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Invited paper:

Insights in nutrition programs for the developing ruminant

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Abstract: As the world population grows and resources for food animal production become more limited, animal efficiency must increase. The dairy industry has made progress in reducing age at first calving from 27 to 25 mo., but heifers remain unproductive for over half of their life while still consuming resources. As pre-ruminants, offering restricted amounts of milk to neonatal heifers (conventional system) increases concentrate consumption which drives rumen development. However, accelerated milk programs improve pre-weaning growth rate and the balance between these two systems is still under continuous investigation. Solid feed is important for papillary and musculature development in addition to establishment of a microbial population, which increase transition success when calves are weaned gradually. Furthermore, the optimal target weight for calving is 550 kg at 23 to 24.5 mo., which increases 305-d lactation yield. Increased milk production is desired, but a costly rearing period without producing milk only increases as age at first calving increases, which also increases total number of replacement heifers and total herd green-house emissions. Strategies to achieve desired body weight and age at first calving while reducing input include, using compensatory growth, restricting intake and precision feeding. Compensatory growth can increase average daily gain and feed efficiency; moreover, precision feeding increases feed efficiency even further by reducing nutrient metabolic costs in comparison to ad-libitum systems. Restricting intake provides increased rumen retention time for fiber, non-structural carbohydrates, protein, and other nutrients to be highly digested. Nutrient digestibility is important when comparing these feeding methods because dry matter intake has the greatest impact on efficiency, specifically when different amounts of forages are fed. Using different strategies during the weaning, pre-pubertal and post-pubertal period of dairy heifers can significantly improve performance, nutrient and resources utilization during this conditioning growing phase of dairy cattle.

Key words: Dairy heifer, Development, Precision feeding, Rumen, Weaning

Conocimientos en programas de nutrición para rumiantes en desarrollo

Resumen: A medida que la población mundial crece y los recursos para la producción animal de alimentos se vuelven más limitados, la eficiencia animal debe aumentar. La industria láctea ha progresado en la reducción de la edad al primer parto de 27 a 25 meses, pero las novillas siguen siendo improductivas durante más de la mitad de su vida mientras consumen recursos. Como pre-rumiantes, ofrecer cantidades restringidas de leche a las novillas neonatales (sistema convencional) aumenta el consumo de concentrado, lo que impulsa el desarrollo del rumen. Sin embargo, los programas acelerados de leche mejoran la tasa de crecimiento antes del destete y el equilibrio entre estos dos sistemas todavía está bajo investigación continua. La alimentación sólida es importante para el desarrollo papilar y de la musculatura, además del establecimiento de una población microbiana, que aumenta el éxito de la transición cuando los terneros se destetan gradualmente. Además, el peso objetivo óptimo para el parto es de 550 kg entre 23 y 24,5 meses, lo que aumenta el rendimiento de la lactancia en 305 días. Se desea aumentar la producción de leche, pero un período de crianza costoso sin producir leche solo aumenta a medida que aumenta la edad al primer parto, lo que también aumenta el

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número total de novillas de reemplazo y las emisiones totales en invernaderos de rebaños. Las estrategias para lograr el peso corporal deseado y la edad al primer parto, al tiempo que reducen el ingreso, incluyen el uso de crecimiento compensatorio, la restricción de la ingesta y la alimentación de precisión. El crecimiento compensatorio puede aumentar la ganancia diaria promedio y la eficiencia de la alimentación; además, la alimentación de precisión aumenta aún más la eficiencia alimenticia al reducir los costos metabólicos de los nutrientes en comparación con los sistemas *ad-libitum*. La ingesta restrictiva proporciona un mayor tiempo de retención del rumen para que la fibra, los carbohidratos no estructurales, las proteínas y otros nutrientes sean altamente digeridos. La digestibilidad de nutrientes es importante cuando se comparan estos métodos de alimentación porque la ingesta de materia seca tiene el mayor impacto en la eficiencia, específicamente cuando se alimentan diferentes cantidades de forrajes. El uso de diferentes estrategias durante el período de destete, prepúber y postpúber de las novillas lecheras puede mejorar significativamente el rendimiento, la utilización de nutrientes y recursos durante esta fase de acondicionamiento del ganado lechero.

Palabras clave: Alimentación de precisión, Desarrollo del rumen, Destete, Novilla lechera

Importance of the developing ruminant

Food production is an essential issue with respect to the challenge of feeding the growing world population. Animal scientists need to be aware of their responsibility in meeting this challenge through the development of technologies to balance constantly increasing demand for food products with limited resources. Efficiency in production of highly nourishing products like milk and meat has to be taken into consideration to sustain the world human population and development. Currently USDA estimates the population of U.S. dairy replacement heifers at approximately 4.0 million, which represents 50% of the total dairy cow inventory (USDA, 2017). The proportion of heifers to cows (around 0.85) between 1944 and 2007 has been constant; however, age at first calving (AFC) has been reduced from 27 to 25 mo. (Capper *et al.*, 2009). Lactating cows spend more than half of their lives as unproductive heifers (average culling age 55 mo.; DHIA, 2017). Thus, there is opportunity to reduce costs and greenhouse gas (GHG) emissions of the dairy industry by focusing on heifers.

Weaning strategies and transition into solid feed

Neonatal calves are pre-ruminants because of the rudimentary development of this compartment affecting function and the establishment of microbial communities (Steele *et al.*, 2016). Thus, calves receive a high proportion of highly available nutrients (milk or milk replacer; MR) during the pre-weaning period to enable passive immunity and enhanced absorption (Gelsinger and Heinrichs, 2017). It has been shown that calves that are offered reduced amounts of MR, to encourage the consumption of grain sources, improve rumen development (Anderson *et al.*, 1987; Kertz and Lofton, 2013). On the contrary, accelerated programs, where increased amounts of

MR are fed, result in greater preweaning ADG (Jasper and Weary, 2002; Chapman *et al.*, 2017). Solid dry feed is necessary for a calf to transition successfully from pre-ruminant to ruminant through the production of volatile fatty acids (mainly butyrate and propionate), muscularization (physical stimulation and reduction of keratinization) and vascularization (Beharka *et al.*, 1998; Coverdale *et al.*, 2004; Suarez-Mena *et al.*, 2015). Stimulation of healthy papillae development aids in the absorption of nutrients in the rumen as well as in the establishment of microbial communities to enhance adaptation to energy dense/nutrient diverse diets fed post-weaning (Hill *et al.*, 2010; Steele *et al.*, 2016).

The first transition period in the newborn dairy calf is the post-weaning period. This is a highly stressful time where rumen development and microbial establishment is challenged to adapt rapid switch from being highly dependent on milk to diverse sources of nutrients in the new grain mix (Khan *et al.*, 2011). Thus, weaning strategies during this phase become extremely important to ameliorate possible digestive and health problems that these animals are exposed to (Baldwin VI *et al.*, 2004; Hill *et al.*, 2016). Calves that are weaned abruptly tend to have a harder time transitioning to a completely solid diet which can reduce ADG and stunt rumen development (Sweeney *et al.*, 2010; Wood *et al.*, 2015). Calves that are weaned gradually, transition better into a solid feed diet and do not show a dramatically reduced ADG (Wang *et al.*, 2014).

Optimal weight and age at fist calving

A minimum BW at calving must be achieved to reduce events, such as dystocia, metritis, or retained placenta, which could present post calving metabolic problems or lead to early culling (Erb *et al.*, 1985) and

to maximize production potential (Heinrichs, 1993). Van Amburgh *et al.* (1998) reported that heifers calving with a BW of 500 kg produced 325 kg less milk in a 305-d lactation than those calving at 550 kg, concurrent to these findings, it has been previously demonstrated an AFC of 24 mo. may decrease days of productive herd life, but increases total lifetime milk produced (Gill and Allaire, 1976). Summarizing all the investigations regarding BW and AFC, several studies (Crowley *et al.*, 1992; Hoffman and Funk, 1992; Zanton and Heinrichs, 2005) have concluded that heifers should calve at 22 to 24 mo. of age and have a weight of 550 kg. In accordance with this, Ettema and Santos (2004), conducted a retrospective study in three commercial dairy herds in California grouping heifers that calved around 23 mo., between 23 and 24.5 mo., and > 24.5 mo. They concluded that optimal AFC is between 23 and 24.5 mo. based on increased milk production, fewer metabolic and health problems, and reduced rearing costs associated with this group.

Environmental impact of heifer rearing

When raising dairy replacement heifers, consideration has to be given to the fact that these animals are consuming resources and producing GHG and air pollutants without contributing to milk output (Place and Mitloehner, 2010). Cattle emit approximately 50% of the ammonia (NH₃) released to the environment from agricultural sources in the U.S. (Battye *et al.*, 1994). Optimal AFC is between 23 and 24 mo., however heifers in many herds calve later and have a larger impact on the number of heifers present at the farm and on CH₄ and NH₃-N emissions produced. It has been calculated that if AFC increases from 24 to 27 mo. of age on a farm with 100 lactating cows, the number of heifers will rise 12% and total CH₄ emissions by heifers will increase by 30% (Garnsworthy, 2004). Predicted contributions of dairy heifers total herd emissions for CH₄ and NH₃-N are 27 and 15% for a dairy producing 9,000 L/yr per cow (Garnsworthy, 2004; Bell *et al.*, 2011).

Strategies to reduce intake and improve efficiency

A strategy that has been used for growing heifers is compensatory growth. Compensatory growth is a term used to describe the nutrient utilization and growth that follow a period of nutrient restriction. During this period, animals accomplish higher gains when fed diets that meet or exceed nutrient demands (Fox *et al.*, 1972; Carstens *et al.*, 1991; Ford, Jr. and Park, 2001). Usually the rate at which gain occurs after restriction is equivalent to the deprivation level

to which animals were subjected (Lopez-Sabidet and Verde, 1976; Drouillard *et al.*, 1991). Feed efficiency is improved with this kind of system, which has been widely used and investigated in the beef cattle industry. Sip and Pritchard (1991) found that overall efficiency of conversion of feed energy to gain was improved for steers restricted and then put back to regular feeding, agreeing with results found by Hicks *et al.* (1990). However, temporary growth restriction usually results in additional number of days that animals have to be fed to equal growth of animals on normal diets.

One method that results in substantial reduction in costs is optimizing nutrient intake, where nutrients would be supplied to the animal to meet its requirements for a targeted ADG and not in excess. Precision feeding has been used to replace the typical ad libitum feeding approach, and refusals have been reduced achieving improved feed efficiency (Moody *et al.*, 2006; Zanton and Heinrichs, 2007; Lascano *et al.*, 2016). NRC (2001) states that when energy intake increases above maintenance level the amount of fat being deposited is higher due to a lack of protein deposition, but restricting intakes and feeding a more nutrient dense diet may control caloric intake, reducing feed costs and nutrient excretion (Hoffman *et al.*, 2007). Gravid heifers may present a problem with over conditioning that may jeopardize lactation performance. Feeding high fiber forages and low energy diets controls caloric intake, minimizing problems at calving (Hoffman, 1996).

Metabolic nutrient costs are higher when higher amounts of nutrients are being supplemented in the diets. The tissues responsible for digestion, absorption, and intermediary metabolism must support intense oxidative metabolism, which determines availability of nutrients remaining for maintenance, growth, and productive functions. This is due to the fact that GI tract, pancreas, spleen, and liver account for 40 to 50% of whole body oxygen consumption, increasing metabolic activity and utilization of nutrients (Huntington and Reynolds, 1983). Loerch (1990) observed that feed efficiency was significantly improved when intake was restricted by 20 and 30% from ad libitum diets in growing steers. In this study when the same NE available for gain was maintained, feed conversion increased by 30% with highly dense diets fed at limited rates. The possible reasons for these results are reductions in feed waste, animal activity, and size of the gut and liver, reducing energy requirements for maintenance, which furthermore will increase diet digestibility (Hicks *et al.*, 1990).

Peculiarities of reducing intake and increasing efficiency in dairy heifers

Under an *ad libitum* feeding system rate of passage is higher when more concentrates are fed in comparison to diets containing a higher levels of forages (Colucci *et al.* 1990; Van Soest, 1994). However, when intake is controlled and fed to meet the animal's requirement to attain a targeted ADG or milk production, ruminal retention time is greater as intake is decreased (Eng *et al.*, 1964; Colucci *et al.* 1989; Murphy *et al.*, 1994). Fractional passage rates (kp) of a specific pool can be calculated by dividing ruminal output or flow to the omasum (mass of a specific pool that leaves the rumen per unit of time) by the ruminal volume. For liquid this is usually called dilution rate and is directly affected by percentage of forage and feed intake level of the diet. A reduction in kp results in an increased exposure of feed to microbial degradation and a logical increase in digestion of the feedstuffs fed to the animal. Rumen retention time of digesta can also be affected by F:C and Lascano and Heinrichs (2009) reported a linear decrease in rumen retention when dairy heifers were fed restricted intakes of a diet containing 40:60, 60:40, and 80:20. When different levels of intake were compared in dairy cows fed different levels of forage, intake level yielded lower rumen retention times and lower digestibilities and these parameters were decreased linearly as the proportion of forage offered to the animals decreased from 80 to 55 and 30% (Colucci *et al.*, 1994).

The flow of liquid and particles from the rumen is increased when greater amounts of DM are offered to the animals (Owens and Goetsch, 1988). Thus, to increase the efficiency at which nutrients are being utilized by the animal and fermented by the microbes in the rumen, an optimal balance between fiber, non-structural carbohydrates, protein, and F:C is necessary when intakes are controlled. One of the main effects associated with a decrease in DMI is the decrease in the size of organs and the total GI tract. Most of the studies determining the details of this aspect of precision fed diets have been conducted using sheep. When sheep were fed straw at various levels of intake for 3 mo., reticulorumen contents and fresh weights at slaughter were reduced in the animals fed the lower level of intake, organ size was also reduced by 18% (Colucci *et al.* 1989). Therefore, a significant part of the total oxygen input should be used for maintenance purposes and most of the costs associated with absorption of food are derived from arterial blood. When animals were fed a diet with equal intake of ME between different F:C,

there was a significant effect on organ mass (McLeod and Baldwin, 2000), this would explain the underestimation of energy being used by the portal drained viscera that does not account for the maintenance energy required from the organs (El-Kadi *et al.*, 2008).

The main factors that influence digestibility of nutrients in ruminants are: 1) digesta load, 2) passage rate, 3) digesta degradation, 4) N or S deficiency, 5) rate of fermentation, and 6) particle size (Tyrell and Moe, 1975). All of these parameters can be manipulated to increase digestibility of feedstuffs. Interactions between these factors can tremendously affect utilization of components of the diets fed to ruminants. Of these factors, the one with the most impact on nutrient digestibility is digesta load, which is directly related to DMI. This is reflected by an increase in DM digestibility of 1.42% per every 10% reduction in intake in beef steers restricted fed similar diets (Murphy and Loerch, 1994). Increased total tract digestibility was observed when heifers were controlled fed (Firkins *et al.*, 1987), but ADF rumen digestion was reported to be only 94% in the controlled fed heifers while it was 100% of the fully fed ones. This explains how passage rate through the whole digestive system is faster when feed intake is increased, decreasing overall total tract digestibility.

Not all of the studies reported have observed increased digestibility (Murphy *et al.* 1994; Waldo *et al.*, 1997; French *et al.*, 2001), but a review by Zanton and Heinrichs (2010) extrapolating results from Tyrrell and Moe (1972) demonstrates that responses in diet digestibility are dependent on the F:C of the diet. As more forage is incorporated in the diet, the decrease in digestibility is smaller as the intake of the animal is increased, while when diets have a greater proportion of grain, decreases in digestibility are more obvious. When feed intake is reduced there is an increased mean retention time and this has been reported to decrease the outflow of microbial protein from the rumen (Murphy *et al.*, 1994) and to increase energy required for maintenance from the microbial population (Wallace, 1996). This could in part explain why no effects in diet digestibility have been observed. Other studies have compared the effect of F:C when diets have been fed to be isocaloric and isonitrogenous by varying the amount of DM offered to animals. Improvements in DM digestibility have been a constant (Moody *et al.* 2007; Hoffman *et al.*, 2007; Lascano *et al.*, 2009a; Zanton and Heinrichs, 2009; Lascano and Heinrichs 2011; Greter *et al.*, 2011).

Studying the microbial population when switching from LC to HC diet, Tajima *et al.* (2001), looked at 13 different species when diets were switched from LC to HC. These researchers observed that cellulolytic bacteria were hugely depressed by the third day and continued to be reduced after 28 d, Prevotella and *S. bovis* populations were increased by the third day but were back to normal levels after 28 d. *Selenomonas* spp. were increased 3 fold after 3 d and doubled after 28 d. From these results, it appears that lactic acid using bacteria increased in response to higher lactic acid concentrations in the rumen environment. In another study, Klieve *et al.* (2005) from CSIRO Australia, when hay diets were switched to 75% barley diets, numbers of *Megasphaera elsdenii* were barely detectable in the hay diet but rapidly increased when the 75% barley diet was offered. Surprisingly, in this study all of the animals but one had pH > 6. Protozoa number is also important and it has been suggested that higher numbers are observed when diets contain 50 to 60% concentrate; it is important to note that the type of diet (e.g. NSC source, use of neutral detergent-soluble fiber, among others) will influence protozoa numbers. Adaptation to higher concentrate diets is important for protozoa as well, and protozoa also play a role in buffering the degradation of starch in HC diets.

The type of grain included in the diets may also be of concern. Beauchemin and McGinn (2005) fed high corn grain or high barley grain diets to finishing steers and found that CH₄ emissions per kg of DMI were significantly lower for high corn grain diets, meaning that some high grain diets may be more efficiently utilized than others. In addition to HC feeding, more highly digestible forages, like

corn silage, can be substituted for lower digestibility forages in prepubertal heifer rations. Corn silage is a very common feedstuff for dairy heifers. Its popularity is partially due to the ease with which the whole plant can be ensiled to provide a palatable and uniform, high energy forage (Tyrrell and Moe, 1972). Coppock (1970) described corn silage as whole plant silage resulting in an energy yield that is unsurpassed by any other crop.

Furthermore, negative effects of feeding rapidly fermented non fiber carbohydrates (NFC) to dairy cattle on fiber digestion and acidosis incidence are commonly reported in the literature (Palmquist and Jenkins, 1980). In a study conducted by Anderson *et al.* (2009), they noticed that dietary fat was close to 5% when a large portion of the heifer diet was supplied by wet distiller's grains with solubles. These diets maintain similar ADG and overall growth performance; and similar total-tract nutrient digestion in dairy heifers compared with control diets containing corn and soybean meal fed ad-libitum (Schroer *et al.*, 2014). Another study by Suarez Mena *et al.* (2015) using incremental DDGS proportions included to different forage levels, reported that DMI can be reduced as more DDGS were added, by indirectly increasing dietary fat content with no negative effects on nutrient utilization. This allows the inclusion of more energy dense ingredients and the reduction of DMI, resulting on enhanced efficiency of nutrient (starch, protein, fiber) utilization (Lascano and Heinrichs, 2011). These results suggest that DMI can potentially be reduced further by using fat as an energy source in a precision feeding program.

Conclusions

Pre and post-weaning strategies are of great influence on calf health and efficiency. The amount of liquid feeding (MR) pre-weaning affects both, rumen development and the establishment of the microbial population, and weaning strategies seem to have a big impact on performance on dairy calves after weaning. The use of precision feeding alters the absorption of nutrients when applied to ruminant animals; feed efficiency and nutrient digestibility have been shown to be improved by this system. At the same time, high concentrate diets are more metabolically efficient regarding energy and protein utilization when compared to empirical high forage diets used to rear dairy heifers. Even though the conjunction of these two systems might represent advents to ruminant

animal nutrition, rumen fermentation patterns may be challenged decreasing the impact of these strategies. Finally, the insights presented here unveil a gap in the understanding of feeding dairy heifers. How fiber levels can affect nutrient utilization and its interaction with protein degradation and utilization, what is the extent to which ruminal protein digestion impacts N efficiency, how the F:C level interacts with protein and fiber utilization under different feeding strategies, the feasibility of replacing a starch with soluble fiber through the application of precision feeding and altered protein degradability, and can intake be further reduced by using more caloric dense ingredients without affecting fermentation and nutrient digestibility.

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