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# Nutrition, Metabolic Status and Reproductive Efficiency in Dairy Herds

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## Abstract

**Nutrition of transition period in dairy cows dramatically increases requirements for energy, glucose, amino acids and other nutrients in dairy cows and, parallel to that, feed intake is depressed. An insufficient or imbalanced nutrient intake might lead to the malfunction of organs, causing reproductive failure. To minimize the metabolic/reproductive damage caused by negative energy balance (NEBAL), feeding of a glucogenic and lipogenic diet containing fat-enriched supplements is recommended. In heat-stressed dairy cows, the reduction of dry matter intake causes an energy deficit, thereby accentuating NEBAL. Heat stress may also have a direct impact on oocyte quality due to the high ovarian temperatures. The intrauterine environment is also compromised in heat-stressed cows, with reduced blood flow to the uterus and increased uterine temperature; this may impair embryonic development, increase early embryonic loss and reduce the proportion of successful inseminations. Postpartum NEBAL suppresses immune function and promotes metabolic disorders, potentially explaining relationships between infectious and noninfectious transition disorders. In postpartum dairy cows, pathologic ovarian phenomena including ovulatory (cystic corpora lutea) and non-ovulatory (follicular and luteal cysts) forms frequently occur causing decreased fertility. The main objective of this review was summarizing the most relevant information regarding nutrition and reproduction in dairy cows.**

## Keywords

**Dairy Cattle, Reproduction, Nutrition, Metabolic Status**

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## 1. Introduction

Efficient reproduction in dairy cattle herds is of great economic importance. Increased milk production together with suboptimal farm management (especially nutrition or reproduction) can reduce fertility. Over the past decades, the calving interval has increased in parallel with milk production in several countries including the US and Hungary (**Table 1** and **Figure 1**).

Extreme selection pressure for milk production in dairy cows has been highly successful. Unfortunately, there are clear negative correlations between milk yield and fertility, presence of mastitis, and other health traits. The decline in fertility is of multifactorial origin and not exclusively associated with increased milk production. To improve the decreased fertility, cow longevity, health and fertility have been used as selection criteria in many breeding programs in numerous countries [4]. Factors such as management and husbandry, nutrition and reproductive diseases determine reproductive performance (number of open days, calving interval, number of AI per pregnancy, pregnancy rate, and early/late embryonic loss). Over the past few years, several trials have been conducted to determine the effect of a more economical dry period length [5] on the postpartum health [6], production [7] [8], and reproduction [9] [10] of dairy cows.

## 2. Nutrient Intake, Metabolic and Hormonal Status and Reproductive Failures

The major problem in postpartum cows is the imbalance between the body reserves and milk production. The transition (late pregnancy to early lactation) period dramatically increases requirements for energy, glucose, amino acids and other nutrients in dairy cows and, parallel to that, feed intake is depressed. This is why a negative energy balance (NEBAL) occurs in the background of reduced fertility (**Figure 2**).

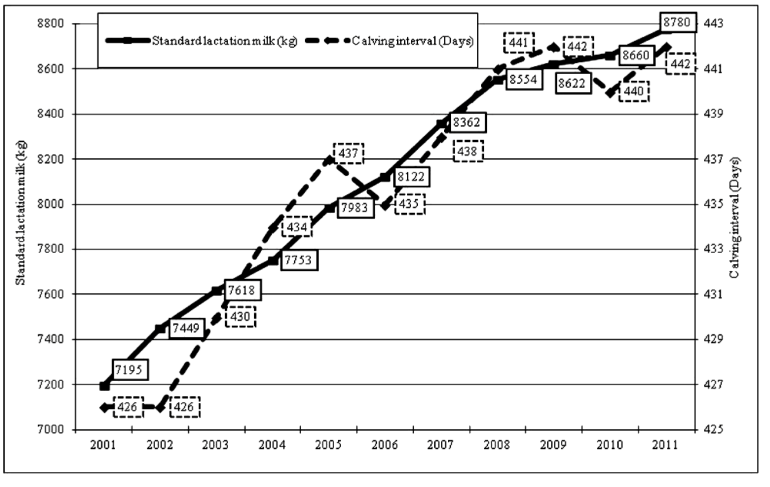


**Figure 1.** Changes of milk production and calving interval in Hungary between 2001 and 2011 [3].

**Table 1.** Change of the calving interval (days) in the Holstein breed in the US.

| Parity | Nieuwhof *et al.*, 1989 [1] | Hare *et al.*, 2006 [2] |
|---|---|---|
| 1 | 394.2 | 402.9 |
| 2 | 392.8 | 402.4 |
| 3 | 394.6 | 403.4 |
| 4 | 398.1 | 406.2 |
| 5 | 400.4 | 408.9 |
| 6 | 404.7 | 410.8 |
| 7 | | 412.9 |

Since the transition period involves the most important physiological changes of the time around calving, it is a favorable target for reproduction and nutrition physiologists. Both calving and the start of milking act as stress factors for cows, influencing metabolic and hormonal changes (**Figure 3**). An insufficient or imbalanced nutrient intake might lead to the malfunction of organs (liver, hypothalamus, hypophysis, ovary, uterus), causing reproductive failure.

## 3. Calving and Immune Function

It is estimated that approximately 30% - 50% of cows are affected by some form of metabolic and/or infectious diseases in the periparturient period. Calving itself represents a major oxidative stress for cows. Oxidative stress is an imbalance between radical-generating and radical-scavenging activity, resulting in oxidation products and tissue damage. The production of free radicals and reactive metabolites is one of the basic mechanisms underlying reproductive diseases, and antioxidant status is a major determinant of reproductive function in farm animals [11].

Calving disorders have a strong influence on the postpartum period. Retained fetal membranes (RFM) and puerperal metritis are more frequent when calving is assisted. During the postpartum period, rapid and uneventful involution of the uterus, early resumption of normal ovarian activity, and accurately detected estrus are re-

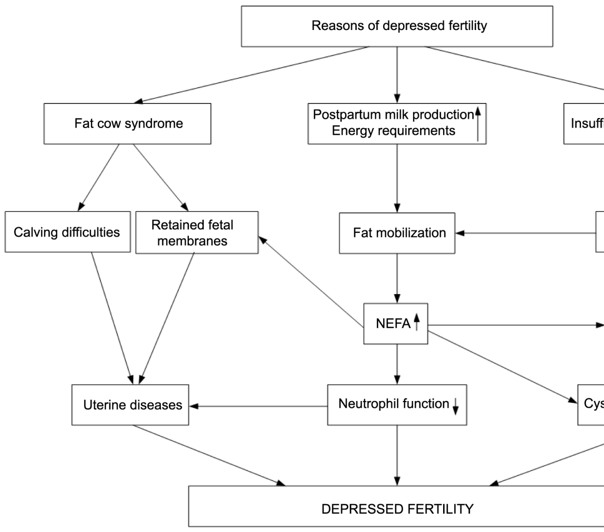


**Figure 2.** Most common causes of depressed fertility.

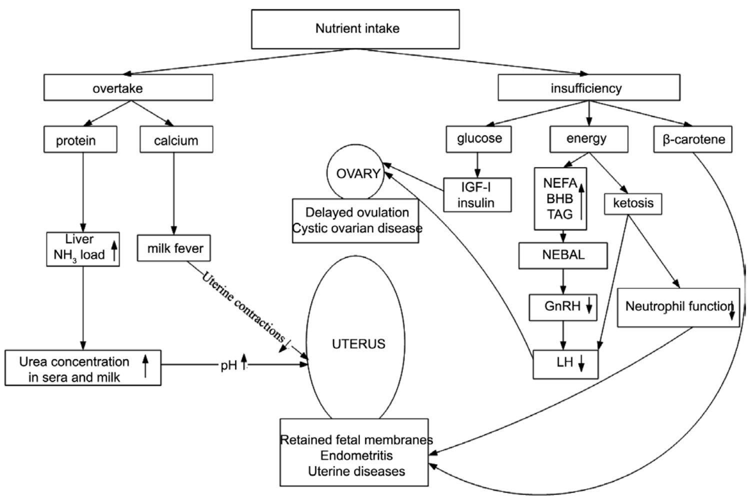


**Figure 3.** Effect of possible nutritional factors on ovaries and uterus in the transition period.

quired. Most cows develop a mild non-pathological endometritis during the early puerperal phase. This physiological condition, together with reduced immunocompetence due to high milk production, NEBAL and poor calving hygiene, can cause puerperal endometritis [12]. Metritis causes endometrial damage, which can delay conception.

## 4. Different Dietary Solutions for the Prevention of Metabolic Imbalance and Reproductive Disorders

To minimize the metabolic/reproductive damage caused by NEBAL, feeding of a glucogenic and lipogenic diet containing fat-enriched supplements is recommended [12]. This issue has been the focus of an extremely high number of studies, which sometimes brought contradictory results (**Table 2**).

Gluconeogenic materials (propylene glycol, glycerol, propionic acid) are precursors of glucose in the liver and increase glucose concentration of the serum. Elevated serum glucose concentration results in decreased fat mobilization (lower energy demand and increased insulin level), and indirectly improves reproductive efficiency. Gluconeogenic feed additives are thought to exert their favorable effect through the stimulation of insulin secretion [27].

Propylene glycol seems to be the most effective gluconeogenic substance, as it was found to decrease the plasma non-esterified fatty acid (NEFA) and beta-hydroxybutyrate (BHB) levels and increase the blood insulin and glucose concentrations in several experiments. Propylene glycol and its metabolites (lactate, pyruvate) directly stimulate insulin secretion [28].

Glycerol supplementation seems to have moderate metabolic effects: it did not modify plasma glucose, insulin, NEFA and BHB levels [29]. However, in another trial [30] 1 kg glycerol applied as a drench increased plasma

**Table 2.** Literature review of the effect of dietary gluconeogenic and fat supplementation on reproductive efficiency.

| Nutritional factor | Product | References | Comment |
|---|---|---|---|
| Gluconeogenic feed additives | Propylene glycol (PGL) | [13] | Despite evidence of improved metabolic status, PGL failed to increase LH pulse frequency, and failed to increase the proportion of first postpartum follicle waves resulting in ovulation |
| | | [14] | Reduced interval from calving to first ovulation was observed and pulsatile release of LH at 2 and 5 weeks was greater in cows fed PGL |
| | | [15] | Cows fed PGL commenced ovarian cyclicity earlier than controls |
| | | [16] | Improved conception rate (33 to 57%) and day of first ovulation from 44.5 Day to 32.3 Day |
| | PGL + Ca-propionate | [17] | Treatment did not change the proportion of puerperal diseases and reproductive performance |
| | Glycerol | [18] | No effect on DMI, glucose ↑, NEFA and BHB ↓ |
| | | [19] | Conception rate and insulin cc. ↑ |
| | Propionate salts | [20] | Improves reproductive efficiency |
| Fat supplementation | Ca-long chain fatty acid (LCFA) | [21] | Pregnancy rate per AI increased from 35.5% to 51.1% |
| | Fish oil | [22] | Reduced PGFM |
| | Ca-LCFA of palm oil | [23] | From cows fed 800 g fat/day a higher percentage of oocytes developed into blastocysts |
| | Soybean oil refining by-products (SORB) | [24] | Loss of body condition was less and first ovulation was experienced earlier in cows fed SORB |
| | Saturated fatty acid (FA), Ca-salts of t-octadecanoic FA, Ca-salts of safflower oil FA | [25] | Mean concentrations of glucose, IGF-1 and P4 were higher in cows fed a safflower oil enriched diet |
| | Ca salts of palm oil, Ca salts of safflower oil (SO) and fish oil (FO) | [26] | Overall pregnancy rate per AI was higher in cows fed an SO diet and pregnancy loss was reduced in FO-fed cows |

glucose and insulin and decreased plasma NEFA concentration.

The sometimes contradictory results can be attributed to the different experimental conditions (e.g. dosage, duration and method of, application, lactation period, level of NEBAL, and certainly the body condition of cows).

The feed intake of cows is lower in early lactation, and therefore dietary fat supplementation in the early postpartum period alters energy status even though a more energy dense ration is fed. Increasing the caloric density of the ration by fat feeding might improve the reproductive parameters of cows. Improvement of the energy status of dairy cows has been found to influence reproduction by increasing the frequency of LH pulses [31], modulating the number of larger follicles, altering the size of the dominant follicle, and increasing progesterone concentrations during the luteal phase of the estrous cycle [32]. Supplemental fat improves ovarian follicular dynamics, which is in a positive correlation with pregnancy rate [33] [34]. The use of fat in dairy cow diets usually increases the energy density of the ration and improves reproduction; however, these effects might be mediated by the fatty acid (FA) composition of the fat source. Polyunsaturated fatty acids (PUFA) can influence different levels of the hypothalamo-pituitary-ovarian axis, and they can locally stimulate follicular growth by altering hormone and metabolite levels. Fatty acids are precursors for ovarian steroidogenesis and for the synthesis of endometrial eicosanoids ($PGF_{2\alpha}$, $PGE_2$). Different PUFAs are important mediators of uterine involution and the ovulatory processes. Feeding sunflower oil rich in linoleic acid (C18:2, n-6) promotes uterine involution. Supplementation of linseed ($\alpha$-linolenic acid, C18:3, n-3) or the feeding of fish oil containing a high amount of eicosapentaenoic acid (C20:5, n-3) and docosahexaenoic acid (C22:6, n-3) may inhibit endometrial $PGF_{2\alpha}$ synthesis through mechanisms such as the decreased availability of its precursor, arachidonic acid. PUFAs of the n-3 family suppress luteolytic signals around the maternal recognition of pregnancy. This might improve the mechanism of embryo preservation and support embryonic survival in cattle.

The natural defense of postpartum cows is based on both cellular and humoral (local) immunity. An increased level of antioxidants should prevent the depression of neutrophil function caused by free radicals in the postpartum period. It was found that adequate beta-carotene supplementation significantly reduced the incidence of RFM and metritis [35]. Administration of vitamin E and/or selenium has been reported to reduce the incidence of postpartum reproductive disorders such as RFM, metritis and cystic ovaries, and improved fertility in cattle. Circulating NEFA and BHB are known to have a direct negative effect on neutrophil function.

## 5. Environmental Factors Influencing Fertility through Metabolic Imbalance

Since 2002, two databases [Catus: ultrasound examinations of the cow's reproductive tract; Bopella: laboratory examination of pregnancy and late embryonic loss by pregnancy-specific protein B (PSPB) and P4 ELISA tests] have been developed in our institute for recording the metabolic and reproductive data of dairy herds (**Figure 4**). These databases provide an opportunity for analyzing relationships between the results of ultrasonic, endocrine and metabolic measurements.

### 5.1. Effect of Ambient Temperature on Postpartum Reproductive Performance

Extremely high ambient temperature may cause heat stress, which considerably impacts production and reproduction in dairy cattle. In heat-stressed dairy cows, the reduction of dry matter intake causes an energy deficit, thereby accentuating NEBAL. In addition, reduced rumination and/or absorption of nutrients together with increased maintenance requirements also result in a net decrease of dry material/energy intake. Heat stress may also have a direct impact on oocyte quality due to the high ovarian temperatures. The intrauterine environment is also compromised in heat-stressed cows, with reduced blood flow to the uterus and increased uterine temperature; this may impair embryonic development, increase early embryonic loss and reduce the proportion of successful inseminations. During the hot summer period, poor expression of estrus, a rapid decrease in pregnancy rate and a pronounced increase of late embryonic loss (LEL) are common.

Based on the assessment of ~68,000 samples for serum pregnancy PSPB concentration and re-checking the pregnant cows by transrectal palpation, the rate of pregnant samples (RPS) decreased while LEL increased (**Figure 5**) parallel to the rise of daily average temperature [36].

### 5.2. Effect of Ambient Temperature on Metabolic Status

The mean plasma NEFA and BHB concentrations were significantly higher (**Figure 6** and **Figure 7**), while se-

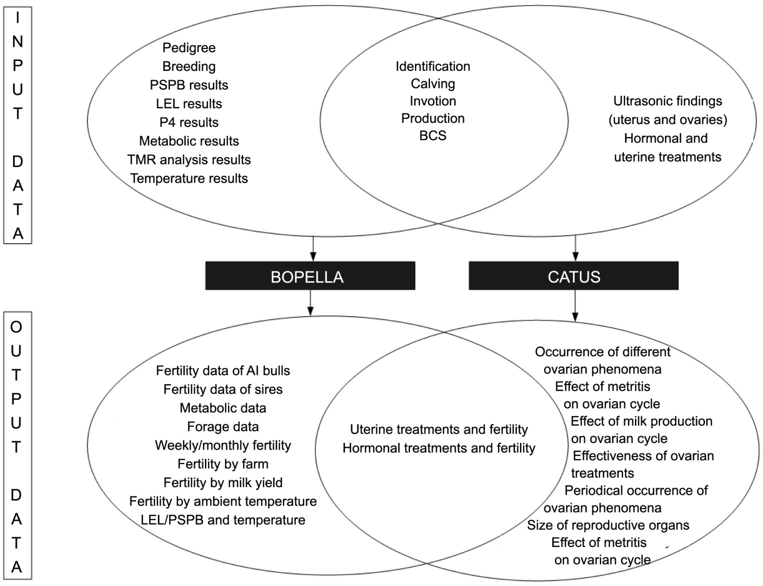


**Figure 4.** Structure of Bopella and Catus databases.

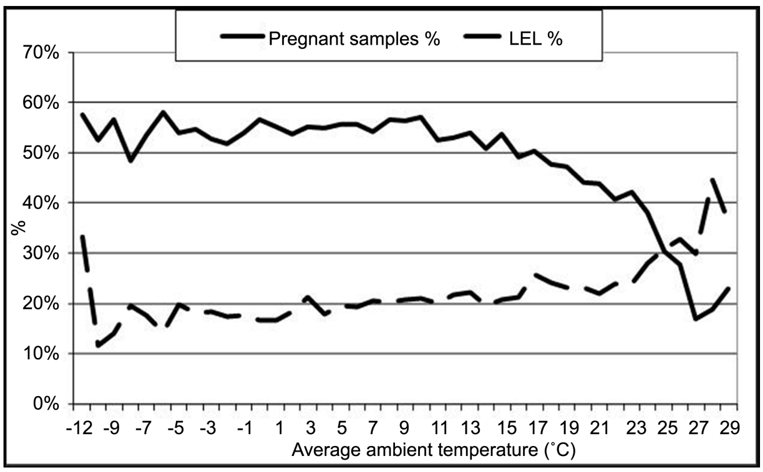


**Figure 5.** Relationship of the rate of pregnant samples and late embryonic losses (LEL) with ambient temperature [36].

rum carotene and plasma IGF-I concentrations were significantly lower in summer than in winter. The high plasma NEFA concentration found in summer appeared to be in association with the lower body condition score (BCS) caused by depressed appetite. Statistical analysis supports the hypothesis that increased plasma NEFA and BHB and decreased plasma IGF-I concentrations may result in reduced fertility in summer. These changes may be associated with the more frequent appearance of cystic ovarian diseases (COD, **Table 3**) and probably have a negative effect on ovarian function and/or oocyte quality [37].

## 6. Ultrasonic Ovarian Morphology in Postpartum Cows

Postpartum NEBAL (indicated by lower BCS as well as higher plasma NEFA and BHB levels) suppresses immune function and promotes metabolic disorders, potentially explaining relationships between infectious and noninfectious transition disorders. In postpartum dairy cows, pathologic ovarian phenomena including COD and ovulatory fluid-filled ovarian phenomena (corpus luteum with cavity and cystic corpus luteum) frequently occur. Some of these phenomena are associated with metritis, but due to the increased plasma concentrations of NEFA the possible effect of NEBAL could not be excluded either. Oocytes can accumulate fatty acids, which may

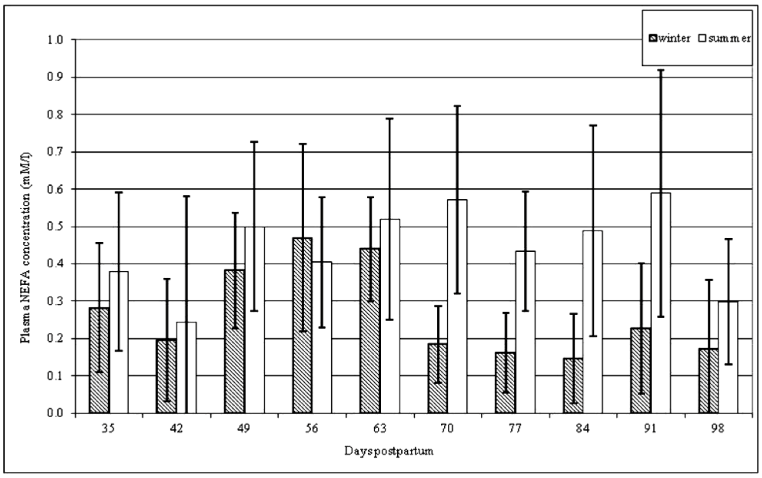


**Figure 6.** Plasma NEFA concentrations (mean ± SD) in summer and winter [37].

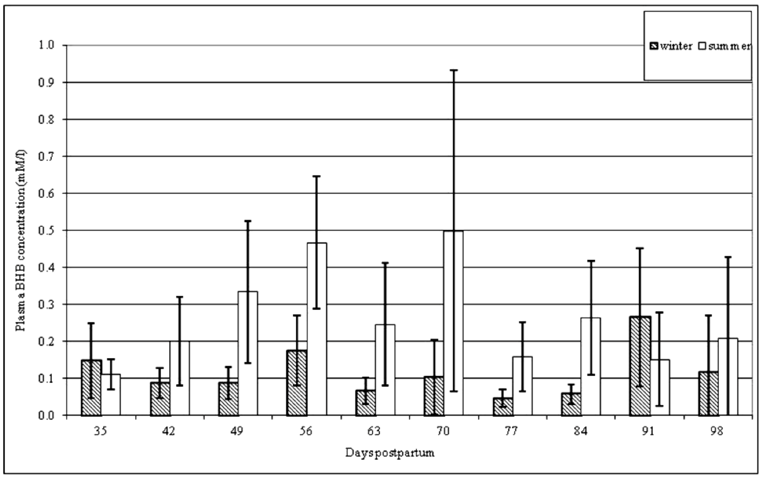


**Figure 7.** Plasma BHB concentrations (mean ± SD) in summer and winter [37].

**Table 3.** Frequency and rate of ovulatory (ovulatory fluid-filled ovarian phenomena, OFOP) and non-ovulatory (non-ovulatory cystic ovarian phenomena, NCOP) ovarian phenomena (source: Catus database, 2008-2011).

| | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|
| Number of ultrasound examinations | 659 | 547 | 454 | 619 |
| Number of detected NCOP | 83 | 84 | 76 | 142 |
| NCOP, % | 12.6 | 15.4 | 16.7 | 22.9 |
| Number of detected OFOP | 119 | 61 | 59 | 70 |
| OFOP, % | 18.1 | 11.2 | 13.0 | 11.3 |
| Daily milk production (kg) in NCOP cows | 36.9 | 37.9 | 37.9 | 38.2 |
| Daily milk production (kg) in OFOP cows | 35.9 | 36.2 | 36.1 | 37.1 |

change their lipid content and composition. The accumulation of lipid in oocytes and embryos can reduce their quality and cryotolerance.

Ultrasound examination of dairy cows in the same Hungarian dairy herds between 2008 and 2011 showed a definite increase in the rate of non-ovulatory cystic ovarian phenomena (**Table 3**) in parallel with a decreased rate of ovulatory fluid-filled ovarian phenomena and increased milk production (**Table 3**).

## 7. Conclusion

Increased milk production together with suboptimal farm management (especially nutrition or reproduction) can reduce fertility. The major problem in postpartum cows is the imbalance between the body reserves and milk production. This is why a negative energy balance (NEBAL) occurs in the background and causes reduced fertility. An insufficient or imbalanced nutrient intake might lead to the malfunction of organs, causing reproductive failure. Supplementation of gluconeogenic materials (propylene glycol, glycerol, propionic acid) indirectly improves reproductive efficiency. Our recently developed databases (Catus and Bopella) provide an opportunity for analyzing relationships between the results of ultrasonic, endocrine and metabolic measurements.

## Acknowledgements

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## Abbreviation Note

AI—Artificial insemination
BCS—Body condition score
BHB—Beta-hidroxy butyrate
COD—Cystic ovarian diseases
DMI—Dry matter intake
FA—Fatty acid
FO—Calcium salts of fish oil
LCFA—Calcium-long chain fatty acid
LEL—Late embryonic loss
LH—Luteinizing hormone
NEBAL—Negative energy balance
NEFA—Non-esterified fatty acid
P4-Progesterone
$PGE_2$—Prostaglandin $E_2$
$PGF_{2\alpha}$—Prostaglandin $F_{2\alpha}$
PGFM—$PGF_{2\alpha}$metabolite
PGL—Propylene glycol
PSPB—Pregnancy-specific protein B
PUFA—Polyunsaturated fatty acids
RFM—Retained fetal membranes
RPS—Rate of pregnant samples
SO—Calcium salts of safflower oil
SORB—Soybean oil refining by-products