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Forage production and nutritional content of silage from three varieties of pearl millet (*Pennisetum glaucum*) harvested at two maturity stages

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1 ABSTRACT

The aim of this study was to evaluate the production and nutritive value of silage of three varieties of pearl millet (*Pennisetum glaucum*) harvested at two stages of maturity. The study was conducted in the semiarid region of Northern Mexico under temporary conditions with three varieties of pearl millet (ICMV-221, ICMV-7704 and HHBVC Tall). Four samples of forage for each variety were harvested at flowering and grain-filling stages. The production of dry matter *per* hectare was determined and the samples were ensiled in bags until the analyses for nutritional value (dry matter content, crude protein, soluble protein, available protein, fibre, digestibility, energy, non-structural carbohydrates and minerals) determined by the NIRS method (Near Infrared Reflectance Spectroscopy). The production of dry matter *per* hectare did not differ among the varieties ($P<0.05$). The content of crude protein was higher in flowering stage ($P<0.05$), meanwhile, the dry matter content and non-structural carbohydrates were higher in the grain-filling stage; but these variables were not affected by the variety ($P>0.05$). The content of fibre and minerals, digestibility and energy values did not differ between stage of harvest or among varieties ($P>0.05$). The study concluded that any of the varieties of pearl millet tested could be ensiled without reducing production or nutritional content in semi-arid conditions in northern Mexico.

2 INTRODUCTION

In the arid and semi-arid regions of northern Mexico, the seasonal drought reduces for long period of time the quantity and quality of the browsing vegetation available, causing a recurrent state of undernourishment in the animals (Echavarría *et al.,* 2006). In animals, when nutritional requirements are not meet, they start using their body reserves, which adversely affect body weight, body condition and productive and reproductive efficiency (Rosales Nieto *et al.,* 2011). Alternatively, supplementation with harvested traditional forages (e.g. maize and/or sorghum) during the critical period is a strategy that contributes to keep the animals in a desired nutritional status that would help them to achieve acceptable levels of productivity. However, traditional forage production is constantly affected by erratic distribution of precipitation and presence of early frosts (Villanueva *et al.,* 2001). Thus, in this region is required a forage species with low water requirements and with the ability to be harvested in short period and with good nutritional value for livestock. The pearl millet (*Pennisetum americanum*) is a cereal with low water requirement, high precocity (Hernández *et al.,* 2009) and nutritional value (Urrutia *et al.,* 2014). In several countries, pearl millet is harvested primarily for grain, but is also used for forage production. Recent studies, under a scheme of low precipitation, have shown that pearl millet produces more dry matter and gross energy than traditional forage such as maize or sorghum (Hernández *et al.,* 2007). In addition, it has been demonstrated that in semiarid conditions pearl millet attains early maturity and can be harvested 25 days before maize or sorghum (Hernández *et al.,* 2009). Additionally, pearl millet is a highly prolific species because each plant, depending on variety and environmental conditions, can produce up to six tillers at different stages of development (Maiti and Bidinger, 1981; Amodu *et al.,* 2001; Akmal and Sulfikar, 2002; Hernández *et al.,* 2013). In the semi-arid conditions in northern Mexico, the production and nutritive value of hay and fodder of the variety ICMV-221 of pearl millet (Hernández *et al.,* 2007) and the quality of ensilage harvested at different stages of maturity have been evaluated (Urrutia *et al.,* 2011). However, it is not known whether the nutritive value of pearl millet depends on whether the variety is selected for production of forage, grain or dual purpose. Therefore, the objective of this study was to evaluate the production and nutritive value of silage of three varieties of pearl millet selected for dual purpose (grain and forage) or grain and harvested at flowering or grain filling.

3 METHODOLOGY

3.1 Experimental Conditions: The study was conducted during spring-summer under semiarid conditions in 2011 at the county of El Zapotillo in San Luis Potosi, Mexico (Latitude 22° 25' 53" N; Longitude, 100° 42' 01" W, 1700 MAMSL; INEGI, 2009). According to Köppen classification, the weather is considered as steppe cold dry (García, 1973). The average annual temperature is 17.8 °C (range -9 to 36 °C) and annual precipitation of 341.0 mm; which 82% of the precipitation is concentrated from May to October (Medina *et al.,* 2005). The soil is classified as vertisol with clay texture (INEGI, 1988).

3.2 Varieties and Crop management : The varieties ICMV-7704 (dual purpose; grain-forage), HHBVC Tall (dual purpose; grain-forage) and ICMV-221 (grain) of pearl millet were used. Each variety was established in a plot of 300 m^2 (8 furrows of 45 m long). The sowing was done under semiarid conditions in furrows at distance of 83 cm and the separation between plants was 10 cm (120,000 plants ha^{-1}). Fertilizer was applied at ratio of 40 kg of nitrogen and phosphorus, respectively. During the agricultural cycle, the crop received 186 mm of precipitation and the average temperature was 19.2°C.

3.3 Harvest and Forage Management: Forage harvest was done at two stages of maturity; when more than 50% of the plants attained the flowering stage or the grain-filling stage in each plot per variety were harvested. A total of eight samples at random per variety were collected; four samples at flowering and four samples at grain-filling. Each sample consisted of the total forage presented in three furrows of five meters long excluding the edge of the crop. Immediately after harvesting, the forage was weighed and chopped at ratio of 5 cm length with a silage maker (Azteca®) equipped with gasoline engine. A sample (approximately 10 g) of chopped forage was collected to determine the dry matter content by dehydrating the sample at 100 ºC for 15 min with a moisture analyser OHAUS® (model MB35). These data was used to determine the production of dry matter per hectare. The rest of the chopped forage was ensilaged manually in plastic bags (60 x 90 cm and calibre of 300) and kept in shade until nutritive analysis. No additives or inoculants were added.

3.4 Lab analyses: Ensilage bags were opened 45 days after and a sample of silage was taken (approximately 300 gm) from the centre of the bag. The samples were properly labelled and sent to the lab to determine the content of protein (crude protein, soluble protein, degradable protein), carbohydrates (non-structural carbohydrates, water-soluble carbohydrates), crude fat, fibre (acid detergent fibre, neutral detergent fibre, lignin, lignin linked to neutral detergent fibre), digestibility (in vitro digestibility at 30 hours, total digestible nutrients), energy (net energy for lactation, net energy for maintenance, net energy for gain, metabolizable energy) and minerals (phosphorus, calcium, magnesium, potassium, chloride and sulphur). Samples were analyzed on a computer NIRS 5000 (FOSS®) at the lab of the Ganadera de Aguascalientes S.A. de C.V. (FOGASA). The NIRS 5000 was calibrated with the following proceeding: a) samples selected at random, b) analyses by primary methods, c) reading of spectra from the same samples in the equipment NIRS, d) adjust of curves e) validation of curves (comparing the results obtained by methods b and c). To determine the nutritional values, an equation of prediction based on the data generated by the Dairy One Cooperative Incorporation was used.

3.5 Statistical analyses: Statistical analyses were performed using JMP Star Statistics version 4.0.3 Academic (SAS Institute, 2000). The data were analysed in completely randomized design with a 3 X 2 factorial; where Factor A were three varieties of pearl millet (ICMV-7704, HHBVC Tall and ICMV-221), Factor B were two stages of maturity (flowering and grain-filling) and with four repetitions. Tukey test was used to compare means at the same level when statistical difference was detected ($P < 0.05$). Two-way interactions were included in the analyses.

4 RESULTS

4.1 Dry Matter Production: At the experimental location, 186 mm of precipitation was recorded that were distributed from July to October. The samples at flowering stage were collected between 27 and 28 days before the samples at grain-filling stage were collected (Table 1). On average 2.4-ton ha^{-1} of dry matter were produced among varieties and between harvest stages.

Table 1: Dry matter production (Ton ha^{-1}), sow and harvest date, days at harvest and water available during the growth period of plants of three varieties of pearl millet and harvested at two stages of maturity.

Variety	Stage	Ton ha^{-1}	Sow date	Harvest date	Days at harvest	Water available (mm)
ICMV-221	Flowering	2.35±0.61	12-jul	08-sep	59	173.6
	Grain-filling	2.35±0.47	12-jul	06-oct	86	182
HHBVC	Flowering	2.76±0.51	12-jul	21-sep	71	173.6
	Grain-filling	2.51±0.50	12-jul	19-oct	99	186.4
ICMV-7704	Flowering	2.38±0.37	12-jul	21-sep	71	173.6
	Grain-filling	2.16±0.62	12-jul	19-oct	99	186.4

4.2 Silage Nutritive Value: On average, the dry matter content in silage at flowering stage was 21.8% and 29.5% at grain-filling stage (Table 2). Dry matter content in silage differ between harvest stage ($P < 0.05$), but not among varieties or the interaction between varieties and harvest stages ($P > 0.05$; table 2). The percentage of crude protein ($P < 0.05$), degradable protein ($P < 0.005$) in silage differ among varieties; but the rest of the variables did not differ ($P > 0.05$; table 2). The percentage of crude protein ($P < 0.001$), soluble protein ($P < 0.05$), non-structural carbohydrates ($P < 0.001$) and crude fat ($P < 0.05$) differ between harvest stages; but the rest of the variables did not differ ($P > 0.05$; table 2). The interaction between varieties and harvest stages differ only for soluble protein and degradable protein ($P < 0.05$); but not for the rest of the interactions ($P > 0.05$).

Table 2: Nutritive value (dry mater [DM], protein [crude protein, soluble protein), of silage from three varieties of pearl millet (ICMV-7704, HHBVC Tall and ICMV-221) harvested at two stages of maturity (flowering and grain filling). Values are expressed in percentage.

Variable	ICMV-221		HHBVC-Tall		ICMV-7704	
	Flowering	Grain-filling	Flowering	Grain-filling	Flowering	Grain-filling
Dry matter	20.8±2.5^{a}	27.7±2^{b}	21.9±1.2^{a}	30.4±2.3^{b}	22.8±0.5^{a}	30.4±3.4^{b}
Crude protein	16.1±1.5^{a}	12.2±0.7^{b}	14.4±2.9^{ab}	12.4±0.4^{b}	17.1±1.5^{a}	14±0.9^{ab}
Soluble protein	62.0±2.9^{b}	67.7±2.2^{ab}	72.0±3.5^{a}	63.7±6.3^{ab}	70±3.1^{a}	61.7±3.7^{b}
Degradable protein	75.7±1.5^{c}	79.7±2.3^{abc}	84.0±1.8^{a}	80.7±2.5^{ab}	83.5±2.1^{ab}	79±2.7^{bc}
Non-structural carbohydrates	13.7±4.9^{c}	24.6±4^{ab}	17.6±2.0^{bc}	21.5±2.6^{ab}	14.1±1.5^{c}	19.9±4^{abc}
Water-soluble carbohydrates	4.0±3.5^{a}	7.4±2.6^{a}	9.3±5.3^{a}	8.7±2.2^{a}	6.2±1.6^{a}	9.4±1.2^{a}
Crude Fat	3.6±0.7^{ab}	3.3±0.29^{ab}	3.1±0.21^{ab}	2.9±0.1^{ab}	3.7±0.3^{a}	2.7±0.6^{b}
Acid detergent fibre	35.8±3.2^{a}	33.9±3.1^{a}	35.2±3.3^{a}	36.6±4.7^{a}	34.2±1.9^{a}	35.9±0.9^{a}
Neutral detergent fibre (NDF)	59.1±5.1^{a}	52.9±3.8^{a}	57.6±2.9^{a}	57.6±2.1^{a}	58.2±2.7^{a}	57.6±2.1^{a}
Lignin	3.9±0.6^{a}	3.7±0.8^{a}	3.3±0.6^{a}	3.3±0.5^{a}	3.6±1.3^{a}	3.8±0.6^{a}
Lignin linked to NDF	6.8±1.6^{a}	6.9±1.5^{a}	5.8±1.4^{a}	5.6±0.8^{a}	6.3±2.2^{a}	6.6±0.9^{a}

^{abc} Means with the different letter are significantly different ($P < 0.05$); means with similar letter are not significantly different ($P > 0.05$).

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The in vitro dry matter digestibility, percentage of total digestible nutrients and content of energy in dry matter did not differ among varieties and between harvest stages (P > 0.05; table 3). Neither the interaction between varieties and harvest stages was significant for any of these variables (P > 0.05).

Table 3: Percentage of in vitro dry matter digestibility, total digestible nutrients and content of energy (expressed in Mcal Kg-1) in silage from three varieties of pearl millet (ICMV-7704, HHBVC Tall and ICMV-221) harvested at two stages of maturity (flowering and grain filling).

Variable	ICMV-221		HHBVC-Tall		ICMV-7704	
	Flowering	Grain-filling	Flowering	Grain-filling	Flowering	Grain-filling
In vitro dry matter digestibility	83±3[a]	84±2[a]	84±3[a]	83±1[a]	84±1.3[a]	82±1[a]
Total digestible nutrients	60±3[a]	63±3[a]	62±2[a]	63±2[a]	62±2[a]	61±2[a]
Net energy for lactation	1.2±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.2±0.1[a]
Net energy for maintenance	1.2±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.3±0.1[a]	1.3±0.1[a]
Net energy for gain	0.7±0.1[a]	0.7±0.1[a]	0.7±0.1[a]	0.7±0.1[a]	0.7±0.1[a]	0.7±0.1[a]
Metabolizable energy	2.3±0.1[a]	2.4±0.1[a]	2.3±0.1[a]	2.4±0.1[a]	2.4±0.1[a]	2.3±0.1[a]

[abc] Means with the different letter are significantly different (P < 0.05); means with similar letter are not significantly different (P > 0.05).

The content of ash in silage differ between harvest stages (P < 0.05); but was similar among varieties (P > 0.05). The interaction between varieties and harvest stage was not significant for the content of ash in silage (P > 0.05; table 4). The concentration of minerals in silage among varieties and between harvest stages was similar (P > 0.05); but, the concentration in silage of potassium was higher (P < 0.05; table 4) and phosphorus tended to increase (P=0.057) at the flowering stage in the three varieties. The interaction between varieties and harvest stage was not significant for the concentration of mineral in silage (P > 0.05; table 4).

Table 4: Content of ash and minerals in silage from three varieties of pearl millet (ICMV-7704, HHBVC Tall and ICMV-221) harvested at two stages of maturity (flowering and grain filling). Values are expressed in percentage.

Variable	ICMV-221		HHBVC-Tall		ICMV-7704	
	Flowering	Grain-filling	Flowering	Grain-filling	Flowering	Grain-filling
Ash	10.5±1.0[a]	9.0±1.2[ab]	9.1±1.4[ab]	7.6±1.3[b]	9.4±0.7[ab]	7.8±1[b]
Phosphorus	0.5±0.1[a]	0.4±0.1[a]	0.4±0.9[a]	0.4±0.1[a]	0.5±0.1[a]	0.4±0.0[a]
Calcium	0.4±0.1[a]	0.2±0.1[a]	0.4±0.2[a]	0.3±0.1[a]	0.3±0.1[a]	0.3±0.1[a]
Magnesium	0.4±0.1[a]	0.3±0.1[a]	0.4±0.1[a]	0.4±0.1[a]	0.3±0.1[a]	0.4±0.0[a]
Potassium	4.1±0.6[a]	2.9±0.7[b]	3.7±0.4[ab]	2.6±0.5[b]	3.7±0.2[ab]	2.9±0.5[b]
Chloride	0.9±0.7[a]	0.8±0.2[a]	0.6±0.2[a]	0.7±0.1[a]	0.7±0.2[a]	0.6±0.1[a]
Sulphur	0.2±0.0[a]	0.1±0.0[a]	0.2±0.0[a]	0.2±0.0[a]	0.2±0.0[a]	0.2±0.0[a]

[ab] Means with the different letter are significantly different (P < 0.05); means with similar letter are not significantly different (P > 0.05).

5 DISCUSSION

This study observed that the varieties ICMV-7704, HHBVC Tall and ICMV-221 of pearl millet could be harvested at flowering or grain filling and being ensiled without reducing production or nutritional content in semi-arid conditions in northern Mexico. Although, pearl millet has been tested for its capacity to produce grain (Hernández *et al.,* 2009) and forage (Urrutia *et al.,* 2011, 2014); this study results extend previous observations by Hernández *et al.* (2009) and Urrutia *et al.* (2011) in similar conditions on the potential of pearl millet to be used as forage, due to its nutritive value, to feed animals under extensive conditions in northern Mexico. In addition, we observed that pearl millet has the capacity to produce, with less than 175 mm of precipitation, more than 2.3-Ton ha^{-1} of dry matter with 14% of crude protein during the productive cycle. Previously, Hernández *et al.* (2009) observed that pearl millet has the capacity to produce grain in schemes of low precipitation (< 300 mm). The production of forage of pearl millet observed is surprising for the conditions on which the experiment was conducted. This is highly important because producers in the arid and semi-arid regions in northern Mexico, usually, sow maize and sorghum which water requirements are higher that the water requirements of pearl millet (Hernández *et al.,* 2013). Consequently, the crop of maize and sorghum, frequently, is lost due to drought or early frosts. Nevertheless, independently of the harvest stage, pearl millet is a highly viable option for producers in the arid and semi-arid regions in northern Mexico to obtain forage of good quality in schemes of low precipitation. Within the varieties tested of pearl millet, the variety ICMV-221 attains the flowering stage 12 days earlier than the other varieties. Although ICMV-221 is, primarily, use for grain production; its forage production and nutritive value in ensilage were similar to the other varieties for dual purpose (ICMV-7704 y HHBVC-Tall). These results indicate that ICMV-221 is a good alternative to use to produce forage in schemes of low precipitation such as the ones in the arid and semi-arid regions in northern Mexico. Therefore, in these conditions, selecting a precocious variety of forage would be a competitive advantage. Dry matter content did not differ between harvested stages. This was probably because only 12.8 mm of precipitation were recorded between harvested stages. In ensilage, the dry matter content increases as forage maturity advances (Meeske *et al.* 1993; Johnson *et al.,* 2003; Hassanat *et al.,* 2006; Urrutia *et al.,* 2011) and usually is recommended to ensilage forages with more than 30% content of dry matter (Bolsen *et al.* 1996). However, Hassanat *et al.* (2006) observed that the content of dry matter in ensilage of pearl millet varies from 19% to 24%. Nevertheless, pearl millet has the capacity to produce good amount of dry matter in a scheme of low precipitation. The content of crude protein was higher when the forage was harvested at the flowering stage rather than the grain-filling stage, regardless the variety. Our results are extended by previous studies (Amodu *et al.,* 2001; Hassanat *et al.,* 2006; Urrutia *et al.,* 2011). In pearl millet, Gupta and Pradhan (1975) observed a decrease of the 50% in the content of crude protein from the pre-flowering stage to the post-flowering stage. Interestingly, while in the ICMV-221 variety, the content of protein soluble and protein available decreased as forage maturity advanced; an opposite tendency was observed in the other two varieties (ICMV-7704, HHBVC Tall). This was probably because in varieties selected for grain production, the number of grains is higher than in the varieties selected for forage or dual purpose (Mendoza, 2014). In addition, the content of protein soluble and protein available is higher in grain rather than leaves or steams (Piccioni, 1970) and the ratio leave: stem is higher in the varieties selected for forage or dual purpose and lower in the varieties selected for grain (Mendoza, 2014). Nevertheless, in the regions of northern Mexico, harvest the pearl millet at flowering stage will increase the protein content in ensilage. In addition, the variety ICMV-221 appears to be the best economical option due to its precocious characteristic. Further studies are required to elucidate this conclusion. In general, the digestibility in silage observed in this experiment was more than 80% and it did not differ among varieties and harvested stages. This is surprising because varieties selected for forage production tend to increase the ratio leaf: stem; therefore, it was expected that the varieties HHBVC and ICMV-7704 had higher percentage of digestibility than the variety selected for grain (ICMV-221). Similarly, it was expected that the samples harvested at flowering stage had higher percentage of digestibility than the samples harvested at grain filling. Our results counter with previous observations; where digestibility of 65% was observed when the pearl millet was harvested at boot and dough grain and where the digestibility tended to decrease as forage maturity advanced (Urrutia *et al.,* 2011; 2014). The expected decrease in digestibility is, probably, due to the translocation of nutrients from the leaves and stems to development flowering and grain filling (Center *et al.,* 1970) and the gradual process of lignification of the plants as maturity advances (Jung and Vogel, 1992). The energy content in ensilage was not affected by the variety or harvest stage. Our results indicate that pearl millet provides adequate levels of energy, which constitutes a feasible option as supplement for animals during the drought in the arid and semiarid region of Northern Mexico. Moreover, the concentration of non-structural carbohydrates in silage differs between harvest stages, regardless the variety. This was, probably, due to the presence of grains in the panicle because grains are primarily formed by soluble carbohydrates. On the other hand, the concentration of minerals in silage was not influenced by the variety or harvest stage. We observed that the calcium levels were lower than the required in ruminants (Suttle, 2010); which will be necessary to provide an additional source of calcium. We conclude that any varieties of pearl millet tested in this experiment are suitable in these conditions for ensilage. Furthermore and regardless the variety, the quality of silage obtained at flowering stage suggests that this stage of maturity is, probably, the best time to harvest the pearl millet. In addition, harvest at flowering stage reduce the agricultural cycle and consequently reduce the risks of lost due the early frosts and opens the possibilities to obtain a second harvest, when the conditions of temperature and precipitation are adequate.

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