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Inclusion of amaranth (*Amaranthus* sp.) as a protein source in the diets of lactating dairy goats

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ABSTRACT

Objective: To determine the productive performance and milk quality of goats, including two levels of popped amaranth in their diet.

Methodology: Forty-five lactating goats, randomly distributed into three groups of 15, were studied. Each group was allocated a treatment that matched the isoenergetic and isoproteic diets with increasing percentages of popped amaranth grain, in replacement of soybean meal: T1, 0%; T2, 20%; and T3, 30%. Data were collected across three intervals during the 45-day experimental period. Milk production was recorded, along with its crude protein (CP), fat, and total solids (TS) content.

Results: Milk production differed significantly ($p<0.05$) between treatments, increasing as the amount of amaranth in the diet increased, with values of 1.35, 1.38, and 1.65 kg d^{-1} for T1, T2, and T3, respectively. Milk composition did not record any difference between treatments, with averages of 28.07, 32.89, and 113.7 g kg^{-1} of milk for crude protein (CP), fat, and total solids (TS), respectively.

Study Limitations/Implications: Given the exploratory nature of this study, determining the functional components of milk is required to complement the study.

Conclusions: Amaranth grain can be used as a protein source in animal feed. Including 30% of amaranth in the diet of dairy goats has been proven to increase production compared to conventional protein sources. However, no changes were observed in the main milk components.

Keywords: Goats, milk, amaranth, protein, family production.

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INTRODUCTION

Both amaranth and goat milk significantly benefit human nutrition, as a result of their nutritional value, the presence of functional compounds that promote health, and the diversity of their by-products. However, their production and effective dissemination must be promoted to encourage their consumption (Ayala *et al.*, 2016). According to SIAP (2024), amaranth is produced in six states of central Mexico, with 3,173.21 ha harvested in 2023 and a yield of 5,660.81 tons of grain —88.25% of which was produced in Puebla

and Tlaxcala. The grain is mainly popped with heat to produce traditional sweets (Espitia, 2012). The unpopped grain and/or residual popped grain is an important protein source in family production units that raise animals, such as dairy goats.

Studies on the use of amaranth to feed ruminants have primarily focused on the use of the plant as fresh and ensiled forage or as stubble. Peiretti (2018) determined that amaranth has high nutritional value both as forage and grain, partly attributed to the fact that its protein is resistant to ruminal degradation. However, this author also mentions that, depending on the amaranth species and the plant's vegetative stage, forages can include antinutritional compounds, such as tannins, saponins, lectins, and trypsin inhibitors. These compounds are reduced during the ensiling process and when the grain is subjected to the heat treatment.

Consequently, feeding dairy goats amaranth grain by-products, foliage, and crop residues is a potential strategy for the comprehensive use of the crop to generate healthy and nutritionally valuable products. To date, the use of amaranth grain in ruminant feeding has been the subject of a limited number of studies. Therefore, the objective of this study was to determine the productive response and milk quality of goats, resulting from the inclusion of two quantities of popped amaranth in their diet.

MATERIALS AND METHODS

Experiment location

The study was conducted in the municipality of Libres, Puebla, where goat milk production is a traditional and important activity, predominantly carried out in family production units. It is located at 19° 27' 38" N and 97° 38' 57" W, at 2,357 m.a.s.l. The prevailing climate is semiarid with summer rains, an annual precipitation that can range from 400 to 800 mm, and an average monthly temperature of 12 to 18 °C (INEGI, 2023).

Animals used and treatments

Forty-five dairy goats representative of the region were used. They included multiparous specimens from crossbreeds of the Alpine French and Saanen breeds, with 90 ± 10 days of lactation, and an average weight of 45 ± 6 kg. Prior to the experiment, they were internally dewormed and randomly distributed into three homogeneous groups of 15 animals. Each group was fed a diet with a different percentage of amaranth, according to the treatments evaluated: T1, 0%; T2, 20%; and T3, 30%. Amaranth replaced soybean meal as the primary conventional protein source. The amount of feed provided to the goats was estimated at 4% of live weight (1.8 kg goat^{-1} day^{-1}). Commercial mineral salts were mixed into the feed and water was provided *ad libitum*.

The popped amaranth was purchased in the municipality of Altzayanca, Tlaxcala, and the other ingredients were sourced from regional distributors. The isoenergetic and isoproteic diets (Table 1) were formulated for dairy goats, according to the nutritional requirements for the second third of the lactation period (NRC, 2001).

The experimental diet was analyzed following the AOAC methods (2007). Dry matter (DM) content was determined drying the sample in a forced-air oven for 24 hours at 105 °C. Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were analyzed according to

Table 1. Percentage composition and nutritional value of the diets with amaranth provided to dairy goats.

Diet Composition (%)	T1=n15	T2=n15	T3=n15
Ground corn stover	63	60	60
Amaranth	0	20	30
Soybean meal	17	10	7.5
Dried orange peel	17.5	7.5	0
Urea	0.5	0.5	0.5
Minerals	2	2	2
Total	100	100	100
MS (%)	91.6	91.4	92.1
PC (%)	14.5	14.4	14.4
PD (%)	70	70	70
PND (%)	30	30	30
ENL (Mcal/kg)	1.64	1.62	1.63
EM (Mcal/kg)	2.6	2.6	2.6
TND	71.9	72.1	72.1
FDN	57.6	57.1	56.2
FDA	24.3	23.6	23.8
Ca	0.8	0.8	0.8
P	0.4	0.4	0.4
Non-protein nitrogen (NPN)	0.07	0.07	0.07

DM (MS)=dry matter; CP (PC)=crude protein; DP (PD)=degradable protein; UDP (PND)=undegradable protein; NEL (ENL)=net energy for lactation; ME (EM)=metabolizable energy; TDN (TND)=total digestible nutrients; NDF (FDN)=neutral detergent fiber; ADF (FDA)=acid detergent fiber.

the method of Van Soest *et al.* (1991). Crude protein (CP) content was obtained using the Kjeldahl method, proc. 988.05 (AOAC, 2000), ether extract (EE) was determined using the Soxhlet method, proc. 920.39 (AOAC, 2005), and ash content was measured using a muffle furnace at 550 °C, proc. 942.05 (AOAC, 2000).

Experimental period and goat management

The 45-day experiment was divided into three 15-day measurement periods. During the 10-day adaptation period to which all goats were subjected, the amounts and ratios of diet ingredients were gradually adjusted for each group. The feed was offered twice daily (at 8:00 a.m. and at 4:00 p.m.). Water was provided *ad libitum*. The animals were housed in comfortable pens that protected them from external factors. They were milked manually once a day between 7:00 and 8:00 a.m.

Variables evaluated

Dry matter intake (DMI). The weight of feed offered (FO) and feed refused (FR) was recorded daily for each group of goats, using a Wild® electronic scale with a capacity of 200 kg. The daily dry matter intake (DMI) was calculated as the difference between FO and FR and the result was then divided by the 15 goats to estimate their individual daily intake (kg day^{-1}).

Milk production. Each goat was measured individually on two consecutive days, at the start of the experiment and again in each experimental period. On the first measurement day of each experimental period, 150 mL milk samples were collected from each goat, placed in a cooler at 4 °C, and transported to the laboratory of the Faculty of Agricultural and Livestock Sciences of the Benemérita Universidad Autónoma de Puebla for its analysis. Chemical composition of the milk. The evaluated variables were crude protein (CP), fat, and total solids content. CP was measured using the Kjeldahl method, proc. 988.05 (AOAC, 2000). Fat content was determined using the Goldfisch method, proc. 989.05 (AOAC, 2000). For total solids (TS), 20 mL milk samples were placed in Petri dishes and weighed on a digital scale. The samples were then placed in a forced-air oven for 48 hours at 60 °C. Finally, the following equation was used:

$$TS=(m1-m)/(m2-m)*100$$

where: $m1$=weight of the Petri dish with solids, $m2$=weight of the Petri dish with milk, and m=weight of the empty Petri dish (NOM-116-SSA1-1994).

Statistical analysis

A completely randomized experimental design with three treatments and seven replications was used for this study. The results were analyzed using the GLM procedure of the Statistical Analysis System software (SAS, 2002). An analysis of variance was performed for each recorded variable, followed by a comparison of means using Tukey's test ($p<0.05$). For the intake variables, a repeated measure analysis of variance was conducted over three periods.

RESULTS AND DISCUSSION

Dry matter intake

Dry matter intake (DMI) was similar ($p>0.05$) between the treatments evaluated, with an average of 1.79, 1.76, and 1.60 kg day^{-1} for T1, T2, and T3, respectively. However, there were significant differences ($p<0.05$) in the first and second intake periods (Table 1). The DMI decrease in T3 (which included 30% amaranth) may have been caused by the palatability of amaranth, as it is known to contain phenolic compounds and phytic acid (Solano, 2002), which could cause animals to initially reject it. However, the results of the study did not reflect this effect, possibly because the animals fully adapted to the palatability of amaranth over time, making all diets equally consumable and accepted by the goats.

With the average daily intake per animal of 1.71 kg of DM, the experiment recorded a daily intake per animal of 246 g of CP, 972 g of NDF, and 4.45 Mcal of ME. These results match the findings of other authors who used a different set of ingredients (Martínez *et al.*, 2012; Emami *et al.*, 2016; Rúa *et al.*, 2017). This reference supports the findings of this study.

Table 2. Dry matter intake of lactating dairy goats fed diets with increasing levels of amaranth (kg day^{-1}).

Period*	T1=n15	T2=n15	T3=n15	DSH (0.05)
1	1.89[a]	1.91[a]	1.72[b]	0.21
2	1.92[a]	1.89[a]	1.65[b]	0.29
3	1.56[a]	1.49[a]	1.44[a]	0.10
Average	1.79[a]	1.76[a]	1.60[a]	0.20

* 15-day period; T1: 0%, T2: 20%, T3: 30% (amaranth). HSD (DSH)=Honest Significant Difference (0.05). Means with the same letter are not significantly different.

The main protein source used in milk production is soybean meal. Completely replacing soybean meal with amaranth would not be feasible, given the economic implications of this proposal. At current prices, a kilogram of soybean meal costs MXN$13.10 and contains 42% protein, while amaranth costs MXN$35.00 per kilogram and contains 17% protein. Soybean protein costs MXN$30.95 per kg, while amaranth protein costs MXN$176.00. However, the purpose of this proposal is to provide information for production units, workshops, or industries where amaranth residues are generated.

Milk production

Significant differences ($p<0.05$) were observed in milk production among the treatments. T3 recorded the highest milk production ($p<0.05$) at 1.65 kg day^{-1}, recording an increase of 18% and 16% compared to T1 and T2 (1.35 and 1.39 kg day^{-1}, respectively). Meanwhile, T2 had a 3.0% difference ($p<0.05$) with regard to the control treatment (Figure 1). This response is likely due to the high digestibility (93%), balanced amino acid composition (Pisarikova *et al.*, 2006), and greater supply of limiting amino acids (*e.g.*, lysine and methionine) of amaranth protein (Algara *et al.*, 2016). Other qualities of amaranth protein —such as its carbohydrate content and functional compounds— may positively impact the animal's health and the quality of the milk produced. Arco *et al.* (2017), Sari *et al.* (2009), and other authors have studied alternative feeding sources, finding the same

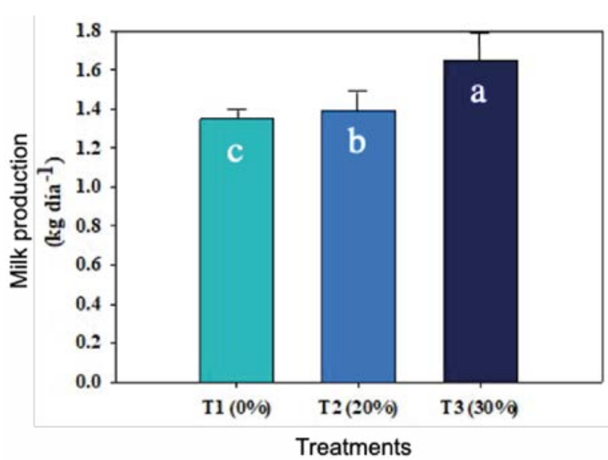

Figure 1. Milk production (kg day^{-1}) of goats fed increasing amounts of amaranth. Letters (a, b, c)=($p<0.05$). The lines above the bars belong to the standard deviation.

range of values as those of this study; those studies have thereby expanded the knowledge about the potential use of other local resources for milk production.

Physicochemical quality of goat milk

Table 3 shows the chemical composition, including no differences (P>0.05) between treatments. Based on the comparison of the data obtained in this experiment with the NMX-F-728-COFOCALEC-2007 standard —which specifies that goat milk must contain a minimum of 28% protein and 30% fat—, values fall within the parameters of this standard, except for T3, which has a slightly lower protein content.

Crude protein (CP)

In their analyses of several studies, Morand-Fehr *et al.* (2007) mention that the protein content in milk does not record great variability between different feeding systems and seasons of the year. The change of ingredients reflects this principle and the recorded values are similar to those reported in other studies (Avondo *et al.*, 2015; Schmidely and Andrade, 2011).

Fat

Milk fat is a component that can be manipulated based on the diet provided to goats and cows, with a greater response to fiber content. (Morand-Fehr *et al.*, 2007). In this study, the source and amount of fiber in the diet were consistent across treatments and, consequently, the fat content remained acceptably similar between the three treatments.

The fat yield reported in this study was similar to the results (32 g kg^{-1}) reported by Avondo *et al.* (2015), who included broad beans (*Vicia faba*) in the diet of Girgentana goats. Similarly, Shi *et al.* (2015) reported slightly lower fat yields (29.7 g kg^{-1}) in Xinong Saanen goats fed 30 g kg^{-1} DM of extruded flaxseed.

Total solids (TS)

The total solids (TS) in milk match the sum of its main components: protein, fat, lactose, and minerals. On the one hand, the values found in this study are similar to those reported by Caroprese *et al.* (2016), who recorded 130.5 g kg^{-1} in grazing Garganica goats supplemented with 0.15 kg day^{-1} of flaxseed. On the other hand, Kholif *et al.* (2018) reported 124.0 g kg^{-1} of TS in Anglo-Nubian goats fed a diet containing 20% sesame seed meal. Both cases showed values similar to those reported in this study.

Table 3. Chemical composition of milk from goats fed increasing amounts of amaranth.

Content	T1=n15 0% amaranth	T2=n15 20% amaranth	T3=n15 30% amaranth
Protein (g kg^{-1})	28.4±12.67^{a}	28.17±1.78^{a}	27.5±1.30^{a}
Fat (g kg^{-1})	32.1±7.53^{a}	32.89±7.63^{a}	33.7±12.25^{a}
Total solids (%)	108.0±14.0^{a}	110.3±13.1^{a}	123.0±25.7^{a}

Means with the same letter are not significantly different (p>0.05).

CONCLUSIONS

In conclusion, amaranth grain is a viable alternative source of protein in animal feed. As the percentage of amaranth inclusion in the diet increased, milk production was significantly higher than with conventional sources. The feed intake in the evaluated treatments was similar and did not lead to changes in the milk components. An additional in-depth research should be conducted about the content of peptides, fatty acids, and other nutritional and healthy compounds that could benefit both consumers and the animals themselves.

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REFERENCES

Ayala, G. A., Espitia R. E., Rivas V. P., Martínez T. G., Almaguer V.G. Eduardo. 2016. Análisis de la cadena del valor de amaranto en México. *Revista Agricultura Sociedad y Desarrollo. Vol. 13*, No. 1. https://revista-asyd.org/index.php/asyd/article/view/280

SIAP. 2024. Servicio de Información Agroalimentaria y Pesquera. Gobierno de México. https://nube.siap.gob.mx/avance_agricola/ (consultada en abril 2024)

Espitia, R. E., 2012. Amaranto: ciencia y tecnología, México, INIFAP/SINAREFI, p. 354 (Libro Científico núm. 2).

Peiretti, P. G. 2018. Amaranth in animal nutrition: A review. *Livestock Research for Rural Development. Vol. 30*, No. 5. http://www.lrrd.org/lrrd30/5/peir30088.html

INEGI. 2023. Climatología. https://www.inegi.org.mx/app/mapas/

NRC. Nutrient requirements of dairy goat. 2001. 7th Revised Edition. Washington DC, USA: National Academy Press.

AOAC. Official Methods of Analysis. 2007. 18th Edition, Association of Official Analytical chemists, Gaithersburg, MD, USA.

Van Soest PJ, Robertson J B, Lewis B A. 1991. Methods for dietary fiber, neutral detergent fiber, and non starch polysaccharides in relation to animal nutrition. *Journal of Dairy Science*, 74, 3583-3597.

AOAC. Official Methods of Analysis.2000. 17th Edition, The Association of Official Analytical Chemists, Gaithersburg, MD, USA.

AOAC. Official method of Analysis. 2005. 18th Edition, Association of Officiating Analytical Chemists, Washington DC.

NORMA OFICIAL MEXICANA NOM-116-SSA1-1994, bienes y servicios. determinación de humedad en alimentos por tratamiento térmico.

SAS. 2002. User's guide. Statistics, SAS ver.9.0

Solano, J. R. 2002. Cuantificación del contenido de ácido fítico en cuatro harinas del grano de amaranto obtenidas con diferentes tratamientos y en el grano sin tratar. Universidad de El Salvador 10-42. Disponible en: https://ri.ues.edu.sv/id/eprint/6089/1/10103052.pdf

Martínez M. A, Gómez CP, Gómez CG, Juárez M, Pérez AL, Pérez HM, de la Fuente MA. 2012. Effects of feeding increasing dietary levels of high oleic or regular sunflower or linseed oil on fatty acid profile of goat milk. *Journal of Dairy Science*, 95, 1942-1955. DOI: 10.3168/jds.2011-4303

Emami A, Fathi Nasri M H, Ganjkhanlou M, Rashidi L, Zali A. 2016. Effect of promegranate seed oil as a source of conjugated linolenic acid on performance and milk fatty acid profile of dairy goats. *Livestock Science*, 193, 1-7. Doi: 10.1016/j.livsci.2016.09.004

Rúa B. C; Rosero N. R.; Posada O. S. 2017. Effect of production system on milk production and food consumption in goats. *Rev. MVZ Córdoba 22*(3):6266-6275. DOI: 10.21897/rmvz.1131

Pisarikova B, Zraly Z, Kracmar S, Trckova M, Herzig I. 2006. The use of amaranth (genus Amaranthus L.) in the diets for broiler chickens. *Veterinarni Medicina, 51*, 2006 (7): 399-407. Disponible en: https://www.agriculturejournals.cz/publicFiles/61171.pdf

Algara S. P., Gallegos M. J. Reyes H. J. 2016. El amaranto y sus efectos terapéuticos. *TLATEMOANI*, No 21. Pp 55-63. https://www.researchgate.net/publication/304251542_EL_AMARANTO_Y_SUS_EFECTOS_TERAPEUTICOS/citations#fullTextFileContent

Arco PA, Ramos ME, Yañez RD, Albecia L, Martin G A. 2017. Nutritive evaluation and milk quality of including of tomato or olive by- products silages with sunflower oil in the diet of dairy goats. *Animal Feed Science and Technology*, 232, 57-70. Doi: 10.1016/j.anifeedsci.2017.08.008

Sari M, Naserian AA, Valizadeh R. 2009. Effects of abomasal pectin infusion on milk production, digestion and nitrogen utilization pattern of lactating Saanen dairy goats. *Small Ruminant Research*, 84, 1-7. Doi: 10.1016/j.smallrumres.2009.02.009.

Avondo M, Pennisi P, Lanza M, Pagano, RI Valenti, B, Gregori, PD, Di Trana A. 2015. Effect of the aS1 - casein genotype and its interaction with dict degradability on milk production, milk quality, metabolic and endocrinal response of Girgentana goats. *Small Ruminant Research*, 123, 136-141.

Schmidely PH, Andrade PVD. 2011. Dairy performance and milk fatty acid composition of dairy goats fed high or low concentrate diet in combination with soybeans or canola seed supplementation, *Small Ruminant Research, Volume 99*, Issues 2-3. 135-142. Doi: 10.1016/j.smallrumres.2011.04.010

Morand-Fehr P, Fedele V, Decandia M, Le-Frileux Y. 2007. Inuence of farming and feeding systems on composition and quality of goat and sheep milk. *Small Ruminant Research* 68: 20-34. doi:10.1016/j.smallrumres.2006.09.019

Shi H, Luo J, Zhang W, Sheng H. 2015. Using safflower supplementation to improve the fatty acid profile in milk of dairy goat. *Small Ruminant Research*, 127, 68-73. dOI: 10.1016/j.smallrumres.2015.04.001

Widson. M. dos Santos, Guimarães G. A.C., De Caldas N. M.S., De Souza P. Á.M., Dos Santos P. E.V., Dos Santos K.M.O., Floren-tino E.R., Alonso Buriti F.C. 2023. Goat milk as a natural source of bioactive compounds and strategies to enhance the amount of these beneficial components. *International Dairy Journal* 137. doi.org/10.1016/j.idairyj.2022.105515

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