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Performances and nutritional values of a new hooded barley (cv. Mochona) and a high yield triticale (cv. Titania) as hay or silage for sheep under Mediterranean conditions

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A B S T R A C T

The hooded barley phenotype produces an extra sterile flower in spikelets instead of awns. Hence, it might improve the nutritive value of the whole plant. The aim of this work was to evaluate a new variety of hooded barley (cv. Mochona) and a high yield triticale (cv. Titania) harvested and processed as hay and silage during 2 consecutive years for sheep. Digestibility was determined using 32 ewes which were distributed in 2 balanced groups by treatment, and fed with hay and silage sequentially. Results showed differences in the chemical composition of hay and silage according to harvesting year, but no differences were found on voluntary intake by year, species, or their interaction. Both forages showed high sheep fill values (**sFV**) either as hay or as silage (2.65 ± 0.030 and 3.09 ± 0.042 sFV/kg DM, on average, respectively). Impact on apparent nutrient digestibility coefficients varied according to preservation method, the digestibility of hays being mainly affected by the harvesting year, and that of silages by species. Digestible undegradable protein values were greater in hooded barley than in triticale for silages. In conclusion, marked compositional differences between years, but slight differences between species, were observed. Consequently, intake was similar, although triticale revealed slightly greater nutritive values than hooded barley. The obtained values for hooded barley as forage were greater than those reported in the literature for common fodder barley.

1. Introduction

Cereals are the most important source of carbohydrates for humans and livestock, and are recognized as a major source of food energy (Pascari et al., 2019). Although cereals are usually harvested for grain, they can also be used for forage (i.e., pasture, hay, or

Abbreviations: ADF, acid detergent fiber; ADL, acid detergent lignin; BCS, body condition score; BW, body weight; CF, crude fiber; CP, crude protein; CPd, crude protein digestibility; DE, digestible energy; DM, dry matter; DMd, dry matter digestibility; DMI, dry matter intake; GE, gross energy; ME, metabolizable energy; NDF, neutral detergent fiber; NDFd, neutral detergent fiber digestibility; NDFI, neutral detergent fiber intake; NE_L, net energy lactation; OM, organic matter; OMd, organic matter digestibility; OMI, organic matter intake; PDI, protein digestible in the intestine; PDIA, rumen undegradable dietary protein; RPB, rumen protein balance; UFL, feed units for lactation.

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silage) or harvested for double purpose (i.e., forage followed by grain).

Barley (*Hordeum vulgare* L.) has several advantages over other cereals, e.g. vigorous, tolerant to drought and salinity, resistant to diseases and plagues, and low production costs (Francia et al., 2006; Nikkhah, 2013). Barley is cultivated in more than 100 countries, being the fourth cereal in surface and production in the world (FAO, 2022). Furthermore, barley is the typical cereal of Mediterranean arid lands, as Spain, where it occupies more than 2.5×10^6 ha and being the first cereal commodity (MAPA, 2021). Ramírez-García et al. (2015) showed a low variability between different barley cultivars, when compared as cover crop under Mediterranean semiarid conditions, by using a multicriteria decision analysis.

As a consequence of its genetic diversity, there are barley cultivars able to be sown in winter or in spring, having spikes with different row numbers (two to six rows), with hulled or hulless grains, as well as with or without awns, among others (Baik and Ullrich, 2008; Martínez-Moreno et al., 2017). Awns are long distal appendages characteristic of most grass species (Poaceae), and a plant protection strategy against grazing (Wallsten, 2008; Würschum et al., 2020). The hooded barley mutant phenotype leads to the overexpression of the *K* gene, which produces the development of an extra sterile flower in the spikelet, instead of the characteristic awn, resulting in cultivars of seemingly imberbe spikes (Badr et al., 2000; Roig et al., 2004). Awns can produce injuries in the mouth and digestive mucosa of cattle, as reported by Karren et al. (1994). Consequently, hooded cultivars may be safer and more palatable when barley is used directly for feeding herbivores or preserved as hay or silage.

Performances and nutritive value of hooded barley in ruminants has been studied in Cyprus (Hadjipanayiotou et al., 1981), the USA (Todd et al., 2003; Brummer and Pearson, 2004), South Korea (Park et al., 2008) and México (Romero-Bernal et al., 2013). Although chemical composition was indicative of greater nutritive values of hooded than those of conventional fodder barleys (6 rows), no differences were found on dry matter and organic matter digestibility in sheep (Hadjipanayiotou et al., 1981) and beef cattle (Todd et al., 2003). Nevertheless, these reports showed confounded effects of the varieties used and agricultural conditions, mainly the effect of the climatic conditions of the year. In Spain, with the exception of our preliminary work with only one harvesting year (Ajenjo--Puigderrajols, 2018), no further studies have assessed the nutritive value of hooded barley as forage for ruminants. Moreover, Bikel et al. (2020) showed greater nutritive value of barley, as hay or silage, when compared to wheat in dairy cows. No similar studies have been done with hooded barley in sheep.

On the other hand, hybrid triticale (×*Triticosecale* Whim) has demonstrated high yields when used for grain or for forage (i.e., silage, hay, or directly grazed) (Peña, 2004; Ramírez-García et al., 2015). In addition, triticale combines biotic and abiotic stress tolerances, making it suitable for producing on marginal areas (i.e., arid, saline, or soils with extreme pH and heavy metal toxicity) (François, 2015). Regarding the multicriteria comparative study of different cover crop species in Spain, in which barley was included, Ramírez-García et al. (2015) reported that triticales were high yielders, being Titania the cultivar that perform the best as cover crop and fodder. Despite this, triticale production is still today low in Spain (MAPA, 2021).

On our knowledge, no nutritional values of hooded barley and very few from triticale, are available as forage in the reference nutritive tables for ruminants (NRC, 2007, 2021; INRA, 2018), and feedstuff data websites such as FEDNA (www.fundacionfedna.org/tablas-fedna-composicion-alimentos-valor-nutritivo), Feedipedia (www.feedpedia.org) and INRAE-CIRAD-AFZ (www.feedtables.com).

With this aim, a new variety of hooded barley (cv. Mochona) was assessed and compared to triticale (cv. Titania), as alternative winter cereal forages produced under dry Mediterranean conditions in Spain. The comparison was done using two preservation modes (hay and silage) in two consecutive years, by assessing their chemical composition, ingestibility and digestibility values in adult sheep. Also, a new experimental dispositive based on free adaptation to metabolic cages was implemented for the measurement of ingestibility and digestibility to reduce sheep distress.

Table 1
Monthly total rainfall and mean daily temperature, at the experimental fields in Bellaterra (Barcelona, Spain), during the two growing seasons of the study.

Month	Average rainfall (mm)			Average temperature (°C)		
	2016	2017	2018	2016	2017	2018
January	26.4	34.1	72.7	9.55	6.50	9.40
February	31.8	42.6	85.5	9.95	10.55	6.10
March	20.9	115.7	86.1	9.95	12.00	10.15
April	55.7	40.3	91.2	12.95	12.80	13.80
May	21.9	16.4	44.9	15.65	17.75	16.55
June	18.2	23.6	43.6	20.90	23.85	21.30
July	16.3	6.1	18.5	24.45	24.00	24.70
August	1.1	14.3	26.2	24.10	24.65	24.90
September	43.4	23.2	41.5	21.70	19.30	22.00
October	52.7	79.0	142.3	16.75	17.65	16.40
November	70.7	4.2	106.3	11.55	10.40	11.60
December	28.8	5.4	6.9	9.30	7.20	9.30

2. Materials and methods

2.1. Cultural practices

In November (autumn) of consecutive years (2016 and 2017), two plots of 0.75 ha located at the experimental fields of the Servei de Granges i Camps Experimentals of the Universitat Autònoma de Barcelona in Bellaterra (41°30′20′’N and 2°05′46′’E; with an altitude of 162 m.a.s.l.), were sown with hooded barley (*Hordeum vulgare* cv. Mochona; 150 kg/ha) or triticale (×*Triticosecale* Whim cv. Titania; 220 kg/ha) from Semillas Batlle (Bell-lloc, Lleida, ES) according to the common cultural practices done in the area. The plot soils had silt-loam texture, low salinity, medium level of carbonates, and pH = 8.1. They were not fertilized or irrigated in both years, and rainfall and average annual temperature data are reported in Table 1. In May of the following years, both forages were harvested at the same day (196 and 168 d for H1 and H2, respectively) and at similar soft-dough stage (BBCH 85, based on visual examination). A single cut harvesting was done using a tractor provided with a rotary disc mower (Mod. Manlleu, Compar, Sant Pere de Torelló, ES) and preserved as hay and silage. Hays were sun-cured (7 d), wilted, packed in rectangular bales (1 × 0.5 × 0.4 m), using a low-pressure baling machine (Mod. IH LBX 422, Case, Hamburg, DE) and stored indoors. For silage, the cut forages were immediately pick upped, chopped in a vertical chopper-mixer (Mod. Boy Mix 8 m^3, Compar) and ensiled in 1 m^3 (1.1 × 0.9 × 1 m) rectangular plastic containers provided of openable drainers and wrapped with a plastic film. On the second year, a mix of an heterofermentative fermented plant extract inoculant (FPE Fermentierter Pflanzenextrakt, Multikraft Productions & Trading, Pichl bei Wels, AT) and sugar cane molasses (tap water solution at 20% and6.5%, respectively) was used for improving the anaerobic stability of the silages and minimizing dry matter (**DM**) losses. The inoculant mixture was sprayed over the silage at a rate of 1.5 L/t. Both forages, hay and silage of barley and triticale were preserved for 10 months before use in the 2 harvesting years (H1, 2017; H2, 2018).

2.2. Animals, management and feeding conditions

Animal care conditions and management practices agreed with the Spanish Royal Decree 52/2013, on the protection of animals used for experimental purposes, and were approved by the Ethical Committee of Animal and Human Experimentation of the Universitat Autònoma de Barcelona (CEEAH reference 3871).

A total of 32 adult, dry and open ewes, were divided in 2 balanced groups of similar body weight (**BW**) and body condition score (**BCS**) and used for forage evaluation according to year (H1, n = 12; H2, n = 20). To reduce the measurement errors on the animal results, the number of ewes was increased in the second year. The ewes were from 2 dairy breeds of similar characteristics (Manchega, n = 22, 78.0 ± 3.2 kg BW and 3.5 ± 0.1 BCS; Lacaune, n = 10, 75.6 ± 2.0 kg BW and 3.4 ± 0.1 BCS). Forages were randomly allocated to each group of ewes and offered in sequential periods, starting with the forage as hay, and following as silage. Each group of ewes was only fed with one forage species (barley or triticale) for one year, as required by the CEEAH approved protocols. All ewes were weighed at the start and the end of each experimental period (Tru-Test AG500; Auckland, NZ; accuracy, 0.2 kg). The experimental schedule is shown in Fig. 1.

To ensure the adaptation of the ewes and to reduce the stress during the experiment, they were first adapted (1–10 d) to the corresponding pen and forage as a group, letting them choose where to feed freely. Subsequently, the pens (3 m^2/ewe) were straw-bedded and the metabolic cages assembled in the front line and were used for feeding and watering. The metabolic cages consisted of plastic containers (120 × 100 × 122 cm; foldable large load carrier 1000 L, Auer Packaging, Amerang, DE) modified to allocate individually 2 sheep in tied-stalls, each one with a plastic feeder (40 × 30 × 23 cm; Auer Packaging) and a water bowl (20 × 30 cm; Suevia 125, Kincheheimam Neckar, DE) connected to a water tank (20 L). Therefore, the ewes were trained (11–15 d) to eat the assigned forage being tied in the metabolic cages which were used as individual tied-stalls during the daytime (0800–2000 h), and being released during the night (2000–0800 h). Finally, during the measurement period (16–20 d), the ewes were tied day and night and the metabolic cages used for total feces collection and to measure individual daily intake for ingestibility and digestibility (5–d period). All the ewes enrolled in the experiment adapted satisfactorily to the new dispositive.

Facilities	Straw bedded pens with metabolic cages		Metabolic cages	Straw bedded pens
Experimental period	Adaptation		Measurements	Washout
Day (0800 to 2000)	Free	Tied stalls	Tied stalls	Free
Night (2000 to 0800)	Free	Free	Tied stalls	Free
Days	1 2 3 4 5 6 7 8 9 10	11 12 13 14 15	16 17 18 19 20	21 22 23 24 25 26 27

Fig. 1. Experimental design schedule used for assessing the in vivo ingestibility and digestibility of the forages in ewes.

2.3. Ingestibility and digestibility

All forages were offered once a day ad libitum (fixed at 115% of the previous day's consumption). Voluntary daily intake (g/kg $BW^{0.75}$) was calculated by measuring the difference between offers and refusals and expressed as dry matter intake (**DMI**), neutral detergent fiber intake (**NDFI**) and organic matter intake (**OMI**), according to Demarquilly et al. (1995). Feces were collected during the tied-stalls period by using perforated plastic boxes (60 × 40 × 17 cm EO64/17; lattice box, Auer Packaging) covered by plastic mesh to allow the drainage of urine to a solid plastic box (60 × 40 × 12 cm EG64/12 HG WB; blind box, Auer Packaging) that were placed under the metabolic cages. Offers, refusals and feces were individually weighed using an electronic scale (Gram K3, Gram Precision, Barcelona, ES) and daily sampled taking aliquots (5–10%). All samples were kept at -20 ºC until analyses.

The apparent digestibility of each forage was determined by using feed intake, fecal output, and chemical analyses according to Demarquilly et al. (1995) and McDonald et al. (2010). Digestibility coefficients were expressed as dry matter digestibility (**DMd**), organic matter digestibility (**OMd**), neutral detergent fiber digestibility (**NDFd**) and crude protein digestibility (**CPd**). At the end of each digestibility period, the ewes had a washout period (7 d) where they were fed with the new forage under free pen conditions (Fig. 1), to avoid digestive contamination with the feed used in the previous experimental period.

2.4. Chemical analyses

Prior to analysis, the frozen hay and feces samples were thawed in the fridge and conditioned at 60 °C for 24 h, whereas silage samples were ice-dried (LyoAlfa 15, Testar, Klosterneuburg, AT). Thereafter, all samples were homogenized and grinded through a cyclone mill (Retsch SM2000, Retsch, Haan, DE) with a mesh of 1-mm.

The chemical analyses of forages were carried out according to the AOAC (2005) in duplicate and at the beginning of the experiment. Thus, DM was determined at 103 °C for 24 h and ashes burnt at 550 °C for 5 h. Organic matter (**OM**) was calculated as the difference between DM and ashes content of each sample. Crude protein (**CP**, AOAC method 990.03) was calculated as N × 6.25 by the Dumas method using a Leco Analyser (Leco Corporation, St Joseph, MI, USA), corrected according to Müller (2017). Crude fiber (**CF**, AOAC method 978.10) was analyzed according to Weende method, whereas, neutral detergent fiber (**NDF**, AOAC method 2002.04), acid detergent fiber (**ADF**, AOAC method 973.18) and acid detergent lignin (**ADL**, AOAC method 973.18) were sequentially determined on an ash-free basis according to Van Soest et al. (1991) adding sodium sulfite and thermostable α-amylase. All fiber determinations above mentioned were performed using an Ankom200 Fibre Analyser (Ankom Technology, Fairport, NY, USA). Additionally, silage pH values were measured daily in each digestibility trial of both experimental years, using a pH meter (sensION^{+}pH31, Hach, CO, USA). Finally, the chemical composition and the measured digestibility values under ad libitum conditions, were used to calculate the feeding values of each forage for lactating ruminants, according to INRA (2018). Nutritional energy values, such as gross energy (**GE**), digestible energy (**DE**), metabolizable energy (**ME**), as well as net energy for lactation (**NE_L**), were expressed as MJ/kg DM, and converted to feeding units for lactation (**UFL**) according to 1 UFL = 7.11 MJ/kg DM. The formulae (or equations) described in INRA (2018) were used to calculate the energy values for ruminants above mentioned. Total digestible values (TDN) may also be calculated as TDN = DE × 22.7, according to NRC (2007). Regarding protein partitioning, values were expressed as protein

Table 2
Chemical composition, ingestibility (I) and apparent digestibility (d) of the hays of cereal species (S) of hooded barley (cv. Mochona) and triticale (cv. Titania) in consecutive harvesting years (H1, 2017; H2, 2018).

Hay item	Species				±SEM	*P* value		
	Hooded barley		Triticale			Main effect		Interaction
	H1	H2	H1	H2		H[1]	S[2]	H×S[3]
DM, g/kg	918[a]	910[b]	923[a]	904[b]	0.1	0.001	0.10	0.001
Composition, g/kg DM								
CP (N × 6.25)	128	92	122	83	9.3	0.003	0.61	0.98
CF	320[b]	402[a]	322[b]	375[a]	1.5	0.001	0.001	0.001
NDF	650[b]	689[a]	641[b]	656[a]	2.0	0.001	0.001	0.004
ADF	400	398	398	397	1.0	0.20	0.12	0.86
ADL	55[a]	54[a]	44[b]	37[c]	1.0	0.002	0.001	0.014
OM	838	856	874	889	1.1	0.001	0.001	0.12
Ash	162	144	126	111	1.1	0.001	0.001	0.12
Ingestibility, g/kg $BW^{0.75}$								
DMI	27	29	36	31	2.6	0.47	0.10	0.43
OMI	23	27	33	31	1.9	0.52	0.001	0.10
NDFI	17	22	25	23	1.3	0.27	0.008	0.05
Digestibility, coefficient								
DMd	0.64	0.52	0.70	0.50	0.031	0.001	0.40	0.12
OMd	0.56	0.59	0.64	0.60	0.020	0.88	0.040	0.13
NDFd	0.62	0.34	0.67	0.34	0.011	0.001	0.033	0.37
CPd	0.55[b]	0.60[a]	0.60[a]	0.61[a]	0.007	0.002	0.002	0.001

[1] Effect of the harvesting year; [2]Effect of the cereal species; [3] Effect of harvesting year and cereal species interaction ([a-c] Mean values with different letter in the same row differ at $P < 0.05$); SEM, standard error of the mean.

digestible in the intestine (**PDI**, g/kg DM), calculated as the total sum of protein digestible in the intestine from dietary origin (**PDIA**) and of microbial origin. Moreover, the rumen protein balance (**RPB**, g/kg DM), was calculated using the equation RPB =– 84.5 + 0.61 × CP, according to INRA (2018).

2.5. Statistical analyses

All data were analyzed by the MIXED procedure of SAS v.9.4 (SAS Institute Inc., Cary, NC, USA). The statistical mixed model contained as fixed effects the forage species (hooded barley or triticale), experimental year (H1, H2) and their interaction. As random effects it was considered the animal and the residual error. Furthermore, CORR procedure of SAS, was used to identify Pearson correlation coefficients between chemical composition and voluntary intake and apparent digestibility values. Differences between least square means were determined by t-tests using the PDIFF option of SAS. Significance was declared at $P < 0.05$ and tendency at $P < 0.10$, unless otherwise indicated.

3. Results

3.1. Chemical composition of hays

The composition of hays (Table 2) varied according to forage specie ($P < 0.001$), except for DM (914 ± 0.1 g/kg, on average), CP (106 ± 9.3 g/kg DM, on average) and ADF (398 ± 1.0 g/kg DM, on average) values. On the contrary, the harvesting year affected all chemical components ($P < 0.001$–0.003), except ADF. The H×S interaction was significant for DM, CF, NDF and ADL.

Both forage species showed less CP content in H2 than in H1 (-30%, on average; $P = 0.003$; Table 2), mainly due to differences in weather conditions between years (i.e., drought in H1 and rain in H2 during sun-drying, Table 1). Nevertheless, the hooded barley showed, on average, a numerically greater CP content (10%) than the triticale, but also with a higher ash content. Consequently, the hooded barley showed a lower OM content than triticale (847 ± 0.7 g/kg vs. 882 ± 0.8 g/kg, on average and DM basis; $P < 0.001$). Regarding fiber composition, hooded barley showed higher values than triticale (NDF, 670 ± 1.4 g/kg vs. 648 ± 1.4 g/kg; ADL, 55 ± 0.7 g/kg vs. 41 ± 1.0 g/kg, on average and DM basis; $P < 0.001$), although no differences in ADF content were observed. Additionally, both species showed lower ADL values in H2 than in H1 ($P = 0.002$), although with higher NDF values in H2 than in H1 ($P < 0.001$)

3.2. Ingestibility and digestibility of hays

No differences were detected on voluntary intake (Table 2) of the ewes expressed as DMI (31 ± 2.6 g/kgBW$^{0.75}$, on average) for both forage species and year. Similarly, no differences were detected by year when expressed as OMI and NDFI. However, the hooded barley showed lower digestibility data than triticale for OMI (25 ± 1.4 g/kgBW$^{0.75}$ vs. 32 ± 1.3 g/kgBW$^{0.75}$, on average; $P < 0.001$)

Table 3
Chemical composition, ingestibility (I) and apparent digestibility (d) of the silages of cereal species (S) of hooded barley (cv. Mochona) and triticale (cv. Titania) in consecutive harvesting years (H1, 2017; H2, 2018).

Silage item	Species				±SEM	*P* value		
	Hooded barley		Triticale					Interaction
	H1	H2	H1	H2		H[1]	S[2]	H×S[3]
pH	4.10	3.72	3.90	3.34	0.10	0.001	0.001	0.60
DM, g/kg	280	322	282	297	36.0	0.33	0.10	0.33
Composition, g/kg DM								
CP (N × 6.25)	125	105	107	100	6.3	0.18	0.25	0.47
CF	299[b]	342[a]	314[b]	336[a]	7.7	0.001	0.06	0.002
NDF	522[b]	579[a]	525[b]	617[a]	1.3	0.001	0.008	0.001
ADF	316[b]	354[a]	332[b]	349[a]	4.4	0.001	0.13	0.001
ADL	40	42	32	37	0.4	0.001	0.001	0.06
OM	827[b]	919[a]	849[b]	905[a]	4.8	0.001	0.32	0.001
Ash	173[a]	81[b]	151[a]	95[b]	11.0	0.001	0.32	0.001
Ingestibility, g/kg BW$^{0.75}$								
DMI	27	38	32	30	2.7	0.24	0.70	0.12
OMI	23[c]	37[a]	30[b]	30[b]	1.7	0.012	0.85	0.013
NDFI	15	24	18	20	1.3	0.005	0.87	0.06
Digestibility, coefficient								
DMd	0.53	0.53	0.62	0.61	0.077	0.74	0.001	0.82
OMd	0.57[b]	0.61[a]	0.65[a]	0.57[b]	0.018	0.44	0.36	0.027
NDFd	0.52	0.60	0.58	0.61	0.015	0.020	0.12	0.21
CPd	0.60	0.59	0.63	0.63	0.042	0.44	0.001	0.44

[1] Effect of the harvesting year; [2]Effect of the cereal species; [3] Effect of harvesting year and cereal species interaction ([a-c] Mean values with different letter in the same row differ at $P < 0.05$); SEM, standard error of the mean.

Table 4
Nutritive values of hays and silages according to the cereal species (S) and the harvesting year (H1, 2017; H2, 2018).

Item (DM basis)	Hay								Silage							
	Species				±SEM	*P value*			Species				±SEM	*P value*		
	Hooded barley		Triticale			Main effect		Interaction	Hooded barley		Triticale			Main effect		Interaction
	H1	H2	H1	H2		H[1]	S[2]	H×S[3]	H1	H2	H1	H2		H[1]	S[2]	H×S[3]
Energy, MJ/kg																
GE	19.9	19.5	19.8	19.5	0.04	0.001	0.37	0.95	20.6	20.0	20.3	19.7	0.04	0.001	0.002	0.64
DE	10.4^{c}	10.8^{b}	12.1^{a}	11.1^{b}	0.04	0.001	0.001	0.001	11.1^{b}	11.6^{a}	12.6^{a}	10.8^{b}	0.21	0.023	0.19	0.003
ME	9.5	9.2	10.2	9.4	0.10	0.010	0.014	0.10	9.2^{b}	9.7^{a}	10.6^{a}	9.0^{b}	0.10	0.021	0.08	0.002
NE_L	5.2^{c}	5.6^{b}	6.4^{a}	5.8^{b}	0.18	0.54	0.010	0.020	5.5^{b}	5.9^{b}	6.6^{a}	5.4^{b}	0.09	0.030	0.12	0.003
Feeding values/kg[4]																
sFV[5]	2.62	2.78	2.47	2.74	0.030	0.003	0.052	0.20	3.07^{b}	2.81^{b}	3.56^{a}	2.92^{b}	0.042	0.002	0.010	0.034
UFL[6]	0.71^{c}	0.77^{b}	0.87^{a}	0.79^{b}	0.011	0.54	0.004	0.010	0.76^{b}	0.81^{a}	0.90^{a}	0.73^{b}	0.014	0.040	0.21	0.010
PDIA[7], g	22	16	21	15	0.7	0.004	0.37	0.97	22	19	19	18	0.4	0.020	0.020	0.12
PDI[8], g	68	65	72	65	0.7	0.008	0.12	0.12	68^{a}	69^{a}	69^{a}	67^{b}	0.4	0.37	0.37	0.040
RPB[9], g	–15	–36	–18	–41	1.5	0.001	0.06	0.54	–15	–27	–26	–30	1.4	0.006	0.010	0.06

[1] Effect of the harvesting year; [2]Effect of the cereal species; [3] Effect of harvesting year and cereal species interaction ([a-c] Mean values with different letter in the same row differ at $P < 0.05$); SEM, standard error of the mean. [4]Estimated according to INRA (2018); [5]Fill value for dairy sheep (sFV = 1 kg DM of reference grass); [6]Feed units for lactation (7.11 MJ of NE_L); [7]Protein digestible in the intestine from dietary origin; [8]Protein digestible in the intestine from dietary and microbial origin; [9]Rumen protein balance.

and NDFI (20 ± 1.0 g/kgBW$^{0.75}$ vs. 24 ± 1.1 g/kgBW$^{0.75}$, on average; $P = 0.008$). In addition, an H×S interaction was observed in NDFI ($P = 0.05$), as shown in Table 2.

Regarding apparent digestibility data (Table 2), there was no difference between species on DMd, but differences were detected as effect of harvesting year (H1 vs. H2, 0.67 ± 0.025 vs. 0.52 ± 0.022, on average; $P < 0.001$) because of the previously indicated differences on compositional values by year. Therefore, a positive relationship was found between DMd and CP content (r = 0.70; $P = 0.026$), but the relation was negative with NDF content (r = -0.70; $P = 0.011$). On the other hand, the hooded barley showed lower digestibility than the triticale for OMd (0.57 ± 0.017 vs. 0.62 ± 0.016, on average; $P = 0.040$), NDFd (0.48 ± 0.010 vs. 0.50 ± 0.008, on average; $P = 0.033$), and CPd (0.58 ± 0.008 vs. 0.61 ± 0.007, on average; $P = 0.002$). Hence, OMd did not show negative correlations with NDF content and ADL content.

On the other hand, harvesting year showed differences for NDFd (H1 vs. H2, 0.64 ± 0.009 vs. 0.34 ± 0.010, on average; $P < 0.001$), agreeing with the greater CP content observed in H1 vs. H2 (Table 2). Congruently, the lower ADL values in the H2 could explain their greater CPd (H1 vs. H2, 0.58 ± 0.006 vs. 0.61 ± 0.008, on average; $P = 0.002$). The H×S interaction was only significant for CPd ($P < 0.001$; Table 2), the CPd values being negatively correlated with ADL (r = -0.75; $P = 0.004$) and ADF (r = -0.66; $P = 0.02$) contents.

3.3. Chemical composition of silages

Both forages showed an adequate final pH value after ensiling (pH ≤ 4.1; Table 3), although they were greater for hooded barley than for triticale (3.9 ± 0.03 vs. 3.6 ± 0.04; on average, respectively; $P < 0.001$).

A few differences in the chemical composition were detected between silages of both forage species (Table 3), except for NDF and ADL content. Respect to the effect of year (H1 vs. H2), the harvesting year had marked influence. Regarding the H×S interaction, significant effects were observed in CF, NDF, ADF, OM and ash contents ($P < 0.002$), as shown in Table 3.

3.4. Ingestibility and digestibility of silages

No differences were observed in DMI (Table 3) between forage species and harvesting year. Additionally, no differences in intake were detected between species when expressed as OMI and NDFI. Nevertheless, hooded barley harvesting year showed greater values in H2 than in H1 (Table 3) for OMI and NDFI. The H×S interaction was significant in the case of OMI ($P = 0.013$). No correlations were detected between DMI and CP content or NDF content nor pH.

Apparent digestibility data of the silages are summarized in Table 3. The DMd and CPd showed differences between species with hooded barley values being lower than those of triticale. No differences were observed between species for OMd and NDFd while harvesting year only affected NDFd ($P = 0.020$), which was lower in H1 vs. H2 (0.55 ± 0.017 vs. 0.61 ± 0.014, on average, respectively). The H×S interaction was significant only for OMd ($P = 0.027$).

3.5. Nutritive values of hays and silages

3.5.1. Energy values

Partitioning of energy values for hays of hooded barley cv. Mochona and triticale cv. Titania, are shown in Table 4. Except for GE the hooded barley had lower energy values than the triticale when expressed as DE, ME and NE_L. On average, the climate differences between harvesting years resulted in superior energy values for H1 hays than H2 hays of both species, when expressed as GE values (1.8%; $P < 0.001$), DE (2.7%; $P < 0.001$) and ME (5.9%; $P = 0.010$) values, although no differences were detected for NE_L. Additionally, significant differences were detected in the H×S interaction of DE ($P < 0.001$) and NE_L ($P = 0.020$), suggesting greater sensitivity of triticale to drought. Moreover, the greater GE obtained in H1 when compared to H2, might be explained by the greater CP content of H1 (Table 2) and because the greater GE value of proteins in comparison to carbohydrates.

Energy values for silages of hooded barley cv. Mochona and triticale cv. Titania, are also shown in Table 4. Differences were detected between species only for GE, the values of hooded barley being 1.5% greater than triticale ($P = 0.002$). The effect of the harvesting year (H1 vs. H2) produced differences in all energy values expressed as GE, DE, ME and NE_L ($P < 0.001$–0.030). Consequently, GE showed positive correlation with CP content (r = 0.93; $P = 0.07$) and negative for NDF content (r = -0.94; $P = 0.05$). The H×S interaction had significant effects for DE ($P = 0.003$), ME ($P = 0.002$) and NE_L ($P = 0.003$), which also support a greater sensitivity of triticale than hooded barley to drought.

3.5.2. Feeding values

Ingestibility of forages is predicted from their intake capacity, conditioned by the physical bulk limitation and metabolic regulation in comparison to a forage of reference (i.e., standard grass hay); the value is expressed as sheep fill value (sFV) according to INRA (2018). The sFV of our hays, varied according to the forage species (hooded barley, 2.70 ± 0.02 vs. 2.61 ± 0.03, on average; $P = 0.052$) and year (H1 vs. H2, 2.55 ± 0.02 vs. 2.76 ± 0.02; $P = 0.003$), respectively. An H×S interaction was detected for UFL values ($P = 0.010$; Table 4), although those of hooded barley hay were 11% lower than those of triticale (0.74 ± 0.01 vs. 0.83 ± 0.03 kg/DM, respectively; $P = 0.004$).

The protein nutritive values of hays are also summarized in Table 4. There were no significant differences between hooded barley vs. triticale in protein values expressed as PDIA and PDI, but RPB showed a tendency to differ between both forages ($P = 0.06$). On the contrary, marked differences were observed by effect of the harvesting year (H1 vs. H2) on PDIA ($P = 0.004$), PDI ($P = 0.008$) and RPB

($P = 0.001$).

Ensiled forages differed on sFV according to species (2.94 ± 0.044 vs. 3.24 ± 0.042 for hooded barley and triticale, respectively; $P = 0.010$), years (H1 vs. H2, 3.32 ± 0.041 vs. 2.87 ± 0.032; $P = 0.002$) with a significant H×S interaction ($P = 0.034$), as shown in Table 4. No differences were observed for UFL values between silage species. However, harvesting year ($P = 0.040$) and the H×S interaction ($P = 0.010$) had significant effects agreeing to rain differences.

With the exception of PDI, that did not differ between species, the hooded barley silage showed greater PDIA (21 ± 0.4 g/kg DM vs. 19 ± 0.3 g/kg DM) and RPB (-21 ± 1.0 g/kg DM vs. -28 ± 1.1 g/kg DM) contents than triticale (Table 4). Differences were also observed between harvesting years (H1 vs. H2) for PDIA ($P = 0.020$) and RPB ($P = 0.010$). Nevertheless, no differences were detected on PDI between years. Likely as previously reported for hays, a positive correlation was detected between CP content and RPB value (r = 0.99; $P < 0.001$). Furthermore, H×S interaction was significant in PDI content ($P = 0.040$) and a tendency was observed for RPB ($P = 0.06$), as shown in Table 4.

4. Discussion

4.1. Chemical composition of hays

Environmental conditions, such as water availability, soil type and fertilization, mainly affect the CP content in forage cereals (Romero-Bernal et al., 2013) which is critical for nutritive value. Aguilar-López et al. (2013) mentioned that barley may reach 19% CP before ear emergence and dramatically decreases with plant maturity. Reference CP content values of fodder barley hay range from 78 to 130 g/kg (Carr et al., 2004; Greg and Marc, 2011), although Aboagye et al. (2021) did not find differences on CP contents among different cereals harvested as forages, including barley and triticale (92 g/kg DM, on average).

The mean CP content of hooded barley cv. Mochona in our results, was higher or similar than other hays of hooded barley cultivars (cv. Haybet, MT981060, Westford and Washford) reported by Robinson et al. (2001), Todd et al. (2003), and Brummer and Pearson (2004). Nevertheless, it was lower than the one reported by Romero-Bernal et al. (2013) 124 g/kg DM for hooded barley, and greater than the reference value for barley hay in Feedipedia (2023).

Hooded barley showed higher NDF and ADL contents than triticale, and lower NFE and OM contents, suggesting a more advanced phenological stage. Forage lignification degree is related to cell wall digestion in ruminants (Van Soest, 1982), but we did not find differences between our hooded barley and triticale. Nevertheless, we observed significant differences between years, but these changes did not affect ingestibility and digestibility, as discussed hereafter. Additionally, fiber contents were inversely correlated to CP contents (r = -0.84; $P = 0.002$), agreeing with Hoover (1986) and Harper and McNeill (2015), and with the phenological changes.

4.2. Ingestibility and digestibility of hays

According to Coleman and Moore (2003), CP content limits intake when dietary CP content is lower than 8%. Consequently, due to the greater CP contents measured in both forages (hooded barley and triticale, 110 and 103 g/kg, on average, respectively) we did not observe correlation of CP with DMI ($P = 0.47$). Moreover, Givens et al. (2000) and Harper and McNeill (2015) also stated that the relationship between NDF contents and DMI is not always consistent.

No effects of species and year were found on DMI of our hooded barley cv. Mochona and triticale cv. Titania. On the contrary, Andueza et al. (2012) reported 17% lower DMI for six-row awned barley than triticale (54 vs. 64 g/kg $BW^{0.75}$) in wethers. Meanwhile, Todd et al. (2003) did not find differences for DMI in fattening steers fed ad libitum, when three hooded barley and one two-row awned barley were compared (2.66 vs. 2.75% BW). Consequently, the hypothesis that the absence of awns might give an advantage on the voluntary intake of barley in ewes, was not supported by Todd et al. (2003) and our results. Both forages were similarly palatable for ewes under our ad libitum conditions.

Regarding to digestibility, differences of our DMd values may be a consequence of the variations in chemical composition by effect of the experimental year. Our hooded barley hay results were similar to those of Todd et al. (2003) obtained in steers under ad libitum conditions (DMd, 0.58 and NDFd, 0.44). Nevertheless, Andueza et al. (2012) reported higher apparent digestibility data for a six-row awned winter barley compared to triticale (DMd, 0.69 vs. 0.65; OMd, 0.71 vs. 0.68; NDFd, 0.65 vs. 0.56; respectively) in wethers which maybe a consequence of the lower lignin content in barley than in triticale.

Despite the slight differences observed on the comparison of ingestibility and apparent digestibility of our hooded barley and triticale hays, both forages have greater CP contents and lower OMd values, than those reported in Feedipedia (2023) for the reference fodder barley hay (CP, 87 g/kg DM; OMd, 0.67). Aguilar-López et al. (2013) reported greater CP and TDN (total digestible nutrients) values for two-row awned barley than for triticale hays, although the samples were processed at an early maturation stage (145 d). No data on whole cereal crop hays are currently available in the NRC (2007) and the INRA (2007, 2018) feed tables.

4.3. Chemical composition of silages

Adequate pH values were obtained for both hooded barley and triticale silages according to Driehuis et al. (2001) and Kung et al. (2018), although the use of additives in H2, improved the ensiling conditions. Cereals as barley and triticale, have enough water-soluble carbohydrate concentration for lactic bacteria, as well as a low buffering capacity, so they ensiled adequately (Preston, 2016). In our study, the use of heterofermentative inoculant in H2 reduced the pH values, which numerically allowed more DM recovery after ensiling. On the other hand, a rapid decrease of pH would help to limit the protein breakdown in the silage by inactivating plant proteases, and to enhance its quality (Muck et al., 2018).

Regarding silage CP content values, Nair et al. (2016) evaluated the nutritional value of seven commercial barley varieties grown for silage and harvested at the mid-dough stage. They obtained an average CP content across varieties similar to our results (112 g/kg vs. 115 g/kg). In our results, CP contents in H2 were greater for silages than for hays because in H2 suffered rain during the sun-curing process and, consequently, their CP contents were washed. This reinforces the known practical advantage of ensiling vs. sun-curing. In agreement with our results, several studies did not observe differences on CP content between fodder barley vs. triticale silages, as reported by McCartney and Vaage (1994) 120 vs. 116 g/kg), Jedel and Salmon (1995) 97 vs. 98 g/kg, and Nikkhah (2013) 124 vs. 127 g/kg), even though, some studies (Siefers et al., 1996; González-García et al., 2016), reported greater CP content for barley than triticale silages (125 vs. 92 g/kg).

4.4. Ingestibility and digestibility of silages

No differences were observed on DMI between forage species and harvesting years, despite than in H2 the use of additives improved silage pH and palatability and nutritive value could be modified. Our results agree with Nikkhah (2013) who did not report DMI differences when fodder barley and triticale silages were compered in dairy cows.

Apparent digestibility data of our silages disagree with the values reported by McCartney and Vaage (1994), who found greater DMd in fodder barley vs. triticale silages (0.64 vs. 0.59) in wethers, although they did not detected differences on OMd and NDFd as we observed. In our study, no differences on DMd or OMd by harvesting year or by silage additive in both forages were found. The ensiled forages with additive might have improved their aerobic stability mainly due to the antifungal action (Oliveira et al., 2017), preserving its nutritional quality once opened but without effects on intake and digestibility.

4.5. Nutritive values of hays and silages

4.5.1. Energy values

Hooded barley hay had lower energy values than triticale hay, except for GE (Table 4). Most likely this was a consequence of the lower value of OMd of hooded barley than triticale (-8.9%, on average; $P = 0.040$; Table 2), although, no correlation was detected between OMd and ME ($P = 0.30$). Consequently, the triticale hay showed greater energy content for milk production (NE_L), than hooded barley hay. Compared to values reported in Feedipedia (2023), fodder barley hay has less GE values (18 MJ/kg DM), than those we obtained in the case of hooded barley hay (20 MJ/kg DM, on average). On the contrary, the DE value was approximately 7% lower in our hooded barley hay (11.4 vs. 10.6 MJ/kg DM), because the greater OMd reported in Feedipedia (2023) with regard to the value measured in our hooded barley hay (0.67 vs. 0.58, respectively). This may be consequence of our greater NDF values. No data are available for NE_L comparison in hooded barley vs. triticale hay, and consequently, our data may be proposed to be used in Feedipedia.

Regarding silage values, to our knowledge, no data are available for hooded barley silage. Nevertheless, comparing our results with those reported in the feed tables of INRA (2018) for fodder barley silage (#FE4790), our values were greater for GE (20.3 vs. 18.9 MJ/kg DM) and ME (9.5 vs. 8.8 MJ/kg DM), respectively. Additionally, the referential NE_L value informed by NRC (2007) for fodder barley silage is lower than we obtained for hooded barley silage (5.7 vs. 5.2 MJl/kg DM, respectively). According to Sauvant and Nozière (2016) and INRA (2018), the OMd has a key role for conversion efficiency from EM to NE_L.

4.5.2. Feeding values

Rumen protein balance (RPB) integrates the quantitative effect of energy × nitrogen interactions on digestive processes and particularly on OMd and microbial growth (Sauvant and Nozière, 2016; INRA, 2018). The digestive microbiota dramatically decreases when RPB is under zero (Sauvant and Nozière, 2016). Therefore, when both forages were compared as hay, our hooded barley showed lower RPB value than triticale. Unfortunately, there is no referential data available on RPB values for fodder barley hay, as well as for hooded barley and triticale hays, in the feed tables of INRA (2018).

Both ensiled forages had higher values than the theoretical forage of reference (sFV = 1.36) of INRA (2018) because their lower intake and high bulk effect. According to the feed tables of INRA (2018; #FE 4790) and FEDNA (2016), the UFL values reported for fodder barley silage (0.73 and 0.72 UFL/kg DM, respectively) were lower than the value obtained in our hooded barley silage (0.79 UFL/kg DM; Table 4). No referential data are available for UFL of triticale in the FEDNA (2016) and INRA (2018) feed tables. Our hooded barley silage had a greater RPB value than triticale (less negative), being also greater than the reported by INRA (2018) for fodder barley silage expressed as PDIA (21 vs. 14 g/kg DM), PDI (69 vs. 60 g/kg DM) and RPB (-21 vs.–27 g/kg DM).

Therefore, the values obtained in our study may be proposed as referential data for hay and silage of hooded barley and triticale, which correspond to those of a poor forage of low intake and high bulk effect.

5. Conclusions

Despite the marked differences between harvesting years, there were small differences in the chemical composition of the hooded barley (cv. Mochona) and the triticale (cv. Titania) species studied. Comparing hooded barley and triticale, no differences were detected in CP content, but lower fiber contents (NDF and ADL) were observed for both hay and silage. Moreover, DM intake in sheep did not differ for both preservation methods when the two forage species were compared.

Regarding apparent digestibility, the hooded barley hay had lower OMd and energy values than triticale hay, apparently due to greater fiber contents. Moreover, greater PDIA and RPB values were found in the hooded barley than triticale when preserved as silages. Even though the high sFV values observed in all forages studied, hooded barley had lower bulk effect and lower deficit protein in the rumen than triticale when preserved as silage.

We conclude that the hooded barley cv. Mochona and triticale cv. Titania, may be good alternatives as fodder resource for sheep under Mediterranean conditions. Hooded barley showed greater nutritional value than references reported for barley forage, and we recommend earlier harvesting stages. Finally, the values obtained herein could be considered for completing the compiled data of feeding resources for ruminants.

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CRediT authorship contribution statement

Santiago A. Guamán: Methodology, Writing – original draft, Formal analysis, Data curation. **Elena Albanell**: Conceptualization, Methodology, Writing – original draft, Supervision, Funding acquisition. **Oriol Ajenjo**: Formal analysis, Investigation. **Ramon Casals**: Methodology, Funding acquisition. **Abdelaali Elhadi**: Formal analysis, Data curation. **Ahmed A. K. Salama**: Methodology, Investigation. **Gerardo Caja**: Conceptualization, Methodology, Writing – original draft, Supervision.

Declaration of Competing Interest

The authors declare no conflict of interest.

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