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REVIEW

Moringa oleifera: a forage resource for efficient livestock farming in tropical regions

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SUMMARY

Livestock feeding in tropical regions is based mainly on locally available forage resources. In most cases, these forage materials are not nutritionally optimal since they do not meet all the requirements of such animals. This generates imbalances or negative interactions between minerals, proteins, and energy, resulting in low productive parameters. In such conditions, it is essential to carry out strategic supplements, with adequate protein-energy levels, especially in times such as drought. In this sense, *Moringa oleifera Lam.* is recognized by various authors and institutions as a possible solution not only in animal feed but even in human nutrition, thanks to its enormous nutritional wealth. Additionally, its secondary metabolites regulate the fermentation conditions and the associations between some methanogenic bacteria and other microbes. Therefore, its inclusion in bovine diets reduces methane emissions (CH4) from these animals, aspects that are reviewed in this article.

Moringa oleifera: un recurso forrajero para una ganadería eficiente en las regiones tropicales

RESUMEN

La alimentación del ganado en regiones tropicales está basada principalmente en recursos forrajeros de disponibilidad local. En la mayoría de casos, estos materiales forrajeros nutricionalmente no son los óptimos puesto que no suplen la totalidad de los requerimientos de tales animales, lo cual genera desequilibrios o interacciones negativas entre los minerales, proteínas y energía, que termina con la expresión de bajos parámetros productivos. En tales condiciones es fundamental realizar suplementaciones estratégicas, con adecuados niveles energético-proteicos, especialmente en épocas como la sequía. En este sentido, *Moringa oleifera Lam.* es reconocida por diversos autores e instituciones como una posible solución no solo en la alimentación animal, sino que incluso en la desnutrición humana, gracias a su enorme riqueza nutricional; adicionalmente sus metabolitos secundarios regulan las condiciones de fermentación y las asociaciones entre algunas bacterias metanogénicas y otros microbios. Por lo cual su inclusión en dietas para bovinos reduce las emisiones de metano (CH4) por parte de estos animales, aspectos que son revisados en este artículo.

PALABRAS CLAVE

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INTRODUCTION

Alternative feeding in livestock production is based on providing food that can replace traditional ingredients, maintaining efficient nutrition while seeking to reduce production costs (Schrage, 2018). Feeding in intensive production systems represents at least 60% of the total costs of the final product, and the difference in this value between different regions is related to the variation in the availability of the ingredients used in the preparation of the diets (Hauschild *et al.*, 2010, p. 714-723). Adapting the feeding of farm animals to the regional and economic realities of producers is essential in the search for the viability of local production with forage species with recognized productive potential.

Livestock is conditioned to vegetable consumption, so that plants or non-traditional species, that are already used in animal feed, can be a way to optimize the animal production system in some regions. This occurs because these plant species are better adapted to local edaphoclimatic conditions, with lower production costs, escape the instability of prices of ingredients of traditional use, and do not generate direct pressure on food for people. Some of these species require less need for machinery, fuels, inputs, and fertilizers, and are grown in a production system that takes into account temporary polycultures, to protect the land (Schrage, 2018).

According to Reyes et al. (2006a, p. 231-242), the incorporation of tree and shrub species in animal production systems can be a viable alternative to improve land use and, at the same time, improve the diet of animals. Many of these plant species are easily propagated, do not require a high level of management, and also have leaves with higher levels of crude protein than other diets traditionally used in animal feed (Cabrera et al., 2019).

Foidl et al. (1999, p. 5), in the electronic conference of the Food and Agriculture Organization of the United Nations (FAO), point out that *Moringa oleifera* has great potential in animal and human food due to its nutritional content, possibility of use in animal production, and the fight against human malnutrition. This is possible because the plant has an interesting mineral profile in its different parts, in addition to natural antioxidants, vitamins, beta-carotenes, and proteins that contain essential amino acids (Okuda et al., 2001, p. 405-410; Moura et al., 2010). Furthermore, due to its great variety of phytochemicals (Falowo et al., 2018, p. 317-334), it also has medicinal properties, being used to combat various diseases (Gupta et al., 2018, p. 1-11). *M. oleifera* is also a source of latex for rubber and fuel, it has potential even in soil restoration as a form of green manure, as well as in cosmetology and soap production (González, 2012, p. 39-46). Other research shows an additional advantage of *M. oleifera* over other forage species such as leucaena (*Leucaena leucocephala* (Lam.) de Wit), which also has high crude protein, but does not have high levels of antinutritional factors, although there is speculation that *M. oleifera* can produce macrophets and give a bitter taste to milk, which is still under discussion. It is clear that *M. oleifera*, despite being a shrub, can be cultivated as a forage plant with high planting densities and with systematic cuts, which guarantee a high production of high-quality protein per hectare throughout the year. Additionally, its drying, crushing, and pelletizing are conceived to obtain raw materials for the preparation of balanced formulations for the production of meat, eggs, and milk (Schrage, 2018).

NUTRITION-REPRODUCTION BOVINE RELATIONSHIP

Livestock in Colombia is characterized by racial mixtures descended from animals with genetic traits different from our environment and therefore not adapted to the local. This leads in part to a deficit in productive and reproductive parameters, a situation that is potentiated by adverse environmental conditions, low quality of forages, and the lack of economic energy sources of high nutritional power, basically due to deficiencies, imbalances, or negative interactions between minerals, proteins, and energy. These deficiencies are serious in the offspring, especially due to the metabolic requirements in their physiological processes of growth, weaning, and entering puberty. In adult cows, these effects are observed mainly in pregnancy and lactation, causing silent or irregular heat, repetition of hot flashes, greater number of services per conception, and in the worst cases infertility (Perdomo *et al*., 2017, p. 19).

Among the factors that most affect the productivity and profitability of a livestock company is the reproductive efficiency of the herd (Bolívar *et al*., 2009, p. 14-23). If reproductive efficiency is low, the productivity and economic profitability of the livestock activity are compromised, increasing the production costs with the rise of the service period and therefore the calving interval, and simultaneously reducing the useful life of the bellies due to the consequent increase in the discard rate of the females (Flamenbaum & Galon, 2010, p. 36-41).

Nutrition also affects the productivity and profitability of a farm. Nutrition is the main factor influencing reproductive performance in mammals, being so the relationship between nutrition and fertility has been widely studied throughout the world, and it continues to be an area of strong research. In general, optimal nutrition will be reflected in a higher pregnancy rate, and better reproductive indices as long as the welfare of the animal and general management are adequate (Meléndez & Bartolomé, 2017, p. 407-417). It is clear that for there to be competitiveness and efficiency in a livestock production system, the cows must be cycling as quickly as possible to achieve the goal of any beef cattle production system or dual-purpose, which consists of the production of one calf per cow each year (Walsh *et al*., 2011, p. 127-138).

A frequent condition in herds of the tropics is the simultaneous deficiency of energy-protein in the postpartum period in cows from dual-purpose that calve very late in the rainy season or the beginning of the dry season. Blood chemistry findings suggest the aforementioned deficiency: in these conditions, the animals are exposed to very intense summers, which causes a decrease in the formation of propionic acid, a glucose precursor, being able to observe metabolic imbalances and reproductive problems associated with the lack of appetite due to heat stress and high circulating humidity (Góngora & Hernández, 2010, p. 141-151). In this sense, the nutritional effect has been studied in first-time and lactating cows, through energy supplementation for short periods (flushing) in anestrus, and with suboptimal body condition under grazing in native pastures. These studies found a good short-term response with the consequent reactivation of the cycle, thus achieving an improvement in the pregnancy rate and an increase in the number of deliveries (Domínguez *et al*., 2007, p. 37-50). Rúgeles (2001, p. 24-30) mentions that a large percentage of reproductive problems are related to the poor nutritional quality of the pastures, which have a low content of protein, calcium, and phosphorus, and the rations poor in protein, both of the true as non-protein nitrogen. These factors reduce digestibility, decreasing the flow of microbial protein, which results in a delay in the growth of heifers and a delayed restart of postpartum ovarian activity. On the other hand, the use of protein supplements in the diet of cows in the postpartum period increases the consumption of dry forages, which means that the total amount of energy must also be increased, while if they are supplied with large amounts of starch (energy only), forage intake is reduced by keeping the total energy in the diet the same or reduced (Campos *et al*., 2020, p. 10-27).

There are problems related to low and high body conditions (CC). The main problem is when cows have a CC below four on a scale of one to nine, triggering events such as lack of cyclicity, low conception rate, increased calving interval, and the incidence of weak calves. When the cow has a high CC, above eight, in addition to the problems similar to the low CC, there is a high cost of maintaining these cows in the herd. A low conception rate is an important factor in calf production. In cows with CC below four, the conception rate is drastically compromised (Granja *et al*., 2012, p. 458-472). Biehl *et al*. (2011, p. 335-364) mention that, on this same scale, it is recommended that the bellies have an average body condition between five to seven points. Likewise, it has been shown that inadequate nutrition can affect CC and consequently increase the incidence of anestrus and decrease the conception rate because the contribution of nutrients directly affects the reproductive organs (Granja *et al*., 2012, p. 458-472). Fertility is correlated with body weight, weight changes, and CC, that is, muscle, intramuscular fat, and subcutaneous fat (availability, reserve, and protein-energy interrelation). Therefore, the postpartum restart of ovarian activity is also correlated with the CC at the time of calving. Thus, cows with CC greater or equal to 2.5 on a scale of one to five show their heat earlier and vice versa (Salas *et al*., 2011, p. 385-392).

In the tropical environment, the management of bovine calves is related to environmental and nutritional factors, responsible for the initiation of reproductive function. So, if growth or daily weight gain (GDP) is affected, the age at first service will be modified, which in turn is correlated with factors inherent to the animal such as weight at birth and weaning, and, consequently, the same GDP, which in turn depends on the predominant breed type. This productive indicator is affected by the practices of the productive system such as pasture management and feeding, and by environmental factors like as the area and climate of the farm (González *et al*., 2007, p. 39-46). Females grazing in improved grass-legume pastures present higher conception rates than those maintained in unimproved native pastures (Soca *et al*., 2007, p. 42-55). It means that, in this environment, due to the poor quality of the forages, not only is it necessary to carry out adequate forage associations, but supplementation is also necessary to improve the fertility of the herd.

In the case of heifers, nutritional restriction directly affects their future reproductive efficiency, because their body development will be delayed, causing late puberty, specifically interfering in folliculogenesis, especially if there is a negative energy balance. This leads to an anestric state due to not developing an adequate size of the follicle to exert its dominance, subsequent maturation, and ovulation capacity, given by the inhibition of the secretion of luteinizing hormone (LH) and reduction in the secretion of insulin-like growth factor 1 (IGF-1) and therefore in the concentration of blood glucose. A relationship has also been found between hypoglycemia and levels of corticotropin-releasing hormone (CRH), adrenocorticropin hormone (ACTH), gonadotropin-releasing hormone (GnRH), luteinizing hormone (LH), and ß-Endorphins with ovarian activity (Donzelli *et al*., 2010, p. 183-194). Studies report that administration or supplementation in heifers about to enter reproduction makes them reach an adequate body weight for conception faster than those that are not supplemented, resulting in better heat and pregnancy rates in the first 20 days of coverage (Granja *et al*., 2012, p. 458-472).

During pregnancy, especially in the last third, given the demands of the fetus, the needs for all essential nutrients increase, mainly energy, where glucose constitutes 50% of the energy substrate for it, 25% lactate, and the remaining 25% comes from amino acids (Rúgeles, 2001, p. 24-30). Under these conditions, the negative energy balance that may occur can lead to an inability to expel the fetal membranes and added to a deficiency of estrogens necessary for uterine contraction during labor, end up causing uterine atony with retention of the placenta (Gómez & Campos, 2016, p. 147-156).

After calving, the demand for nutrients for milk production increases considerably. The factor responsible for reproductive disorders in this particular stage is the magnitude of the net energy secretion in the milk (Rúgeles, 2001, p. 24-30), which makes it necessary to increase the contribution of dry matter in the diet. The deficit in energy intake, technically called negative energy balance, affects some reproductive processes such as the development of follicles and the potential of oocytes to develop embryos. The negative energy balance also causes a delay in the first postpartum ovulation, with a drop in serum progesterone concentrations during the second and third postpartum cycles, which can affect embryo survival (De Kruif *et al*., 2008, p. 29-33). Therefore, providing foods with a high energy-protein ratio during this stage is essential since cows reduce their ingestion capacity but at the same time, their nutritional needs are the highest during the entire reproductive period, taking into account that in most cases the energy supplied by the forage is not enough for its maintenance and milk production (Campos *et al*., 2020, p. 10-27). In this period, the cow must restart its reproductive process and start its milk production, so it enters a period of anestrus, while its metabolism is regulated. But this period can last longer than normal generally due to the negative energy balance that results in low fertility and a decrease in milk and meat production, as well as weight loss and CC (Balarezo *et al*., 2020). Inadequate nutrition contributes to prolonged postpartum anestrus, especially in cows that graze in the tropical zone, and has a direct relationship with negative factors such as genetic, environmental, and management (Montiel & Ahuja, 2005, p. 1-26). Therefore, protein-energy supplementation is recommended to make up for these deficiencies (Campos *et al*., 2020, p. 10-27).

Some authors mention the importance of measuring blood urea nitrogen (NUS) or in milk (NUL) as an indication of the protein supply of the diet, to use it as an indication of precision in nutritional supplementation to favor the consumption and the degradation of forages. Thus these measurements would help regulate the energy level required because the high concentrations of urea and ammonia in blood and uterine fluids affect the viability of sperm, ovum, and embryo (Pinedo & Meléndez, 2010, p. 41-48); while low concentrations are related to inadequate ovarian and uterine development that leads to reproductive problems (nutritional infertility) (Rúgeles, 2001, p. 24-30). In a study carried out under conditions of the low tropics, in the eastern plains of Colombia, it was found that the levels of NUL and NUS in dual-purpose cows are directly affected by the amount of protein crude, and the protein: energy ratio of the diet (Pardo *et al*., 2008, p. 387-397), and if they are grazing tropical forages, these relationships change according to climatic variations (Kanuya *et al*., 2006, p. 511-519). High levels of NUS can be found in the natural secretions of the oviduct and endometrium, where it can be transformed back to ammonia, which can cause fertility problems or embryonic death due to its toxicity (Ancco, 2019).

Specifying the effects of inorganic nutrition on reproduction, minerals have been widely studied, and in general, the physiological processes inherent to reproduction such as development and growth, estrous cycle, gestation, lactation, and nutrition of the neonate, require an adequate and constant supply of minerals. As forages have a limited content of these nutrients, mineral supplementation is essential. If this supplementation is not done properly can lead to a mineral deficiency or imbalance, or even condition the use of other nutrients, such as fiber digestion and microbial protein synthesis at the rumen, which can be affected by sulfur and phosphorus deficiencies.

Another example is given by sodium, since due to its relationship with potassium to maintain the integrity of the functioning of the cell membrane and the triggering of the action potential for nerve conductivity, it is basic for the adequate presentation of the estrous cycle, since the expressiveness of the behavioral signs of heat depends on it, which although they are produced by high concentrations of estrogens, needs the nervous response for the female to show the behavior of heat and acceptance of the mount (Campos & Hernández, 2008). Calcium plays a fundamental role as an intracellular messenger, regulating vital functions in cells, as well as in muscle contraction, therefore, its deficiency during childbirth can lead to dystocia and retention of the placenta (Destefani *et al*., 2018). Inadequate calcium levels end up generating the loss of the calcium-phosphorus balance, which is characterized by the presentation of irregular heat or long periods of anestrus (Valdez *et al*., 2019, p. 11-18). The manganese deficit, cause irregular return to heat, low follicular development, ovarian cysts, low conception rates, among other factors, in addition their absorption is affected by excess iron (Noval *et al*., 2016, p. 371-380). Selenium is found in high concentrations in the ovary, placenta, pituitary, and adrenal glands, and its deficiency affects thyroid function, which shows its importance in the reproductive process, where together with iodine influence sexual behavior. Selenium deficiency also results in suppression or decrease in estrogen levels, although its main function is given as an antioxidant, thus protecting the cell membrane from destruction due to oxidative processes, even in the absence of vitamin E. Therefore, its deficiency can result in retention of the placenta, delays in the involution of the uterus, metritis, ovarian cysts, among other reproductive disorders (Silva, 2019). Zinc binds steroidal hormones to its receptors in organs or target tissue and its deficiency produces an inadequate synthesis of prostaglandins. This mineral plays an essential role in the functioning of DNA, so alterations in the nuclear and cytoplasmic maturation of oocytes directly determine low gestation rates (Anchordoquy, 2012). Cobalt and copper deficiencies, and excess molybdenum affect the hypothalamic-pituitary-gonadal axis, which negatively affects reproductive processes at all levels (Gómez *et al*., 2019).

Vitamin A supplementation has little risk of toxicity, while its deficiency can delay the appearance of the first heat, induce silent jealousy, increase the number of ovarian cysts, reduce conception rates, cause abortions, embryonic deaths, and weak calves at birth, although its mechanism of action is still unclear. In addition, vitamin A has the function of maintaining the integrity of the epithelia. Vitamin A deficiency can decrease the gestation period, and increase the presentation of cases of retention of the placenta and stillbirths, while optimal levels favor the normal development of the placenta and the embryo, including the bony development of the fetus and the early resumption of the reproductive process, that is to say, the heat after uterine involution. The absorption of calcium and phosphorus is affected by deficiencies in vitamin D, which also implies reproductive losses. In turn, vitamin E deficiencies are considered responsible for the retention of the placenta, metritis, and ovarian cysts (Cordeiro, 2020).

In summary, adequate fertility will not be expressed if nutrition and food management are suboptimal, and unfortunately, most of the forages of tropical grasslands are poor in protein, calcium, and phosphorus, deficiencies that are related to reproductive disorders. The protein-poor rations (with low levels of non-protein nitrogen and degradable protein in the rumen) show a reduction in digestibility, decreasing the flux of microbial protein, which results in a delay in the growth of heifers and a late restart of postpartum ovarian activity (Rúgeles, 2001, p. 24-30).

Because of that, some producers use woody forage and shrub species for animal feed, which is an ancient practice. This practice has recently received greater attention due to the growing need to seek local alternatives that reduce dependence on external inputs and maximize production (Aldana *et al*., 2009, p. 130-143). On the other hand, excess protein causes a high production of urea and BUN that causes the death of the ovum and sperm in the mother, failure of fertilization, death of the zygote, embryonic death, and abortions. It also harms gametogenesis (spermatotoxic) at the testicular level causing an increase in the proportion of sperm abnormalities, necrospermia and zoospermia (Rúgeles, 2001, p. 24-30). That is why the nutritional contribution of protein in the diets of bovines should be according to their requirements.

MORINGA (MORINGA OLEIFERA LAMARCK)

Generalities

M. oleifera belonging to the *Moringaceae* family, it is composed of a single genus (*Moringa*) with 14 known species. It is native to South Asia and grows near the Himalayan mountains, from northwestern Pakistan to northern India. This species has been introduced in many parts of the world, including America, from Mexico to Peru, Caribbean islands, Paraguay, and Brazil. It is a perennial tree, but of short longevity, that can live a maximum of 20 years (González, 2012, p. 40-42). *M. oleifera* presents a rapid growth, reaching rates of 1.50 cm/day, arriving at 7-12 m in height with great leaf production (Batista, 2006; Barreto *et al*., 2009, p. 893-897).

M. oleifera is characterized by its great ecological plasticity since it develops well in different conditions of soil (**Figure 1**), precipitation, and temperature. Its cultivation advantages include tolerance to poor soils, great resistance to drought, and easy cultivation. It also has great regrowth capacity, and therefore to accept frequent pruning, adapting better to slightly acidic to neutral soils (Foidl *et al*., 2003, p. 5; González, 2012, p. 40-42; Passos *et al*., 2013, p. 113-120). De Jesús *et al*. (2013, p. 23) mention that this plant can be grown in the most diverse types of soil, however, it has growth limitations in those where there is the possibility of waterlogging (poorly drained soils). The optimum ambient temperature for its growth is around 25-35°C, being able to tolerate momentary temperatures of up to 48°C. This species is not very cold tolerant, but it is known that it still produces leaves at a temperature of up to 14°C. Despite the scarcity of information on the response of the plant to low temperatures, some farmers are cultivating *M. oleifera* in regions with low temperatures such as Venâncio Aires, in the state of Rio Grande do Sul in Brazil. The farmers carry out the pruning procedure before winter, that is to say during the period of milder temperatures so that the plant can enter a dormant state and recover as spring enters.

M. oleifera is recognized by the FAO as a possible solution to the problems of human (Oyeyinka & Oyeyinka, 2018, p. 127-136) and animal malnutrition. This plant has a profile of important minerals, and its leaf meal contributes as a source of protein since its dry matter contains approximately 27% of this macronutrient (Anwar *et al*., 2007, p. 17-25). Additionally, Moura *et al*. (2010) mention that the leaves have antioxidant compounds such as polyphenols, and also have carotenoids, the latter compound being a precursor of vitamins. Although all parts of the plant are edible and its content of proteins, vitamins, and minerals is greater in the leaves. So, the leaves of *M. oleifera* constitutes one of the most complete forages, with an excellent acceptability, being these leaves eagerly consumed by all kinds of animals.

It is important to mention that comparatively *M. oleifera* contains more vitamin A than carrots (1,130 VS 315 mg), more vitamin C than orange (220 VS 30 mg), more calcium than milk (440 VS 120 mg), more potassium than bananas (259 VS 88 mg), and more protein than milk (6,700 VS 3,200 mg) (Benítez, 2012,

Figure 1. *Moringa oleifera cultivated in Colombian Orinoquia (Moringa oleifera cultiva en la Orinoquia Colombiana).*

p. 171-174). Mojica *et al*. (2017, p. 463-477) found that depending on the regrowth time, the content of fatty acids can vary between 1.2 to 1.97% of the dry matter (DM), and within these, it contains 0.26-0.44 g/kg DM of myristic (C14:0), 2.47-4.87 g/kg DM of palmitic (C16:0), 0.87-1.83 g/kg DM of stearic (C18:0), 0.44-0.73 g/kg DM of oleic (C18:1), 1.19-2.89 g/kg DM of linoleic (C18:2), and 1.54-3.55 g/kg DM of linolenic (C18:3). *M. oleifera* is currently used worldwide mainly as a perennial vegetable, and it is proving to be a first-class resource with a low production cost per hectare (Sosa *et al*., 2017, p. 207-211).

The different parts of *M. oleifera* are used for the treatment of inflammation, cardiovascular diseases, gastrointestinal, hematological, liver, and kidney disorders, among others (Anwar *et al*., 2007, p. 17-25), as well as it can be used as a natural flocculant to purify water (Francisco *et al*., 2014, p. 143-152), as a windbreaker, green manure, and for the production of honey, ethanol, and rubber (González, 2012, p. 40-42). Its ripe seeds contain 38 to 54% edible oil, which contains a high level of unsaturated fatty acids, oleic being the most abundant of this type, while the dominant saturated fatty acids were palmitic, lauric, stearic, linoleic, and linolenic acid. Additionally, the extracts of *Moringa spp.* could be an effective source of natural antimicrobials with versatile potential applications (Özcan, 2020, p. 25-31). *Moringa* seed oil is of very high quality, not very viscous and sweet, and due to its oleic acid content, which reaches up to 73%, it is nutritionally similar to olive oil. So, its seed oil can be used in the kitchen since it does not turn rancid and it is useful for dressing salads. It can also have interesting applications in cosmetology. In this way, the production of this plant species can have several applications in different sectors of the economy, also contributing to the sustainability of the ecosystem (Benítez, 2012, p. 171-174).

According to Foidl *et al*. (1999, p.5), yields of *M. oleifera* can vary from 2.6 to 34 ton/ha per cut in dry matter for densities of 95 to 16 million plants/ha, respectively, since it can produce large amounts of fresh biomass, even at high crop densities. However, the optimal density value is 1 million plants/ha (8.3 ton/ha.cut of DM), due to biomass production fresh, the cost of sowing, and the management of the cut, among other factors. These same authors mention that above this amount, there is high competitiveness between plants, via phototropism, leading to losses of seedlings of 20-30% (at cut-off intervals of 45 days), in addition to a loss of material due to the reduction of stem diameter and sprouts. Reyes *et al*. (2006a, p. 231-242), showed that the ideal conditions for the production of fresh biomass are a density of 500,000 seedlings per hectare and cutting frequencies every 45 and 60 days in the rainy and dry season, respectively. In this regard, Navas (2019, p. 207-218) under environmental conditions of the Colombian Orinoquia found an average forage production of 98 and 21.6 ton/ha.year in fresh and dry matter, respectively. Like any other crop, *M. oleifera* has a positive response to proper management (García *et al*., 2020, p. 1529-1537) and fertilization (Cerdas, 2017, p. 145-163). Hernández *et al*. (2020) found that the best harvest is 60 days after regrowth with applications of nitrogen, phosphorus, and potassium in quantities from 13 to 38 kg/ha.

Additionally, the crop of *M. oleifera* positively impacts the soil since it increases the content of minerals and saturable bases, organic matter, organic carbon and edaphic macrofauna. This is possible due to the ability of this tree species to recover nutrients from deep soil profiles and place them on the surface through the litter. *M. oleifera* also improves the water retention capacity in the soil; aspects important in forage production and adaptation to extreme climatic conditions (Navas, 2019, p. 207-218).

Use of Moringa oleifera in bovine production

Moringa can be used as an interesting supplement in the diet of dairy and beef cattle (**Figure 2**), as well as in birds, fish, shrimp, pigs, goats, and sheep due to the nutritional contents already mentioned. Likewise, its rustic characteristics show great advantages for livestock, since, in trials in different parts of the world with cattle, pigs, sheep, goats, and poultry, significant increases in yield were observed, both for the weight gain as for milk production when *Moringa* is supplied as a food supplement (González, 2012, p. 40-42).

Figure 2. Cattle supplemented with elephant grass (*Pennisetum purpureum*) mixed with *Moringa oleifera* in conditions of the Colombian Orinoquia. (Ganado suplementado con pasto de corte *Pennisetum purpureum* mezclado con *Moringa oleífera* en condiciones de la Orinoquia Colombiana).

According to Ferreira *et al*. (2008, p. 431-437) in general, the plant of *M. oleifera* presents low concentrations of antinutritional factors, although the seeds present glucosinolates (65.5 µmol/g), phytates (41 g/kg) and hemagglutinating activity, while the leaves present appreciable amounts of saponins (80 g/kg), phytates (21 g/kg), and tannins (12 g/kg). Its flowers contain caseinolytic proteins and milk coagulants, such as aspartic proteases, which may have a potential application or use in the dairy industry (Pontual *et al*., 2012, p. 1848-1854), such as in the production of cheeses (Ismail, 2019, p. 739-755).

In the case of bovine livestock, because the herds reduce productive efficiency caused by the climatic variations, either due to rainfall or variation in temperature that result in low availability and quality of forage, a potential strategy for bovine production is the use of *M. oleifera*, due to its response to these limiting adversities, in addition to having the advantage of its nutritional characteristics and its high yield in fresh biomass. In dairy cattle supplementation with 40-50% of *Moringa* in the diet, the milk production increased to 10 kg/cow.day, while animals without supplement produced 7 kg/animal.day. In beef cattle daily weight gains of 1,200 g/day have been recorded, compared to 900 g/day without the use of *Moringa* (Pérez *et al*., 2010, p. 1-16). *M. oleifera* has great potential, both as a single diet (mainly for dairy cows) and as a food supplement for fattening cattle or other species of economic interest (Schrage, 2018).

Sun *et al*. (2017) in study with cows fed *M. oleifera* silage reported higher crude protein digestibility and lower concentrations of propionate and isovalerate in milk, which could be interpreted as a better energy use of the diet. On the other hand, Cohen *et al*. (2016, p. 75-83) evaluating the inclusion of *M. oleifera* mixed with wheat hay and sugar-cane for silage production, found that, although the intake is better when it is administered in this form that as an exclusive supplement, the milk yield, fat content, and antioxidant activity is higher when it is done in the latter form. About this, Malik *et al*. (2019, p. 70-74) observed that the supplementation of cattle (200-250 kg) with *Moringa* through multi-nutritional blocks of urea improves the consumption and digestibility of DM and organic matter (OM), where the best results were observed with the inclusion of 15%. In another contribution in this regard, Reyes *et al*. (2006b, p. 24-31) found that the inclusion of *Moringa* as a protein supplement in low-quality diets for dairy cows improves DM intake and digestibility of the diet, and increases milk production but without affecting its composition. these authors also corroborated that the organoleptic characteristics such as the smell, taste and color of milk are not affected. Yang *et al*. (2019, p. 211-216) studying the effects of *Moringa* on the intake and ruminal digestibility of the substitution of alfalfa hay in dairy cow diets, found that DM intake and the apparent digestibility of DM, crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) increased without affecting ruminal pH. These authors also found that the concentration of N-ammoniacal was less, and total ruminal volatile fatty acids, acetate, propionate, and butyrate were higher in cows fed the *M. oleifera* diet. Additionally, they found greater microbial proliferation of *Fibrobacter succinogenes*, *Butyrivibrio fibrisolvens*, *Ruminobacter amylophilus*, *Streptococcus bovis*, and *Prevotella ruminicola*. Thus, the decrease in the levels of N-ammoniacal could be associated with a greater synthesis of microbial protein and, therefore, a greater digestibility of the nutrients due to the better ruminal fermentation, since the *Moringa* favors the degradation of proteins and carbohydrates in the diet, and therefore increases the concentrations of volatile fatty acids, which ultimately ends up improving the total apparent digestibility of the gastrointestinal tract.

For Garavito (2008), *M. oleifera* is important in animal feed due to its nutritional content, and it can be an important complement for dairy and meat cattle, as well as in the diet of birds, fish, and pigs because it favors a nutritional balance. However, according to the same author, care should be taken with the use of fresh forage since the milk has a peculiar taste, requiring three hours between ingestion of *M. oleifera* by animals and milking to avoid it. Garavito (2008) also cites that this plant causes dystocia (not only in bovine species), due to the excessive size of the fetus, so it is necessary to anticipate delivery. The author comments that due to high percentage of water in the forage and little fiber, it is indicated to mix the ingredient with sources of fiber to avoid watery stools, reducing the potential weight gain. In this regard, González (2012, p. 40-42) mentions that these aspects presented by Garavito (2008), indicate that it is important to dehydrate the plant before offering it to animals to decrease the water content and allow a higher concentration in nutrient levels. When feeding with *Moringa* is started, an adaptation period may be required, being able to offer up to 27 kg of fresh material/animal.day, without incurring ruminal or metabolic disorders because the contents of antinutritional substances such as tannins and saponins are minimal in this plant and no trypsin or lectin inhibitors have been found (Foidl *et al*., 1999, p. 5). Roy *et al*. (2016, p. 1-9) evaluating the intake, digestibility, and growth of bulls fed with *Moringa* forage, comparing it with forage silage (Australian Sweet) and with corn silage, found that the consumption and digestibility of DM and CP, and weight gain were higher in those animals fed with *Moringa*.

The addition of *M. oleifera* in the diet for ruminants, even in which there is a source of microbial protein, considered of high biological value, favors muscle development because its balance of amino acids (AA) is similar to that of muscle tissue, with a high digestibility (about 85%). There are differences between animals as to which are the limiting AA in production since this factor will depend on the non-degradable AA sources present in the diet (BEEFPOINT, 2004), although normally the AA described as limiting are lysine and methionine. Methionine, for example, participates in the synthesis of cysteine, which is one of the components of proteins in living organisms, and by providing sulfur in its composition contributes to the synthesis of glutathione, an important natural antioxidant. The essential AA composition of the leaves of *M. oleifera* is comparable to that of soybeans, with high levels of leucine, which is one of the branched-chain AA that contributes to muscle health, and also stimulates muscle growth and improves insulin sensitivity (MY-PROTEIN, 2016). Lysine is known for its antiviral properties and its action in the production of antibodies, being an important AA for the immune system (Leite, 2015), although the most abundant AA are glutamic acid, arginine, and aspartic acid (Sánchez *et al*., 2010, p. 175-180).

According to Makkar & Becker (1996, p. 211-228), the high crude protein content and the high values of potentially digestible proteins in the intestine present in the leaves of *M. oleífera* suggest that the ingredient is a good source of protein supplement for high production cows. This occurs because, among other factors, a higher NDF degradation rate is observed, which suggests that the quality of its fiber is also good. Furthermore, the presence of soluble AA found in its leaves increases the efficiency of microbial protein synthesis. The presence of antinutritional factors in the leaves such as tannins is negligible, trypsin and lectin are absent, and they have low levels of saponins and phytates. The results obtained by the aforementioned authors show that around 95% of the total crude protein is available in the rumen or after it, while the potentially digestible protein in the intestine (DPI) was 50%, which is available to the animal for production purposes. The DPI values obtained by the authors for the leaves of *M. oleifera* were much higher than those of several conventional protein supplements, such as coconut seed, cotton seed, peanut, sesame, and sunflower bran. In lambs the dietary manipulation can alter the quality of meat, which is why *M. oleifera* improves the quality of livestock products, obtaining more tender and leaner fillets (Cohen *et al*., 2017a, p. 110-116). For this reason, the inclusion of *M. oleifera* in ruminant diets brings not only productive benefits, but also positively impacts aspects inherent to the final consumer.

García *et al*. (2008, p. 191-196) studying the acceptability of tropical tree foliage in ruminants found 26.6% of crude protein, 42.5% of NDF, and 10.3% of ash, a voluntary consumption in cattle of 0.48 g DM/kg LW/6 hours, and a degradability *in situ* of the dry matter of 90.4%. Gutiérrez *et al*. (2018, p. 227-232) in Alpine breed goats observed that when the forage grass *Cenchrus purpureus* cv. Cuba OM-22 is replaced by *Moringa* in 80% of the diet, there is the highest consumption of dry matter and protein compared to live weight (3.5% LW and 220 g/day respectively) and nitrogen digestibility (92.31%). Therefore, the inclusion of *Moringa* in the diet of these animals improves the voluntary consumption and utilization of nitrogen, increasing its digestibility and retention, and reducing the excretion of nitrogen into the environment.

The benefits of feeding cattle with *M. oleifera* are not limited to productive benefits, but can also promote the natural defense mechanisms of the body. Cohen *et al*. (2017b, 1174-1186) evaluated the antioxidant characteristics of this plant, finding that the ensiling process not only preserves this capacity, but also increases it since a higher antioxidant capacity was observed in silages than in fresh and dry of *M. oleifera* plants possibly attributed to the accumulation of AA and low molecular weight peptides. Because of this, the cows fed with *Moringa* silage had higher milk production and antioxidant capacity and lower somatic cell count in milk compared to controls during some stages of lactation. In this regard, Cheng *et al*. (2019) found that the methanolic extract of *M. oleifera* leaves has beneficial effects on bovine mammary epithelial cells through its anti-inflammatory, antioxidant, and casein-producing properties since *in vitro* tests the *Moringa* extract decreased the reactive oxygen species produced by lipopolysaccharides (LPS) in cells. The authors also observed that methanolic extract of *M. oleifera* leaves attenuated the expression of inflammatory cyclooxygenase-2 induced by LPS through the down-regulation of the signaling cascade of the nuclear factor enhancer of the kappa light chains of activated B cells (NF-κB). Therefore, nutritional supplementation with this forage species is a good food supplement to protect the udder of cows from inflammatory responses due to mastitis. On the other hand, Gutiérrez *et al*. (2015, p. 7-16) found that the silage of the mixture *Pennisetum purpureum* and *Moringa oleifera* in proportion 40: 60% in fresh matter reaches a ruminal degradability of DM of 69.8%, even with *Moringa* silage, dairy cows can be fed in large quantities to produce the same quantity and quality of milk as traditional grain-based feed-based diets (Mendieta *et al*., 2011, p. 1039-1047).

Regarding effects at the reproductive level, Barakat *et al*. (2015, p. 67-75) observed that the relative abundance of genes related to the maturation of sheep oocytes was affected by the concentration of *M. oleifera* extract and meiotic progression. Furthermore, sheep oocytes cultured with hormones more *M. oleifera* extract expressed high levels of calcium concentration. Therefore, *M. oleifera* combined with hormonal supplements improves the maturation rate of oocytes by acting as a promoter to induce mRNA expression and synthesis of essential proteins, for example, maturation promoting factor (MPF), for these processes.

Finally, the last point in favor and which is very important to highlight is that high-quality forages, with high levels of protein content are essential to maximizing productive performance in dairy production. Ruminal fermentation also produces methane (CH_4) and carbon dioxide (CO_2) that contribute to global warming, estimating that livestock is responsible for 18% of CH_4 production and 9% of CO_2. Therefore, exploring forages that allow improving the productive parameters but that, at the same time, mitigate the production of these gases at the enteric level could be a solution to this problem. Supplementation with saponins, tannins, or essential oils in low to moderate doses has enormous potential for this, being promising natural additives in the manipulation of microbial ecosystems through the inhibition of the proliferation of methanogenic bacteria in the gastrointestinal tract. This produces a better ruminal fermentation, to finally mitigate ruminal CH_4 production and thereby reduce the environmental impact of livestock production (Ugbogu *et al*., 2019, p. 915-925). Elghandour *et al*. (2017, p. 1229-1238) inoculating *Moringa* leaves in increasing replacement (0-100%) of soybean meal as a source of protein in goats and steers found that the rations containing *Moringa* decreased methane production, the ruminal N-ammonia, and the total number of protozoa, while that of bacteria increased in the rumen, what resulted in greater degradability of organic matter and DM. Therefore, including *M. oleifera* as a protein source in ruminant diets is a potential sustainable strategy to reduce CH_4 emissions. Similarly, Ebeid *et al*. (2020, p. 1271-1282) studying the potential of *M. oleifera* seed oil to modulate the rumen microflora and thereby mitigate methane production, found that supplementation with this oil effectively alters the parameters of fermentation and CH_4 production since this oil increases the concentration of propionate, butyrate, and microbial protein, in parallel with a decrease in that of acetate.

This is also corroborated in other ruminants. The addition of *M. oleifera* in combination with probiotics in the diets of goats helps to mitigate the emissions of CH_4 and CO_2 by these animals (Pedraza *et al*., 2019, p. 779-786). From a production point of view with a focus on sustainability, enteric methane produced in ruminal fermentation represents a substantial waste of food energy for these animals. Dong *et al*. (2019) found that the inclusion of *M. oleifera* not only improves the fat content of milk but also changes the composition and diversity of methanogenic microorganisms, indicating that the secondary metabolites of this plant can regulate the fermentation conditions and the associations between some methanogenic bacteria and other microbes. Therefore, its inclusion in bovine diets reduces CH_4 emissions from these animals.

CONCLUSION

Taking into account that among the factors that most affect the productivity and profitability of a livestock company is the reproductive efficiency of the herd, and that adequate fertility will not be expressed if nutrition and feed management are suboptimal, and that unfortunately most of the forages of the Colombian grasslands are poor in protein, calcium, and phosphorus, among many other nutrients, nutritional supplementation with *M. oleifera* may be the solution since due to its richness in protein and minerals and low content of anti-nutritional metabolites, when it is included in the diet of cattle, their productive response is optimized in parallel with a decrease in their methane production.

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