reduced (105 g NH_3-N/kg N) by treatment with 4 L/tonne fresh herbage of a formic plus propionic acid containing additive. Ethanol concentrations (14–20 g/kg DM) were above maximum recommendations to avoid milk taint (8 g/kg DM; Eurofins, 2019), but ethanol concentrations are expected to be reduced by treatment with a high dose of a preservative based on propionic acid or chemicals ($NaNO_2$, hexamine, benzoate) (Randby et al., 2015).

4.3. Feed intake by dairy cows

Intake of SHD silage in the present study was similar to that observed by Hill and Leaver (1999) with WCWS offered as the sole forage and with the same level of concentrate supplementation. Higher intake of SHD than of ED silage was in line with calculated Silage Dry Matter Intake indexes (Huhtanen et al., 2007), and could be ascribed to lower concentrations of fermentation acids and NDF, and higher DM concentration.

Higher intake of processed than of unprocessed WCWS was probably due to shorter particle length, in line with Einarson et al. (2004) who observed 0.8 kg per day increased DM intake in cows offered barley silage, when chop length was reduced from 19 to 10 mm. In young cattle offered barley silage, also Soita et al. (2002, 2003), Rustas et al. (2010) and Rustas and Nadeau (2011) observed increasing intake with decreasing chop length. Maximum NDF intake per kg BW, 12.0 g, was obtained with processed ED silage. This was slightly below the level 12.5 g recommended by Mertens (1994) that is assumed to support maximum milk yield.

Rustas and Nadeau (2011) evaluated the effect of chopping of whole crop barley silage on diet selection and composition of feed

Table 5
Effect of maturity stage and kernel processing of whole crop wheat silage on particle size distribution in faeces after wet sieving, g per kg dry matter retained on each sieve and on bottom pan (<0.10 mm).

	Early dough		Soft-to-hard dough			*P* value		
Pore size of sieve, mm	Unprocessed	Processed	Unprocessed	Processed	SEM	Maturity	Processing	Interaction
4.0	37.7	37.5	50.0	42.4	3.58	0.002	0.11	0.13
2.5	10.5	7.1	11.7	9.6	1.19	0.10	0.02	0.57
2.0	5.2	4.3	8.2	4.5	1.19	0.12	0.03	0.18
1.0	110	111	122	114	5.12	0.16	0.48	0.42
0.50	152	150	150	166	6.55	0.27	0.29	0.14
0.25	179	176	168	183	7.39	0.76	0.40	0.21
0.20	73.4	82.5	74.5	64.2	7.67	0.28	0.94	0.22
0.10	18.9	17.0	17.5	15.9	3.46	0.73	0.62	0.97
Bottom pan	413	415	399	400	7.15	0.005	0.65	0.96

residues. They found substantial differences in the composition of residues compared with the offered silage, where sugar concentrations in residues were down to 71% of sugar in offered feed. Still, sorting only affected the composition of ingested barley silage slightly compared with the offered feed. They concluded that for feed selection to affect the composition of the ingested diet substantially, residues must be present in large amounts. This is in line with observations in the present study.

4.4. Total tract apparent digestibility, and whole grains and particle size in faeces

In the present study, OMD decreased slightly with advancing maturity. This can be explained by the high proportion of NDF compared with starch plus WSC at both maturity stages. The decreasing NDF digestibility with advancing crop maturity counteracted the effect of increasing proportion of highly digestible starch plus WSC, also observed by Sutton et al. (2002). Still, NDF digestibility of SHD diets may have been influenced by the high dietary proportion of rapidly degradable (starch plus WSC) to slowly degradable (NDF) carbohydrates giving rumen load indexes of 0.925 with unprocessed and 0.865 with processed wheat. According to Volden and Larsen (2011) this may slow down rumen degradation rate of NDF to 0.65 of the rate otherwise expected. However, DOMD based on observed OM digestibility by the experimental cows (Table 3) were slightly higher than calculated DOMD in WCWS based on in vitro rumen fluid digestibility (Table 1). This suggests that NDF, starch and other nutrients were well digested in the present study. In order to avoid rumen acidosis in these potentially high-starch diets, experimental cows were daily provided 200 g of a $NaHCO_3$-containing feed supplement that may have prevented at least a severe reduction in NDF digestion.

Digestibility of WCS differs among animal species. Sheep can chew and break the pericarp of the kernels more efficiently than cattle (van Soest, 1994), so digestibility studies with sheep to determine digestibility in cattle can be misleading. Starch digestibility of urea-treated WCW was essentially complete in sheep, whereas digestibility by dairy cows varied from 0.75 to 0.90 (Sutton et al., 1997).

Südekum et al. (1995) found greater or equal digestibility of wheat silage diets from three stages of maturity (late milk, ED and hard dough) in cattle compared with sheep. Diets contained 0.9 of wheat silage, and dietary starch digestibility averaged 0.99 in both species at maintenance as well as at *ad libitum* intake. This suggests that starch in whole wheat kernels were completely digested even at hard dough harvested at approximately 500 g DM/kg. This is in line with results from the present study, using wheat silage at ED and SHD, at DM levels 334 and 430 g/kg, respectively. Although, numerically, more DM in whole grain was excreted from cows offered unprocessed SHD silage than from the other three treatments, the resulting undigested amount of DM and starch was too low to influence digestibility. Also Walsh et al. (2008) observed a low concentration of whole grains in faeces of cattle offered WCWS from a similar crop (419 g DM/kg and 229 g starch/kg DM), but starch digestibility was high. This indicated a good utilization of grain contents, and that processing of WCWS was not required.

The magnitude of differences in faecal particle size due to maturity stage or processing was small, although significant, and of limited practical interest. Across treatments, the major proportion, 0.536, of total faecal particles was between 0.1 and 2 mm, in line with Rustas et al. (2010), when feeding whole crop barley silage at dough stage to dairy steers.

Complete starch digestibility was also found in high yielding dairy cows by Jaakkola et al. (2009) using wheat silage at ED and SHD at DM levels of 300 and 340 g/kg, respectively. Those diets included grass silage and concentrates. Also Sutton et al. (2002) observed essentially complete starch digestion in cows offered WCWS harvested at early to hard dough, at DM levels of 300–510 g/kg.

In contrast to these observations, Sutton et al. (1998) measured dietary total tract starch digestibility by cows to be from 0.81 to 0.91 in WCW harvested at hard dough, at 720–810 g DM/kg. In a companion study using the same forage for cannulated cows, Abdalla et al. (1999) observed whole wheat grains at duodenum and poor rumen starch digestibility. Jackson et al. (2004) observed lower starch digestibility in unprocessed wheat (0.85 − 0.90) than in processed wheat (0.96 − 0.97) harvested at the hard dough, growth stage 87, with DM contents of 650–710 g/kg. Sutton et al. (1997) found low starch digestibility, 0.75 − 0.90 in WCWS harvested at 645 g DM/kg, growth stage 92, which is regarded as ripe grain with hard caryopsis (Zadoks 1974). It is well known that digestibility by cattle of whole kernels from ripe oats and barley is much lower than of crushed or ground grain. Breirem and Homb (1970) reported OM digestibility by cattle of 0.56 and 0.54 for whole oats and barley, respectively, with increases to 0.72 and 0.80, for the respective crushed grains. No further increase in digestibility was found for coarse or finely ground oats or barely.

Although a positive correlation often is found between growth stage at harvest and DM level of WCW, this correlation may vary between years, sites, crop cultivars, etc. Anyway, the cited studies suggest that wheat crops harvested at maturity stages up to 87 (hard dough) and with DM contents up to 510 g/kg, have close to complete starch digestion in cattle without any processing. Growth stages 87 or later, with DM contents above 650 g/kg, however, may give poor starch digestibility. Hypothesis 1 in the present study, on improved starch digestibility with kernel processing, was rejected. Due to the missing digestibility response in hypothesis 1, hypothesis 2, on greater effect of processing at SHD compared with ED, could not be tested.

4.5. Milk production, nutrient balance and feed utilization

Advancing maturity stage of wheat silage from ED to SHD tended to increase ECM and milk fat yield in line with Jaakkola et al. (2009), however, the ECM response was only apparent with unprocessed wheat. In line with Sinclair et al. (2003), higher forage starch concentration associated with later maturity stage of WCWS, was the probable reason for increased milk protein concentration in cows offered SHD silage compared with ED silage. Increasing dietary inclusion rate of high-starch WCWS may also increase milk protein concentration (Sinclair et al., 2007). Various inclusion rates, 0, 0.25, 0.50 and 0.75 on DM basis, of processed, urea treated WCW from growth stage 92 were studied using extensively fermented grass silage (176 g total acids/kg DM) with 688 g/kg DM

DOMD and low intake potential. Those cows were in early lactation, 29 days in milk vs. 155 in the present study. Total DM intake increased up to a WCW inclusion rate of 0.75, whereas ECM yield peaked at an inclusion rate of 0.25. At inclusion rates above 0.25, body condition score increased instead, giving 360 g/day increase in BW at inclusion rate 0.75 (Sinclair et al., 2007). A similar BW gain, 370 g/day (standard deviation 223) as a mean for all cows during all four periods was observed in the present study. According to Nielsen and Volden (2011), using 11.5 MJ NE per kg BW deposition, the calculated average energy balance, 5.2 MJ NE_L would have supported a daily gain of 450 g.

With ED diets, the yield response for processed silage, 0.8 kg ECM, was close to expectations from the 0.5 kg DM and 1.8 MJ NE_L increased energy intake, estimated to give 0.6 kg ECM. With SHD diets, however, milk yield declined by 0.5 kg ECM when silage was processed, although forage intake was 0.4 kg DM and 1.7 MJ NE_L higher, estimated to give 0.5 kg ECM increased milk yield. Reduced rate and extent of ruminal NDF digestion due to high rumen load indexes may reduce rumen microbial protein production and thereby the production of precursors for mammary milk synthesis. Although calculated rumen load index at SHD, due to slightly higher starch concentration was even higher in unprocessed than in processed silage, it may be speculated if whole wheat kernels release starch more slowly in the rumen, and thereby not affect NDF degradation negatively to the same extent as in processed wheat kernels.

This study confirms conclusions given by others: WCWS harvested at dough stages is a feed with a rather high intake potential (Hill and Leaver, 1999) that increases with advancing maturity (Sutton et al., 2002). It has low digestibility (Sutton et al., 2001) that decreases slightly with advancing maturity (Sutton et al., 2002). Milk yield is low compared with the high intake, but in line with the low digestibility. There is no evidence of poor efficiency of utilization of ME in WCWS (Sutton et al., 1998).

5. Conclusions

Starch in whole kernels in whole crop wheat silage harvested at soft-to-hard dough, growth stage 86 or earlier, at a dry matter concentration up to 430 g/kg, is completely digested in dairy cows without any processing. This result is obtained with low yielding cows in mid-to-late lactation, offered whole crop wheat silage as the sole forage. Early lactating, high yielding dairy cows on mixed diets may have another response.

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Conflict of interest

The authors confirm that there are no known conflicts of interest associated with this publication.

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