Translational Animal Science, 2022, **6**, 1–7
https://doi.org/10.1093/tas/txac100
Advance access publication 23 July 2022
Ruminant Nutrition

Canola as a potential forage

Amir Reza Safaei,[†] Yousef Rouzbehan,[†,1] and Majid Aghaalikhani[‡]

[†]Department of Animal Science, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran
[‡]Agronomy Department, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran
[1]Corresponding author: rozbeh_y@modares.ac.ir

ABSTRACT

The nutritive quality of four cultivars of canola forage (*Brassica napus* L.), Orient, Midas, Global, and Hybrid (Cobra × Regent), which were harvested in the early-spring period, were compared with green-winter barley (GWB) in terms of their yields, chemical composition, in vitro gas production variables, in situ crude protein (CP) degradation, and predicted dry matter intake (PDMI). Data were statistically analyzed using a completely randomized design with four replications and three samples per replication. The study was based on a randomized complete block design, and data were analyzed using SAS, general linear model procedure for normal distribution. The canola dry matter (DM) yield was highest in Orient cultivar and lowest in Midas ($P < 0.05$). Organic matter (OM), CP, neutral detergent fiber (NDF), and lignin(sa) concentration of the four cultivars ranged from 862 to 865, 218 to 247, 295 to 340, and 35 to 53 g/kg DM, respectively. The estimated OM disappearance (OMD), effective degradability of CP, effective rumen degradable protein (ERDP), digestible undegradable protein, and metabolizable protein (MP) of the forages were from 636 to 671 g/kg, 878 to 910, 172 to 193, 1.9 to 3.4, and 112 to 126 g/kg DM, respectively. Compared to Global and Hybrid cultivars, Orient and Midas contained higher CP, OMD, ERDP, MP concentration, and PDMI, but lower NDF, acid detergent fiber (ADF), and lignin(sa) concentrations ($P < 0.05$). The level of glucosinolates in the forages ranged from 0.38 to 1.51 µmol/g DM, which is below the detrimental level for ruminants. Compared to winter canola cultivars, GWB had higher DM yield ($P < 0.003$), NDF, lignin(sa), PDMI ($P < 0.01$), and digestible undegradable protein ($P < 0.04$), but had lower OMD ($P < 0.03$), ERDP ($P = 0.01$), and MP ($P < 0.009$). Based on the obtained results, the variation in the nutritive quality among the canola cultivars is relatively small, and the Orient cultivar, which is most comparable to GWB, was judged to be nutritionally the best among the cultivars.

Key words: canola forage, nutritional value, predicted dry matter intake, sheep

INTRODUCTION

Forages are the major part of diet for ruminants and provide energy, protein, vitamins, and minerals (NASEM, 2016). In many parts of the world, winter is a limiting period for the growing of fresh herbage for livestock. Therefore, there is a vital need for fresh forage crops during the period of winter to spring to fill a feed gap on farms, particularly in hot zones where rain is limited. Several canola species *Brassica napus* produce high amount of vegetative biomass (3.0–5.0 tones dry matter [DM] per ha; Brooker, 2015), which are characterized by their high concentrations of crude protein (around 250 g/kg DM, CP), high concentrations of metabolizable energy (ME; around 12 MJ/kg DM), and low concentrations of neutral detergent fiber and acid detergent fiber (around 187 g/kg DM, neutral detergent fiber [NDF]; 14.4 g/kg DM, acid detergent fiber [ADF]) compared to more common forage crops for ruminant feed such as annual ryegrass (Dillard et al., 2020), with high higher palatability (Lemus and White, 2014). Also, North Dakota State University reports, indicate that canola forage is similar to alfalfa in nutrient concentration (Lardy and Anderson, 2009). Brassicas grow well at low temperature (0 to 5 °C) and are tolerant to frost (–10 °C), thereby extending the grazing season in the fall (McCartney et al., 2009). The extension of the grazing season can reduce winter feeding costs and increase the profitability of the operation (Penrose et al., 1996). Lauriault et al. (2009) reported that brassicas often have forage DM yields equal to or higher than winter cereals (Lauriault et al., 2009). Moreover, ruminants consuming new varieties of canola forage had no problem with goiter due to the low glucosinolates (Gls) concentration (Lardy and Anderson, 2009).

Winter cereals such as green winter barley (GWB) are commonly grown as winter fodder source (i.e., grown and harvested at the same time of the winter canola forage), so GWB was used as the control in this experiment. Hence, the nutritive quality of four cultivars of canola forage (*B. napus* L.), Orient, Midas, Global, and Hybrid (Cobra × Regent), which were harvested in the early-spring period, were compared with GWB in terms of their yields, chemical composition, in vitro gas production (IVGP) variables, in situ CP degradation, and predicted dry matter intake (PDMI).

MATERIALS AND METHODS

The Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) was followed for housing, feeding, transport, proper and humane care and use of animals, veterinary care, occupational health and safety, program management and procedures. The Committee of Animal Science of Tarbiat Modares University (Iran) approved the experimental protocols.

Received April 14, 2022 Accepted July 21, 2022.

Forages Preparation and Sampling Method

Samples consisted of four cultivars of *B. napus*, being Orient, Midas, Global, and Hybrid (Cobra × Regent) and GWB. The cultivars were planted in autumn, in a field (covers 1,000 m^2) located at Tarbiat Modares University (Tehran, Iran). The area is located at an altitude of 1,215 m above sea level. The mean annual rainfall and temperature were 305.8 mm and 15 °C, respectively. Weather data during the growing season and ensiling period are presented in Table 1. The soil at the experimental field is loam (185 g/kg clay, 400 g/kg silt, and 415 g/kg sand) Calcic Xerosol in the Food and Agriculture Organization of the United Nations taxonomy. Since canola is considered to be a nitrogen (N) demanding crop (Barraclough, 1989), N fertilizer at the rates of 150, 200, 250, or 300 kg N/ha was applied throughout the growing season. Because the optimal biomass production and leaf-to-stem ratio was noted with cultivars that received 250 kg N/ha, the canola forages grown under this fertilizer rate were assessed in this experiment. The canola cultivars were harvested in early spring at the pod-setting stage of maturity (i.e., at 182 days after planting) because, after this stage, leaf abscission is observed in all canola forages. In this study, GWB (*Hordeum vulgare* L.) was used as control forage because it is the common forage planted in autumn, and used in the period of early spring in Iran. There were four replicates and three samples for each cultivar (four canola cultivars and GWB) (i.e., three locations/replication). All the samples were harvested by knife and air-dried in the shade for three days. Later each replicate was analyzed in triplicate (i.e., four replications and three samples per replication).

Chemical Analyses

Samples of forages were ground to pass through a 1 mm sieve and analyzed for DM (method 930.15), ash (method 924.05), N (method 984.13), ether extract (method 920.39), NDF and ADF (method 973.18) according to procedures of AOAC (1996). Lignin(sa) was determined by solubilization of cellulose with sulfuric acid (Robertson and Van Soest, 1981). Acid detergent insoluble N (ADIN) was determined by estimating N concentration, using the Kjeldahl methods, on the ADF residue. Calcium and P were measured by atomic absorption (method 968.08), and a ultraviolet-visible spectrophotometer (method 965.17), respectively (AOAC, 1996). The Mg and Cu concentration of the forages were determined using inductively coupled plasma optical emission (G.B.C. Scientific Equipment, Victoria, Australia) according to procedures outlined by Christian and Feldman (1970), and Anderson (1996). High-performance liquid chromatography (HPLC) (Hitachi Company, Japan) by elution gradient was used for total Gls determination ((ISO Norm, 1992). The desulfoglucosinolates were separated using a type C18 column (CAPCELL PAK C18, Type: C18 AG 120 A, Size 4.6 mm × 150 mm, 5 µm) with a flow rate of 0.5 mL/min at 30 °C. Elution of desulfoglucosinolates from HPLC was performed by a gradient system of water (A) and acetonitrile/water (25:75, v/v, B).

IVGP Variables

A probe used for ruminal fluid collection from three rumen-fistulated sheep prior to their morning feeding. The animals had been offered twice daily (0700 and 1900 h) a diet containing 650 g/kg (on a DM basis) forage (300 g/kg alfalfa hay and 350 g/kg mix of the five treatments, GWB, and four canola cultivars) plus 350 g/kg (on a DM basis) concentrate mixture (contained 500 g/kg barley grain, 250 g/kg wheat bran, 200 g/kg soybean meal, and 10 g/kg minerals and vitamins premix [being 185 g Ca, 104 g Mg, 2.25 g Co, 44.0 g Mn, 36.4 g Zn, 1.3 g I, 10,000,000 IU retinol, 2,000,000 IU vitamin D_3, and 40,000 IU β-tocopherol per kg]). Ruminal fluid was pooled (v/v), flushed with CO_2, strained through two layers of cheesecloth, and mixed (1:2, v/v) with an anaerobic mineral buffer solution (Menke and Steingass, 1988). The mixture of the buffer-ruminal fluid was kept stirred, under CO_2 flushing at 39 °C, using a magnetic stirrer fitted on a hot plate. The in vitro OM disappearance (OMD) was assessed in three runs by incubating 200 mg (DM) of feed samples. Feed samples were incubated in 100 mL glass syringes based on the Menke and Steingass (1988) procedure. Petroleum jelly was applied to the piston to ease movement and prevent escape of gas. Syringes were pre-warmed (39 °C) for 1 h before addition of 30 ± 0.5 mL of buffer-ruminal mixture into each syringe, and incubated in a water bath maintained at 39 ± 0.1 °C. Syringes were gently shaken every hour during the first 8 h of incubation. Analyses were completed with readings of IVGP recorded after incubation for 2, 4, 6, 8, 12, 16, 24, 48, 72, and 96 h. Differences in the composition and activity of the ruminal fluid were standardized by two measurements: 1) incubation of buffered ruminal fluid without substrate (gas produced from blank test, Gb0) and 2) incubation of a standard hay meal (200 mg DM; Hohenheim University hay standard) which should give a mean IVGP of 44.16 mL within 24 h (gas produced from standard hay, GbH). From these measurements it was possible to correct for each series

Table 1. Monthly temperature (°C) and precipitation (mm) during the growing season

Month	Absolute temperature		Average temperature			Precipitation
	Minimum	Maximum	Minimum	Maximum	Mean	
September	15.0	37.8	18.9	32.5	25.7	0.3
October	8.6	33.2	14.7	27.4	21.1	0.7
November	5.0	24.6	9.9	19.2	15	50.4
December	–2.0	14.2	3.3	10.9	7.1	28.1
January	–5.0	14.4	-1.2	7.9	3.4	8.4
February	–1.0	17.6	4.0	13.6	8.8	40.4
March	–4.0	25.0	5.2	15.6	10.4	25.4

of determinations using the correction factor 44.16/(GbH – Gb0).

For a more precise estimation of IVGP throughout the duration of in vitro fermentation, a nonlinear equation was used to analyze the kinetic data (France et al., 2000). The concentrations of OMD and ME were calculated using equations of Menke and Steingass (1988) as:

$$\text{OMD} = 14.88 + 0.889 \times \text{GP} + 0.45 \times \text{CP} + 0.0651 \times \text{XA}$$

$$\text{ME} = 2.20 + 0.136 \times \text{GP} + 0.057 \times \text{CP} + 0.0029 \times \text{CP}^2$$

where OMD was the estimated OMD (g/100 g OM), GP the net gas production (mL/200 mg DM), CP the crude protein (g/100g DM), XA the ash (g/100g DM), and ME was the ME (MJ/kg DM).

In Situ CP Degradability

Three rumen-fistulated sheep (live weight 46 ± 2.5 kg) were used to determine the rate of degradability of CP according to the standard method described by AFRC (1992). The animals were fed 1.18 kg/d of a ration consisting alfalfa hay, mix of four canola cultivars forage, and GWB (on fresh weight basis) with a forage to concentrate (wheat bran and barley grain; 50:50) ratio of 60:40 (DM basis), which was calculated to provide energy 5–10% above maintenance level (AFRC, 1993). Sheep were adapted to the diet for 14 days. In situ bags were made from a Dacron material (21 × 10 cm) with a pore size of 45 µm (Bucksburn, Aberdeen, AB21 9SB, UK) (AFRC, 1992). All samples of the five treatments (four canola forages and GWB) were oven-dried at 60 °C for 48, and hand milled through a 4.0 mm sieve in a Cyclotec TM 1093 Sample Mill (Foss Companies, Hillerød, Denmark). Then, 5 g of each sample was put in the in situ bags, and all bags were placed at the same time in the rumen and incubated for 3, 6, 12, 24, 48, and 72 h. In each animal, one bag was used for each time interval. Bags were attached on semi-rigid stalks to ensure immediate insertion within the liquid of the ruminal concentrations while allowing free movement. After withdrawing the bags from the rumen, they were washed in a washing machine (Hoover OPSH612, London, UK) for 1 h using cold water and dried for 48 h at 50 °C. The degradability value at time 0 was obtained by washing two bags per replicate in a washing machine for 1 h using cold water. The residue from each bag was analyzed for CP. Degradability at each incubation time was calculated by taking the values obtained from the three bags (i.e., $n = 3$). The ruminal degradability (Y) of CP at time (t) was obtained from an exponential curve as $Y = a + b\,(1 - e^{(-ct)})$. This was fitted to the experimental data by iterative regression analysis (Ørskov and McDonald, 1979). In this equation, e is the base of the natural logarithm, the constant "a" represents the soluble and very rapidly degradable component, and "b" represents the insoluble but potentially degradable component which degrades at a constant fractional rate (c) per unit time (t). The effective degradability of protein (ED) in each cultivar was then estimated (Ørskov and McDonald, 1979) as "$ED = (a + bc)/(c + k)$" where ED is the effective degradability (g/kg DM), constant "a" the soluble and very rapidly degradable component, "b" the insoluble but potentially degradable component which degrades at a constant fractional rate (c) per unit time, and k is the fractional outflow rate of small particles from the rumen. An assumed value for k was 0.05 fraction/h.

Short-term Intake Rate and PDMI

There is a positive correlation between short-term intake rate (STIR) and DM voluntary intake (Ingentron et al., 2016), therefore, this method was used for the estimation of dry matter intake in this trial. All four canola cultivars and GWB were screened using the STIR technique to assess the effect of each cultivar on potential DM intake (DMI) (Romney and Gill, 1998). Five sheep (live weight 50 ± 1.5 kg) were used in a 5 × 5 change-over design. The animals were allocated randomly and were individually housed in metabolism crates with free access to mineral block (containing 100 g Ca, 35 g P, 200 g Na, 25 g Mg, 4 g K, 2 g Mn, 1.2 g Fe, 3 g Zn, 450 mg Cu, 20 mg Co, 25 mg Se, and 70 mg I per kg) and water. They were fed a basal diet of a mix of the five treatments (four cultivars and GWB) and barley grain (60:40 DM basis), and adapted to this diet for 14 d before commencing the estimation of STIR of the cultivars and GWB. Following the adaptation period, on the STIR estimation day animals were offered, 25% of their normal daily ration at 0900, to avoid unnecessary stress by denying them feed at a time when they were accustomed to receiving it. After 1 h, all feed was removed and animals were fasted for four hours. After fasting, 500 g of each of chopped experimental forages was offered to each animal for a period of 4.5 min. Time spent actively eating, defined as mastication of feed, was determined accurately using a stopwatch. Four observers were used for the STIR recording. At the end of the 4.5 minutes' period, all spillage was carefully collected. The above procedure was repeated for four consecutive days to estimate the STIR of the cultivars. The STIR value for each cultivar was calculated using the equation reported by Rymer (2006):

$$\text{STIR (g DM/min/kg metabolic body size)} = (\text{W1-W2}) / (\text{T} \times \text{M}^{0.75})$$

where STIR value is short-term intake rate (g DM/min/kg metabolic body size), W_1 is the weight of feed offered to the animal (500 g), W_2 the weight of feed remaining (g), DM the dry matter percentage of the feed, T the time spent actively eating (min), and M is the live weight (kg) of the animal.

Using the following equation (Rymer, 2006), the PDMI of each feed was then calculated:

$$\text{PDMI}\left(\text{g DM/kg liveweight}^{0.75}\right) = (82.9\ \text{STIR}) + 17.9$$

This was then converted to PDMI (g DM/head/day) by multiplying PDMI by $M^{0.75}$. The effect of treatment on estimates of STIR and PDMI (g/head/day) was estimated using analysis of variance, after taking account of the effect of animal and day.

Statistical Analysis

The obtained data were subjected to analysis of variance using the GLM procedure of SAS (2001). Data on chemical composition, and in situ CP degradability were analyzed using a completely randomized design with four replications and three samples per replication based on the statistical model $Y_{ijk} = \mu + S_i + e_{ij} + \delta_{ijk}$ where Y_{ijk} is the general observations, μ the general mean, S_i the ith effect of forage cultivar on the

observed parameters, e_{ij} the experimental error term, and δ_{ijk} the sampling error term.

Data on IVGP were analyzed using a completely randomized design with four replications, three samples per replication, and three runs based on the above statistical model with an additional run error term.

Data obtained from STIR and PDMI were analyzed as a 5 × 5 change over design based on the statistical model $Y_{ijk} = \mu + T_i + P_j + A_k + e_{ijk}$ where Y_{ij} is the observation, μ the general mean, T_i the effect of canola cultivar, P_j the day, A_k the animal, and e_{ijk} the standard error term. Multiple comparisons among means were performed with the Duncan's Multiple Range Test.

RESULTS

Yield and Chemical Composition

Table 2 shown that the canola DM yield was highest in Orient and lowest in Midas ($P = 0.05$). There were no differences among the DM concentration of the four canola cultivars. Compared to Global and Hybrid cultivars, Orient and Midas contained higher CP ($P = 0.02$), and lower NDF, ADF, and lignin(sa) concentrations ($P = 0.05$). The canola forages contained 0.38 to 1.51 μmol Gls/g DM. The concentration of Gls was lowest ($P = 0.05$) in the Hybrid cultivar. There were no significant differences among the cultivars in ash or mineral concentration.

The fresh yields of canola cultivars were significantly greater ($P = 0.008$) than GWB, but DM yield of GWB was higher ($P = 0.003$) than those in canola cultivars. Canola cultivars contained higher ($P = 0.021$) CP and Ca, but lower DM ($P = 0.041$), NDF ($P = 0.01$), and lignin ($P = 0.012$).

IVGP and Fermentation Variables

A potential gas production (A_p), OMD, and ME values of Orient and Midas were greater than those in Global and Hybrid (Table 3). Compared to winter canola cultivars, GWB had higher A_p ($P = 0.019$), but lower ($P = 0.034$) of OMD.

In Situ CP Disappearance and Estimated Variables

The soluble fraction (A) for all the canola cultivars was higher ($P = 0.021$) than GWB (Table 3), whereas the fermentable CP (B fraction) concentration and the rates of degradation (C) had the opposite trend of the soluble fraction concentration ($P = 0.009$; $P = 0.025$, respectively). Among the canola cultivars, effective rumen degradable protein (ERDP) and metabolizable protein (MP) concentrations of Orient and Midas were significantly higher than those in Global and Hybrid. Compared to canola cultivars, GWB had lower ERDP ($P = 0.01$), and MP ($P = 0.009$).

STIR and PDMI

Table 3 shown that STIR for Orient and Midas were significantly ($P = 0.01$) greater than those in Global and Hybrid.

Table 2. Yields of the fresh forages and dry matter (kg/ha), leaf: stem ratio, and chemical composition (g/kg DM or as stated) of four cultivars of canola forages and green-winter barley (GWB) ($n = 4$)

	GWB	Canola cultivars				SEM	*P*
		Orient	Midas	Global	Hybrid		
Fresh yield, kg/ha	48,600^{d}	62,873^{b}	57,780^{c}	57,895^{c}	74,423^{a}	440.9	0.009
Dry matter yield, kg/ha	10,303^{a}	8,613^{b}	7,164^{d}	7,758^{c}	8,187^{b}	74.8	0.008
Leaf:stem ratio, DM basis	-	0.25^{c}	0.26^{c}	0.31^{b}	0.38^{a}	0.007	0.010
Chemical composition							
DM, g/kg fresh weight	212^{a}	137 ^{b}	124 ^{b}	134 ^{b}	110 ^{b}	2.3	0.041
OM	877	865	863	862	862	5.0	0.252
CP	90.0^{c}	247^{a}	243^{a}	228^{b}	218^{b}	5.0	0.021
EE	-	18	19	18	16	0.9	0.351
NDF	567^{a}	295^{c}	313^{c}	338^{b}	340^{b}	2.8	0.011
ADF	-	240^{b}	254^{b}	272^{a}	276^{a}	2.0	0.024
ADIN	21.2	20.0	20.0	20.0	20.0	3.0	0.800
Lignin, sa	76^{a}	35^{d}	42^{c}	52^{b}	53^{b}	0.3	0.012
Glucosinolates, μmol/g DM	-	1.42^{a}	1.51^{a}	1.46^{a}	0.38^{b}	0.03	0.019
Ash	123	135	137	138	138	5.75	0.183
Ca	2.95^{b}	11.2^{a}	12.4^{a}	12.0^{a}	11.3^{a}	0.23	0.049
P	2.63	2.0	2.3	2.2	2.2	0.30	0.289
Ca:P	1.1^{b}	5.6^{a}	5.4^{a}	5.5^{a}	5.1^{a}	0.15	0.046
K	-	48.4	45.0	53.6	46.0	2.51	0.073
Na	-	4.5	4.7	5.8	5.6	0.35	0.089
Mg	-	2.2	2.4	2.4	2.2	0.10	0.152
Cu, ppm	-	4.9	6.0	5.8	5.6	0.26	0.082

GWB, green-winter barley; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; Lignin(sa), lignin measured by solubilization of cellulose with sulphuric acid; NDF, neutral detergent fiber; ADF, acid detergent fiber; ADIN, acid detergent insoluble nitrogen; ppm, part per million. Within the canola cultivars, means in the same row with different superscripts differ ($P < 0.05$).

Table 3. In vitro gas production variables, estimated parameters, in situ CP disappearance, short term intake rate (STIR, g DM/min/kg metabolic body size), and predicted dry matter intake (PDMI, g DM/kg liveweight$^{0.75}$) of four cultivars of canola forages and green-winter barley (GWB)

	GWB	Canola cultivars				SEM	*P*
		Orient	Midas	Global	Hybrid		
Gas production parameters							
A_p	56.0 [a]	39.9[b]	39.2[b]	37.9[c]	37.6[c]	1.35	0.019
μ	0.052	0.071	0.101	0.101	0.098	0.011	0.120
L	0.28	0.26	0.31	0.30	0.30	0.098	0.099
OMD[1]	600[b]	671[a]	662[a]	646[b]	636[b]	3.6	0.034
ME[2]	9.1[c]	10.3[a]	10.1[a]	9.6[b]	9.4[b]	0.21	0.009
In situ disappearance of CP	600						
A[3]	535[c]	771[a]	756[a]	743[a]	719[b]	9.2	0.021
B	359[a]	195[d]	213[c]	222[c]	253[b]	2.5	0.009
C (%/h)	0.30[a]	0.116 [b]	0.126 [b]	0.126 [b]	0.118[b]	0.05	0.025
ED	765[b]	908[a]	910[a]	899[a]	878[a]	5.1	0.049
ERDP	112[c]	193[a]	192[a]	178[b]	172[b]	0.4	0.010
DUP	7.1[a]	2.7[b]	2.2[b]	3.1[b]	2.3[b]	0.59	0.040
MP	76.2[c]	126[a]	125[a]	117[b]	112[b]	3.1	0.009
STIR	1.1[a]	0.82[b]	0.73[b]	0.60[c]	0.58[c]	0.05	0.010
PDMI (g DM/kg liveweight$^{0.75}$)	109[a]	85.9[b]	78.4[b]	67.6[c]	60.0[c]	7.20	0.001
PDMI (g/head/day)	2092[a]	1614[b]	1474[b]	1271[c]	1128[d]	69.90	0.010

[1]OMD (organic matter disappearance) calculated as: OMD (g/kg) = 14.88 + 0.8893 GP + 0.0448 CP + 0.0651 ash (Menke et al., 1979).
[2]ME (metabolizable energy) calculated as: ME (MJ/kg DM) = 2.20 + 0.136 × GP + 0.057 × CP + 0.0029 × CP^2) (Menke et al., 1979).
[3]A, soluble and very rapidly degradable fraction (g/kg DM); B, insoluble but potentially fermentable CP fraction (g/kg DM); C, fractional degradation rate of B (/h); ED, the effective degradability of CP calculated for an outflow rate of 0.05/h (g/kg CP); ERDP, effective rumen degradable protein (g/kg DM); DUP, digestible undegradable protein (g/kg DM); MP, metabolisable protein (g/kg DM); STIR, short-term intake rate (g consumed feed/min/kg metabolic body weight); PDMI, predicted dry matter intake (g DM/head/day).
Means in the same row with different superscripts differ ($P < 0.05$).
Ap, a potential gas production (mL/200 mg DM); μ, fraction rate of gas production (/h); *L*, lag time (h); GP, gas production.

Compared to winter canola cultivars, GWB had higher STIR ($P = 0.001$) and PDMI ($P = 0.01$).

DISCUSSION

Yield and Chemical Composition

The lower DM yield of the canola cultivars in comparison to GWB was due to the lower DM in the former (Rao and Horn, 1986). Moreover, DM accumulation rate in GWB is higher compared with the canola (Penning de Vries and Van Laar, 1982). The CP concentration of our canola forages was similar to findings obtained by Kirkegaard et al. (2008) who found that canola forage (in winter) had high CP concentration (approximately 200 g/kg DM). However, Fouche (2001) reported lower CP concentration value (164 g/kg DM) for canola forage. Such protein concentration is enough to meet nitrogen requirements to support acceptable performance for ruminants (NASEM, 2001). The NDF, lignin(sa), and ADIN concentrations of the canola were lower than those in alfalfa hay (416, 76.0, and 24.0 g/kg DM, respectively; NASEM, 2016). The ADF fraction in canola varieties was a large proportion of the NDF, which indicate high concentration of cellulose and low level of hemicellulose. Moreover, these forages contained low levels of Gls (0.38 to 1.51 μmol/g DM). Bush et al. (1978) reported that growing steers appeared to tolerate dietary Gls concentration of 10 to 15 μmol/g DM diet, without detrimental effect on growth and feed conversion. Also, Ingalls and Sharma (1975) noted that a dietary Gls level of 11 μmol/g DM should be safe for dairy cows. Furthermore, Laarveld et al. (1981) noted the effect of dietary Gls level less than 10 μmol/g DM was negligible on intake and digestibility in young lambs.

Mineral concentration in forage often mirrors the concentration of minerals in the soil (Hale and Olson, 2001). Pasture fertilization schemes and stage of maturity of the forage affect mineral concentration and mineral bioavailability (Spears, 1994; Topps, 1992). Information about minerals in canola forages species, particularly about microelements is limited. The Ca:P ratio in our study was ranged from 5.1:1 to 5.6:1, which means that these forages are unlikely to be a well-balanced source of minerals (i.e., well-balanced Ca:P ratio is 2:1; NASEM, 2016). However, increasing Ca:P ratio in diets of sheep and goats is believed to assist in the prevention of phosphatic uroliths NASEM Tables (2016). The potassium (K) concentrations of canola cultivars (ranged from 45.0 to 53.6 g/kg DM) were greater than 30 g/kg DM, that recommended by NASEM Tables (2016) as the allowable level for ruminant animals. Feeding K in excess of that needed to meet requirements can put the ruminants at risk of developing acid-base imbalance, cardiac arrest (Suttle, 2010), metabolic and physiological challenges, and can increase excretion of K into the environment (NASEM, 2016). Therefore, when feeding these forages, one should be concerned about K concentrations (i.e., it should not be offered as the solely forage in the ration of ruminants). Also, the Na concentration for the cultivars (ranged from 4.5 to 5.8 g/kg DM) was lower than the bearable dietary concentration (16 g/kg DM) and greater than the minimum level (1.6 g/kg DM) for lactating cattle (NASEM, 2001). Magnesium is an activator

of many metabolic enzymes, and dairy cattle need about 2 g Mg/kg dietary DM (NASEM, 2001). The Mg concentrations of the canola cultivars (2.2 to 2.4 g/kg DM) were less than a maximum tolerable level (4.0 g/kg DM) in dairy cattle as recommended by NASEM (2001). The canola forages have fairly similar Mg concentration to that in alfalfa hay (2.8 g/kg DM; NASEM, 2016). The Cu levels in our study (ranged from 4.9 to 6.0 mg/kg DM) were lower than the toxic level (i.e., 115 mg Cu/kg of ration DM) in beef cattle (NASEM, 2016), and Cu level of 11 mg/kg diet considered adequate for the lactating cattle (NASEM, 2016). The canola forages contained lower Cu concentration than alfalfa hay (i.e., 7.3 mg/kg DM), and NASEM (2016) recommended concentration of Cu (i.e., 10.0 mg Cu/kg DM). Overall, the mineral concentrations in the canola cultivars do not exceed the normal requirements of ruminants suggesting that it could be used to feed ruminants with no adverse effects. However, the dietary requirement for minerals depends on animal factors, processing, the bioavailability, and interaction among minerals which differs among feedstuffs and diets (NASEM, 2016). Compared with CS, AMS had higher Ca and lower phosphate concentrations. These Ca levels were lower than in other studies (Rezaei et al., 2014).

IVGP and Fermentation Variables

Greater IVGP characteristics of Orient and Midas compared to Global and Hybrid could be due to the lower lignin(sa) concentration, which negatively affected the in vitro fermentation (Van Soest, 1994). The estimated digestibility coefficients are similar to those reported for brassica forage (Dove and Milne, 2006). However, the in vivo OM digestibility of high-quality canola forage reported by Kirkegaard et al. (2008) was greater (i.e., above 800 g/kg) than those obtained in the current study. Compared with GWB, canola cultivars had higher in vitro OM, which probably due to higher protein and less lignin in the canola cultivars (Van Soest, 1994).

In Situ CP Disappearance and Estimated Variables

The very high soluble CP fraction (A) for all the canola forages could be a result of adding high level of N fertilizer during the autumn season which has less photosynthetic capacity to assimilate N into true protein (Leite et al., 2021). Nitrogen assimilation is a true photosynthetic process, in which light energy is used to power the reductive incorporation of a simple inorganic molecule into organic compounds (Leite et al., 2021). In other words, the photosynthetic capacity for N assimilation into true protein is less during the autumn season than that in spring or summer. Feeding forages with high soluble protein tends to cause ruminal bloat and ammonia toxicity (Van Soest, 1994) as well as increasing the risk of N loss to the environment (Leite et al., 2021). Therefore, high soluble CP concentration should be balanced with fiber and energy, which may lead to better synchrony of energy and protein, to optimize ruminal microbial function and nutrient use by the animal (Cassida et al., 1994), and to prevent bloating (Van Soest, 1994). In all the canola cultivars, the high ED of protein concentration was similar to those obtained by Dove and Milne (2006) who suggest that these forages could be used as CP supplements to forage of low nutritive value. The greater ERDP and MP concentrations of Orient and Midas compared to those in Global and Hybrid were parallel to greater CP concentrations.

STIR and PDMI

There is a positive correlation between STIR and DM voluntary intake (Ingentron et al., 2016). Rymer et al. (2002), also, illustrated that STIR could be used as a predictor of DMI for forages. They noted a high correlation between STIR values and the predicted DMI *in vivo* for different feeds and mixtures offered to goats. In the present study, the greater values of STIR and PDMI for Orient and Midas than those of Global and Hybrid were probably due to the lower lignin(sa) concentration and higher OMD in the Orient and Midas cultivars in comparison to the Global and Hybrid.

CONCLUSION

With respect to high CP concentration, OMD, and PDMI, the tested canola forages have a potential as ruminant feedstuff and are comparable to traditional forages, such as alfalfa. However, in vivo trials are needed to assess the potential of these canola offered together with other forages, with high ruminal available energy, to balance the high soluble protein degradability in these forages. In addition, environment may affect the nutritive quality and thus in the future studies, this effect can be surveyed.

Acknowledgments

The authors wish to thank Mr. Gary Easton for his English language corrections, and Dr. Ali Mokhtassi-Bidgoli, Dr. J. Rezaei, Mr. A. Dadashi (Tarbiat Modares University) for editing, statistical amendment, and farm work of the manuscript.

Conflict of Interest Statement

The authors declare that there were no conflicts of interest.

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