



## Perinatal Nutrition of the Calf and Its Consequences for Lifelong Productivity\*

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**ABSTRACT** : Provision of an optimal environment for the calf is critical to establishing the patterns of growth and development essential to allow the heifer to express its genetic potential for milk output and reproductive capacity during its productive life. Maternal nutrition during gestation is now recognised as a key to genetic programming *in utero* and this influence is extended through the complexity of hormones, growth factors and immunostimulants incorporated into colostrum and milk consumed by the neonatal calf. This natural process is most often disrupted as calves are weaned abruptly to maximise milk output for commercial exploitation. The key then is to accelerate the rate of maturation of the ruminal epithelium through the provision of concentrate starter rations and high quality forage, which promote VFA production. Management systems to promote these processes in Holstein Friesian cattle are well developed, however, little is known of these processes with buffalo and *Bos indicus* dairy cattle such as the Sahiwal. The development of methods to program the neonate to grow faster to puberty in these species will be important to improving their productivity for the dairy industries in tropical and sub-tropical environments in the future. (**Key Words** : Perinatal Nutrition, Calf, Buffalo, Productivity)

### INTRODUCTION

The potential for growth and high health status in the newborn calf is largely influenced by the health and metabolic status of their dam. Much of the focus of cow management has been on the perinatal period as the calf prepares for delivery into a totally foreign environment in which placentally derived nutrition is replaced by the initial lacteal secretion from the mammary gland, colostrum. The composition of this secretion is extremely important in establishing the growth potential and life-long productivity of the calf. This then reverts to normal milk which acts as a

source of dietary energy and protein through to the point when the calf is able to be weaned. This initial phase is most often termed the pre-ruminant period during which milk is passed directly into the abomasum through the reflex closure of the oesophageal groove. This initial period of development is termed the pre-ruminant phase and varies in duration from 14-21 days depending on the animal's ability to initiate the intake of dry feed. During the subsequent 3-6 weeks ruminal function develops and the calf derives more of its nutrient substrate from this source than from milk. At this point the animal is weaned and derives its nutrient substrate solely from dry feeds through the activity of the newly established ruminal microbial population: this describes the ruminant phase of calf development.

This process is universal for bovine species although there are many variations in procedures used in different parts of the world.

### PROGRAMMING DEVELOPMENT FROM CONCEPTION

Feeding cows to support the protein, energy, vitamin and mineral requirements of the growing conceptus is now recognised as just one factor that influences the life-long

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productivity of the calf. We are now aware of the importance of environmental factors on gene expression patterns and therefore development much earlier during embryogenesis. These so-called epigenetic mechanisms challenge the very basis of Darwinian evolutionary theory that the variability in populations occurs exclusively through random mutations. The mechanism through which this occurs is by altering gene methylation patterns (Khosla et al., 2001) which might not only regulate the growth potential of the calf but also alter the germline which may then persist as mutations across subsequent generations (Surani, 2001). Factors that initiate these changes which may persist differentially across different regions of DNA are influenced by changes in dietary components providing methyl groups for this mechanism. Synthetic xenobiotics (Danzo, 1998), the estrogenic molecules in plants the phytoestrogens and isoflavones, all of which can be found in the cow's diet contribute to these changes (Guerrero-Bosagna et al., 2005).

Thus at calving the growth potential of the animal may have already been compromised by factors other than the mere supply of nutrient substrate to support the growth process.

#### THE IMPORTANCE OF COLOSTRUM

It is generally considered that the newborn calf should receive 4 L of colostrum in the first 12 h, although up to 6 L is often recommended for the first day (University of Sydney, 2007). Requirements will depend on the quality of colostrum usually determined by assessing its density associated with immunoglobulin (Ig) content: the presence of enzymes to form curd in the abomasum is also a rate limiting factor for Ig absorption (Gregory, 2003; Mastelloni et al., 2005).

The observation that over 100 hormones and growth factors have been identified in colostrum or milk (Koldovsky, 1995; Koldovsky, 1996) suggests that these secretions are complex biological fluids designed to extend the influence of the dam over developmental processes beyond the uterine environment. These include hormones of the hypothalamic-pituitary, the thyroid-parathyroid group, gastrointestinal regulatory hormones as well as growth factors. While the physiological significance of growth hormone regulatory peptides is most apparent the importance of the gonatropin regulatory peptide GnRH at this early stage is more obscure. However the developmental processes that these hormones regulate are most likely important when calves are born into a challenging environment in which ambient temperature varies significantly from that experienced *in utero* and when pathogen loads are high. The provision of key nutrients to support growth is also an integral function of milk with

proteins, essential and non essential amino acids, lactose, fatty acids, vitamins and minerals all contributing to these requirements. Other non-nutritional factors include nucleotides, polyamines, enzymes as well as functionally important proteins such as lactoferrin (Blum and Hammon, 1999; 2000) serve specific roles in directing growth processes. Lactoferrin has also been extensively characterized in buffalo milk (Sharma et al., 1999).

Cellular components are also incorporated including mammary epithelial cells, erythrocytes macrophages, polymorphs, lymphocytes, plasma cells and epithelial cells (Uruakpa et al., 2002) while a number of the non-nutritional and bioactive molecules are sequestered from the circulation. These include growth hormone, prolactin, oestrogen, insulin and glucagon, all of which play a role in regulating protein and energy metabolism. It is often difficult to envisage a functional role for these protein hormones since they will be hydrolysed extensively in the abomasum prior to accessing functional receptors. However the key may reside in their co-secretion with the immunoglobulins, most notably IgG1.

These macromolecules comprise more than 90% of the protein content of colostrum and appear at concentrations 5-10-fold higher than in the circulation (Larson, 1992). Their sequestration coincides initially with higher oestrogen levels up to 1 month *pre-partum* and subsequently with elevated corticosteroids, growth hormone and prolactin in the last week and then with depressed progesterone at 48 h pre-calving.

The functional significance of these relationships is yet to be established. Equally intriguing is the mechanism that facilitates preferential uptake of IgG1, which is typically 10-fold higher than IgG2 in colostrum, but present in equivalent concentrations in the circulation. This imbalance provides a definitive characteristic of colostrum and is explained by the presence of specific receptors on the basal membrane of secretory epithelial cells which actively endocytose IgG1 and pass it to the secretory lumen of the alveolus (Butler, 1983; Barrington et al., 2001). It is important to note that this mechanism is only in place during colostrum synthesis and therefore IgG1 concentration falls markedly after the colostrum phase (Kemler et al., 1975). The immune status of the buffalo calf post-colostrum feeding is influenced also by the vitamin status of the dam: circulating Ig levels were increased by 80% in calves fed colostrum from their dams receiving bolus injections of vitamins A., D<sub>3</sub> and E late in pregnancy (Sikka and Lal, 2005). VitE and selenium also limit the adverse effects of endotoxin from *E coli* infections associated with many calf rearing systems (Sharma et al., 2005).

Further protection against pathogenic bacteria and viruses is provided by the presence of antimicrobial

proteins, lactoferrin and lysozyme. Lactoferrin is an iron binding moiety that prevents microbial growth through depriving microbial of this essential mineral and by binding to bacterial cell membranes thereby compromising their permeability (van Hooijdonk et al., 2000), while lysozyme lyses bacterial cell walls (Lonnerdal, 2002). Interestingly these two proteins are capable of acting synergistically to enhance their bacteriostatic activity (Pakkanen and Aalto, 1997).

The immunoglobulins are accompanied by a range of protease inhibitors including trypsin inhibitor,  $\alpha$ 2-macroglobulin,  $\alpha$ 2-antiplasmin, antithrombin III, C1-inhibitor, inter- $\alpha$ -trypsin inhibitor, bovine plasma elastase inhibitor and bovine plasma trypsin inhibitor, all of which serve to protect their functional integrity (Christensen et al., 1995).

Other multi-functional proteins are coming to light including a proline-rich polypeptide colostrinin. This was originally found as a fraction accompanying sheep colostrum immunoglobulins which promoted T cell-tropic and maturational activity. It is also associated with the development of precognitive functions which inhibit pathological states centrally (Zimecki, 2008).

In addition to the role of the simple carbohydrate lactose in providing energy, more complex carbohydrates also add to the multi-functionality of colostrum. Sialyloligosaccharides are present in high concentrations for the first 12 h of lactation in the cow and are thought to be important in preventing infections acting against rotavirus, reovirus and *Helicobacter pylorum* (Nakamura et al., 2003). Interestingly they also appear to be involved in the development of cognitive processes in the brain, with the supplementation of milk for piglets with sialic acid improving learning and

memory in the piglet (Wang et al., 2007). There is little reason to suspect that suckling behaviour in both cows and buffalo is not influenced by these molecules, although bovine and human milk diverges in the concentration and composition of their sialyloligosaccharide content; this has implications for the development of infant formulae (Martín-Sosa et al., 2003). Interestingly buffalo milk gangliosides appear to have greater toxin binding and anti-inflammatory properties than cows milk suggesting some potential novel applications for the product from buffalo in the future (Colarow et al., 2003). This is also important for the survival of the buffalo calf in environments with high pathogen loads. Certainly buffalo milk is highly valued as an alternative to breast milk among Indian mothers (Kaushal et al., 2005).

The composition of colostrum changes rapidly and its provision to the calf during the first 24 h of life is critical to the calf's survival.

### COLOSTRUM AND THE DEVELOPMENT OF THE GASTROINTESTINAL TRACT

The rich mix of hormones, growth factors, cytokines and nutrients in colostrum provide the ideal developmental mix to initiate digestive activity in the abomasum, small and large intestines. The initiation of the functional integrity of the intestinal epithelium is essential for the absorption of nutrients and bioactive molecules to direct developmental processes in the body. In particular the apical junctional complex plays an important role in maintaining the integrity of this epithelium and prevents access for pathogens to the circulation. A wide range of cytokines and growth factors influence tight junction integrity, with IFN- $\gamma$ , TNF- $\alpha$ , HGF,

**Table 1.** The composition of colostrum and milk (Blum and Hammon, 2000; Klimes et al., 1986)

Nutrient	Colostrum (1 <sup>st</sup> milking day 1)	Mature milk (5-14days postpartum)
Total protein (%)	17.12	3.57
Fat (%)	4.69	5.26
pH	6.31	6.43
Gross energy (MJ/L)	6.0	2.8
Crude protein (g/L)	133	32
Immunoglobulin G (g/L)	81	<2
Lactoferrin (g/L)	1.84	0.36 (at 4 <sup>th</sup> milking)
Transferrin (g/L)	0.55	0.21 (at 4 <sup>th</sup> milking)
$\gamma$ -glutamyltransferase ( $\mu$ kat/L)	509	52
Alkaline phosphatase ( $\mu$ kat/L)	19	4
Aspartate aminotransferase ( $\mu$ kat/L)	1.5	0.1
Tumour necrosis factor- $\alpha$ ( $\mu$ g/L)	5	<2
Insulin ( $\mu$ g/L)	65	1
Glucagon ( $\mu$ g/L)	0.16	0.01
Prolactin ( $\mu$ g/L)	280	15
Growth hormone ( $\mu$ g/L)	1.4	<1
Insulin-like growth factor-I ( $\mu$ g/L)	310	<2
Insulin-like growth factor-II ( $\mu$ g/L)	150	ND

ND = Not determined.

TGF- $\alpha$ , IGF-I, IGF-II, VEGF, IL-1, IL-4 and IL-13 all decreasing barrier function while EGF, TGF- $\beta$ , GDNF, neurturin, IL-10, and IL-17 have the opposite effect (Sawada et al., 2003). Clearly this is a closely regulated and functionally important property which can be influenced by the balance of these factors present in colostrum. Again there is evidence to suggest that the intestinal epithelium in the buffalo calf is more resistant to some infections including paratuberculosis (Sivakumar et al., 2006).

### NUTRIENT REQUIREMENTS FOR THE NEWBORN CALF

The calf requires nutrients for both maintenance and growth and it is important that the requirements for these two processes are combined. Environmental factors are extremely important in determining requirements with both extremes of heat and cold, high pathogen loads and physical and psychosocial stressors contributing to requirements. The activation of the immune system and the role that maternal immunity plays in this process is important to animals calving in sub-optimal environments (Chase et al., 2008).

As a guideline the metabolisable energy requirements for a 45 kg calf under thermoneutral conditions is 7.3 MJ/day. Since cow's milk contains 22.5 MJ ME/kg of solids they require 2.5 L of whole milk, while the equivalent with lower fat status milk replacers is around 3 L (Drackley, 2008). Others recommend higher intakes up to 10 and 12% of bodyweight per day to support growth (University of Sydney 2007). Milk requirements will be lower in the buffalo as milk fat content is higher than in cows milk, although colostrum fat content is the same in each species (Ganovski, 1979).

Protein requirements for maintenance are low in the neonate (30 g/d for a 45 kg calf) and reflect rates of protein turnover in tissue. However the requirements for growth are approximately 6-fold higher than this, equating to 250-280 g of crude protein from milk replacer (Drackley, 2008). In general milk replacers containing up to 25% crude protein are recommended as long as dietary energy is not limiting. Amino acid composition of replacers is also important with those most closely resembling the composition of cows milk being most effective.

Changes in energy requirements in cold and hot environments are quite dramatic as body temperature is not buffered by the heat of fermentation in the undeveloped rumen. Maintenance ME increases by approximately 20% for each 10°C incremental decrease from 20 to -20°C (National Research Council, 2001). In contrast the effects of heat stress have not been published although older animals require an additional 20-30% ME (National Research Council, 2001): the ready availability of water on demand

and shade for calves is well established yet not always adhered to in many countries.

The water content of body tissues is in the vicinity of 70% (Diaz et al., 2001), thus the constant availability of water is mandatory in any production system. Promoting the intake of dry concentrate feeds to enhance rumen development is also dependent on constant water availability.

Requirements for minerals and vitamins have also been documented (Council, 2001). Whole milk provides an adequate source of all minerals with the exception of iron and sometimes selenium and manganese. As most milk starters are supplemented with minerals and fat soluble vitamins these rarely compromise calf health and growth.

The only major concerns are with Vitamins A and E: NRC recommendations for Vitamin A are considered to be too high leading to potential toxicity, while those for vitamin E are under-estimated (Drackley, 2008). While a state of deficiency will rarely be found, finding the correct dose for optimal growth represents a greater challenge.

### DEVELOPING THE RUMEN

The general rule of thumb is to adopt strategies that allow calves to consume 700-900 g of concentrate ration by the time that they are weaned. Essentially this requires calves to commence intake of concentrates within 14 days *post-partum* (University of Sydney, 2007). Animals consuming 10% of their own bodyweight as milk per day will in general be consuming up to 300 g of concentrate by day 25. The microbial population accumulating in the rumen will ferment carbohydrate to form predominantly butyric acid and then propionic acid which in turn promote the differentiation of the ruminal epithelium to form the characteristic papillae (Heinrichs and Lesmeister, 2005). Different sources of fermentable carbohydrate yield different responses, with corn and wheat based diets promoting ruminal development faster than oats or barley (Khan et al., 2008). Similarly processing can exert and influence the growth response: steam flaking of corn for example induced ruminal epithelial development faster than either dry rolling or leaving grain whole (Lesmeister and Heinrichs, 2005). These studies showed also that processing can influence the pattern of volatile fatty acids released. Other alternative concentrate sources such as *phalaris minor* seeds have also been assessed as providing appropriate carbohydrate sources to support volatile fatty acid synthesis and rumen development (Kaur et al., 2006).

Much has been written on the role of fibre and the so called "tickle factor" in the diet of the pre-ruminant calf. Results vary widely with concentrate *per se* being more effective in some studies (Klein et al., 1987), while in others forages provided at a specific particle size (8-19 mm)

with concentrates gave superior results (Coverdale et al., 2004). In further studies pelleted diets yielded superior responses to mixed length fibre with other dietary ingredients held constant (Bach et al., 2007). Clearly our understanding of the development of the ruminal environment requires further investigation, although the role of the volatile fatty acids in this process is well established. The inclusion of cellulolytic enzymes as feed additives also provides a beneficial growth effect if included as a substitute for more conventional additives in buffalo calf diets (El-Kady et al., 2006).

### CALF REARING: THE PAKISTANI EXPERIENCE

Pakistan, like many developing countries has an agrarian rural based economy. The livestock sector is a major contributor to the national (12%) and agricultural (50%) economy (Pakistan Economic Survey, 2006). This sector is growing quickly and provides a livelihood for more than 35 million people. The productivity of livestock for meat and milk is low, with improper calf management programming animals for a life of low productivity. High market prices for milk dictate that calves are weaned very early without appropriate quality milk replacers being used to meet the demand of the calf for growth and development. Male calves are most often sold for slaughter or left to feed on poor quality roughages. The slow growth of heifer calves results in delayed puberty and age at first calving. Thus both the efficiency of milk and beef production are compromised.

### FEEDING THE TRANSITION BUFFALO

Late pregnant or transition Holstein cows can be affected by a range of production diseases associated with their inability to cope with the metabolic demands of high production. These include hypocalcaemia, hypomagnesaemia, ketosis, retained placenta, displacement of the abomasum and laminitis (Mulligan and Doherty, 2008). These are often associated with an imbalance in metabolites entering key biochemical pathways (Payne, 1972) which may lead to infertility.

Similar problems are associated with buffalo production, although the causes are most likely related to under-nutrition. The pregnant buffalo needs to support the nutrient demands of both lactation and growth of the foetus. Yet the condition score of most small-holder buffalo remains very low despite the need for additional nutrients to meet these demands. Very few studies have been conducted to investigate these relationships, but a positive relationship has been shown between liveweight of the calving dam and the calf. At lower body weights (350-573 kg) calf birth weight increased by 18 g for each kg increase in weight of

dam. This increment decreased to 5.5 g per kg liveweight in dams weighing 576-815 kg (Usmani et al., 1987; Usmani and Inskip, 1989).

As with the cow the first 24 h post-calving are critical for the buffalo calf to absorb colostrum. In fact total protein and Ig levels are higher in the buffalo than in cross-bred cows (Singh and Ahuja, 1993). In this study 75% of Ig and 68% of colostrum protein were absorbed within 1 h of feeding a 7 h old calf. This rate of absorption declined rapidly after the first feed. However little other data are available on colostrum usage to account for high susceptibility to infection of buffalo calves.

### CALF MORTALITY

Neonatal calf morbidity and mortality are major causes of economic losses in livestock production. It is roughly estimated that a calf mortality of 20 percent can reduce the net profit of an enterprise by 60% (Blood and Radostits, 1989). Ideally calf mortality should be less than 5 percent with growth rates of 0.5-0.7 kg/d (Blood and Radostits, 1989). Mortality rates for different countries employing different production systems are detailed in Table 2.

Very high mortality rates of over 50% have been reported in buffalo calves to one month of age. Foot and mouth disease (FMD) and haemorrhagic septicaemia (HS) are endemic to Pakistan and account for up to 31 and 21.5% respectively of deaths in buffalo calves aged from 6-12 months (Ramakrishna, 2007). On other farms extreme mortality rates of up to 80% have been recorded (Tiwari et al., 2007). Although disease contributed to this statistic, the failure to provide colostrum, to deworm, to disinfect naval cords and to provide an adequate milk substitute and appropriate shelter and water all played their role in the etiology of these mortalities. Other causes of calf mortality include the greater susceptibility of crossbred and primiparous animals (Rao and Nagarcinkar, 1980). The failure to provide colostrum has also often been implicated (Afaq et al., 1992).

The giving of colostrum to friends is a custom found in some regions and as such the calf is inevitably deprived. Overall farmers in many regions consider calf rearing a very low priority, as the commercial value of this practice is not apparent to them.

### SUCKLING AND HAND FEEDING OF BUFFALO CALVES

The average birth weights for buffalo and Sahiwal calves are 34.85±0.46 and 21.87±0.20 kg respectively (Ahmad, 1988). The method of provision of milk for these calves has been shown to influence their growth efficiency. For example calves reared by restricted suckling of their

**Table 2.** Incidence of mortality (%) among buffalo and cow calves in different countries

Age (days)	Mortality (%)	Country	Reference
<b>Buffalo calves</b>			
30	7.1	Pakistan	(Khan, 1994)
1-30	51.8	India	(Ramakrishna, 2007)
30	27.5	India	(Bhullar and Tiwana, 1985)
90	34.0	India	(Bhullar and Tiwana, 1985)
15	12.6	Vietnam	(Sharma et al., 1984)
16-30	29.9	Vietnam	(Sharma et al., 1984)
30	51.7	India	(Khera, 1981)
<b>Cow calves</b>			
30	11.0	Pakistan	(Khan, 1994)
15	32.5	India	(Veerapandian et al., 1993)
0	61.6	U.S.A.	(Bellows et al., 1987)
1-10	23.4	U.S.A.	(Bellows et al., 1987)
2	8.2	Ireland	(Mee, 1988)
14	56.4	Germany	(Fink, 1980)
4-7	1.2	Italy	(Mariani et al., 1986)
28	3.0	Norway	(Simensen, 1986)
90	8.7	Nigeria	(Umoh, 1982)
28	12.5-26.0	Libya	(Gusbia and Hird)
30	6.9	Iraq	(Maarof et al., 1987)

dams yielded better growth rates than if the milk was provided in a feeder or pail (552 vs. 370 g/d) (Khan and Preston, 1992) and 500 vs. 350 g/d in the study of (Gaya et al., 1977). If adequate milk is provided these high growth rates are attainable: the provision of 15% of the milk production from Sahiwal cows or buffalo which equates to 10% of the calf's bodyweight has resulted in these growth rates (Ahmad, 1988). The training of buffalo calves to the use of automatic suckling units may compromise their growth performance by limiting intake (Rossi et al., 2004). Given these problems it is most likely more effective to delay the weaning of buffalo calves reared in sub-optimal environments particularly as the buffalo dams display strong maternal instincts. Thus the provision of some milk to calves combined with the harvest of milk from a second milking each day for commercial sale or home consumption may provide the most effective means of rearing the calves of Sahiwal cattle and buffalo. This method also negates the need to use oxytocin to induce milk let-down: use of the calf is biologically more sustainable.

### STARTER RATIONS FOR CALVES

Poor growth rates result from the limited milk supply, low protein and energy of fodders and concentrates that are available for calves. In order for the farmer to sell a high proportion of his milk, cost-effective milk replacers need to be developed. Starter rations containing 17% crude protein and total digestible nutrients of 75% have resulted in growth rates of up to 470 g/d (Ahmad and Jabbar, 2000).

Similar results have been achieved through the substitution of milk with soybean milk containing 1% soybean oil (Matter et al., 2005). The levels of protein used

in these studies are below recommendations for Holstein Friesian calves: thus productivity could be boosted further through the use of higher protein supplements. The importance of offering calves a soluble concentrate ration high in protein and energy from calving should be considered.

### FEEDING POST WEANING

Feeding strategies used post-weaning involve the use of low quality crop residues, straws and stovers characterized by high fibre and low crude protein. Numerous studies have been undertaken to improve their efficiency of utilization largely through their treatment or use in conjunction with strategic supplements (Sarwar et al., 2002).

Urea treatment of straw is popular as it increases the N content of roughages. The addition of molasses then provides a balance of N and energy for the rumen microbial population to utilise in digesting the insoluble carbohydrates. Wheat straw treated with varying levels of urea (0%, 2% and 4%) and molasses (2% and 4%) ensiled with 30% cattle manure (on dry matter basis) for different fermentation periods (20, 30 and 40 days) proved to be an ideal supplement providing linear growth responses with amount fed in buffalo calves (Sarwar et al., 2006). Similar results were achieved by Khan et al. (1992) who reported that crude protein increased by 18.4% to 22.2% in sugarcane bagasse ensiled with cattle manure for 30 and 60 days, respectively. However, the increasing cost of urea world-wide may make this option prohibitive.

Caution must be used in the evaluation of supplements. In one study sunflower meal was substituted for cottonseed

meal at 0, 12, 24 and 36% on an isonitrogenous basis to 11 month-old buffalo calves (Yunus et al., 2004). The sunflower meal yielded inferior responses both biologically and on a cost basis, suggesting that its use should be approached with caution. Maize has proved to be an effective concentrate for buffalo and Sahiwal calves in a number of studies. In comparing starter rations based on maize, oats and their combination normalized to 20% crude protein and 80% TDN, growth rates on the maize based diet were 18% higher (Rafique and Manzoor, 2000).

Supplementing with protein that is resistant to ruminal digestion can also yield excellent responses, such as has been achieved through the use of formaldehyde treated mustard cake (Chatterjee and Walli, 2003). Again caution should be used as if the basal diet consists of poor quality roughage more cost effective supplements providing any source of N and energy to the rumen may yield similar responses.

### CONCLUSION

The key to successful calf rearing commences with the appropriate feeding of the late pregnant or transition cow, as any metabolic disturbance will have consequences for the growth potential of the calf. Increasingly we are becoming aware of the key metabolic cues responsible for programming the growth and ultimately the production potential of the calf. Disturbingly most of the available literature pertains to the growth and development of the Holstein Friesian calf. In spite of the importance of the buffalo and the Sahiwal cow to the provision of dairy products for Asia, our fundamental understanding of these processes in these animals is poorly developed. Future research should focus on the nutritional regulation of these developmental processes in late pregnancy through to weaning: if this is not optimised then research on feeding of the weaner calf is compromised.

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