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Research Article
Hydroponics Technology of Fodder Barley Production Used to Improve Feeding Livestock in Arid Regions of Tunisia

[1]Aida Bouajila, [1]Zohra Hamdi, [2]Hajer Ammar, [3]Abdallah Ameur, [3]Sabrine Ziadi, [2]Jihene Khechini, [4]Mohammed Kamoun and [1]Abdelwahed Ghorbel

[1]Centre of Biotechnology of Borj Cedria, BP 901, Hammam-Lif 2050, Tunisia
[2]Higher School of Agriculture of Mograne, Zaghouan 1121, Tunisia
[3]Higher Institute of Applied Sciences and Technology of Mahdia, Mahdia 5121, Tunisia
[4]National School of Veterinary Medicine of Sidi Thabet, Ariana 2020, Tunisia

Abstract
Background and Objective: In Tunisia, the deficiency of feeding livestock increased by drought. Sprouting barley is a solution to feeding ruminants. This study was conducted to enhance the evolution of chemical composition, *in vitro* gas production, organic matter digestibility and metabolizable energy in four sprouting barley cultivars. **Materials and Methods:** Daily sampling was assessed to determine dry matter concentration and nutritional value on the 8th and 12th days with comparison to the original barley grains. Although, *in vitro* gas production and its parameters of sprouting barley were estimated using rumen fluid. **Results:** The crude protein, Fe, Zn, N, Ca, Mg and K contents were significantly higher ($p<0.05$) on the 8th day of germination for all cultivars followed by a gradual decrease on the 12th day. There was a 20 and 26% increase in the yield of dry matter of sprouts barley on the 8th and 12th day of germination, respectively compared to the original barley grain. Concentrations of neutral detergent and acid detergent fibre increased as days of development increased and remained highest on the 12th day at 36.47 and 16.24%, respectively. The highest gas production (78 mL/0.2 g), organic matter digestibility (94%) and metabolizable energy (3.8 Mcal g^{-1}) values were recorded ($p<0.05$) in fodder barley cv "Ardhaoui" harvested at 8 days of germination and the lowest (61 mL/0.2 g, 75%, 2.78 Mcal kg^{-1}) in sprouting barley "Rihane" sampled at 12 days. The gas production (75 mL/0.2 g), OMd (88.6%) and ME (3.2 Mcal kg^{-1}) values of original barley grain were similar to barley sprouting "Rihane" and "Souihli" sampled on the 8th day of germination. **Conclusion:** The barley sprouting cv "Ardhaoui" was the most suitable candidate as regards energy and protein contents followed by Rihane-Souihli and Arbi, thus it could be suggested to improve the quality of ruminant's diet, especially in the arid regions of Tunisia.

Key words: Hydroponics, barley, harvesting time, nutritional value, *in vitro* gas production, metabolizable energy, digestibility

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Corresponding Author: Aida Bouajila, Centre of Biotechnology of Borj Cedria, BP 901, Hammam-Lif 2050, Tunisia Tel: +216 79325855 Fax: +21679325638

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

In Tunisia, agriculture is considered a basic sector since it represents 8.5% of the national PIB and offers employment for 15%. Livestock production, particularly sheep and cows are the main source of milk and meat. During the last decade, milk production increased regularly and reached 1218000 t. Likewise, red meat production increased and reached more than 121000 t, which corresponds to 90% of total demand. However, grassland production in Tunisia systemically suffers from irregularities in the quantity and quality of fodder produced during the year (grassland area 330 thousand hectares). Water resources and salinity are major constraints for pastoral and agricultural (cereals and tree cultivation) activities, especially in arid regions. More than 8% of Tunisian areas are already affected by salinity to various degrees[1]. This leads to an imbalance situation between the food supply and nutritional requirements of the animals. This deficiency in forage production has increased in recent years with periods of drought. On the other hand, the continuous increase in population rate accentuates too the problem by reducing the agriculture area[2]. These constraints make it necessary to look for forage security production in the medium and long term. This requires optimization of the existing grassland system and diversification of food resources. In recent years, the development of a new forage production technique based on sprouted seed results in the growth of young cereal plants in trays and leads to obtaining in 7-10 days important biomass with high nutritional quality[3]. Hence, the production of above-ground fodder could be an alternative and represent a way of intensification livestock production systems mainly in regions characterized by a short herbage period[4]. This technique is approved as more efficient in terms of surfaces and use of water and pesticide, being completely independent of climatic conditions[5]. This technology requires only about 2-5% of the water used under field conditions[6]. Beyond these promising agronomic performances, hydroponic green fodder has bromatological properties as compared with other forage. During germination, the improvement of protein quality (amino acid profile), free fatty acid content and B group vitamin levels were observed to increase nutritional value and digestibility[7]. Numerous studies reported that a suitable harvesting date was the 7th or 8th day following the sowing in terms of nutritional value, fibres (NDF, ADF), phytase activities, vitamins, metabolizable energy and minerals of the fodder[7] with good appreciation and therapeutic effects on animals[8]. Thus ingestion of this forage would have a positive effect either on production (milk and meat) and zoo technical performances (fertility, puberty and sexual behaviour) or the health of ruminants[9]. Moreover, hydroponic forage could contribute widely to reducing greenhouse gas emissions issued either from the ruminant specie (CH4 and N20) or from the land (fertilizer)[6]. However, the intake of large amounts of cereal grains rich in phytate (anti-nutrient) may cause several mineral deficiency symptoms and increase phosphorus pollution[10]. The main objectives of this study were to assess the effect of harvesting time and sprouting barley cultivar on chemical composition, gas production, metabolizable energy and organic dry digestibility and select the best sprouts barley cultivar. This information would help to integrate the best sprouting barley cultivar in feeding livestock in arid regions.

MATERIALS AND METHODS

Plant material and germination of barley grains in Hydroponic unit: The study was conducted in 2020. Three cultivars of barley (Arbi, Souihli and Ardhaoui) and improved variety Rihane, were collected from the main geographic area in the North African coastline of Tunisia (North-West, Center-East and South-East) and were used as plant material. At harvesting, the grain moisture content was measured 12% for all cultivars. The growth of all cultivars was done in a steel hydroponic unit as described by Bouajila *et al.*[11]. The seeds of barley (*Hordeum vulgare* L.) were washed and soaked in tap water in polyethylene containers (100 g seeds were soaked in 100 mL of water) for 4 hrs at 23°C. After rinsing the soaking water, samples were spread in the trays with a seed rate of 4 kg m^{-2} at 21°C. The samples were irrigated 9 folds/day with a flow of 4.5 mL of water per minute (without nutritive solution and pesticides). All the samples were harvested on the 8th and 12th days of germination and dried (at 55°C, 72 hrs) for chemical and digestibility analysis. In order, to investigate the effect of germination on the nutrient quality and digestibility characteristics of barley fodder cultivars, each treatment was performed in three replicates under the same conditions.

Chemical analysis: Mineral element concentration in grains and green barley fodder, such as Fe, Cu, Zn, Mg and Ca, was determined according to the method cited by Omotoso *et al.*[12]. Collected samples were oven-dried at 55°C for 72 hrs to determine dry matter (DM). Approximately 1 g of dried powder samples were homogenized with 10 mL of nitric acid and 3.0 mL of 70% hydrogen peroxide and kept for wet digestion in a closed microwave system for about 30 min at 200°C and finally filtrated. Mineral elements were determined using Atomic Absorption Spectrometer (Shimadzu AA6300, Illinois, USA). Phosphorus was determined by the molybdovanadate using a spectrophotometer (Shimadzu AA 6300) and the absorbance was measured at 430 nm. The nitrogen content of samples was determined by Kjeloplus Kjelodist CAS VA (Pelican Inc.). Crude protein (CP) was calculated by multiplying the percentage of nitrogen found by a factor of 6.25. Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were obtained using Fibroplus FBS 08P (Pelican Inc.).

***In vitro* gas production:** The samples were incubated *in vitro* with rumen fluid in calibrated glass syringes[13] in the Laboratory of animal feed, National School of Veterinary Medicine of Sidi Thabet, Tunisia. Rumen fluid was obtained from two fistula male cows. Ground samples (200 mg) were incubated in 30 mL of diluted rumen fluid (10 mL rumen fluid +20 mL medium) in 115 mL serum under a pre-warmed CO_2 atmosphere at 39°C to perform the growth of the microbial population[14]. Three serum bottles containing rumen fluid without substrate were incubated as blanks. The volume of gas produced was reported at various incubation times (3, 6, 9, 12, 16, 21, 26, 31, 36, 48, 60, 72, 96, 120 and 144 hrs after inoculation time), using a pressure transducer[13]. Incubations were accomplished in three repeated runs (two bottles/sample per run).

The gas volume and pressure measurement data were used to adjust the ruminal fermentation kinetics following this formula:

$$\text{GP (mL)} = \frac{A}{\left[1+\left(\frac{B}{t}\right)^{c}\right]}$$

Where:

GP (mL)	=	Volume of gas produced during a time t after incubation
A (mL g^{-1} DM)	=	Potential gas production
B (h)	=	Time after incubation at which 1/2 of (A) was produced
C	=	Constant that determines x inflection point position of the curve
t (h)	=	Gas pressure reading time after incubation

Metabolizable energy (ME) and organic matter digestibility (OMD) were estimated[12]:

$$\text{ME (MJ kg}^{-1}\text{ DM)} = 2.20+0.136\text{ GP}+0.057\text{ CP}+0.0029\text{ CP}^2$$

Where:

GP = 24 hrs net gas production (mL/200 mg)
CP = Crude protein (%)

$$\text{OMD (\%)} = 14.88+0.889\text{ GP}+0.45\text{ CP}+0.0651\text{ XA}$$

Where:

XA = Ash concentration (%)

Statistical analysis: Each measurement of grain and green fodder barley was carried out in three replications. The Analysis of Variance (ANOVA) was conducted using general linear models (PROC GLM) of SAS V8.0 (SAS Institute, Cary, NC) to assess changes in nutrient quality, *in vitro* gas production and digestibility of organic matter and metabolizable energy in barley grains and germinated barley fodder.

RESULTS AND DISCUSSION

Four sprouted barley cultivars and the original barley grain were used to determine the differences in chemical composition, gas production (GP), digestibility of organic matter (OMD) and metabolizable energy (ME).

Effect of cultivar and harvesting time in nutrient value of sprouts barley: Cereal germination is the most widely used technique and can be regarded as the simplest and most economical. In addition, barley grain germination can improve nutritional quality, reduce the anti-nutritional components of food grains and improve the bioavailability of essential minerals such as phosphorus, calcium, iron and zinc[14].

At harvesting of the kernel, the thousand-grain weight (TGW) per cultivar of *H. vulgare* was determined from North to South of Tunisia (Arbi, 40 g, Rihane, 34.5 g, Souihli, 33.5 g and Ardhaoui, 42 g). The thousand kernel weight is an essential sign to evaluate the quality of grains and determined the growth and vigour of seedlings. The nutritional composition of barley sprouts harvested at 8 (G8) and 12 (G12) germinating days and barley grain were presented in Table 1. As shown in Table 1, the dry matter of sprouting barley decreased significantly (p<0.05) on the 8th (12.5%) and 12th (11.75%) days of germination (DM<20%). Conversely, barley grain showed the highest dry matter 87%. This reduction of dry matter of germinated grain might be explained by the increase in biomass production. Following the findings, the reduction of dry matter during 12 days of germination has also been reported in the previous studies[15]. Furthermore, during soaking and germination, the grains drop the dry matter as a result of using energy reserves of grains for the growth and also oxidation of plants[16]. The ranges of organic matter and the ash content of barley sprouts were (p<0.05) 94-95% (G8, G12), 4.85-5.1% (G8) and 5.1-5.5% (G12) respectively. However, barley grains showed the highest organic matter

Table 1: Changes in the chemical composition of Tunisian barley sprouting and barley grain

		Arbi		Souihli		Ardhaoui		Rihane		
Parameters/green fodder	Barley grain	8 days	12 days	8 days	12 days	8 days	12 days	8 days	12 days	SE
Dry matter (%)	88[a]	12.5[b]	11.71[b]	10.26[b]	9.14[b]	10.43[b]	9.89[b]	11.94[b]	11.07[b]	0.23
Organic matter (%)	97.57[a]	95.1[a]	94.9[a]	95.15[a]	94.7[a]	94.9[a]	94.55[a]	95.03[a]	94.5[a]	0.33
Ash (%)	2.43[b]	4.9[a]	5.1[a]	4.85[a]	5.3[a]	5.1[a]	5.45[a]	4.97[a]	5.5[a]	0.25
CP (%)	11.06[c]	19.16[a]	15.12[b]	18[ab]	16.68[b]	21[a]	15.06[b]	15[b]	12.31[c]	0.01
N (%)	1.76[d]	3.06[a]	2.41[c]	2.88[b]	2.67[b]	3.36[a]	2.41[c]	2.4[c]	1.97[d]	0.15
P (%)	0.39[c]	0.64[b]	0.27[d]	0.67[b]	0.513[b]	1.06[a]	0.32[c]	1.43[a]	0.50[b]	1.23
K (%)	0.35[d]	0.35[d]	0.4[c]	0.57[ab]	0.39[c]	0.50[b]	0.43[c]	0.62[a]	0.48[bc]	0.023
Ca (%)	0.03[e]	0.14[c]	0.12[d]	0.20[b]	0.15[c]	0.28[a]	0.18[b]	0.24[ab]	0.11[d]	0.123
Mg (%)	0.14[b]	0.19[a]	0.13[b]	0.21[a]	0.15[b]	0.20[a]	0.15[b]	0.23[a]	0.12[b]	0.131
Fe (mg kg^{-1})	83.39[ab]	65.66[b]	54.41[c]	64.51[b]	60.27[b]	86.12[ab]	64.57[b]	91.03[a]	48.06[c]	0.147
Cu (mg kg^{-1})	4.40[a]	5.49[a]	4.29[a]	5.58[a]	4.53[a]	5.44[a]	4.62[a]	5.64[a]	4.81[a]	0.031
Zn (mg kg^{-1})	36.53[b]	53.09[a]	24.13[d]	42.43[b]	28.52[c]	37.96[b]	19.05[d]	46.50[b]	20.29[d]	0.012
NDF (%)	23.27[c]	29.43[ab]	36.47[a]	30.21[ab]	33.45[ab]	27.42[b]	30.58[ab]	26.13[b]	28.05[b]	0.022
ADF (%)	9.08[d]	14.72[ab]	15.74[a]	12.11[c]	16.11[a]	14.98[a]	16.28[a]	10.99[e]	14.02[ab]	0.021
Yield of DM kg^{-1} of grain	0.88[b]	1.03[a]	1.21[a]	0.84[b]	0.89[b]	1.06[a]	1.1[a]	0.95[a]	1.2[a]	0.054

DM: Dry matter (%), CP: Crude protein, NDF: Neutral detergent fibre, ADF: Acid detergent fibre, SE: Standard error and means with different letter superscripts are significantly different at p<0.05

(97%) and the least ash content (2.43%). There was a significant decrease in the ash content of grains before the germination process. The total dry matter (DM) produced by sprouts depends on the yield of sprouts from each kilogram of grain used and the DM of the sprouts. The yield of dry matter produced in grains and sprouts was 0.88% (grains), 0.84-1.06 (G8) and 0.8-1.2 (G12), respectively (Table 1). The production rate of fodder barley (G8) ranged from 6.5-9 kg of fresh fodder corresponding to 0.77-1.13 kg of dry with 19-27 cm of high fodder. One kg of ungerminated seed yields 8-10 kg green forage in 7-8 days[6]. After 12 days of germination, there was a 17, 16 and 14% increase in the production of dry matter in Rihane, Souihli and Arbi cv, respectively.

The estimation of crude protein reflects the total nitrogenous and non-nitrogenous proteins percent in the sample[17]. The crude protein (CP) varied significantly from 15 (Rihane) to 21% (Ardhaoui cv) and the maximum increase was reached only eight days after harvesting. By extending the period growth to 12 days, CP was decreased ($p<0.05$) in all cultivars. However, barley grain showed the least CP content (11%) compared to barley sprouts (Table 1). There was a 90% increase in crude protein from barley grain to sprouts barley harvested on the 8th day of germination. This increase may be explained by the loss of carbohydrates in the dry matter and other nutrient changes in sprouting grain through respiration during germination[17]. Since no source of nitrogen was added to the water of irrigation. Following our results, high crude protein content (25%) on the 8th day of germination was reported by AL-Saadi[6]. However, Al-Baadani *et al.*[18] revealed that crude protein content was about 14%. For sprouting sorghum varieties, crude protein values ranged from 13.94-17.27% on the 8th day of growth[19]. These differences in results may be attributed to longer soaking periods which reduce protein due to the loss of low molecular weight nitrogen compounds during seed soaking and rinsing. In the present study, hydroponic fodder barley harvested at 8 days of all cultivars (CP>10%) is not deficient in PDIN (PDIN: Protein digested in the small intestine when rumen-fermentable nitrogen) relative to its PDIE (PDIE: Protein digested in the small intestine when rumen-fermentable energy) content[12]. These authors assume that hydroponic fodder barley with low CP (<10%) should be unbalanced (PDIN<PDIE). Hence, a protein source supplementation to these green fodder would be essential to rebalance the ratio (PDIN = PDIE) when barley fodder is distributed to animals. Thus, the current study showed that high CP fodder (CP >10%) can satisfy the nutritional needs of herbivorous animals[12].

It is determined that the cell wall components increased significantly with the progress of the harvest days in this investigation ($p<0.05$). The fibre content of the sprouted barley increased with the germination time and remained highest on the12th day (NDF: 36.47% ($p<0.05$), ADF: 17.74%) (Table 1). The fiber content (NDF: 23% and ADF: 9%) was recorded less ($p<0.05$) in the original barley grain (Table 1). Arbi and Ardhaoui showed the highest level of NDF and ADF, 36.47 and 16.24%, respectively on the 12th day of harvest (Table 1). There was a 22.73% increase in NDF of fodder barley "Arbi" from 8-12 days of germination. Also, 30 and 66% increase in NDF and ADF, respectively were found between ungerminated grains and sprouts barley G8. This increase might be due to the synthesis and accumulation of lignin during the sprouting of barley. The rate of maturation and irrigation increased the plant height and enhanced the neutral detergent fibre (NDF) and acid detergent fibre (ADF)[18]. Fibre content reported herein agreed with those presented by Al-Baadani *et al.*[18] amounting to 16.45 and 35.3% for ADF and NDF, respectively. Nevertheless, according to several reports lower values were obtained. As reported by Chethan *et al.*[20] the NDF and ADF in sprouted sorghum were only 29.27 and 10.16%, respectively. Ikoyi and Younge[21] reported that fodder with reduced values of ADF (<30-35%) and NDF (<40-45%) is recommended regarding good feeding value. Numerous studies reported a similar enhancement that loss of dry matter from the original grain after sprouting for 6-8 days of growth was a result of hydrolysis of starch and cellular materials (fats, protein and carbohydrates) with enzymes that could elucidate the extension in fibre content during germination process[22]. Mineral element and trace element concentrations varied in the original barley grain and sprouts barley (G8 and G12). The current study showed that there was a significant variation in each mineral concentration at different growth periods. The maximum values of N, Ca, P, Mg, Fe, K and Zn concentrations were significantly much higher in all cultivars harvested at G8 than the original barley grain and G12 (Table 1). Ardhaoui and Rihane showed a maximum value ($p<0.05$) of the most mineral element in 8th day of germination such as zinc (Zn), magnesium (Mg), calcium (Ca), phosphorus (P), potassium (K) and iron (Fe). Only copper (Cu) was not significant between forage barley cultivars from G8 to G12 (Table 1). Following results, AL-Saadi[6], reported significant differences between mineral elements, N, K, Ca and Mg were, respectively 4.08, 0.86, 0.319 and 0.38%. The concentrations of Mn, Cu, Mn, Zn and Fe were 3.78, 16, 23, 58 and 92 mg g^{-1}, respectively. However, a study cited by Al-Baadani *et al.*[18], reported a significant difference in K, P and Zn with lower concentrations, respectively 180, 150 and 4.634 mg kg^{-1} in barley fodder compared to our results. A similar trend has been seen in the nutritive value of barley fodder grown in a hydroponics system and reported as Ca and P was 0.104 and 0.47%, respectively[18]. Although, found some mineral element values were significantly higher or lower in several studies.

This increase of mineral elements might be due to the activation of endogenous grain phytase and breakdown of certain anti-nutrients like phytate and protease inhibitors and improved the bioavailability of essential minerals like phosphorus, calcium, iron and zinc[21]. Thus, during the 12 days of germination, the phytate content of the same sprouted barley decreased, however, the phytase activity showed the maximum value on 8th day of germination for all cultivars (5.83-7.72 U g^{-1}). Nonetheless, in the original barley grain, phytate content and phytase activity ranged from 4.2-4.7 mg g^{-1} and 0.6-1.6 U g^{-1}, respectively[11]. In addition, the variation of this increase of sprouts barley will be explained by the cereal grain (species, variety and cultivar) and drying and storage conditions.

The discrepancies among different investigations are large because of soaking and growing conditions (temperature, humidity, density of grains, time of soaking, nutrient solution or tap water) and barley variety (growing area, climate). Those factors could influence the differences in mineral concentrations and make the comparison of the data difficult. In this study, all local barley cultivars were grown in standard methods and conditions to select hydroponic cultivar(s) of barley with more nutrient-rich. Thus, the 8th germinating day is the most appropriate harvesting stage corresponding to the higher yield of green fodder, crude protein and availability of most mineral elements and phytase activity[11]. The sprouting Ardhaoui cultivar was shown as the nutritive source for feeding livestock in arid regions of Tunisia followed by Rihane, Arbi and Souihli. Some studies reported that in hydroponic cultivation a specific varieties should be selected to obtain the desired nutritional features (such as soybean, raspberry and strawberry material)[23]. In agreement with current findings, previous research has expressed higher nutritive values such as crude protein and ether extract in the soilless barley fodder[6]. Palermo *et al.*[24] reported that hydroponic soybeans enhanced the nutritional quality in terms of fats and dietary fibre. Further, soilless strawberries have the potential to provide a superior nutrient-dense crop (contents of ascorbic acid, tocopherol and total polyphenolic compounds) compared to soil-grown plants[23].

***In vitro* analysis:** The gas production, organic matter (OM) digestibility and ME content of hydroponic barley harvested at 8 and 12 days of germination as well as barley grains were presented in Table 2. All sprouting barley cultivars showed the highest GP, OMD and ME at the first harvesting time of 8 days and then tended to decrease gradually in 12 days of sampling (Table 2). The highest gas production (78 mL/0.2 g), OMD (94%) and ME (3.8 Mcal g^{-1}) values were recorded ($p<0.05$) in fodder barley cv "Ardhaoui" harvested at 8 days of germination and the lowest (61 mL/0.2 g, 75%, 2.78 Mcal kg^{-1}) in sprouting barley "Rihane" sampled at 12 days. The gas production (75 mL/0.2 g), OMd (88.6%) and ME (3.2 Mcal g^{-1}) values of original barley grain were similar to barley sprouting "Rihane" and "Souihli" sampled at G8 (Table 2). Similar results have been revealed that 96 hrs of cumulative gas production content, ME and OMD were decreased by the increasing number of harvesting times (4th, 7th, 8th, 10th and 13th)[25]. However, the suitable harvesting time was the 4th and 6th day

Table 2: Effect of barley sprouting cultivars on *in vitro* gas production, organic matter digestibility and metabolizable energy as well as the original barley grain

		Ungerminate grains/fodder barley								
		Green fodder 8 days				Green fodder 12 days				
Barley cultivars	Grains	Arbi	Souihli	Ardhaoui	Rihane	Arbi	Souihli	Ardhaoui	Rihane	SE
IVGP for 24 hrs (mL/0.2 g)	75[a]	63[c]	68[b]	78[a]	70[b]	61[c]	58[c]	70[b]	61[c]	0.75
OMD (%)	86.6[b]	79.43[c]	84[b]	94[a]	84[b]	76[d]	74[d]	84[b]	75[d]	0.69
ME (Mcal kg^{-1} DM)	3.2[b]	3.08[b]	3.2[b]	3.8[a]	3.16[b]	2.83[c]	2.84[c]	3.16[b]	2.78[c]	0.37

IVGP: *In vitro* gas production for 24 hrs (mL/200 mg), OMD: Organic matter digestibility (%), ME: Metabolizable energy (Mcal kg^{-1} dry matter), SE: Standard error and means with different letter superscripts are significantly different at p<0.05

following the sowing for *in vitro* gas production, ME and OMD of barley fodder. Some reports revealed that the gas production is correlated negatively with cell wall components[26] and is proportional to the number of digestible carbohydrates, thus it is highly correlated to the energy value of feeds[27]. In this study, grain and grain sprouts both have high digestibility and metabolizable energy (ME). The higher ME and OM digestibility of fodder barley harvested at G8 were probably due to the high leaf and root length and thickness (Table 2), enzyme activity and its lower NDF and ADF content compared to barley sprouts G12 and the original barley grains since it is mainly fibre that influences digestibility[28]. Only the sprouting barley "Ardhaoui" harvested at 8 days of germination showed the highest GP, ME and OM digestibility than the original barley grain and all sprouting cultivars harvested at 12 days (Table 2). There was a 16, 7 and 4% increase in ME, OMD and GP contents in sprouting barley Ardhaoui after germination for 8 days. The ME and OM digestibility of fodder barley G12 were lower due to its higher NDF and ADF content (Table 2). The ME and OMD of different barley sprouts G12 varied from 74-84% and 2.78-3.16 Mcal kg^{-1} DM, respectively. The fibre itself was not better digested, however, the reduced fibre content enhanced the availability of rumen microbiota and digestive enzymes to their substrates. Bouajila *et al.*[11] reported a high phytase activity markedly during the 8th day of germination ($p<0.05$) in all barley cultivars, accompanied by a significant decrease in phytate content (anti-nutrient) (1.01 mg g^{-1}) particularly sprouts Ardhaoui showed the maximum increase in phytase activity (7.72 U kg^{-1}). Accordingly, the differences in gas production, ME and OMD between barley sprouting cultivars are caused by variations in their chemical composition, especially water-soluble carbohydrates and fibre fractions[29]. The high gas production is attributed to readily fermentable substrates (fodder)[30]. Many studies have shown an increase in lysine with sprouting through transamination of amino acids of prolamins after its degradation. This may be an indication of the benefit of the bacterial microbiota of ruminants. There is conflicting evidence that sprouting improves or reduces OM digestibility. Our study showed that gas production, ME and OMD values of sprouted barley G8 are higher compared to results cited by Al-Baadani *et al.*[18]. Similarly, numerous studies reported that sprouted grains increased nutrient digestibility compared to barley grain[31]. This discrepancy can be caused by the barley cultivars and their growing conditions (lighting: 615 lux or 100,000 lux, sowing time, number of irrigation, Temperature) in commercial operators or traditional culture, chemical composition, incubation time, source and composition of rumen liquor used in vitro conditions. Thus, the barley sprouting cv "Ardhaoui" was the most promising in terms of the feeding value of the fodder (GP, ME, OMD at G8) followed by Rihane-Souihli and Arbi, hence, it could be recommended as a more suitable candidate in the diet of livestock, particularly in the arid regions of Tunisia. Furthermore, the sprouting barley Ardhaoui G8 showed a 48 and 21% increase in ME content and OM digestibility, respectively based on the comparison of our results with literature data of cactus forages (*Opuntia ficus indica*) (1.91 Mcal kg^{-1} DM ME, 73.8% OMD)[32,33]. Ben Salem *et al.*[34], reported that cactus pads contain a large number of soluble carbohydrates and a lower value of fibre digestibility mainly this composition has a depressing effect on the gut microbiota of ruminants. Furthermore, plant feeds exhibited the presence of anti-nutrients such as saponins and tannins[35] that causes less nutrient digestibility[36]. The gut microbiota, whilst is playing an essential role in the maintenance of the health of the host. Further research permitted to investigate of the relationship between bioactive compounds, dietary fatty acids, microelements of sprouting barley and other feed ingredients and microbiota that pose important biological activities, including antioxidant, antimicrobial activities and performance of ruminants.

CONCLUSION

Hydroponic technology fully automated (the irrigation systems and ventilation, thermal screens for the control of the illumination, lighting) is needed in arid regions of Tunisia because of the advantages of using less water and gaining increased productivity. Results presented herein have shown a maximum ($p<0.05$) of nutritional value (macro elements and crude protein, fibre)in sprouting barley cv on the 8th day of harvesting. There is a 16, 7 and 4% increase in ME, OM digestibility and GP of sprouting barley Ardhaoui pronounced on the 8th day of germination compared to the original barley grain. This source of energy (3.8 Mcal kg^{-1} DM) and crude protein (21%) of Ardhaoui G8 may reduce the use of concentrated feeds and expensive fodder crops and raise ruminant production in dry areas.

SIGNIFICANCE STATEMENT

This study discovered that sprouting of local barley cultivar "Ardhaoui" with high nutrient value and OM digestibility can be used as an alternative source of energy and protein in diet ruminal in arid regions.

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