INFLUENCE OF REPLACEMENT LEVELS OF ORANGE WASTE SILAGE ON INTAKE, NUTRIENT DIGESTION, RUMINAL FERMENTATION AND MILK YIELD IN BARKI GOATS

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Abstract

Exploring new alternative sources of feedstuffs can contribute to animal production sustainability in some Mediterranean regions in order to overcome the rising food demand. The influence of dietary replacement of wheat straw (WS) with orange waste silage (OWS) on nutrient intakes, apparent digestibility, ruminal fermentation and blood biochemical constituents and milk production of dairy goats were evaluated. Forty pregnant goats (46.30±1.6 kg BW) were housed in individual pens in a completely randomized design and fed (*ad libitum*) a TMR for 75 days period. Goats were assigned to four experimental diets with the forage amounts consisting of either WS as a control diet (1000 g WS/kg DM in the TMR), a 50:50 mixture of both WS and OWS (500 g WS and 500 g OWS/kg DM in the TMR), an orange waste silage (1000 g OWS/kg DM in the TMR) or corn silage as a positive control (1000 g CS/kg DM in the TMR). The DMI increased linearly ($P<0.01$), while fiber fractions intake decreased linearly ($P<0.01$) with increasing of OWS in the diet. Ruminal pH was increased quadratically ($P<0.01$), whereas $\text{NH}_3\text{-N}$ concentration and total protozoa abundance decreased quadratically ($P<0.01$) with increasing OWS in the diet. Ruminal acetate content was increased linearly ($P = 0.012$) by diet; whereas linear effects were observed on propionate and butyrate proportions ($P<0.01$) as OWS amount increased. Blood urea nitrogen (BUN), non-esterified free fatty acids (NEFA) and β -hydroxybutyrate (BHBA) levels decreased linearly ($P<0.01$) with ascending amounts of OWS. Serum glucose, BUN, NEFA and BHBA levels were lower ($P<0.01$) for goats fed the OWS diet than those fed the CS diet. Milk yield and milk nitrogen efficiency were linearly increased ($P<0.01$), whereas quadratic effects ($P = 0.049$) were observed on milk urea nitrogen content with increasing dietary OWS. In conclusion, the replacement of WS with OWS enhanced rumen fermentation and milk yield of late pregnant and early lactation Barki goats.

Key words: orange waste silage, ruminal constituents, digestibility, Barki goat, milk production

In Egypt, berseem (*Trifolium alexandrinum* L.) is the main feed ingredient for animals during the wet season. However, in the dry season, due to increased feed costs and associated harsh climate conditions, feed scarcity causes malnutrition, which is a challenge for animal production sustainability. Due to its enhanced physical and nutritional characteristics, corn silage (CS) is a high-quality forage used in dairy farms if appropriately ensiled, leading to proper ruminal fermentability and maximizes animal production during the summer season (Guyader et al., 2018). Nevertheless, CS-based feeding has become more expensive and may cause some metabolic disorders, such as ruminal acidosis and reduced fiber digestibility (NRC, 2001). Meanwhile, wheat straw (WS) has been commonly utilized in ruminant diets in some of Mediterranean countries as a feedstock ingredient during the dry season. However, the high fiber, low protein and carbohydrates contents of WS limit its wide usage as it causes low digestibility and poor fermentability (Aquino et al., 2020).

The annual production of orange fruits in Egypt has been estimated to approximately 2 million tons that generates about 40,000 tons of pulps and peels as highly wet waste (El-Sheekh et al., 2009) while citrus juice extraction produces large amounts of waste as peel, pulp and seeds. Citrus (orange) peel contains high pectin cellulosic biomass with considerable amounts of crude protein (90 g/kg DM), pectins (209 g/kg DM), soluble sugars (90 g/kg DM), cellulose (339 g/kg DM) and lignin (69.3 g/kg DM) (Rivas-Cantu et al., 2013). In addition, dried citrus pulp, the main citrus residue, contains approximately 12–40% sugars and 22–44% neutral detergent-soluble carbohydrates and large amounts of pectic substances (Hall et al., 2010). Therefore, citrus wastes can be used as a promising feedstock ingredient that can help to overcome the poor-quality ruminants feed occurring during the dry season. Citrus waste has been used as a source of energy with high pectin content for growing heifers and lactating cows (Miron et al., 2001), stimulating ruminal fermentation and adding extra nutrients digestibility (Jetana et al., 2009). Ruminal fermentation of pectin (soluble NDF) activates the production of acetate at the expense of lactate, eliminating pH decline (Chen et al., 2019). Moreover, citrus waste is a good source of flavonoids bioactive components (hesperidin and naringin) that provides extra health-promoting potentials (Bampidis and Robinson, 2006). Citrus pulp silage has been used as an alternative ingredient for hay forage for growing lambs (Scerra et al., 2001). Previous studies have shown the significance of replacing grains with ensiled sliced oranges that improved milk fat content of lactating sheep (Volanis et al., 2004). In other experiment, dried citrus peels as a concentrate replacement reduced the risk of ruminal acidosis and blood glucose concentration (Cribbs et al., 2015). Ensiled citrus pulp successfully replaced concentrates in the diet of lambs of up to 40% without any adverse effect on feed intake and growth performance (Sharif et al., 2018).

Orange waste silage (OWS) is a highly palatable and promising feed ingredient that can be used as a potential alternative in high quality forage due to its abundant nutrients availability for ruminants. Differences between OWS and WS in NFC (mainly starch, sugars and pectins content) and NDF fractions creates relevant diversity in ruminal degradation characteristics that can be exploited as favorable alternative feed ingredient for WS. To the best of our knowledge, studies that investigate

the replacement of dietary roughages with OWS and comparisons between OWS and CS in lactating Barki goats diet are limited. Herein, the main objectives of this study are to: 1) investigate the impacts of replacing WS with increasing levels of OWS. 2) Compare the effects of including equal dietary levels of OWS and CS on feed intake, ruminal fermentation patterns, nutrients digestibility, blood biochemical constituents and milk yield without any prejudicial effect on goat health.

Material and methods

This study was carried out at Borg Al-Arab Research Station (30°50'56" N 29°36'42" E), Animal Production Research Institute, Agricultural Research Centre, Dokki, Giza, Egypt. All samples were analyzed at the Laboratory of Animal Nutrition, Department of Animal Production, Faculty of Agriculture, Alexandria University. All experimental goats were cared of and handled in accordance with the guidelines and established protocols approved and authorized by Institutional Animal Care and Use Committee of the Alexandria University (ALEXU-IACUC/08-19-05-14-3-24).

Preparations of orange and corn silage

Discarded orange wastes (peel, membranes and pulp) collected after juice extraction from a citrus processing plant located in Borg Al-Arab region (Egypt), were mixed well and chopped to approximately 25–50 mm. Whole corn plants were harvested 10 cm above ground surface at mid-milk seeds stage and chopped into the same size as orange wastes. Each product was ensiled into approximately 1 m high stack for 2 months. The stack silo was compacted, coated with a plastic sheet and covered with soil to secure anaerobic fermentation conditions and protect silage from being exposed to solar radiation. Due to the high moisture contents of orange waste, it ensiled together with chopped wheat straw to avoid ensiling losses (Scerra et al., 2001).

Three representative samples taken out from the fresh silage were pooled and then divided into two subsamples. One was immediately examined for silage color, odor and texture, while the other was the filtrate of 50 g of fresh silage blended with 120 ml of distilled water and kept at 25–27°C on magnetic stirrer for 1 h. To obtain the filtrate, the blended silage was squeezed to pass through Whatman 54 filter paper for $\text{NH}_3\text{-N}$ determination (Brunette et al., 2014). The silage extract was decanted for pH measurement using a portable pH meter (GLP 21 model; Crison, Barcelona, Spain). Silage fermentative fatty acids were determined in 5 mL of the silage supernatant after filtration as described in short chain fatty acid (SCFA) determination method using a gas chromatograph according to the method described by El-Zaiat et al. (2020 a). The chemical composition of CS and OWS is presented in Table 1.

Table 1. Chemical composition of experimental corn silage (CS), orange waste silage (OWS) and wheat straw (WS) and silage fermentation characteristics (g/kg DM)

Items	CS	OS	WS
Chemical composition (g/kg DM)			
organic matter	930	910	899
crude protein	88	74	25
ether extract	27	22	27
non-fiber carbohydrates	285	506	65
starch	237	140	11
total sugar	22	25	2
organic acids	3	4	0.6
pectin	16	287	2
NDFom	530	308	782
ADFom	261	200	537
cellulose	233	185	451
hemicellulose	269	108	245
lignin	28	15	85
iNDF _{estimated}	67	36	204
pdNDF _{calculated}	463	272	578
Ensiling characteristics			
dry matter (g/kg DM)	282	240	—
pH	3.42	3.04	—
ammonia-N (g/kg total N)	51.05	43.13	—
lactic acid (g/kg DM)	69.92	64.56	—
acetic acid (g/kg DM)	22.60	25.65	—
propionic acid (g/kg DM)	1.81	1.92	—
butyric acid (g/kg DM)	1.03	0.97	—
texture	Leafy and soft	Wet and soft	—
color	Yellowish-green	Brownish yellow	—
odor	Light and pleasant	Fruity	—

DM, dry matter; NDFom, neutral detergent fiber expressed exclusive of residual ash; ADFom, acid detergent fiber expressed exclusive of residual ash; SEM, means standard error, Non-fiber carbohydrates; (NFC, g/kg) = $1000 - (\text{NDFom g/kg} + \text{CP g/kg} + \text{EE g/kg} + \text{ash g/kg})$. iNDF; indigestible neutral detergent fiber estimated according to CNCPS (Fox *et al.*, 2004). pdNDF; potentially digestible neutral detergent fiber fraction calculated as the difference between total NDFom and the estimated iNDF.

Experimental design, goats and diets

Forty late pregnant Barki goats (body weight 46.30 ± 1.6 kg and age 36 ± 0.4 months) were allocated into a completely randomized design. Animals were allotted to experimental treatment according to lambing date, body weight and milk production. The experiment lasted for 75 days of which 15 days prepartum (before the expected lambing date) and 60 days postpartum. Goats were housed individually in closed pens with muddy floors bedded with rice straw. Pens were equipped with feeders and buckets always had accessible water. Goats were fed individually a basal total mixed ration (TMR) diet containing 400 g of roughage and 600 g of concentrate

mixture per kg DM to meet their nutritional requirements recommended by NRC (2007).

Table 2. Feed ingredients and chemical composition of experimental TMR diets on DM basis

Items	CS	Replacement levels (OWS replacing WS g/kg) ¹		
		0	500	1000
Ingredients				
wheat straw	0	400	200	0
orange waste silage	0	0	200	400
corn silage	400	0	0	0
yellow corn	378	378	378	378
cottonseed meal	60	60	60	60
linseed meal	60	60	60	60
wheat bran	90	90	90	90
limestone	8.4	8.4	8.4	8.4
salt	3.0	3.0	3.0	3.0
mineral mixtures ²	0.6	0.6	0.6	0.6
metabolizable energy (Mcal/kg DM)	2.50	2.36	2.37	2.58
Chemical composition (g/kg DM)				
organic matter	931	918	920	923
crude protein	131	106	117	127
ether extract	32	35	32	32
non-fiber carbohydrates ³	286	227	322	403
NDFom	482	550	449	361
ADFom	284	339	282	243
cellulose	198	230	186	159
hemicellulose	198	211	167	118
lignin	85	109	96	84
iNDF _{estimated}	204	262	230	202
starch	249	191	215	219
total sugar	21	23	21	19
organic acids	12	2	10	17
pectin	6	8	61	115

¹WS, wheat straw; OWS, orange waste silage; CS, corn silage.

²Contained (g/kg): manganese sulphate 12.58, zinc sulphate 9.3, copper sulphate 3.2, ferrous sulphate 16.67 calcium iodate 0.081, sodium selenite 0.4, magnesium oxide 9.4, cobalt sulphate 0.2, sodium chloride added to kg (Dyano Vet Company, Alexandria).

DM, dry matter; NDFom, neutral detergent fiber expressed exclusive of residual ash; ADFom, acid detergent fiber expressed exclusive of residual ash.

³Non-fiber carbohydrates (NFC, g/kg) = 1000 – (NDFom g/kg + CP g/kg + EE g/kg + ash g/kg).

iNDF; indigestible neutral detergent fiber estimated according to CNCPS (Fox et al., 2004).

Goats were assigned to four experimental diets with the forage amounts consisting of either WS as a control diet (1000 g WS/kg DM, 0% OWS in the TMR),

a 50:50 mixture of both WS and OWS (500 g WS and 500 g OWS/kg DM in the TMR), an orange waste silage (1000 g OWS/kg DM, 0% WS in the TMR) or corn silage as a positive control (1000 g CS/kg DM, 0% WS in the TMR). Goats were fed TMR twice daily in equal portions at 0800 and 1600 h allowing refusal amount of approximately 10% of daily dry matter intake (DMI). The milk nitrogen efficiency was calculated as milk nitrogen yield divided by total nitrogen intake. While, milk energy efficiency was calculated by dividing milk energy output by ME intake. The feed efficiency was calculated as milk yield divided by DMI. The feed ingredients and chemical composition of the experimental TMR are presented in Table 2.

Feed intake and apparent nutrients digestibility

The DMI was measured on days 30, 45, 60 and 75 as the difference between the total daily amount of feed offered per pen and the total daily amounts of weighed-back orts after allowing approximately 10% refusal amount daily of DMI. Samples of TMR were taken weekly from each pen throughout the experiment and frozen at -20°C for later chemical analyses. Daily two fresh fecal grab samples (50–100 g each) were obtained from each animal during the last experimental week about 1 h post-feeding. Feed and faeces acid insoluble ash (AIA) contents were used as an internal marker to estimate the apparent digestibility coefficients according to Van Soest et al. (1991). All aliquots of feces per animal were bulked, and mixed completely. Pooled samples were stored at -20°C for subsequent analysis.

Ruminal fermentability characteristics

On days 30, 45, 60 and 75 from the beginning of the experiment, 20 mL of ruminal fluid were collected from each animal 3 h post-feeding using a stomach tube (Ramos et al., 2014). Ruminal fluid pH was measured immediately after collection using a portable pH meter (GLP 21 model; Crison, Barcelona, Spain). Ruminal $\text{NH}_3\text{-N}$ concentration was measured colorimetrically using commercial lab test as described by Konitzer and Voigt (1963). Aliquot subsample of 2 mL was mixed with 4 mL of methyl green-formalin-saline solution for subsequent enumeration of total protozoa according to the procedure described by Dehority et al. (1983).

The SCFA concentrations were determined using a gas chromatograph (Thermo Fisher Scientific, Inc., Trace1300, Rodano, Milan, Italy) fitted with an AS3800 autosampler and equipped with a capillary column HP-FFAP (19091F-112; 0.320 mm o.d., 0.50 μm i.d., and 25 m length; J and W Agilent Technologies Inc., Palo Alto, CA) as described by El-Zaiat et al. (2020 a). In brief, 1.6 mL aliquot subsamples were prepared with 0.4 mL of 250 g/kg metaphosphoric acid (4:1 ratio) and centrifuged at $15,000 \times g$ for 20 min and 4°C (K1015 Micro Prime; Centurion Scientific Ltd, Stoughton, Chichester, UK). A 0.1 μL aliquot was injected in the splitless mode for the entire run with 31.35 mL/min of H_2 flux (63.432 Pa).

Blood biochemical constituents

On days 30, 45, 60 and 75 from the beginning of the experiment, blood samples (10 mL each) were collected from jugular vein of each goat into clean tube without

anticoagulants before the morning feeding. The blood samples were centrifuged at $2,000 \times g$ for 15 min and the clear serum was separated carefully and immediately stored at -20°C for future serum biochemical processing.

Biochemical blood serum constituents (blood urea nitrogen (BUN), total protein, albumin, glucose, triglycerides, creatinine and cholesterol) were measured colorimetrically using commercial colorimetric kits (Spinreact, Ctra. Santa Coloma, 7, Girona, Spain) according to Young (1995) and Tietz et al. (1995). Globulin concentration was calculated as the difference between total protein and albumin.

The serum β -hydroxybutyrate (BHBA) concentration was determined by a kinetic enzymatic method using a commercially available kit (Ranbut D-3-hydroxybutyrate, Randox, Crumlin Co., Antrim, UK). Serum non-esterified free fatty acids (NEFA) concentration was measured commercially using available kit (Randox Crumlin Co., Antrim, UK) supplied by Randox Laboratories Ltd.

Milk production and composition

Milk yield assessment started three days after parturition. Individual goat milk yield was measured on days 30, 45, 60 and 75 of the experiment (Zamiri et al., 2001). Individual fresh milk samples (30 mL each) were analyzed for fat, lactose, protein total solid (TS) and solid not fat (SNF) by infrared methods (Ekomilk-M ultrasonic milk analyzer, EON Trading 2000, INC, Bulgaria). Milk urea nitrogen (MUN) was measured using commercial colorimetric kits as described by Young (1995) and Tietz et al. (1995). The somatic cell counts (SCC) were determined by Ekomilk scan somatic cell milk analyzer (Bulteh 2000, Ltd, Stara Zagora, Bulgaria). Fat corrected milk (FCM, kg/day) was calculated according to El-Zaiat et al. (2018, 2019 a). Energy corrected milk (ECM, kg/day) was calculated according to Bernard (1997). Feed efficiency was calculated and expressed as milk yield per unit of DMI. Milk energy content (Mcal/kg) was determined according to Tyrrell and Reid (1965). Milk energy output (Mcal/day) was calculated as milk energy content (Mcal/kg) multiplied by milk yield (kg/d).

Laboratory analyses

Feed, Orts and pooled fecal samples for each animal were thawed and dried in a forced-air oven at 60°C for 72 h and then ground to pass 1-mm stainless steel screen using Wiley mill grinder. Ground diets and faeces samples were chemically analyzed according to AOAC (2006) for DM (ID number 930.15), OM (ID number 942.05) and CP (as $6.25 \times \text{N}$; ID number 954.01). Sequential analyses of neutral detergent fiber (NDFom) and acid detergent fiber (ADFom) were performed (Van Soest et al., 1991) using an Ankom 200 Fiber Analyzer unit (Ankom Technology Corporation, Macedon, NY, USA) and expressed exclusive of residual ash. Sequentially on the same sample, lignins content of feed and faeces were determined according to Van Soest (1973) by solubilization of ADF with 720 g/kg sulfuric acid. The total sugars and starch were determined as described by Ting and Deszyck (1961), whereas pectins and organic acids were assayed according to the methods described by Rangana (1986). Dietary non-fiber carbohydrates (NFC, g/kg) were calculated as $1000 - (\text{NDFom g/kg} + \text{CP g/kg} + \text{EE g/kg} + \text{ash g/kg})$. Concentrations of cellulose

(g/kg DM; ADFom – lignin) and hemicellulose (g/kg DM; NDFom – ADFom) were also calculated. Metabolizable energy (ME) of the assessed diets was calculated according to NRC (2001). Indigestible neutral detergent fiber (iNDF) was estimated according to CNCPS (Fox et al., 2004). Potentially digestible neutral detergent fiber (pdNDF) fraction was calculated as the difference between total NDFom and the estimated iNDF.

Statistical analysis

Data were analyzed using PROC MIXED procedure (version 9.1, SAS Inst. Inc. 2002, Cary, NC). Data for DMI, ruminal fermentation (pH, $\text{NH}_3\text{-N}$, SCFA and protozoa count), plasma biochemical constituents (total protein, albumin, BUN, creatinine, glucose, triglycerides, cholesterol, NEFA and BHBA) and milk yield and composition were analyzed as repeated measurements (days 30, 45, 60 and 75) using the model:

$$Y_{ij} = \mu + T_i + P_j + PT_{ij} + E_{ij}$$

where: Y_{ij} = observations mean, μ = overall mean, T_i = fixed effect of treatment ($i = 1, 2, 3$ or 4), P_j = fixed effect of period ($j = 1, 2, 3$ or 4), PT_{ij} = interaction of treatment $\times$ period and E_{ij} = residual error. Data for intake and apparent digestibility of nutrients were analyzed also using the same model excluding the fixed effect of period of measure:

$$Y_{ij} = \mu + T_i + E_{ij}$$

where: Y_{ij} = observations mean, μ = overall mean, T_i = fixed effect of treatment ($i = 1, 2, 3$ or 4) and E_{ij} = residual error. Data were subjected to linear, quadratic and cubic responses analyses to examine the effects of replacing amounts of WS with OWS on the measured variables. However, the analysis showed no cubic effects, therefore the latter were not presented, and their effects were not discussed. The analysis of CS vs OWS was done by ESTIMATE means procedure of SAS for contrast analyses. Effects were declared significant at $P \leq 0.05$, and tendencies were considered at $0.05 < P < 0.10$.

Results

Chemical composition of experimental silages and diets

Compared to the CS, OWS contains less CP, NDF, $\text{NH}_3\text{-N}$ and lactic acid with more NFC, acetate, and propionate, while WS contained less CP, NFC and starch with more NDFom and iNDF content than OWS. In contrast, CS contains more starch but it has less pectin (16 vs. 287 g/kg) than OWS (Table 1). Consequently, increasing OWS in the diet could increase starch, organic acids and pectin concentrations, while the NDFom, ADFom and iNDF concentrations would decrease. As the

proportion of OWS increased in the diet, the amount of NDFom, ADFom and lignin decreased while CP and NFC content increased (Table 2). Compared to the CS diet (100% CS), a minor decline in total sugars was observed with OWS diet (100% OWS) (Table 2).

Intakes and apparent nutrients digestibility

Increasing OWS amounts in the diet at the expense of WS linearly increased ($P < 0.01$) DM, OM, CP, NFC and ME intakes, however, NDFom and ADFom intakes linearly decreased ($P < 0.05$, Table 3). However, intakes of NDFom and ADFom were higher ($P < 0.05$), whereas those of NFC and ME were lower for goats fed the CS diet than for those fed the OWS diet. Increasing levels of OWS increased quadratically ($P < 0.05$) DM, OM, NDFom and ADFom digestibility coefficients, while linear increase of CP and NFC digestibility was observed. However, ascending dietary OWS amounts tended to decrease ($P = 0.078$) EE digestibility linearly. Total replacement of CS with OWS increased DM, OM and NDFom digestibilities ($P < 0.01$) while EE digestibility decreased ($P = 0.026$).

Ruminal fermentation constituents

Mean ruminal pH values increased quadratically ($P = 0.038$) as the amounts of OWS increased in the diet (Table 4). A quadratic decline ($P < 0.05$) was observed for ruminal $\text{NH}_3\text{-N}$ and total SCFA concentrations, isobutyrate and isovalerate proportions and total protozoa number as the dietary OWS proportion increased. Ruminal proportion of acetate (C2) increased linearly ($P = 0.012$) and that of propionate (C3) and butyrate (C4) decreased linearly ($P < 0.05$), resulting in a linear increase ($P = 0.005$) in C2:C3 ratio as the amount of OWS increased in the diet. Ruminal $\text{NH}_3\text{-N}$ concentration, C3 proportion and total protozoa abundance decreased ($P < 0.05$), whereas C2:C3 ratio increased ($P < 0.01$) with the total replacement of CS with OWS.

Blood biochemical metabolites

A quadratic decrease ($P = 0.021$) was observed for serum albumin as the amount of OWS in the diet increased. However, serum globulin and glucose concentrations responded quadratically ($P < 0.05$) to increasing the amount of OWS at the expense of WS in the diet (Table 5). Increasing OWS proportions in the diet resulted in a linear decrease ($P < 0.05$) in BUN, cholesterol, triglyceride, NEFA and BHBA concentrations. Further, serum BUN, glucose, NEFA and BHBA levels were lower ($P < 0.05$) for goats fed the OWS diet than for those fed the CS diet.

Milk yield and composition

Milk, fat, lactose, protein, SNF, TS, FCM and ECM yields and milk energy output increased linearly ($P < 0.05$) upon increasing the level of OWS in the diet (Table 6). Whereas, MUN content decreased quadratically ($P = 0.049$) as the amount of OWS increased in the diet. Milk nitrogen efficiency (g milk N/g N intake) decreased linearly ($P = 0.038$) to increasing the amount of OWS in the diet. Milk energy efficiency was lower ($P < 0.001$) for goats fed the OWS diet than for those fed the CS diet.

Table 3. Effect of dietary replacement of wheat straw (WS) with increasing levels of orange waste silage (OWS) on intake and apparent digestibility of nutrients of Barki goats¹

Item	CS	Levels (OWS replacing WS g/kg) ²			SEM	P-value		
		0	500	1000		levels of OWS		CS vs. OWS
						L	Q	
Intake (kg/day)								
dry matter	1.84	1.59	1.75	1.84	0.05	0.009	0.212	0.999
organic matter	1.71	1.46	1.61	1.70	0.05	0.008	0.223	0.664
crude protein	0.241	0.168	0.204	0.234	0.02	0.001	0.397	0.681
ether extract	0.049	0.056	0.056	0.058	0.01	0.729	0.300	0.521
non-fiber carbohydrates	0.525	0.350	0.562	0.745	0.07	<0001	0.171	<0001
NDFom	0.974	0.873	0.784	0.663	0.06	0.025	0.213	<0001
ADFom	0.480	0.538	0.492	0.446	0.02	0.026	0.966	0.011
ME, Mcal/kg DM	4.58	3.73	4.14	4.74	0.02	0.008	0.060	0.009
Apparent digestibility (g/kg)								
dry matter	677	685	678	715	7.73	<0001	<0001	<0001
organic matter	712	687	688	736	10.06	<0001	<0001	<0001
crude protein	681	610	661	676	14.06	0.004	0.352	0.519
ether extract	661	679	582	555	26.02	0.078	0.446	0.026
non-fiber carbohydrates	841	737	792	849	22.40	0.009	0.911	0.546
NDFom	448	410	535	556	30.12	<0001	<0001	0.001
ADFom	445	333	373	440	23.48	0.038	0.034	0.847

¹n = 10 animals per treatment.

²WS, wheat straw; OWS, orange waste silage; CS, corn silage.

SEM, means standard error; DM, dry matter; NDFom, neutral detergent fiber expressed exclusive of residual ash; ADFom, acid detergent fiber expressed exclusive of residual ash; L, linear; Q, quadratic.

Table 4. Effect of dietary replacement of wheat straw (WS) with increasing levels of orange waste silage (OWS) on rumen fermentation constituents of Barki goats¹

Item	CS	Levels (OWS replacing WS g/kg) ²			SEM	P-value		
		0	500	1000		levels of OWS		CS vs. OWS
						L	Q	
pH	6.58	6.31	6.76	6.61	0.08	0.014	0.038	0.811
Ammonia (mg/100 mL)	15.9	15.2	11.2	12.4	0.97	0.039	0.046	0.017
Total SCFA (mM)	84.9	88.5	83.7	85.3	0.89	0.019	0.048	0.840
Acetate (mol/100 mol)	38.9	36.3	40.6	43.6	1.33	0.012	0.456	<0.001
Propionate (mol/100 mol)	25.2	25.0	22.6	21.2	0.84	0.016	0.377	<0.001
Butyrate (mol/100 mol)	16.3	18.5	14.9	13.8	0.88	0.035	0.264	0.014
Valerate (mol/100 mol)	1.21	1.27	1.37	1.26	0.03	0.699	0.676	0.881
Isobutyrate (mol/100 mol)	1.62	1.78	1.15	1.45	0.12	0.003	0.008	0.332
Isovalerate (mol/100 mol)	1.36	1.89	0.90	1.28	0.18	<0.001	0.001	0.620
Acetate:propionate ratio	1.55	1.45	1.81	2.06	0.12	0.005	0.396	<0.001
Total protozoa (×10 ⁵ /mL)	2.52	2.13	1.49	1.93	0.19	0.035	0.043	<0.001

¹n = 10 animals per treatment.²WS, wheat straw; OWS, orange waste silage; CS, corn silage.

SCFA, short chain fatty acid; SEM, means standard error; L, linear; Q, quadratic.

Table 5. Effect of dietary replacement of wheat straw (WS) with increasing levels of orange waste silage (OWS) on blood biochemical profile of Barki goats¹

Item	CS	Levels (OWS replacing WS g/kg) ²				SEM	P-value			
		0	500	1000	levels of OWS			CS vs. OWS		
					L		Q			
No. of animals	10	10	10	10	10	—	—	—	—	
Total protein (g/dL)	6.78	6.43	6.81	6.69	6.69	0.07	0.356	0.184	0.529	
Albumin (g/dL)	3.29	3.36	3.35	3.26	3.26	0.02	0.001	0.021	0.402	
Globulin (g/dL)	3.49	3.07	3.46	3.43	3.43	0.09	0.047	0.051	0.641	
BUN (mg/dL)	23.6	22.3	20.6	20.1	20.1	0.70	0.031	0.707	0.003	
Creatinine (mg/dL)	1.74	1.62	1.77	1.96	1.96	0.06	0.776	0.903	0.702	
Glucose (mg/dL)	78.7	70.3	73.7	73.6	73.6	1.50	0.057	0.049	0.036	
Cholesterol (mg/dL)	105	123	121	102	102	4.67	0.034	0.454	0.561	
Triglycerides (mg/dL)	68.9	78.3	76.1	59.3	59.3	3.71	0.026	0.912	0.107	
NEFA (mmol/L)	0.442	0.488	0.440	0.264	0.264	0.04	0.027	0.748	0.006	
BHBA (mmol/L)	0.597	0.715	0.458	0.340	0.340	0.07	0.001	0.450	0.001	

¹n = 10 animals per treatment.
²WS, wheat straw; OWS, orange waste silage; CS, corn silage.
SEM, means standard error; BUN, blood urea nitrogen; NEFA, non-esterified fatty acids; BHBA, β -hydroxybutyrate; L, linear; Q, quadratic.

Table 6. Effect of dietary replacement of wheat straw (WS) with increasing levels of orange waste silage (OWS) on lactation performance of Barki goats¹

Item	CS	Levels (OWS replacing WS g/kg) ²				SEM	P-value		
		0	500	1000	levels of OWS		CS vs. OWS		
					L			Q	
Production (g/day)									
yield	698	586	662	699	22.61	<0.001	0.101	0.942	
fat	24.2	20.3	22.8	24.1	0.79	0.023	0.364	0.828	
lactose	25.7	21.8	24.5	26.2	0.85	0.008	0.382	0.526	
protein	24.3	20.9	23.1	24.7	0.74	0.024	0.578	0.518	
solid not fat	60.5	50.9	58.2	62.1	2.14	<0.001	0.151	0.277	
total solid	84.7	71.3	80.9	86.2	2.90	<0.001	0.139	0.448	
FCM	643	539	606	641	21.03	0.002	0.204	0.905	
ECM	709	599	670	710	22.56	0.002	0.232	0.932	
milk energy output (Mcal/day)	0.455	0.387	0.431	0.459	0.01	0.005	0.373	0.931	
Composition (g/kg)									
fat	34.9	34.6	34.4	34.5	0.09	0.872	0.895	0.663	
lactose	36.9	37.3	37.1	37.4	0.10	0.697	0.647	0.433	
protein	34.8	35.7	34.9	35.3	0.18	0.222	0.269	0.441	
solid not fat	86.6	87.0	87.9	88.9	0.44	0.669	0.985	0.626	
total solid	122	122	122	123	0.22	0.780	0.916	0.144	
MUN (mg/dL)	10.90	10.53	8.23	9.39	0.52	0.031	0.049	0.221	
milk energy content (Mcal/kg)	0.654	0.657	0.652	0.657	0.01	0.517	0.511	0.741	
SCC (×10 ³ cell/mL)	2.49	2.56	2.60	2.35	0.05	0.423	0.195	0.245	
Efficiency									
milk N/N intake (g/g)	0.099	0.122	0.112	0.104	0.01	0.038	0.619	0.059	
milk energy output/ME intake (Mcal/Mcal)	0.101	0.103	0.104	0.097	0.01	0.235	0.065	<0.001	
milk yield/DMI (kg/kg)	0.389	0.391	0.384	0.386	0.01	0.430	0.498	0.510	

¹n = 10 animals per treatment.²WS, wheat straw; OWS, orange waste silage; CS, corn silage.

SEM, means standard error; FCM: 4% fat-corrected milk calculated ECM, energy-corrected milk; MUN, milk urea nitrogen; SCC, somatic cell count and transformed by log10 (X+10); DMI, dry matter intake; L, linear; Q, quadratic.

Discussion

Differences in silages fermentative profile along with chemical compositions of the diets are allegedly responsible for the differences in goats nutrients intake and digestibility. Increased DMI could be related to the high OM and reduced lignin proportions in the assessed diets and their associated physical characteristics on ruminal fill and retention time (NRC, 2001). An increased NFC intake was anticipated due to high NFC content and fractions (mainly pectins) of OWS, compared with WS and CS. Additionally, increased DMI is possibly verified by the potential appetizing impact of citrus pulp as a consequence of high palatability, acceptability-related odour, flavour and texture. Furthermore, nutrient intakes can be also controlled by the variations in ruminal pH. This finding could be attributable to the reduction in ruminal C3 via decreased rate of hepatic C3 oxidation (El-Zaiat *et al.*, 2019 b). Goats fed CS relative to those fed with OWS diet exhibited less DMI presumably due to higher starch intake and consequently higher ruminal C3 production (Allen *et al.*, 2009). Increased DMI resulted in an increase in nutrient and ME intakes, suggesting adequate supply of nutrients and energy for milk production. In the present study, high NFC (mainly starch and pectins) intake observed when OWS replaced WS in the diet is considered the major factor that triggered changes in the ruminal fermentation constituents, nutrients digestibility, and hence, milk production.

It is known that dietary NDF content is considered one of the limiting factors in the regulation of DMI (Van Soest, 1994), since ruminal filling limits the maximum intake, implying low ruminal degradation and flow rates (Cooke *et al.*, 2009). Therefore, replacement of WS with increasing levels of OWS reduced the contribution of fiber fractions from WS to total fiber fractions, which may have decreased fiber fractions intakes. Otherwise, fiber fractions and lignin content of WS diet are considerably high, which could harden the fiber colonization and fermentation, that may negatively interfere with the digestibility and DMI. Low fiber and high NFC contents of OWS presumably supports ruminal microflora activity (Madrid *et al.*, 1997) and promotes the activity of polysaccharide-degrading enzymes (Zhao *et al.*, 2013), that could accelerate fiber colonization, a consequence of stimulating growth of ruminal bacteria and fungi. As OWS levels increased in the diet, the enhanced OM digestibility could be due to stimulating ruminal microbial growth which indicates more metabolizable protein supply to small intestine (NRC, 2001). However, increased pectins as OWS levels increased in the diet can motivate ideal ruminal conditions for more efficient microbial activities serving to increase nutrients digestibility.

The low digestibility of NDF for CS-fed goats could also be attributed to proportion of iNDF that may reflect an inverse association with digestibility (Firkins, 1997). Based on this assumption, high dietary lignin and iNDF contents of WS diets, hindered CP and NDF digestibility as a consequence of increased ruminal fill and retention time, a fact that physically constrained DMI. This was supported by Ítavo *et al.* (2000) who reported linear increase in DMI by replacing CS with fresh orange pulp silage. In the present study, decreased fiber digestibility with CS diet was consistent with the reduced ruminal C2:C3 ratio which might be ascribed to higher starch fermentation rate and digestibility.

In the present study, enhanced CP digestibility was consistent with the increased CP intake, which was most likely due to increases in ruminal proteolytic bacteria populations (Pino and Heinrichs, 2016). This result infers that differences in NFC digestibility are possibly justified by the differences in pectin and starch contents and their digestibility (Tebbe et al., 2017). In addition, differences in dietary NDF or NFC fractions content may also explain the ruminal C2 and C3 productions and C2:C3 ratio, as well as milk lactation performance differences. Nonetheless, the tendency of decreasing EE digestibility upon increasing the level of OWS in the diet might be caused by higher water holding activity of pectins or by higher excretion of total fat and bile acids in the faeces (Jenkins et al., 1976).

In the present study, changes in ruminal pH value are often responsive to diet ingredients and sorting behavior of goats allowing overconsumption of short feed particles were associated with the decline in ruminal pH (Havekes et al., 2020). Nevertheless, goats fed high NFC/low NDF diets have the potential to decrease ruminal pH as a result of the rapid ruminal production of organic acids (Hristov et al., 2005), associated with lower secretion of saliva, presumably due to reduced rumination time. In addition, increasing of OWS in the diet displayed acetogenic capability favoring more ruminal C2 as the main SCFA at the expense of C3 production. This finding may explain the higher C2:C3 ratio avoiding ruminal pH depression.

According to Zhao et al. (2013), NFC in corn are mostly consisted of starch while in citrus pulp are mostly neutral detergent soluble fiber and/or sugars source. Therefore, high starch combined with low pectins in WS-fed goats may be due to accumulate ruminal acids reflecting lower ruminal pH. Whilst, NFC in OWS diets tend to produce lower levels of lactic acid in the rumen, thereby might cease their pH-declining effect (Tebbe et al., 2017). However, high concentration of C2 with OWS diet relative to CS may reveal that further conversion of lactic acid into C2 might occur during ensiling period. Likewise, higher CS lactate content may help to explain the increased ruminal C3 proportions presumably due to its conversion to C3 in the rumen (Martin et al., 1994) serving to decrease C2:C3 ratio. Similar results were observed on sheep fed dietary citrus by-products (Piquer et al., 2009), early lactating Holstein cows (Alamouti et al., 2014) and on growing buffalo calves fed diets containing sugar beet pulp (Abo-Zeid et al., 2017).

The quadratic decline in protozoa abundance accompanied by quadratic decrease in branched-SCFA proportions indicated low ruminal CP degradation (Ramos et al., 2009), which in turn explain the reduction in ruminal $\text{NH}_3\text{-N}$ and bacterial nitrogen recycling (El-Zaiat and Abdalla, 2019). However, low $\text{NH}_3\text{-N}$ concentrations may be due to the antimicrobial effect of citrus on some NH_3 -producing microbes (McIntosh et al., 2003). Low rumen protozoa inspire favorable conditions to more C2 at the expense of C3 leading to decrease microbial utilization of peptides and amino acids and microbial CP synthesis (Jouany, 1996). The reduction in ruminal C4 proportion is often caused by the removal of rumen protozoa, as the presence of OS pectin possesses more oxidizable ruminal substrate than other plant polysaccharides (Marounek and Duskova, 1999). Therefore, it is possible to infer that discrepancies in ruminal SCFA patterns are an anticipated evidence which might be explained by differences in chemical compositions and amount of OWS in the diet.

Blood biochemical metabolites are being used to investigate the animal nutritional status, health and metabolic functions. The significant variation in blood albumin concentration could be correlated with dietary CP intake within the normal physiological levels (Kaneko et al., 2008), however has been thought to avoid the protein deficiency sensitivity, as evidenced by improved CP digestibility. The level of BUN basically coincides with the ruminal $\text{NH}_3\text{-N}$ concentrations, reflecting optimal functioning of renal system activity (Kholif et al., 2020).

Changes in blood glucose for OWS diets reflected the suppressing potential of ketone bodies on endogenous glucose production (Sadjadian et al., 2013). In addition, citrus flavonoid components are capable to reduce hyperglycemia prolongation via inhibition of starch digestion, increasing hepatic glycolysis and glycogen concentration and lowering hepatic gluconeogenesis as well (Shen et al., 2012). Relative to goats fed the OWS diet, CS-fed goats elevated blood glucose concentration, which might be due to the corresponding increases in dietary starch and accordingly ruminal C3 proportion (Tebbe et al., 2017). In lactating animals, it is well known that blood glucose and NEFA are positively close to the nutritional and energy status and body tissue mobilization (El-Zaiat et al., 2019 a; 2020 b). As a result, adequate glucose level might decrease the NEFA release presumably because of fat mobilization from adipose tissue for β -oxidation and further glycogenic amino acids as well. It is plausible that the greater proportion of NFC in OWS promoted the hepatic complete β -oxidation of NEFA justified by lower NEFA concentrations. Blood BHBA generally derives mainly from incomplete oxidation of NEFA in liver tissues or C4 conversion in ruminal epithelial cells (Plaizier et al., 2005). The latter finding was confirmed in the current study where the linear decline in plasma BHBA might, in part, be related to the linear reduction of ruminal C4 and blood NEFA concentrations observed as the dietary amounts of OWS increased which is desirable to alleviate the risks of fat mobilization. Goats fed OWS diet relative to those fed CS probably decreased their body tissues lipolysis, it may be one of the reasons for lower NEFA and BHBA concentrations. Nonetheless, high NEFA and BHBA levels observed with CS-fed goats indicates that more body fat reserves were used to cope with their energetic deficit toward milk production in comparison with OWS-fed goats. The current linear decrease of BHBA corresponded to the linear decrease in NEFA indicating that OWS-fed goats diverted greater proportions of dietary nutrients to increase milk yield and body weight recovering as well.

Reduction in plasma cholesterol concentration seems to be associated with the increase in nutrient and ME intakes in order to support the increased requirements of the current stage of lactation (Gross et al., 2015). The linear decrease in serum triglycerides and cholesterol concentrations were similar to those reported by Abo-Zeid et al. (2017) on growing buffalo calves fed increasing levels of sugar beet pulp. Interestingly, pectins are considered as hypocholesterolemia agents, through manipulation of hepatic metabolism (Gladine et al., 2007), caused by enhanced fiber binding capacity or an increased physical form of small intestinal contents (Judd and Truswell, 1982).

In the current study, replacement of WS with 500 and 1000 OWS g/kg dietary DM increased milk yield by 13 to 19%, respectively. Under such conditions of the

current study, higher DMI and ME intake appeared to be the main reasons for increased milk yield by inducing milk lactose synthesis from ruminal C3 (Khattab et al., 2017). It is evident that the higher ME intake and nutrients digestibility indicate better dietary energy has been partitioned into milk production. Thus, changes in nutrients intake and digestibility corresponding with ruminal fermentation patterns likely contributed to increased milk yield (Morsy et al., 2019). High milk fat, FCM and ECM yields could be attributed to the higher NFC and fibers digestibility corresponding to higher C2 production. It can be assumed that higher milk protein yield may likely occur due to increased milk volume by providing α -lactalbumin for lactose synthesis.

High CP supply was positively correlated with higher nitrogen voids via faeces, urine and gases (Tamminga, 1992) and warm season associated with heat stress could be another justification behind the lower nitrogen efficiency (Britt et al., 2003). However, Brun-Laffleur et al. (2010) reported that increasing dietary CP intakes below the animal demands are confirmed to increase milk protein yield and lower milk nitrogen efficiency.

The quadratic decline in MUN concentration indicates that responses in nitrogen efficiency are attributable to the degree of synchrony between available carbohydrate and protein degradation. The quadratic decline in MUN concentration may be explained by lower CP and higher NFC and energy supply for the rumen microbial proliferation of the assessed OWS diets evidenced by quadratic decline in the ruminal $\text{NH}_3\text{-N}$ concentrations.

Additionally, a reduction in MUN concentration might be interpreted as a consequence of the lower BUN diffusion via the secretory tissues of the mammary gland which might have also contributed to low nitrogen efficiency. However, reduction in ruminal $\text{NH}_3\text{-N}$, BUN and MUN concentrations might be due to the differences in diets ingredients and composition. As OWS rates increased in the diet, the similar milk energy content and efficiency might be interpreted as evidence that higher ME intake is paralleled by lower ketone bodies level indicating less body tissues mobilization. Changes in efficiency can presumably be ascribed to differences in partitioning of dietary nutrients for milk and further physiological functions corroborates this argument. Our results showed that feeding OWS seems to be a promising suitable forage for enhancing ruminal fermentation characteristics and nutrients digestibility accompanied with increased milk yields with no adverse effects on milk constituents or goat health.

In conclusion, our results indicate that replacement of WS with OWS enhanced dietary feed intake and apparent digestibility of nutrients and created favorable ruminal fermentation patterns. Replacement of WS with OWS up to 1000 g/kg dietary DM decreased milk nitrogen efficiency, while improving milk yield with no adverse effects on metabolic disorders in goat health particularly under high temperature and dry climate conditions.

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