S O C I E T Y   O F   F E E D   T E C H N O L O G I S T S

RUMINANTS

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Calf nutrition to optimise lifetime performance of dairy cows

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Epigenetics and metabolic programming

The term epigenetics refers to heritable changes in gene expression that do not involve changes to the underlying DNA sequence. An epigenetic change is a common and natural phenomenon induced by environmental factors. For instance, perinatal nutrition can influence metabolism with effects observable much later in life (Jirtle and Skinner, 2007). Perinatal stimuli may include embryonic, lactocrine, and other early life nutritional factors. A first example is the honey bee. Bee colonies consist of thousands of non-reproductive female workers, a few hundred haploid males and a single reproductive individual, the queen. The queen and the workers share identical genotypes, but differential feeding of larvae promotes the occurrence of two very distinct phenotypes (Barchuk et al., 2007). During the larvae stadium, the queen is fed royal jelly and a tenfold greater nutrient supply than a worker. As a result, the phenotypes of workers and queen strongly differ in terms of anatomy, behavior, physiology and longevity. These differences in nutritional experience at critical periods in early life can program an animals' development and metabolism, and is therefore also referred to as metabolic programming.

Another well-studied example of metabolic programming and epigenetics is presented by individuals who were prenatally exposed to famine during the Dutch Hunger Winter in 1944-1945 (Lumey et al., 2007). A bitterly cold period and a German food embargo resulted in a catastrophic drop in the availability of food in the Western part of the Netherlands. These circumstances created a unique population for scientific study, with a well-defined period of severe malnutrition, which allowed epidemiologists to study long-term effects in this population. Results showed that babies exposed to this period of malnutrition, were born smaller, and had higher risks for obesity and disease. The observed effects of exposure to malnutrition were dependent on the stage of pregnancy. Some of these effects seem to even have transferred to the subsequent generation.

Apparently, perinatal environmental conditions can have persistent changes to the metabolism of an animal and its epigenome. These adaptive responses greatly depend on the timing of the exposure and are likely involved to cope with environmental conditions.

Metabolic programming in calves

In recent years, it has become clear that nutrition and management during early life can have long-term effects on lactation performance of dairy cows. Colostrum intake after birth was shown to have great effects on lactation performance. In an experiment, Brown Swiss heifer calves were fed 2 or 4 L of colostrum within the first hour after birth (Faber et al., 2005). Subsequent milk feedings and rearing practices were identical for both groups. Veterinary costs were approximately doubled for heifers fed 2 L of colostrum compared with heifers fed 4 L of colostrum. Average daily gain (ADG) was greater in calves fed 4 L colostrum than those fed 2 L (1.03 ± 0.03 vs. 0.80 ± 0.02 kg/d). In the first two lactations, calves fed 4 L of colostrum at birth produced over 1000 L more milk compared with those fed 2 L. Colostrum contains several components able to induce strong biological effects, at least in the short term. These include immunoglobulins, growth factors, lactoferrin, prolactin, insulin, leptin, relaxin, amino acids and fatty acids. However, the way in which colostrum effects persist in time yet needs to be understood. Improved performance is most likely explained by the strong influence of colostrum on calf's health, which allows for a greater bodyweight gain in early life.

The traditional practice of restricted milk feeding has been challenged by recent research. Soberon et al. (2012) studied the relation between preweaning ADG and first lactation milk yield, using a dataset of 1244 records of the Cornell University herd. This dataset included a large range in ADG (0.11 – 1.6 kg/d). The predicted difference in milk yield per kg of ADG was 850 L for the first lactation, and remained significant for the second and third lactation. The meta-analysis also showed that health is an important aspect of preweaning ADG, linking with evidence on colostrum influence. The effect of ADG on first lactation milk yield was significant for all calves, but calves that were treated with antibiotics produced 623 kg more milk per kg of preweaning ADG, while calves that did not receive antibiotics produced 1407 kg more milk per kg of preweaning ADG. The effect of preweaning ADG on first lactation milk yield has been well established in literature. Overall, increasing nutrient supply from birth up until weaning resulted in an increase in milk yield during the first lactation ranging from 300 to 1300 kg compared with control calves (Table 1).

Table 1. Overview of studied associations between preweaning nutrient intake and first lactation milk yield (adapted from Soberon and Van Amburgh, 2014).

Reference	**Net effect on preweaning ADG, kg/d**	**Net effect on 1st lactation, L**	**Extra milk per extra gain, L/g**
Foldager and Krohn, 1994	na	+1405	na
Morrisson et al., 2009	+0.16	0	0
Shamay et al., 2005	+0.29	+981	3.4
Bar-Peled et al., 1997	+0.29	+453	1.6
Foldager et al., 1997	+0.30	+519	1.7
Ballard et al., 2005	+0.29	+700	2.4
Davis-Rincker et al., 2011	+0.20	+416	2.1
Soberon et al., 2012	+0.38	+552	1.5
Moallem et al., 2010	+0.07	+732	10.5
Raeth-Knight et al., 2009	+0.23	+718	3.1
Drackley et al., 2007 I	+0.23	+1332	5.8
Drackley et al., 2007 II	+0.15	+342	2.3
Terré et al., 2009	+0.10	+624	6.2

The observed effects on milk production may be partly explained by the age-dependency of organ development. Fiebig et al. (1984) showed that organ development (in terms of mass, protein, and DNA) is greatest in the first 50 days of a calf's life. More recently, Soberon and Van Amburgh (2014) compared enhanced milk feeding (70 kg milk replacer in 54 days) to a control group (33 kg milk replacer in 54 days). When assessing weights of organs like kidney, mammary gland, liver, and pancreas at 54 days of age, these were all substantially increased in mass (as such and as a % or BW) for calves provided an enhanced milk feeding scheme. Another study also showed that higher energy and protein intake from 2 to 8 wk of age increased parenchymal mass and parenchymal DNA and RNA in mammary glands of heifer calves without increasing deposition of parenchymal fat (Brown et al., 2005). Of course, one could question whether this effect is persistent and dependent on timing of exposure. Interestingly, increasing energy and protein intake from 8 to 14 weeks of age had no effect on mammary gland development (Brown et al., 2005). Apparently, organ development can be affected substantially before 8 weeks of age. Recent data furthermore indicate that increasing preweaning nutrient intake affects glucose and amino acid signaling, which may play a crucial role in coordinating neonatal metabolism (Wang et al., 2014).

Learn from the calf's choice

Conventionally, dairy calves in Europe and North America have been fed milk at 4-5 L/d. In contrast, dairy calves allowed to suckle from their dam (de Passillé et al., 2008) or with ad libitum access to milk (Jasper and Weary, 2002; Webb et al., 2014) consume 8-12 L/d of milk divided over 7 to 12 feedings (Reinhardt and Reinhardt, 1981; Webb et al., 2014). This means that the average meal size is about 0.8 to 1.5 L. Calves reared with their dam start consuming solids at about 3 weeks of age and the transition to a ruminant diet is completed at about 10 months of age (Reinhardt and Reinhardt, 1981). This is a very gradual process, whereas in intensive calf rearing, weaning is imposed at 6 to 10 weeks of age and in a much more abrupt manner, resulting in stress (Latham and Mason, 2008; Weary et al., 2008).

Gradual weaning after 8 weeks of age

When compared with the conventional rearing strategy, feeding larger amounts of milk reduces starter intake preweaning (Terré et al., 2007; Weary et al., 2008), and rumen development during the milk-feeding period (Khan et al., 2007a,b). Therefore, weaning becomes a greater challenge because of a high preweaning energy intake, and a low solid feed intake. Therefore, at Nutreco Ruminant Research Centre several trials were carried out to study weaning strategies under higher planes of nutrition.

In a first trial (Eckert et al., 2014), the effect of weaning age on performance was studied. Calves fed a high plane of nutrition (8 L of milk replacer per day) were weaned at 6 or at 8 weeks of age. They received free access to water, straw, and starter. Results suggest that calves on an elevated plane of nutrition pre-weaning benefit from extending the time of weaning from 6 to 8 weeks of age based on energy intake, growth, gastrointestinal function and behavior measurements. As can be derived from Figure 1, the energy 'gap' during transition from a liquid to a solid diet was much smaller when weaning at 8 weeks of age.

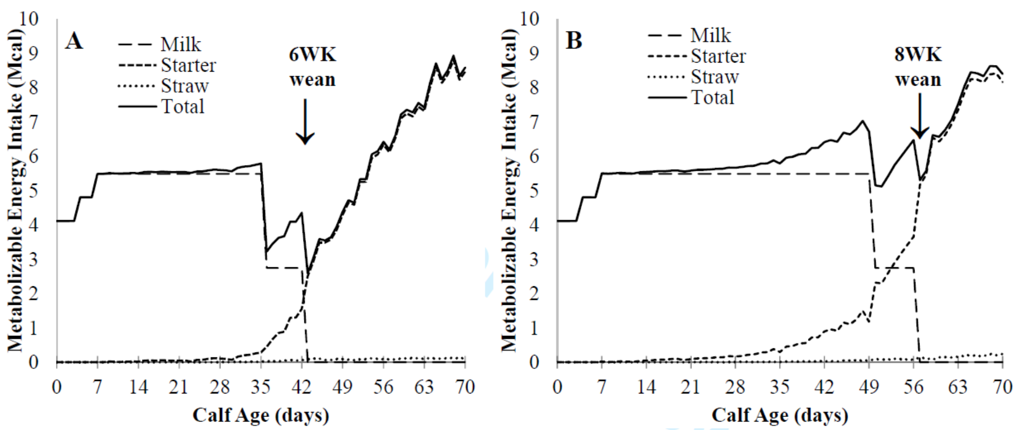

Figure 1. Estimated daily intake of metabolizable energy from milk, starter, and straw from 0 to 70 days of age from calves weaned at 6 (A) or 8 (B) weeks of age (from Eckert et al., 2014)

A second trial was performed at Nutreco Ruminant Research Centre, comparing the effects of *abrupt* weaning in one day versus *gradual* weaning in one week. Results show that gradual weaning prevents a growth dip, and is economically more attractive, as it requires less milk. Gradual weaning also enhanced starter consumption, which is confirmed by literature (Khan et al., 2007; Sweeney et al., 2010). In addition, abrupt weaning can lead to increased cross-sucking and signs of hunger (Nielsen et al., 2008).

Importance of roughage provision and rumen development

The rumen of the neonatal calf is underdeveloped and non-functional. Initiation of solid feed intake and the associated fermentation processes trigger the development of the rumen. Rumen papillae growth is stimulated by volatile fatty acids, in particular butyrate (Tamate et al., 1962) and the physical presence of feed bulk stimulates the muscular development and expansion of ruminal volume (Stobo et al., 1966). Calves start consuming solids at about 14 d of age (Khan et al., 2008), and intake increases rapidly when milk supply is reduced (Khan et al., 2007a,b; Jasper and Weary, 2002). When moving to greater milk intakes in the preweaning phase, starter intake is reduced. Intake of starter in calves fed milk at 10% of BW is twice higher than in calves fed at 20% of BW (Jasper and Weary, 2002; Cowles et al., 2006; Raeth-Knight et al., 2009). This is the logical response of calves fulfilling their nutrient requirements with the milk supply. However, even at unlimited milk supply, ruminants still start to eat solid feed at about 14 days of age (Forbes, 1971; Webb et al., 2014).

A successful transition from liquid to solid feed is of great importance to prevent weight loss and stress. Therefore, the key objective should be to ensure a rapid increase in starter intake and rumen development around weaning. Considering the need to increase solid feed consumption of young calves, introducing roughage during the milk-feeding period was shown to improve ADG and total DMI (Khan et al., 2011). Effects of different roughage sources, when provided in a chopped form and offered separately from starter, on calf performance were studied by Castells et al. (2012). They compared the provision of starter without roughage to the same starter plus chopped alfalfa, rye-grass hay, chopped oat hay, chopped barley straw, corn silage, or triticale silage. Results showed that free-choice provision of each of these roughage sources improved feed intake and performance without impairing the digestibility of DM, organic matter, crude protein, or fiber. Best results were obtained with chopped oat hay, chopped barley straw, or triticale silage. The main reason for a greater feed intake results from an improved rumen environment, because of increased rumination and rumen pH.

Roughage particle size also affects rumen development and would therefore increase feed consumption and performance. Indeed, when compared with ground hay, chopped hay provision improved feed intake and digestibility values in young calves (Montoro et al., 2013).

Our milk replacers and the LIFESTART research program

For more than 50 years Trouw Nutrition has specialized in the production of high quality milk replacers which are now exported to more than 60 countries. The formulation of these milk replacers is based on fundamental research data from over 1000 trials, resulting in products and knowledge being tailored specifically to the needs of the modern calf. Supporting maximum growth and lifetime performance is now the primary objective for professional farmers.

Following up on a new and promising branch of ruminant nutrition research, Nutreco Research and Development initiated our Lifestart research program. The objective is to gain understanding on the underlying mechanisms of above mentioned effects. Underpinning the persistent metabolic changes created by higher nutrient supply during the preweaning phase, we aim to explain and potentiate these positive effects in later life performance. In particular, 70 calves have been subjected to a low or a high plane of nutrition at the Nutreco Ruminant Research Centre and are being followed throughout their lives. Metabolomics techniques are applied to identify bio-markers that can allow us to link early nutrition effects with increased life performance. The project includes also several other studies, as for example an analysis of gene expression at different tissues of animals sacrificed at weaning, or an study of early life nutrition in beef cattle physiology and performance. Project information and progress updates are available at www.lifestartscience.com.

From theory to practice:

The take-home messages for on-farm applications are the following:

- Colostrum is crucial for the neonate calf to enhance feed efficiency, health and later life performance.
- Increasing pre-weaning growth, through enhanced milk feeding, has long term benefits for performance.
- Weaning and rumen development become more important because solid feed intake pre-weaning is impaired with enhanced milk feeding. Calves should be weaned in a gradual manner and after 8 weeks of age to prevent a dip in growth.
- The provision of roughage, separately from starter and from 2 wk of age improves starter intake and performance pre-weaning and post-weaning.
- Roughages should be provided chopped instead of ground, because the physical structure is important from rumination and rumen development.
- All feeds should be fresh and palatable, and water should be provided ad libitum.

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