Chewing activity, metabolic profile and performance of high-producing dairy cows fed conventional forages, wheat straw or rice straw

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Abstract

In this study, production and physiological responses of high-producing dairy cows fed wheat (WS) or rice (RS) straw, as a partial forage replacement for the conventional forages lucerne hay (LH) and maize silage (MS), were investigated. The straws were treated under dry alkaline conditions, adjusted pH (pH ~12), and then ensiled. Twelve lactating Holstein cows were used in a replicated (n = 4) 3 × 3 Latin square design experiment with three periods of 21 days. Cows were offered one of three diets that differed in their forage sources: 1) 20% LH and 20% MS (control); 2) 12.8% LH, 12.8% MS; and 12.8% WS; and 3) 12.8% LH, 12.8% MS and 12.8% RS. Diet 1 had 60% concentrate, and diets 2 and 3 had 61.6% concentrate. Diets were iso-nitrogenous and iso-energetic. Supplemental buffer ($NaHCO_3$) was omitted from the straw diets. However, straw diets contained greater sodium and dietary cation-anion difference (DCAD) compared with the control diet. Cows fed the WS had significantly greater apparent dry matter (DM) (69.7 versus 63.9%) and neutral detergent fibre (NDF) (55.4 versus 42.4%) digestibility than cows fed the control. Additionally, feeding either WS or RS significantly increased dry matter intake (DMI) (27.5 versus 25.6 kg/d) and milk production (48.4 versus 45.6 kg/d) compared with control, but milk components were unaffected by treatments. Plasma minerals and metabolites concentrations and ruminal, urinary and faecal pH were similar across treatments. Feeding WS and RS resulted in lower time spent chewing per kg DMI compared with the control (P = 0.01). Although there were no significant differences in performance between WS and RS, nutrient digestibility (DM, OM, and CP) was significantly higher while total chewing was lower for the WS diet than the RS diet. Partial inclusion of dry treated straw in lactating diets (12.8% DM basis) led to increases in sodium and DCAD levels and improved digestibility, DMI and milk yield without negative effects.

Keywords: Cation and anion difference, cereal straw dietary sodium, lactating cows
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Introduction

Maize silage and lucerne hay/silage are the dominant forage sources that are fed to high-producing dairy cows in most parts of the developed world. However, the availability and yield of these forages are in decline owing to droughts and increasing demand for cereal grains, which result in less land for forage. In response to drought-induced forage shortages, dairies were recommended to feed alternatives such as wheat straw and other by-products (Hall & Chase, 2014). In Iran, approximately 72.2% of agricultural land is devoted to cereal crop production (Anonymous, 2015). This contributes more than 15 million metric tons of straw after the wheat, barley and rice harvests every year. Some of the straw is collected, pressed into transportable bales, and used for bedding, animal feed, and industrial applications or to produce mushrooms. The remainder is used for grazing or burned and ploughed under before planting the next crop. Straws are typically high in fibre (NDF, 65–80%) and low in crude protein (CP) (2–6%), DM digestibility (30–40%), and metabolizable energy (1.44 Mcal/kg DM) (NRC, 2001; Wang *et al*., 2014). In addition, the contents of ash (10–17%), silica (8–14%), and cutin are high in rice straw, which resulted in the lowest nutritive value (Drake *et al*., 2002; Van Soest, 2006). Thus, the use of various cereal straws in dairy diets often decreases rumen microbial protein synthesis, energy intake, and milk yield (Thanh *et al*., 2012; Wang *et al*., 2014). The issue of finding ways to make better use of crop residues is critical to animal agriculture worldwide. Various processing methods and dietary supplements have been examined with varying degrees of success to enhance the digestible energy intake of straw (Van Soest, 2006; Hanafi

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et al., 2012; Ghasemi *et al*., 2013a). Generally, wet treatment with NaOH is considered most effective (Van Soest, 2006). This method, however, reportedly results in contaminated wastewater and a considerable loss of organic matter. As a result, a decline has been witnessed in treatments with NaOH, while more studies have been devoted to using urea and ammonia (Khanal *et al*., 1999), not only for their safety (urea), cost and fungicidal properties, but because they provide a source of CP in which straw is deficient. Surplus ammonia in the rumen, bloodstream, and excretions can be a problem for lactating dairy cows and dairy housing systems, and has been shown to adversely affect reproduction (Butler, 1998). Consequently, over the past decade few studies have been conducted to assess the effect of feeding straw to high-producing dairy cows.

Grain and by-product feeds are often less expensive sources of nutrients than conventional forages (Mertens, 2002). Therefore, lactating cows are sometimes fed high-grain diets, which cause excessive production and accumulation of fermentation acids in the rumen and subsequent acidosis and health problems (Oetzel, 2007). In such conditions, lactating cows respond positively to rumen buffers and higher DCAD diets (Apper-Bossard *et al*., 2006). To achieve a positive DCAD, feedstuffs that are high in sodium (Na) and potassium (K) are chosen and supplemental sources of Na and K added to the diet. It is possible to increase the level of sodium intake and DCAD by partial replacement of forage sources with dry NaOH treated straw. Dry alkali treatment of rice and barley straw at pH 12 has been shown to be a promising method to break the bonds in the lignified matrix and has a swelling effect on cellulosic microfibrils and the cuticlular layer (Ghasemi *et al*., 2013a; Ghasemi *et al*., 2014b). Moreover, the high pH level of alkali-treated straw can be substantially decreased by ensiling. Using this treatment, greater ruminal DM degradability was found for RS compared with lucerne hay (Ghasemi *et al*., 2013a). Further, feeding straw contributes to greater rumination activity and salivary secretion flow (Mertens, 2002; Beauchemin *et al*., 2008). However, information is needed regarding substituting straw for forage that can be used to formulate diets that maintain animal health and performance. This study was therefore conducted to evaluate lactation responses, chewing activity, and metabolic profile of high-producing dairy cows fed dry ensiled alkali-treated RS or WS as a partial forage replacement.

Materials and Methods

Wheat and rice straws were chopped by a tractor-mounted forage chopper to provide a particle size of approximately 1.2 cm. The chopped straw was conveyed to a feeder wagon (DeLaval horizontal mixer) and weighed to 500 kg. The amount of alkali used for treatment (pH 12) was estimated by titration (Ghasemi *et al*., 2014b). Sodium hydroxide solution (1 L water/kg as-fed straw and 70 g NaOH/kg DM straw) pumped from polyethylene containers (220 L) by a drainage pump was poured over the straw and mixed for 10 min. On completion, the treated straw was discharged into a concrete horizontal silo. These processes were repeated eight times before the straws (4000 kg) were packed by a tractor. Finally, the silo was covered with polyethylene sheets and 10 cm sand, and ensiled for two months.

Twelve lactating Holstein cows were assigned to a 3 × 3 Latin square design, composed of 3 treatments, 3 periods of 21 days each, and 4 squares. The first 14 days of each period were used for adaptation and the last 7 days for data collection. The four squares were completed simultaneously. Cows were housed in individual pens (4 × 4 m) in an open barn and randomly assigned to one of the three dietary treatments, which were balanced for parity (2.3 ± 0.47 lactations), days in milk (120 ± 11), and body weight (651 ± 41 kg). Treatments were i) control diet consisting of 20% LH, 20% MS, and 60% concentrate; ii) WS diet consisting of 12.8% LH, 12.8% MS, 12.8% WS, and 61.6% concentrate; and iii) RS diet consisting of 12.8% LH, 12.8% MS, 12.8% RS, and 61.6% concentrate (Table 1). Diets were mixed once daily and fed for *ad libitum* access twice daily at 08:00 (20 kg as-fed basis) and 16:00 (the remainder). Cows were milked three times daily at 9:00, 17:00, and 01:00.

Pre-ensiling and post-ensiling pH value (after two months) of WS and RS were determined on 10 g of each sample added to 200 ml distilled water. Feeds offered and refused (5 to 10 % orts) were weighed and recorded throughout the experiment. Samples were collected during the last week of each experimental period. Faecal samples (grab sampling) were collected from each cow during the last five days of each period. Feeds, orts and faeces were dried at 60 °C for 48 h, composited, and ground to pass a 1-mm screen. The orts were composited by animal proportional to the weight of feed refused each day. Composite samples were analysed for DM (AOAC, 2000), ash (600 °C for 4 hours), and CP (AOAC, 2000). Concentrations of NDF and acid detergent fibre (ADF) were determined sequentially using an ANKOM200 fibre analyser (ANKOM Technology Corp., Fairport, NY) with heat stable alpha-amylase and without sodium sulfite (Van Soest *et al*., 1991). The ADL was determined using 72 % sulfuric acid in a DaisyII incubator (Ankom Technology Corp. Fairport, NY) for three hours at room temperature. The apparent digestibility of DM, organic matter (OM), NDF, ADF, and CP was determined with the acid-insoluble ash ratio technique (Van Keulen & Young, 1977). Milk yield was recorded at each milking event during the last five days of each experimental period. Milk samples were preserved with 2-bromo-2-nitropropane-1,3-diol, and stored at 4 °C until analysis. Milk samples were analysed for fat, protein, lactose, and total solids using the MilkoScan (134 BN Foss Electric, Hillerod, Denmark). Rumen (stomach tube), blood (coccygeal vessels) and urine (manual stimulation) samples were collected at approximately four hours post feeding and pH was measured immediately (HI 8314 membrane pH meter, Hanna Instruments, Villafranca, Italy). Faecal pH was determined after mixing a sample of fresh faeces with an equal weight of distilled water and blending for 1 minute. Blood were centrifuged at 3000 × g for 15 min and stored at -20 °C until analysis. Plasma biochemical constituents were analysed with an auto analyser (Biotecnica, BT 1500, Italy), using commercial clinical investigation kits (Bionic Diagnostic Co, Iran) by Mabna Veterinary Pathology Laboratory (Karaj, Iran). Biochemical measurements were performed for Na, K, chloride (Cl), calcium (Ca), magnesium (Mg), phosphorous (P), glucose, albumin, total protein, creatinine, blood urea nitrogen (BUN), aspartate aminotransferase (AST) and alanine aminotransferase (ALT). Dry samples of feeds were analysed for sodium, potassium, and chloride. Concentrations of potassium and sodium were determined by PFP7 flame emission photometry. Chloride concentration was determined by extracting the feed (5 g) with 0.1 N nitric acid solution for eight hours and measuring chloride by potentiometric titration with silver nitrate using potassium dichromate as an indicator (Chaudhary *et al*., 1996). Actual DCAD (mEq/100 g of DM) was calculated as $(Na^+ + K^+) - (Cl^- + S^{2-})$.

Table 1 Feed ingredients of experimental diets based on dry matter (g/kg DM)

	Diet		
	No straw	**Wheat straw**	**Rice straw**
Lucerne hay	199.9	127.9	127.9
Maize silage	199.9	127.9	127.9
Treated straw	–	127.9	127.9
Barley grain, ground	199.9	201.9	201.9
Maize grain, ground	140.0	146.3	146.3
Soybean meal	56.0	99.0	99.0
Sunflower meal	40.0	2.0	2.0
Maize gluten meal	10.1	10.1	10.1
Cotton seed-high lint	28.2	28.3	28.3
Soybean whole extruded, coarse	54.0	65.1	65.1
Dried beet pulp, shreds	30.2	30.4	30.4
Fat, powder	13.1	13.1	13.1
Sodium bicarbonate	8.6	–	–
Calcium carbonate	3.4	3.6	3.6
Dicalcium phosphate	2.6	2.4	2.4
Salt	2.0	2.0	2.0
Min-premix[1]	6.6	6.6	6.6
Vit-premix[2]	5.5	5.5	5.5

[1]Min-premix contained (per kilogram DM) 10 g Mn, 16 g Zn, 4 g Cu, 0.15 g I, 0.12 g Co, 0.8 g Fe, and 0.08 mg Se
[2]Vit-premix contained (per kilogram DM) 1,000,000 IU vitamin A, 360,000 IU vitamin D3, 15,000 IU vitamin E

Eating and ruminating activities were monitored visually every five minutes for 24 hours during the last day of each experimental period. Each activity was assumed to persist for the entire five-minute interval. Eating was defined as at least 1 min eating activity after at least 20 min without eating. A period of rumination was defined as at least 5 min rumination occurring after at least 5 min without rumination activity. Chewing time represented the sum of the time spent eating and ruminating. The time spent eating, ruminating, and chewing expressed per kg of DM intake was calculated using the average DM intake measured during the last five days of each experimental period.

Diet and forages were analysed for chemical composition (n = 2) and reported as the mean values. Before statistical analyses, repeated measurements on DMI, total-tract nutrient digestibility, milk yield and composition were reduced to period means for each cow. All data were analysed as a multiple Latin square using PROC MIXED (SAS Institute Inc., Cary, NC). The first-order autoregressive covariance structure [AR (1)] and the MIXED model were used for data analysis were:

$$Y_{ijklm} = \mu + S_i + C_{j(i)} + P_k + T_l + (P\times T)_{kl} + \varepsilon_{ijklm}$$

Where: Y_{ijklm} = each observation
μ = overall mean
S_i = fixed effect of square (i = 1 to 4)
$C_{j(i)}$ = random effect of cow within square (j = 1 to 3)
P_k = fixed effect of period (k = 1 to 3)
T_l = fixed effect of dietary treatment (l = 1 to 3)
$(P\times T)_{kl}$ = period × treatment interaction
ε_{ijklm} = random residual error, assumed to be normally distributed

The square × treatment interactions were originally evaluated, but were removed from the final statistical models because they were not significant for any of the variables. Contrast statements were used to determine the influence of straw inclusion (Control versus WS and RS) and straw type (WS versus RS). Treatment effects were considered significant when P <0.05. A trend was considered to exist if 0.05 < P ≤ 0.10.

Results

The pH value of the untreated straws was nearly neutral (6.96), increasing to 11.9 for WS and 12.2 for RS after treatment with NaOH. Once the ensilage period was over, pH reduced to 10.5. The NDF content of straws were approximately 1.5 as great as for the other three feeds. However, untreated wheat straw had more concentrations of fibre (NDF, ADF and ADL) and less ash and CP than rice straw. Alkali treatment and ensilage resulted in an increase in the concentration of ash, but a decrease in NDF, ADF and ADL (Table 2). Therefore, the content of NDF remained consistently across experimental diets (Table 3).

Table 2 Chemical composition of lucerne hay, maize silage and untreated and treated straws

	Control		Wheat straw		Rice straw	
	Lucerne hay	**Maize silage**	**Untreated**	**Treated**	**Untreated**	**Treated**
Dry matter	933	228	923	458	912	466
Crude protein, g/kg DM	147	102	44	42	48	41
Neutral detergent fibre, g/kg DM	486	555	817	567	713	547
Acid detergent fibre, g/kg DM	356	330	500	395	433	355
Acid detergent lignin, g/kg DM	63	23	88	73	41	19
Ash, g/kg DM	106	77	82	183	150	192
Silica, g/kg DM	-	-	-	-	53.2	38.9

DM: dry matter

On the whole, the experimental diets were formulated to be iso-nitrogenous (16.5 % DM as CP) and iso-energetic (NEL 1.64 Mcal/kg DM). The) icarbonateb sodium$NaHCO_3$) buffer was removed from straw diets because of NaOH addition. Nevertheless, straw diets contained greater sodium content (0.71 versus 0.4%) and cation-anion difference (DCAD = %Na × 43.5 + %K × 25.6 -%Cl × 28.2 - %S × 62.5 per 100 g DM) than the NS diet (Table 3). The DCAD of the WS diet (48.4 mEq/100 g) was lower than that of the RS diet (56.2 mEq/100 g) mainly because of lower potassium level (17.3 vs 15.3 g/kg DM).

Table 3 Chemical composition and macro-minerals values of experimental diets

	Diets		
	No straw	**Wheat straw**	**Rice straw**
Dry matter, g/kg	564	618	612
Crude protein, g/kg DM	165	165	165
Neutral detergent fibre, g/kg DM	321	319	317
Non fibrous carbohydrate[1], g/kg DM	399	408	410
Ether extract, g/kg DM	49	51	51
Net energy for lactation[2], Mcal/kg	1.64	1.64	1.64
Calcium, g/kg DM	6.0	5.2	5.2
Phosphorous, g/kg DM	4.0	3.7	3.7
Sodium, g/kg DM	4.0	7.0	7.3
Potassium, g/kg DM	18.0	15.3	17.3
Chlorine, g/kg DM	2.6	3.1	2.6
Sulfur, g/kg DM	1.9	2.0	2.0
DCAD[3], mEq/100g DM	44.3	48.4	56.2

[1]NFC, % = 100 - (%NDF + %CP + %EE + %ash)
[2]Calculated from NRC (2001)
[3]DCAD: dietary cation-anion difference in mEq (%Na × 43.5 + %K × 25.6) – (%Cl × 28.2 + %S × 62.5) per 100 g DM

Voluntary intakes of diet DM were 25.7, 27.6 and 27.4 kg/d for the NS, WS, and RS diets, respectively (Table 4). DMI increased (P <0.01) when either WS or RS was included in the diets. There was no difference in feed intake between WS and RS (P = 0.77). Compared with the NS diet, inclusion of WS in the diet resulted in increased (P <0.01) digestibility of DM, OM, and NDF by 5.8, 5.0, and 13 percentage units, respectively. Moreover, nutrient digestibility (except for NDF and ADF) was greater (P =0.01) for cows fed WS than cows fed RS. Feeding either WS or RS, compared with NS, increased milk yield by 2.8 kg/d per cow (P < 0.01) with no difference between RS and WS diets. Likewise, milk protein and lactose yields were increased for WS and RS compared with NS, but milk fat yield tended (P = 0.06) to be higher in cows fed straw diets than cows fed NS diets. Milk composition was not affected by dietary treatments and the values were similar for the RS and WS diets. Milk efficiency (milk yield/DMI) was not influenced by the diets. There were no differences in bodyweight change among treatment (P >0.05).

The inclusion of either WS or RS in the diets did not affect rumen, faeces and urine pH and rumen ammonia (Table 5). The average value at 4 hours post feeding was 6.41, 7.83 and 7.38 for ruminal, faecal and urinary pH, respectively. Plasma concentrations of Na, K, Ca, Mg, glucose, AST, ALT, creatinine, and BUN were not altered by the various diets (P >0.05). Plasma P concentration tended (P =0.08) to be lower in cows fed RS and WS than cows fed NS and Cl concentration tended (P =0.09) to be lower in cows fed RS than cows fed WS.

The addition of WS or RS to the diets did not affect total time spent chewing, eating, and ruminating (Table 6). However, cows fed WS and RS diets spent less time in eating and total chewing activity, when expressed as a function of DMI or NDF intake (greater feeding rate) than cows fed NS diets (P <0.05). There was no significant difference for eating and ruminating time between WS and RS diets. However, the total chewing time (min/d) tended (P = 0.09) to be greater in cows fed RS than incows fed WS.

Discussion

The availability of high-quality forages as dairy feed may be limited in many areas, whereas cereal straws are potential feed resources because of large annual yields and near-universal availability. On the other hand, the amount of land devoted to forage crops has declined. Lucerne in particular has become more expensive in the last 20 years. Dairy farms increased the substitution of by-products for conventional feeds as a means to reduce diet costs (Hall & Chase, 2014). Use of chemically treated straw may be economical if it can be partially substituted as a forage source for dairy cows. Previous research has indicated that dry treatment of rice straw with sodium hydroxide (NaOH) at pH~12, followed by ensilage, was more effective than rice straw treated with acid, oxidative, or alkaline hydrogen peroxide agents in terms of ruminal degradability (Ghasemi *et al*., 2013a). Treatment with NaOH disrupts ester and β-glucosidic linkages, increases hemicellulose solubility, ruptures aromatic ring and intermolecular hydrogen bonding in cellulose microfibrils, and enhances the release of phenolic compounds in the cell wall components (Van Soest, 2006; Ghasemi *et al*., 2013a). These effects increase the swelling capacity of plant cell walls, and enable the rumen microorganisms to attack more easily the structural carbohydrates, enhancing degradability and palatability of straw (Hanafi *et al*., 2012). In the current study, alkaline treatment of wheat and rice straws increased total tract digestibility of whole diet DM, OM, and NDF. The fibre fractions of the diets containing WS or RS were more extensively degraded in the gastrointestinal tract than the fibre sources in the NS diet. Increased fibre digestibility has been reported in studies (Cameron *et al*., 1990) that used the alkaline hydrogen peroxide treatment of WS. The classic multi-forage meta-analysis by Oba & Allen (1999) suggests that a one-unit increase in NDF digestibility can increase daily DMI by 0.17 kg, resulting in a daily increase of 0.25 kg of 4% fat-corrected milk. Interestingly, in this study, feeding RS and WS increased NDF digestibility by 11% percentage unit and DMI and fat corrected milk (FCM) by 1.8 and 2.4 kg/d, respectively. The enhancement in DMI by cows fed straw diets can be partly attributed to increased feeding rate (decreased eating time/kg diet). The ability of cows to eat WS and RS diet quicker than the control diet was probably attributable to the greater fragility of the fibre of WS or RS compared with the control diet. Wang *et al*. (2014) observed that the higher nutrient digestibility and content of easily fermented carbohydrate in lucerne hay than untreated straw resulted in a higher energy supply and microbial protein for lactation and, hence, higher milk protein yield. In the current study, the opposite trend was observed when lucerne hay and maize silage were partially replaced with treated RS or WS. Replacing untreated straw with treated straw and including urea has been shown to increase not only intake and digestibility, but also microbial protein synthesis in sheep and cattle (Khandaker *et al*., 2012; Ghasemi *et al*., 2014c). Wheat and rice straw are the largest biomass feedstock in the world. In this study, no significant differences were observed between WS and RS in relation to lactational and physiological responses.

Table 4. Performance in lactating cows fed various forage sources

	Diet			SEM	*P*-value	
	No straw	**Wheat straw**	**Rice straw**		**No straw versus straw**	**Wheat versus rice straw**
Dry matter intake, kg/d	25.7	27.6	27.4	0.68	<0.01	0.77
Digestibility, %						
Dry matter	63.9	69.7	66.0	0.88	<0.01	<0.01
Organic matter	66.6	71.6	68.4	0.92	<0.01	<0.01
Crude protein	70.0	72.6	69.6	1.03	0.22	0.01
Neutral detergent fibre	42.4	55.4	51.4	2.27	<0.01	0.10
Acid detergent fibre	38.4	55.6	49.6	3.28	<0.01	0.09
Yield, kg/d						
Milk	45.6	48.4	48.3	0.76	<0.01	0.83
Fat	1.61	1.66	1.69	0.040	0.06	0.48
Protein	1.37	1.47	1.47	0.031	<0.01	0.95
Lactose	2.14	2.31	2.32	0.044	<0.01	0.93
Total solids	5.65	6.03	6.06	0.096	<0.01	0.76
Milk efficiency[1]	1.78	1.77	1.78	0.048	0.89	0.79
Milk composition, %						
Fat	3.55	3.44	3.53	0.092	0.47	0.33
Protein	3.01	3.04	3.04	0.038	0.35	0.98
Lactose	4.71	4.77	4.79	0.035	0.08	0.59
Total solids	12.47	12.46	12.57	0.095	0.60	0.29
Bodyweight, kg	667	671	672	5.33	0.35	0.86

[1]Milk efficiency = milk yield/dry matter intake

Table 5 Rumen, faecal and urine characteristics and plasma parameters in lactating cows fed various forage sources

	Diet				*P*-value	
	No straw	**Wheat straw**	**Rice straw**	**SEM**	**No straw versus straw**	**Wheat versus rice straw**
Rumen pH	6.42	6.27	6.53	0.149	0.87	0.14
Rumen NH_3, mg/dL	8.99	8.79	9.13	0.208	0.87	0.14
Faecal pH	7.80	7.85	7.85	0.065	0.38	0.94
Urine pH	7.39	7.37	7.39	0.132	0.95	0.85
Plasma parameters						
Sodium, mEq/L	139.1	140.6	141.0	2.47	0.45	0.90
Potassium, mEq/L	4.12	4.22	4.28	0.185	0.47	0.59
Chloride, mEq/L	101.1	102.1	100.5	0.85	0.70	0.09
Calcium, mg/dL	7.29	6.74	7.06	0.363	0.25	0.33
Phosphorous, mg/dL	4.79	4.32	3.91	0.306	0.08	0.52
Magnesium, mg/dL	2.40	2.46	2.45	0.225	0.76	0.83
Glucose, mg/dL	53.4	57.5	57.0	2.63	0.18	0.75
Albumin, g/dL	3.04	2.94	3.09	0.118	0.83	0.24
AST[1], units/L	77.7	67.7	70.6	6.90	0.25	0.56
ALT[1], units/L	30.3	26.9	25.2	2.91	0.23	0.52
BUN[2], mg/dL	17.9	16.6	17.5	2.13	0.66	0.62
Creatinine, mg/dL	0.89	0.95	0.92	0.047	0.34	0.84

[1]AST: aspartate aminotransferase; ALT: alanine aminotransferase
[2]BUN: blood urea nitrogen

Table 6 Chewing activities in lactating cows fed various forage sources

	Diet				*P*-value	
	No straw	**Wheat straw**	**Rice straw**	**SEM**	**No straw versus straw**	**Wheat versus rice straw**
Min/day						
Eating	337	309	316	21.8	0.21	0.75
Ruminating	460	460	497	32.2	0.53	0.24
Total chewing	795	770	814	25.9	0.90	0.09
Duration of meal, min						
Eating	33.5	29.6	33.1	3.78	0.53	0.36
Ruminating	38.0	41.3	41.4	2.92	0.20	0.97
Total chewing	35.8	35.0	37.2	2.28	0.86	0.33
Min/kg of dry matter intake						
Eating	13.6	11.4	11.9	0.82	0.02	0.54
Ruminating	18.4	17.2	18.4	1.18	0.59	0.32
Total chewing	31.9	28.6	30.3	0.95	<0.01	0.08
Min/kg of neutral detergent fibre						
Eating	39.2	31.7	31.7	2.54	<0.01	0.99
Ruminating	52.4	47.5	49.1	3.07	0.14	0.58
Total chewing	91.3	79.2	80.9	2.82	<0.01	0.53

Apparent OM digestibility in the RS diet, however, was lower than that of WS diet. This observation can be explained because rice straw differs from wheat straw in having a higher content of silica, a lower content of lignin and an NDF matrix that may have lower digestibility than that in wheat straw (Van Soest, 2006). However, results relating silica and lignin content to degradability of rice straw are equivocal (Ghasemi *et al*., 2013b). Few experiments have compared the performance of dairy cows fed WS and RS. Khanal *et al*. (1999) reported milk yield of lactating buffaloes was increased as a result of urea treatment of both WS and RS.

In terms of wet alkali treatments, dry methods avoid organic matter losses, but have the disadvantage that the treated feed may be less palatable or digestible due to its high alkalinity (Van Soest, 2006). Another drawback with dry treatment of straw may arise from the excessive Na that is left in the straw. In fact, cattle evolved with low dietary sodium to meet nutritional requirements (Van Soest, 1994). Therefore, dairy cattle utilize dietary sodium efficiently, but only small amounts are stored in a form that is readily available for metabolism. Feeding sodium in excess of need results directly in increased excretion (NRC, 2001). The NRC (2001) recommends 0.22% sodium in the diet as the requirement of a Holstein cow producing 45 kg milk per day. In this study, total dietary sodium content of straw diets was greater than no straw diet (0.71% versus 0.4% DM). This led to greater DCAD and lower K : Na ratio (2.2:1 versus 4.5:1) compared with the control diet. Wildman et al. (2007a) examined the effect of dietary ratios of K : Na of 2 : 1, 3 : 1, and 4 : 1 on milk production and showed that milk yield was lower for a ratio of 3 : 1 K : Na compared with ratios of 2 : 1 and 4 : 1. The underlying mechanism responsible for this observation remains unclear. Sanchez *et al.* (1994) reported that DMI and milk yield responses over a range of dietary sodium concentrations (0.11 to 1.20%, DM basis) and DCAD (+58 to +612 mEq/kg of dietary DM) were curvilinear, with maximum performance at 0.75% sodium and +380 mEq/kg DM DCAD (Na + K - Cl). However, responses to sodium differed over the range of dietary concentrations of potassium, chloride, and phosphorus (Sanchez *et al*., 1994). A positive DCAD could alter ruminal fermentation and acid-base homeostasis. Increasing DCAD raises ruminal pH, blood pH, blood HCO_3^- concentration, and urinary pH (Apper-Bossard *et al*., 2006; Hu & Kung, 2009). It may be concluded that the excess dietary sodium intake occurring by partial replacement of forages with WS or RS had a positive effect on ruminal digestive physiology and therefore explained why fibre digestion and intake were greater in straw diets than the NS diet. Based on the positive effect of Na at concentration of 0.5 to 0.8% in lactating cows diets, especially those fed high-grain diets, in several studies (Sanchez *et al*., 1994; Wildman *et al*., 2007b; Hu & Kung, 2009; Apper-Bossard *et al*., 2010), and no negative effects of dietary sodium content at 0.7% on urinary pH and plasma metabolites in this study, only a portion of forages (e.g. 1/3) should be replaced with dry NaOH-treated straw. Feeding greater levels of treated straw could result in high contents of sodium, which might cause faster rumen washout and heavy urination, and consequently have negative effects on digestion and animal systems (Van Soest, 2006; Ghasemi *et al*., 2014a). Further, NRC (2001) suggested that if sodium-containing compounds (in the current study NaOH) is used to supply sodium, it may be necessary to meet the chloride requirement with another supplemental source (e.g., potassium chloride). Overfeeding of macro minerals leads to increased excretion in faeces and urine, and over-application of macro minerals in dairy manure could lead to excessive concentrations in soils, which affects crop production (Norell & Chahine, 2014).

A lower plasma concentration of P in cows fed RS or WS might be as a result of higher DCAD or slightly lower P in the diets compared with cows fed NS diet. Borucki *et al*. (2004) indicated that dietary DCAD could influence P homeostasis in lactating cows, and observed a tendency for lower concentrations of plasma P at high levels of DCAD. In the present work, mould growth in treated ensiled straw occasionally occurred in some part of straw (surface). Exposing straw after alkali treatment to air for two or three days would be another way of drying and preserving it and could be applied on farm (unpublished data).

Conclusion

The current results indicated improved lactational performance of high-producing dairy cows fed either RS or WS, substituted at one third level of forage sources. This response appears to be due in part to increased dietary sodium concentration, DCAD, total tract digestibility and DMI. There was no difference between WS and RS diets in milk production. Feeding dry treated RS or WS (12.8% on a DM basis) did not adversely affect plasma metabolite and electrolytes parameters.

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Authors' Contributions

EG and GRG designed the study. HO, EG and MK participated at acquisition of data. EG was in charge of writing the manuscript and interpretation of the study. All authors have read and approved the final paper.

Conflict of Interest Declaration

The authors have declared that no competing interests exist.

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