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Trace Minerals in Growth, Production and Reproduction in Farm Animals

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ABSTRACT

Inorganic minerals play a critical role in various physiological processes like growth, production and reproduction of animals. Requirements of minerals vary with different physiological states such as age, parity, stage of pregnancy (early vs advanced pregnancy) and stage of lactation i.e. non-lactating or lactating, production status as well as extent of minerals absorption by the body. The classification of minerals is based on their requirements in the animal body. The minerals required in much smaller amounts are referred to as trace or micro minerals i.e. cobalt (Co), Iron (Fe), Copper (Cu), Iodine (I), zinc (Zn), manganese (Mn), selenium (Se), molybdenum (Mo), chromium (Cr), and fluorine (F). In diet, the concentration of microminerals is expressed as ppm (parts per million), mg/kg (milligram per kilogram), whereas in some cases as ppb (parts per billion) or µg/kg (microgram per kilogram) of diet. The optimum amount of macro, as well as microminerals, is of utmost importance for various physiological needs. Deficiency and excess both have detrimental effects on growth, production and reproduction; thus have a significant bearing on the profitability of animal husbandry.
Keywords: Bioavailability, Minerals, Livestock, Nutrition, Production, Reproduction.

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INTRODUCTION

Animal development, productivity, and reproduction depend heavily on inorganic minerals (Goff, 2005; Kumar *et al.*, 2020; Kumar et al., 2022[a]). In addition, variable physiological states such as age, parity, stage of pregnancy (early vs advanced), lactation level (lactating or dry), production status, and extent of absorption in the body affect

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the requirement of minerals. The minerals are classified depending on their level of requirement. Furthermore, many minerals like phosphorus (P), calcium (Ca), sodium (Na), chloride (Cl), sulfur (S), potassium (K), and magnesium (Mg) etc required in greater amounts each day referred to as macrominerals. The concentration macrominerals are expressed as g/kg (grams per kilogram) or percentage of diet (%) of diet. Likewise, minerals required in much smaller amounts are referred to as minerals required in much smaller amounts are referred to as trace or micro minerals i.e. cobalt (Co), Iron (Fe), Copper (Cu), Iodine (I), zinc (Zn), manganese (Mn), selenium (Se), molybdenum (Mo), chromium (Cr), and fluorine (F). In diet, the concentration of microminerals is expressed as ppm (parts per million), mg/kg (milligram per kilogram), whereas in some cases as ppb (parts per billion) or µg/kg (microgram per kilogram) of diet. The optimum amount of macro, as well as microminerals, is of utmost importance for various physiological needs. Deficiency and excess both have detrimental effects on growth, production and reproduction; thus have a significant bearing on the profitability of animal husbandry.

The 'trace elements' are those naturally present in the environment in minute amounts, and excessive bioavailability of these elements can harm living organisms (Wada, 2004). Indeed, trace minerals are limiting factors for the function of many proteins and metalloenzymes; which in turn are essential for many life processes (Kramer *et al.*, 2007). The most common element in serum is Fe which is followed by Cu and Zn at the concentrations of 1.0–2.0, 0.57–1.0 and 0.8–1.2 ppm respectively (Radostits *et al.*, 2007; Andrieu, 2008). Moreover, Mn, I, Co, and Se are needed at the concentration of 18-19, 2.4-14, 1-3, 0.005-0.22 µg/dL respectively, (Radostits *et al.*, 2007; Andrieu, 2008). Minerals are needed for the development of hormones, enzymes, tissue synthesis, energy production, and collagen synthesis (Paterson and Engle, 2005). Major physiological changes can occur even after brief periods of limited food supply (Brugger *et al.*, 2014). Inadequate amounts can affect the quality and quantity of milk produced, as well as embryonic development, postpartum recuperation, and overall animal fertility (Butani *et al*, 2008; Kumar *et al.*, 2009; Buatni *et al.*, 2011; Ashoo *et al.*, 2020; Kumar *et al.*, 2020; Husain *et al.*, 2021; Kaurav *et al.*, 2022; Kumar *et al.*, 2022[b]). Moreover, Jamb *et al.* (2011) opined that trace minerals have an important bearing on the conception rate of embryo recipients cows.

It may change spermatogenesis and decrease libido in male animals. Therefore, dairy animals need to eat and absorb in a balanced way to maintain optimum trace mineral status for proper growth, production and reproduction.

BIOAVAILABILITY OF TRACE MINERAL IN RUMINANTS

The fraction of trace minerals that reach into the blood after ingestion, digestion and absorption by the animals is termed bioavailability. Many factors affect the availability of trace minerals in soil, feeds and fodder and thus the amounts available to animals that consume such feeds and fodder. Research has shown that the condition of the soil affects the mineral composition of feed ingredients. Additional trace minerals are obtained by animals from inorganic sources. Even though some novel organic sources, like sulphates and oxides, have been added recently, the majority of organic sources are still used in animal feeds.

Copper

The copper is third most bountiful trace mineral in the body following Fe and Zn (Tumor and Moller, 2010). The Cu is crucial for development, production and reproduction (Van Emon *et al.*, 2020). This reactive element can be found in an organism in two different oxidation states: as an oxidised, cupric (Cu^{2+}) ion and as a reduced, cuprous (Cu^{+}) ion (Veldhuis *et al.*, 2009). Copper's wide variety of redox potentials and ability to take part in one-electron transfer processes dictate this microelement's biological activity and function. Indeed, Cu is an inorganic cofactor for more than thirty enzymes because of its redox characteristics (Herman *et al.*, 2020; Sharma *et al.*, 2020). Many basic metabolisms *viz.* respiration (cytochrome c oxidase), detoxification of reactive oxygen species, synthesis of connective tissues (lysyl oxidase) and neurotransmitters (peptidyl glycine-amidating monooxygenase and dopamine ß-hydroxylase), as well as iron metabolism (ceruloplasmin and hephaestin), are copper-dependent (Lutsenko *et al.*, 2007; Kodama *et al.*, 2012; Vashchenko *et al.*, 2013). In addition to the aforementioned beneficial effects of copper, the excess of the latter is extremely injurious to all biological systems (Tarrant *et al.*, 2019) under its cytotoxicity and genotoxicity (Van Emon *et al.*, 2020).

Furthermore, copper-induced oxidative damage (Gaetke and Chow, 2003) and other oxidative damage (Li *et al.*, 2024) can be mitigated with vitamin E supplementation. Deficiency of copper results in compromised innate (decline in neutrophil count and antimicrobial function) as well as adaptive immunity (su ppressed T cell proliferation and interleukin secretion) (Gonzalez *et al.,* 2008; Kardos *et al.,* 2018). The deficiency is primarily ascribed to Mo, S, and Fe. Furthermore, there is a battery of interaction between Cu and many trace minerals, making the elucidation of Cu effect immune function more challenging (Van Emon *et al.,* 2020). Thus, copper has a definite role in energy production and prevention of free radical-induced cell injury (Gonzalez *et al.,* 2008; Kardos *et al.,* 2018). Moreover, the maturation and development of the pig's oocyte (*in vitro*) was adversely affected in a Cu-deficient environment/media (Choi *et al.,* 2022). Unlike non-pregnant cows, pregnant cows have more capacity for absorption and retention of Cu and Zn (Vierboom *et al.,* 2003). Zinc affects the absorption of Cu as both have similar absorption pathways, thus there is competition between the two for absorption sites (Vierboom *et al.,* 2003). The copper and selenium interaction boosts the competency of neutrophils to fight infection. The copper deficiency may be compensated for by selenium, whereas the former cannot compensate for selenium deficiency to cope with infection (Vierboom *et al.,* 2003).

As already mentioned, Cu is associated with normal reproduction, it is necessary for pregnancy success. The fertilization ability of sperm is adversely affected if the reproductive health is compromised due to free radical damage (Aydemir *et al.,* 2006). Furthermore, Nazari *et al.* (2019) observed significantly higher Cu concentrations in dairy cattle with normal luteal activity compared to cows with short or prolonged luteal phase, delayed ovulation, and anovulation. Moreover, they recorded higher Cu levels in conceived cows as compared to non-conceived ones. The association of Cu with the function of corpus luteum and conception might have a role of Cu for CL and endometrial cross-talk, as evidenced by a relation between deficiency of copper and declined PG synthesis in rodents (Mitchell *et al.,* 1988). Furthermore, adequate copper supplementation is necessary to produce high-quality oocytes (Tatemoto *et al.,* 2000; Fatehi *et al.,* 2002; Van Emon *et al.,* 2020) and sperm (Ogorek *et al.,* 2017). On the other hand, excess Cu has detrimental effects on cumulus cells as cells exposed to high Cu concentration had lower mitochondrial activity, and increased apoptosis DNA damage than those of unexposed cells (Anchordoquy *et al.,* 2017). Moreover, cumulus cells are important for oocyte viability (Tatemoto*et al.,* 2000; Fatehi *et al.,* 2002); however, improvements in oocyte attributes are limited (Van Emon *et al.,* 2020). Furthermore, FSH, LH and estrogen activity might be a causative factor for bovine anestrus syndrome (Bindari *et al.,* 2013) as anestrus animals have lower Cu concentrations compared to control animals (Ceylan *et al.,* 2008). Copper has an important role in status and can have an impact on the oxidant-antioxidant balance in dairy cows. Although there has been limited research on the impact of copper on oxidative status, heifers provided with a mineral mixture containing copper sulfate were found to have higher levels of vitamins A and E compared to those not receiving any copper supplementation (Sharma *et al.,* 2005). Copper has a significant biological role as a cofactor for many Cu-dependent enzymes and can affect thyroid hormone levels in the blood, indicating potential connections to energy metabolism (Sharma *et al.,* 2005; Chen *et al.,* 2022). Furthermore, cows fed a mixture of copper sulphate plus copper methionate had higher milk yields and 4% fat-corrected milk yields compared to cows provided either supplement alone (Wang *et al.,* 2021).

In humans and many other mammalian species, copper overload and deficiency in the gonads can both have a detrimental effect on the quality of spermatozoa as well as genital health (Kowal *et al.,* 2010; Akinloye *et al.,* 2011; Tvrda *et al.,* 2015; Liu *et al.,* 2016; Ghaffari *et al.,* 2019; Chen *et al.,* 2020). In previous studies on model organisms like yeast, insects, and mice, a suitable quantity of copper is required for meiosis advancement during the process of gamete generation and for the subsequent cell reorganisation that forms mature spermatozoa. Nevertheless, germ cells are poisoned by the elevated copper level. To ensure that the gonads receive a sufficient amount of copper and that it is transported to Cu-dependent enzymes, organisms have created highly regulated molecular processes. These systems also serve to protect the testes from the harmful consequences of copper overload.

Cobalt

Previous workers suggested that cobalt is indispensable for the synthesis of vitamin B_{12} (Gonzalez-Montana *et al.,* 2020; Osman *et al.,* 2021), the latter synthesized by rumen microbiota (Van Emon *et al.,* 2020). Moreover, Vitamin B12 (cobalamin) functions via three premises namely gluconeogenesis, one-carbon metabolism and coenzymes (Suttle, 2010). Furthermore, Suttle (2010) opined that vitamin B12 plays an important role in bio-energetics and the synthesis of acetate, methionine, and methane by rumen microbes. Accordingly, the aforementioned functions (bio-energetics and synthesis of acetate, methionine, and methane) are indirectly regulated by cobalt. Previous studies report too less cobalt requirements (Schwarz *et al.,* 2000; Stangl, 2000). The hepatic and plasma B12 concentration can be reached at the zenith with elevated cobalt requirements to 0.24 or 0.26 mg/kg of dry matter (Stangl *et al.,* 2000). Similarly, Schwarz *et al.* (2000) reported that to augment growth and feed intake 0.12mg/kg and 0.16-0.18mg/kg dietary cobalt is required in beef cattle (Schwarz *et al.,* 2000). Furthermore, breast milk and colostrum are rich sources of vitamin B12, which is necessary for the metabolism of folic acid and the conversion of propionate to glucose. Deficiency of vitamin B12 results in tardy uterine involution, interruption of the oestrous cycle, lower rates of conception, reduced fertility, poor fetal development and premature death of calves (Kumar, 2003). Furthermore, Patel et al. (2006) reported that cobalt concentration did not differ significantly between anestrus and subestrus cattle. The level of cobalt is positively correlated with vitamin B12 *i.e.* when cobalt levels are low, vitamin B12 levels will also be low. Patterson *et al.* (2003) reported that iodine, manganese, and zinc may abate cobalt deficiency in beef cattle.

Available reports suggest that Co may affect ovarian behaviour and embryogenesis, but its exact role in fertility augmentation is not fully elucidated (Van Emon *et al.,* 2020). Cobalt may important bearing in the development of ovine embryos, as evidenced by the work of Girard and Matte (1999), they observed that Cobalt supplemented ewes had a high superovulation response and embryo quality compared to un-supplemented counterparts (Girard and Matte, 1999). On the other hand, the role of cobalt in bovine reproduction is not completely elucidated. Ruminal microbes synthesize sufficient B12 to meet our daily requirements but insufficient to overcome serum B12 fluctuations in parturient cows (Girard and Matte, 1999). In turn, these alterations may affect future fertility; hence the workers are investigating the role of B12 supplementation to augment bovine fertility. Moreover, Duplessis *et al.* (2014) recorded an advanced day of first breeding (by 3.8 days) and a 50% decline in the incidence of dystocia in B12 and folic acid-treated multiparous cows as compared to untreated counterparts, they further suggest that the effect was might be due to improved energy balance in treated cows (Duplessis *et al.,* 2012). Indeed, it is a well-established fact that a negative energy balance negatively affects reproductive performance (Michael *et al.,* 2019). In addition, the majority of aforementioned studies were trying to decipher the role of B_{12} in animal reproduction in combination with folic acid; the role of B12 alone on fertility potential is yet to be deciphered.

Manganese

Manganese acts as a cofactor for enzymes necessary for steroid hormone biosynthesis as well as act as a component of an enzymatic antioxidant namely manganese superoxide dismutase. (Studer *et al.,* 2022). The effect of Mn supplementation was not seen readily, as similar liver Mn concentrations were noted among cattle supplemented with Cu, Co, Mn, and Zn and untreated cattle (Marques *et al.,* 2016). The excretion of bile is the limiting factor for its retention in the body, the efficiency of Mn homeostasis is the function of the difference between its body retention and bile excretion (Gurol *et al.,* 2022). The lower maternal blood manganese is associated with retarded fetal growth retardation and lower birth weight in humans (Wood, 2009). On one hand, proper Mn supplementation is necessary for adequate development of the fetus, on the other hand over supplementation has no additional positive impact. Like Cu and Zn, Mn is also an antioxidant with superoxide dismutase i.e. MnSOD (Manganese superoxide dismutase) (Liu *et al.,* 2022). To cope with free radical-induced damage, the quaternary structure of MnSOD effectively sustains its dismutase as well as catalytic action (Bonetta Valentino, 2022). In addition, the Mn-containing multi-mineral injection has enhanced MnSOD activity more readily than those of dietary-supplemented cotemporaries (Genther *et al.,* 2014). Moreover, Mn deficiency is readily reflected as an alteration in MnSOD activity (Genther *et al.,* 2014). Thus, MnSOD activity can be used as a biomarker to assess Mn levels in the blood. Furthermore, Zhang *et al.* (2022) opined that MnSOD might act as a thermo-receptor at the cellular level, and initiate a a series of physiological changes under low-temperature stress. Available reports suggest that Mn has a vital role in cellular immunity, thus maintaining physiological Mn concentrations is of paramount importance in livestock health.

As earlier mentioned, Mn has a primary role in reproduction. Deficiency of Mn causes many reproductive issues like abortions, declined conception rate, silent estrus, reduced birth weight and an increased birth of male offspring (Milatovic and Gupta 2018). Manganese is essential for the synthesis of cholesterol. Furthermore, the cholesterol is needed for steroid biosynthesis i.e. estrogen, androgens and progesterone. To establish and maintain pregnancy estrogen and progesterone plays an important role. Reduced levels of these hormones result in reproductive dysfunction like anestrus and diestrus (Kumar *et al.,* 2009), decreased conception rates (Kumar *et al.,* 2011[a]), malformed clave births and abortion, serving disability as well as impaired sperm production (Kumar, 2003). Moreover, Manganese supplementation has been shown to decrease postpartum anestrus in dairy cows, hence, fewer services are needed for each conception. As previously mentioned, Mn is required in the production of cholesterol, which in turn is utilised for the synthesis of gonadal steroids, thus incorporation of dietary Mn can augment the fertility performance of bovines (Trumbo *et al.,* 2001). In addition, Mn might have a role in progesterone synthesis by CL, as MnSOD activity is reported throughout the lifespan of sheep corpus luteum (Al-Gubory *et al.,* 2004). The histotroph secretion by endometrium, growth and elongation and placenta formation depends upon luteal progesterone (Spencer *et al.,* 2016). Furthermore, Von Emon *et al.* (2020) reported that manganese might have a role in progesterone production by corpus luteum, and hence indirectly support gestation. Furthermore, Anchordoquy *et al.* (2016) reported that manganese enriched in vitro maturation improves cumulus-oocyte complex, following improved embryo survival. Moreover, fortification of Mn during bovine oocyte maturation rescues cumulus cells from apoptosis and DNA damage without affecting the elongation of cumulus cells (Anchordoquy *et al.,* 2013; Anchordoquy *et al.,* 2016).

Selenium

Selenium (Se) is an essential micronutrient for humans and a beneficial element for plants. Selenium one of the main constituents of exogenous antioxidants, rescues the biological systems from ROS-induced damage (Von Emon *et al.,* 2020). Moreover, Se is the main component of GPx (glutathione peroxidase), and the latter assists in the diminution of peroxide radicals like H_2O_2 (hydrogen peroxides) (Von Emon *et al.,* 2020). Indeed, copper and selenium work synergistically to maintain neutrophil activity, which is important to combat infections and eliminate pathogens. Moreover, nutritional deficiency of copper attenuates the immune system by compromising the function of neutrophils, the effect can be compensated if selenium feeding is adequate (Boyne and Arthur, 1981). In addition, Spears (2003) observed that under proper selenium supplementation (regardless of the level of copper), the neutrophil-GPx function was not compromised; but under selenium deficiency, the neutrophils function was adversely affected, even if copper supplementation is optimum. The same author further opined that non-ruminants have better selenium absorption capacity as compared to ruminants. The rumen-microbiota tends to reduce the bioavailability of oral selenium supplementation (Galbraith *et al.,* 2016) but the bioavailability of sodium-selenite is *at par* with organic selenium in the ewe (Hall *et al.,* 2012). Available reports suggested that ruminants have comparable bioavailability of selenium from selenite and selenate. Plants get the majority of their selenium from soils, and animals get the majority of their selenium from plants. Plant breeding techniques or the use of Se-enriched fertilizers can both help plants growing in poor soils achieve a higher Se status (WHO, 2006). To ensure nutritional needs are met, selenium (Se) is frequently added to animal diets despite these tactics. The use of selenium (Se) as a dietary supplement to improve animal products has gained popularity recently. It is believed that producing meat, milk, and eggs with added selenium is a safe and efficient method of raising human selenium levels (Fisinin*et al.,* 2009).

A variety of items are available for supplementing diets with selenium. Sodium selenite is a typical way to add selenium to diets. On the other hand, adding organic selenium to the diet has drawn more attention. As a feed supplement, organic sources are thought to be more suitable since they are less toxic and can be digested more quickly than inorganic sources (Schrauzer *et al.,* 2001, Schrauzer *et al.,* 2009). Because of its quick growth, ease of culture and great capacity to absorb Se, yeast has emerged as the most widely used vehicle for the addition of organic Se (Suhajda *et al.,* 2000). Selenomethionine is the main byproduct of selenium-fermented yeast. In contrast to the beneficial effects of selenium, the supra-physiological level of Se in the body proves harmful which might be due to selenium pollution secondary to human-associated activities like oil extraction and refining, coal combustion, mining and agriculture (Wang *et al.,* 2024). High Se doses always exhibit hazardous effects (Qu *et al.,* 2023).

Selenium deficiency reduces the chances of reproductive success (Spears and Weiss, 2008). Target tissues of Se are ovaries, especially follicular cells as evidenced by the localization of Se in follicular granulose, moreover, the selenium expression is tenfold greater in granulose cells as compared to corpus luteum (Ceko *et al.,* 2015). These observations suggest that Se have a protective role for oocytes against ROS-induced damage during follicle development. Indeed, Se has a direct effect on the proliferation of granulosa cells and subsequent estrogen production (Basini and Tamani, 2000), the estradiol has a cardinal role in the success of reproduction via negative or positive feedback effect on the hypothalamus and affects the release of GnRH in episodic or surge manner. The GnRH in turn causes estrogen-induced preovulatory LH surge, an essential prerequisite for ovulation. Furthermore, an undernourished ewe model was used to demonstrate the necessity of Se in folliculogenesis, in such ewes the declined proliferation of follicular cells, changes in vascularity and development of fetal ovarian stromal tissues (Grazul-Bilska *et al.,* 2009). Declined cellular apoptosis rate and improved hatching rates of zona have been observed in Se-supplemented oocytes compared to non-supplemented counterparts (Lizarraga *et al.,* 2019). Thus, the available evidence suggests that selenium has two dual functions as far as reproduction is concerned i.e. promoting folliculogenesis (by acting on follicles) and acting directly on oocytes to protect them from oxidative damage. Selenium has a role in parturition and subsequent events, though a complete mechanism remains to be established. Cattles with lower peripheral glutathione peroxidase retain the fetal membranes 12h longer than those of control, thus there is a correlation between retention of the placenta and Selenium-dependent GPx in bovines (Brzezinska-Slebodzinska *et al.,* 1994). Similarly, D' Aloe and coworkers (D'Aleo, *et al.,* 1983) recorded 20% more incidence of retention of fetal membranes in cows fed a low selenium diet. Moreover, Se-supplemented cattle have more selenium concentration in cotyledons (Ranches *et al.,* 2017); the observations suggest that Se from maternal blood reach to fetus by way of placenta and injections of selenium before parturition can reduce the incidence of placental retention. Selenium deficiency causes ovarian dysfunction, retained fetal membrane, and mastitis (Patterson *et al.,* 2003). Selenium has a clear correlation with uterine involution (Arthington, 2005). In dairy cattle, subclinical selenium insufficiency can lead to reproductive disruption, which includes high rates of mastitis, delayed ovulation, and greater services per conception (Goff, 2005). Selenium increases the effect of GPx in body tissues including blood, which helps to improve reproductive efficiency. Whether absorbed through inorganic or organic food sources, selenium passes the placenta with ease. Selenium supplementation raises the rate of conception at first service. Moreover, the selenium content in the dam's diet affects fetal ovarian activity (Grazul-Bilska *et al.,* 2009).

Iodine

Iodine has a significant effect on reproduction as it affects the thyroid gland, it is believed that iodine is necessary for basal metabolism as well as for fetal growth. The iodine stimulates the anterior pituitary gland and the thyroid gland, moreover iodine aids in the release of gonadotropin, which in turn influences the estrous cycle. Iodine deficiency impacts fertility and raises the rate of abortions (Mills *et al.,* 2019), as well as the incidence of retained fetal membranes (Cook and Green, 2007) and postpartum uterine infections. Declined ovarian activity and conception rate are associated with compromised thyroid function. Iodine therefore has a variety of effects on reproduction, and for a cow to be in good reproductive health, she needs to take the appropriate daily intake of 15-20 mg of iodine. A surplus of iodine can also harm reproductive health by causing miscarriages, weak calf deliveries, and a reduction in the immune level of animals (Kumar *et al.,* 2011[b]). Increased stillbirths, reduced oestrous, a higher likelihood of retention of fetal membranes and longer length of pregnancy are the hallmarks of subclinical iodine deficiency (Hess *et al.,* 2008). Inorganic iodine levels in cow plasma should be kept between 100 and 300 ng/ml at normal levels.

Molybdenum

A trace element that is essential to both humans and animals is molybdenum (Mo). It may enable a variety of oxidation-reduction events, including hydroxylation and oxygen atom transfer, which are all possible mechanisms by which it supports proper cell activity. Furthermore, Mo is identified as a component of the active sites of many enzymes (Hille *et al.,* 2011). In animals, a lack of molybdenum is linked to anestrus, a delayed onset of puberty, and a lower rate of conception (Kumar, 2003). The connection between molybdenum and copper stems from the fact that an excess of one element might result in a deficit of the other. Excess levels of molybdenum can be hazardous to reproduction, especially in male animals and humans (Sharma *et al.* 2004).

Zinc

Zinc is important for the structural and functional integrity of skin and mucosal cells ((Haryanto *et al.,* 2015), as well as fertility. The cows have higher Zn concentration in blood, have normal CL function and improved conception rates, as evidenced by the work of Nazari and coworkers, who recorded abnormalities in ovulation and subsequent CL formation and activity; and ultimately conception failure with lower blood Zn concentration (Nazari *et al.,* 2019). The blood Zn values are positively correlated with conception rate, which is attributed to its direct action of Zn on COC (cumulus-oocyte complex) and embryo; consequently increasing the chances of pregnancy success (Anchordoquy *et al.,* 2011). Zinc also has an important bearing in maintaining sexual health after parturition via action on the genital tract. After calving, zinc is essential for the preservation and restoration of endometrial health and hastens the involution of the uterus. Zinc has a crucial role in reproductive cycles and pregnancy maintenance as a coenzyme that contributes to the synthesis of prostaglandins from arachidonic acid (Kumar *et al.,* 2011[b]). Moreover, Butani *et al.* (2009) recorded significant improvement in Zn level in repeat breeder buffaloes who have conceived following treatment as compared to untreated control. Nutritional zinc deficits have been linked to reduced litter size, low conception rates, failed implantation, and delayed puberty. For dairy cattle, the recommended daily intake of zinc ranges from 18 to 73 parts per million (ppm) (Patterson *et al.,* 2003), depending on the stage of the lifecycle and the amount of dry matter consumed. On the other hand, 40 ppm is the minimal threshold (NRC, 2001). For dairy cattle, the recommended daily intake of zinc ranges from 18 to 73 parts per million (Patterson *et al.,* 2003), based on the physiological status of the animal as well as dry matter intake. On the other hand, 40 ppm is the minimal threshold (NRC, 2001).

Iron

Iron is essential for myoglobin and haemoglobin synthesis, as well as for the activity of several enzymes that produce ATP through the electron transport chain. It supports many oxidative enzyme systems and helps supply oxygen to tissues. Indeed, Iron is essential for the differentiation and growth of epithelial tissue (Haryanto *et al.,* 2015; Gombart *et al.,* 2020), adult animals rarely experience deficiencies because there are plenty of food sources available. Goa and coworkers suggested that embryo culture supplemented with iron hastened embryo development and declined the apoptotic cells in the embryo (Gao *et al.,* 2007). Iron deficiency may cause anemia, a decrease in appetite, and poor overall physical health; all negatively impact reproductive health. A significantly higher iron level was recorded in the conceived repeat breeder bovine compared to the non-conceived ones following treatment (Butani *et al* (2009). Moreover, repeat-breeding cows are more likely to have iron deficiency (Kumar *et al.,* 2011[b]), need more care during each conception, and occasionally abort.

Chromium

The metabolism of glucose requires chromium (Tuormaa, 2000; Qiao *et al.,* 2009). The chromium plays a vital role in gametogenesis and embryogenesis and it is abundant in nuclear protein. Additionally, chromium plays a vital role in the restoration of uterine health following parturition and avoids the occurrence of endometritis (Yasui *et al.,* 2014). Moreover, chromium is essential for both LH release, which triggers ovulation, and follicle maturation, which maintains the oestrous cycle. In addition, the deficiency of chromium causes abnormalities of the menstrual period, ovulation, and loss of embryo as well as retarded growth of the fetus (Tuormaa, 2000). Chromium supplementation improves feed consumption and lactation in dairy cattle (Malik *et al.,* 2023). On the other hand, chromium is known for its deleterious effect on male reproductive health as toxic, carcinogenic and mutagenic (Pereira *et al.,* 2021).

CONCLUSION

Growth, production and reproduction are significantly impacted by trace minerals. As was previously mentioned, mineral supplementation can have a direct or indirect impact on the following: mother and offspring health, and reproductive function. Nonetheless, several variables affect the effect of trace mineral supplementation. Before supplementing, it is crucial to ascertain the level of different minerals in animals. This is because excessive supplementation of some minerals may have negative effects or offer no additional benefit at all. It's also critical to comprehend the purposes and functions of the minerals under discussion. Throughout an animal's life, its mineral requirements vary based on several physiological states like age, lactation status, and pregnancy. This affects when certain minerals should be supplemented during pregnancy, after giving birth, or in the early years of life. With this knowledge, farmers can make sure they only supplement minerals when doing so is both economically and physiologically advantageous.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

REFERENCES

Akinloye, O., Abbiyesuku, F.M., Oguntibeju, O.O., Arowojolu, A.O. and Truter, E.J. (2011). The impact of blood and seminal plasma zinc and copper concentrations on spermogram and hormonal changes in infertile Nigerian men. *Reprod. Biol.,* **11**: 83–98.

Al-Gubory, K.H., Bolifraud, P., Germain, G., Nicole, A. and Ceballos-Picot, I. (2004). Antioxidant enzymatic defence systems in sheep corpus luteum throughout pregnancy. *Reproduction*, **128**: 767–774.

Anchordoquy, J. M., Picco, S. J., Seoane, A., Anchordoquy, J. P., Ponzinibbio, M. V., Mattioli, G. A., Peral García, P. and Furnus, C. C. (2011). Analysis of apoptosis and DNA damage in bovine cumulus cells after exposure in vitro to different zinc concentrations. *Cell Biol. Int.,* **35**(6):593-597.

Anchordoquy, J.M., Anchordoquy, J.P. Nikolo, N., Pascua, A.M. and Furnus, C.C. (2017). High copper concentrations produce genotoxicity and cytotoxicity in bovine cumulus cells. *Environ. Sci. Pollut. Res. Int.,* **24**: 20041–20049.

Anchordoquy, J.P., Anchordoquy, J.M., Sirini, M.A., Mattioli, G., Picco, S.J. and Furnus, C.C. (2013). Effect of different manganese concentrations during in vitro maturation of bovine oocytes on DNA integrity of cumulus cells and subsequent embryo development. *Reprod. Domest. Anim.*, **48**: 905–911.

Anchordoquy, J.P., Anchordoquy, J.M., Sirini, M.A., Testa, J.A., Peral-Garcia, P. and Furnus, C.C. (2016). The importance of manganese in the cytoplasmic maturation of cattle oocytes: Blastocyst production improvement regardless of cumulus cells presence during in vitro maturation. *Zygote,* **24**: 139–148.

Andrieu, S. (2008). Is there a role for organic trace element supplements in transition cow health? *Vet., J.,* **176**: 77-83.

Arthington, J. D. (2005). Trace mineral nutrition and the immune response in cattle, In: Proceeding of 64th Annual Minnesota Nutrition Conferences, Minneapolis. 106.

Ashoo, Verma, H.C., Singh, R.K., Kumar, R., Ramakant and Diwakar, R.P. (2020). Incidence of Reproductive Disorders in Cattle and Buffalo under Field Conditions in Eastern Plain Zone of Uttar Pradesh. *Ind. J. Vet. Sci. and Biotech.,* **16**(1): 66-68.

Aydemir, B., Kiziler, A.R., Onaran, I., Alici, B., Ozkara, H. and Akyolcu, M.C. (2006). Impact of Cu and Fe concentrations on oxidative damage in male infertility. *Biol. Trace Elem. Res.,* **112**: 193–203.

Aydemir, B., Kiziler, A.R., Onaran, I., Alici, B., Ozkara, H. and Akyolcu, M.C. (2006). Impact of Cu and Fe concentrations on oxidative damage in male infertility. *Biol. Trace Elem. Res.,* **112**: 193–203.

Basini, G. and Tamanini, C. (2000). Selenium stimulates estradiol production in bovine granulosa cells: Possible involvement of nitric oxide. *Domest. Anim. Endocrinol.*, **18**: 1–17.

Bindari, Y. R., Shrestha, S., Shrestha, N. and Gaire, T. N. (2013). Effects of nutrition on reproduction—A review. *Adv. Appl. Res.*, **4**(1): 421–29.

Bonetta Valentino, R. (2022). The structure-function relationships and physiological roles of MnSOD mutants. *Biosci. Rep.,* **42**(6), BSR20220202.

Brugger, D., Buffler, M. and Windisch, W. (2014). Development of an experimental model to assess the bioavailability of zinc in practical piglet diets. *Arch. Anim. Nutr.,* **68**(2):73-92.

Brzezińska-Ślebodzińska, E., Miller, J. K., Quigley, J. D., 3rd, Moore, J. R., and Madsen, F. C. (1994). Antioxidant status of dairy cows supplemented prepartum with vitamin E and selenium. *J. Dairy Sci*., **77**(10):3087-3095.

Butani, M.G, Kumar, R., Dhami, A.J., Kavani, F.S. and Killedar, A. (2008). Incidence of major infertility problems in crossbred cows and buffaloes under field conditions. *Indian J. Field Vets.,* **4**(2): 1-4.

Butani, M.G., Dhami, A.J. and Kumar, R. (2011). Comparative blood profile of progesterone, metabolites and minerals in anoestrus, suboestrus, repeat breeding and normal cyclic buffaloes. *Indian J. Field Vets*., **7**(2): 20-24.

Butani, M.G., Dhami, A.J., Kumar, R., Hirani, N.D., Ramani, V.P. and Patel, K.P. (2009). Influence of hormonal and antibiotics therapy on fertility and trace minerals profile in repeat breeding buffaloes. *Indian J. Field Vets.,* **4**(3): 12-16.

Ceko, M., Hummitzsch, K., Hatzirodos, N., Bonner,W., Aitken, J., Russell, D., Lane, M., Rodgers, R. and Harris, H. (2015). X-ray fluorescence imaging and other analyses identify selenium and GPX1 as important in female reproductive function. *Metallomics,* **7**(1):71-82.

Ceylan A, Erin I, Aksit H and Seyrek K. (2008). Concentrations of some elements in dairy cows with reproductive disorders. *Bull. Vet. Inst. Pulawy*, **52**: 109–12.

Chen, H., Kang, Z., Qiao, N., Liu, G., Huang, K., Wang, X., Pang, C., Zeng, Q., Tang, Z. and Li, Y. (2020). Chronic Copper Exposure Induces Hypospermatogenesis in Mice by Increasing Apoptosis Without Affecting Testosterone Secretion. *Biol. Trace Elem. Res.,* **195**: 472–480.

Chen, L., Min, J. and Wang, F. (2022). Copper homeostasis and cuproptosis in health and disease. *Signal Transduct. Target Ther.,* **7**(1):378. doi:10.1038/s41392-022-01229-y

Choi, H., Oh, D., Kim, M., Cai, L., Lee, J., Kim, E., Lee, G. and Hyun, S. H. (2022). Copper deficiency affects the developmental competence of porcine oocytes matured *in vitro*. *Front. Cell Dev. Biol.,* **10**: 993030. https://doi.org/10.3389/fcell.2022.993030

Cook, J.G. and Green, M.J. (2007). Reduced incidence of retained fetal membranes in dairy herds supplemented with iodine, selenium and cobalt. *Vet Rec.,* **161**(18):625-626.

D'Aleo, L., Shelford, J. and Fisher, L. (1983). Selenium-sulphur interactions and their influence on fertility in dairy cattle. *Can. J. Anim. Sci.,* **63**: 999.

Duplessis, M., Girard, C., Santschi, D., Laforest, J.P., Durocher, J. and Pellerin, D. (2014). Effects of folic acid and vitamin B12 supplementation on culling rate, diseases, and reproduction in commercial dairy herds. *J. Dairy Sci.,* **97**: 2346–2354.

Duplessis, M., Girard, C., Santschi, D., Lefebvre, D. and Pellerin, D. (2012). Folic acid and vitamin B12 supplement enhances energy metabolism of dairy cows in early lactation. *J. Dairy Sci.,* **95**: 118.

Fatehi, A.N., Zeinstra, E.C., Kooij, R.V., Colenbrander, B., and Bevers, M.M. (2002). Effect of cumulus cell removal of in vitro matured bovine oocytes prior to in vitro fertilization on subsequent cleavage rate. *Theriogenology,* **57**: 1347–1355.

Fisinin, V. I., Papazyan, T. T. and Surai, P. F. (2009). Producing selenium-enriched eggs and meat to improve the selenium status of the general population. *Crit. Rev. Biotechnol.,* **29**(1):18-28.

Gaetke, L. M. and Chow, C. K. (2003). Copper toxicity, oxidative stress, and antioxidant nutrients. *Toxicology*, **189**(1-2): 147-163. doi:10.1016/s0300-483x(03)00159-8

Galbraith, M. L., Vorachek, W. R., Estill, C. T., Whanger, P. D., Bobe, G., Davis, T. Z. and Hall, J. A. (2016). Rumen Microorganisms Decrease Bioavailability of Inorganic Selenium Supplements. *Biol. Trace Elem. Res.,* **171**(2): 338–343.

Gao, G., Yi, J., Zhang, M., Xiong, J., Geng, L., Mu, C. and Yang, L. (2007). Effects of iron and copper in culture medium on bovine oocyte maturation, preimplantation embryo development, and apoptosis of blastocysts in vitro. *J. Reprod. Dev.,* **53**(4): 777-784.

Genther, O. and Hansen, S. A. (2014). Multielement trace mineral injection improves liver copper and selenium concentrations and manganese superoxide dismutase activity in beef steers. *J. Anim. Sci.,* **92**: 695–704.

Ghaffari, R., Di Bona, K.R., Riley, C.L. and Richburg, J.H. (2019). Copper transporter 1 (CTR1) expression by mouse testicular germ cells, but not Sertoli cells, is essential for functional spermatogenesis. *PLoS ONE,* **14**(4): e0215522.

Girard, C. and Matte, J. (1999). Changes in serum concentrations of folates, pyridoxal, pyridoxal-5-phosphate and vitamin b12 during lactation of dairy cows fed dietary supplements of folic acid. *Can. J. Anim. Sci.,* **79**: 107–114.

Goff, J. P. (2005). Major advances in our understanding of nutritional influences on bovine health. *J. Dairy Sci.,* **89**: 1272-1301.

Gombart, A. F., Pierre, A. and Maggini, S. (2020). A Review of Micronutrients and the Immune System-Working in Harmony to Reduce the Risk of Infection. *Nutrients*, **12**(1): 236.

Gonzalez, M., Reyes-Jara, A., Suazo, M., Jo, W.J. and Vulpe C. (2008). Expression of Copper-Related Genes in Response to Copper Load. *Am. J. Clin. Nutr.,* **88**: 830S–4S.

Gonzalez-Montana, J. R., Escalera-Valente, F., Alonso, A. J., Lomillos, J. M., Robles, R. and Alonso, M. E. (2020). Relationship between Vitamin B12 and Cobalt Metabolism in Domestic Ruminant: An Update. *Animals (Basal),* **10**(10): 1855.

Grazul-Bilska, A.T., Caton, J.S., Arndt, W., Burchill, K., Thorson, C., Borowczyk, E., Bilski, J.J., Redmer, D.A., Reynolds, L.P. and Vonnahme, K.A. (2009). Cellular proliferation and vascularization in ovine fetal ovaries: Effects of undernutrition and selenium in maternal diet. *Reproduction*, **137**: 699–707.

Grazul-Bilska, A.T., Caton, J.S., Arndt, W., Burchill, K., Thorson, C., Borowczyk, E., Bilski, J.J., Redmer, D.A., Reynolds, L.P. and Vonnahme, K.A. (2009). Cellular proliferation and vascularization in ovine fetal ovaries: Effects of undernutrition and selenium in maternal diet. *Reproduction,* **137**: 699–707.

Gurol, K. C., Aschner, M., Smith, D. R. and Mukhopadhyay, S. (2022). Role of excretion in manganese homeostasis and neurotoxicity: a historical perspective. *Am. J. Physiol. Gastrointest. Liver Physiol.,* **322**(1): G79-G92. doi:10.1152/ajpgi.00299.2021

Hall, J.A., Van Saun, R.J., Bobe, G., Stewart, W.C., Vorachek, W.R., Mosher, W.D., Nichols, T., Forsberg, N.E. and Pirelli, G.J. (2012). Organic and inorganic selenium: I. Oral bioavailability in ewes. *J. Anim. Sci.,* **90**(2): 568–576.

Haryanto, B., Suksmasari, T., Wintergerst, E. and Maggini S. (2015). Multivitamin supplementation supports immune function and ameliorates conditions triggered by reduced air quality. *Vitam. Miner.,* **4**:1–15.

Herman, S., Lipinski, P., Ogorek, M., Starzynski, R., Grzmil, P., Bednarz, A. and Lenartowicz, M. (2020). Molecular Regulation of Copper Homeostasis in the Male Gonad during the Process of Spermatogenesis. *Int. J. Mol. Sci.,* **21**: 9053.

Hess, B.W., Moss, G.E. and Rule, D.C. (2008). A decade of developments in the area of fat supplementation research with beef cattle and sheep. *J. Anim. Sci.,* **86**: 188-204.

Hille, R., Nishino, T. and Bittner, F. (2011). Molybdenum enzymes in higher organisms. *Coord Chem Rev*., **255**(9-10): 1179-1205.

Husain, S., Kumar, R., Singh, B., Srivastava, S., Kumar, R., Kumar, P., & Haque, N. (2021). Impact of Different Therapeutic Protocols on Blood Biochemical Markers and Fertility in Anestrus Sahiwal Cows. *Ind. J. Vet. Sci. and Biotech.,* **17**(4), 49-53.

Jhamb, D., Kumar, S., Verma, S., Shektawat, J., & Saxena, M. (2011). Conception rate in relation to micronutrients status in embryo recipient cows. *Indian J. Anim. Reprod.,* **32**(1), 1-3.

Kardos J, Heja L, Simon A, Jablonkai I, Kovacs R, Jemnitz K. (2018). Copper Signalling: Causes and Consequences. *Cell Commun. Signal,* **16**:1–22.

Kaurav, P. S., Shukla, S. P., Bajaj, N. K., Singh, A. K., Khare, A., Manjhi, V., & Thakur, R. K. (2022). Serum Trace Minerals Profile in Anestrus Buffaloes Treated With Different Estrus Synchronization Protocols. *Indian J Anim. Reprod.,* **43**(2). 25-30.

Kodama, H., Fujisawa, C. and Bhadhprasit, W. (2012). Inherited copper transport disorders: Biochemical mechanisms, diagnosis, and treatment. *Curr. Drug Metab.,* **13**: 237–250.

Kowal, M., Lenartowicz, M., Pecio, A., Golas, A., Blaszkiewicz, T. and Styrna, J. (2010). Copper metabolism disorders affect testes structure and gamete quality in male mice. *Syst. Biol. Reprod. Med.,* **56:** 431–444.

Kramer, U., Talke, I.N. and Hanikenne, M. (2007). Transition metal transport. *FEBS Lett.,* **581:** 2263-2272.

Kumar, J., Srivastava, S., Kumar, R., Mohan, G. and Chaudhary, V. (2022[b]). Effect of Janova, Sepia andOvsynch Protocol on Blood Biochemical Profile and Fertility in Postpartum Anoestrus Cows. *Indian J. Anim. Res.,* **56**(9): 1077-1083.

Kumar, R., Butani, M.G., Dhami, A.J., Kavani, F.S., Patel, M.D. and Shah, R.G. (2009). Progesterone, metabolites and minerals in anestrus, subestrus, repeat breeding and cyclic cows. *Indian J. Anim. Reprod.,* **30**(2): 19-22.

Kumar, R., Butani, M.G., Dhami, A.J., Kavani, F.S., Shah, R.G. and KilledarAnkita (2011[a]). Management of anoestrus and sub-oestrus cows using hormonal and nonhormonal drugs. *Indian J. Anim. Reprod.,* **32**(1): 24-27.

Kumar, R., Butani, M.G., Kavani, F.S. and Dhami, A.J. (2022[a]). Augmenting Fertility in Anestrus and Subestrus Cows with Hormonal Interventions and Their Effect on Blood Biochemical Profile. *Indian J. Anim. Reprod.,* **43**(1): 15–21.

Kumar, R., Diwakar, R.P., Verma, H.C., Kumar, A., Kumar, P., Singh, K.D., Yadav, V. (2020). The saga of macrominerals and its role in reproduction in domestic animals: a review. *Glob. Vet.,* **22**(5): 267-272.

Kumar, S. (2003). Management of infertility due to mineral deficiency in dairy animals, p. 128–37. Proceedings of ICAR Summer School on "Advance diagnostic techniques and therapeutic approaches to metabolic and deficiency diseases in dairy animals". Held at IVRI, Izatnagar, Uttar Pradesh (15thJuly to 4thAugust).

Kumar, S., Pandey, A.K., Razzaque, W.A.A. and Dwivedi, D.K. (2011[b]). Importance of micro minerals in reproductive performance of livestock. *Vet. World,* **4**(5): 230-233.

Li, C. Y., Lin, W. C., Moonmanee, T., Chan, J. P., and Wang, C. K. (2024). The Protective Role of Vitamin E against Oxidative Stress and Immunosuppression Induced by Non-Esterified Fatty Acids in Bovine Peripheral Blood Leukocytes. *Animals,* **14**(7): 1079.

Liu, J.Y., Yang, X., Sun, X.D., Zhuang, C.C., Xu, F.B. and Li, Y.F. (2016).Suppressive Effects of Copper Sulfate Accumulation on the Spermatogenesis of Rats. *Biol. Trace Elem. Res.,* **174**: 356–361.

Liu, M., Sun, X., Chen, B., Dai, R., Xi, Z. and Xu, H. (2022). Insights into Manganese Superoxide Dismutase and Human Diseases. *Int. J. Mol. Sci.,* **23**(24): 15893.

Lizarraga, R.M., Anchordoquy, J.M., Galarza, E.M., Farnetano, N.A., Carranza-Martin, A., Furnus, C.C., Mattioli, G.A. and Anchordoquy, J.P. (2019). Sodium selenite improves in vitro maturation of *Bos primigenius taurus* oocytes. *Biol. Trace Elem. Res.,* **197**: 149–158.

Lutsenko, S., Barnes, N.L., Bartee, M.Y. and Dmitriev, O.Y. (2007). Function and regulation of human copper-transporting ATPases. *Physiol. Rev.,* **87**: 1011–1046.

Lutsenko, S., Barnes, N.L., Bartee, M.Y. and Dmitriev, O.Y. (2007). Function and regulation of human copper-transporting ATPases. *Physiol. Rev.,* **87**: 1011–1046.

Malik, M. I., Raboisson, D., Zhang, X. and Sun, X. (2023). Effects of dietary chromium supplementation on dry matter intake and milk production and composition in lactating dairy cows: A meta-analysis. *Front. Vet. Sci.,* **10**: 1076777.

Marques, R. S., Cooke, R. F., Rodrigues, M. C., Cappellozza, B. I., Mills, R. R., Larson, C. K., Moriel, P. and Bohnert, D. W. (2016). Effects of organic or inorganic cobalt, copper, manganese, and zinc supplementation to late-gestating beef cows on productive and physiological responses of the offspring. *J. Anim. Sci.,* **94**(3):1215-1226.

Michael, J., Baruselli, P.S. and Campanile, G. (2019). Influence of nutrition, body condition, and metabolic status on reproduction in female beef cattle: A review. *Theriogenology*, **125**: 277–284.

Milatovic, D., Gupta, R.C. (2018). Manganese. In: Veterinary Toxicology: Basic and Clinical Principles, 3rd ed.; Gupta, R.C., Ed.; Academic Press: Cambridge, MA, USA, 2018; pp. 445–454.

Mills, J. L., Ali, M., Buck Louis, G. M., Kannan, K., Weck, J., Wan, Y., Maisog, J., Giannakou, A. and Sundaram, R. (2019). Pregnancy Loss and Iodine Status: The LIFE Prospective Cohort Study. *Nutrients*. **11**(3): 534.

Mitchell, J.B., Costill, D.L., Houmard, J.A., Flynn, M.G., Fink, W.J. and Beltz, J.D. (1988). Effects of carbohydrate ingestion on gastric emptying and exercise performance. *Med. Sci. Sports Exerc.,* **20**(2):110-115. doi:10.1249/00005768-198820020-00002

Nazari, A., Dirandeh, E., Ansari-Pirsaraei, Z. and Deldar, H. (2019). Antioxidant levels, copper and zinc concentrations were associated with postpartum luteal activity, pregnancy loss and pregnancy status in Holstein dairy cows. *Theriogenology*, **133**: 97–103.

NRC (2001). Nutrient requirements of Dairy cattle: 7th edn. National Academic Press. pp: 105-1146.

Ogorek, M., Gąsior, T., Pierzchała, O., Daszkiewicz, R. and Lenartowicz, M. (2017). Role of copper in the process of spermatogenesis. *Postepy Hig. Med. Dosw,* **71**:663-683.

Osman, D., Cooke, A., Young, T.R., Deery, E., Robinson, N.J. and Warren, M.J. (2021). The requirement for cobalt in vitamin B_{12}: A paradigm for protein metalation. *Biochim. Biophys. Acta. Mol. Cell Res.,* **1868**(1): 118896.

Patel, P. M., Dhami, A. J., Savaliya, F. P., & Ramani, V. P. (2006). Postpartum plasma profile of certain trace elements in

Holstein Friesian cows with and without hormone therapy under tropical climate. *Indian J. Animal Reprod.,* **27**(2), 19-24.

Paterson, J.A. and Engle, T.E. (2005). Trace mineral nutrition in beef cattle. Nutrition Conf. Proc. Dep. of Anim. Sci. UT Ext. and Univ. Prof. Dev., Univ. of Tennessee, Knoxville.

Patterson, H.H., Adams, D.C., Klopfenstein, T.J., Clark, R.T. and Teichert, B. (2003). Supplementation to meet metabolizable protein requirements of primiparous beef heifers: II. Pregnancy and Economics. *J. Anim. Sci.,* **81:** 503-570.

Pereira, S. C., Oliveira, P. F., Oliveira, S. R., Pereira, M. L. and Alves, M. G. (2021). Impact of Environmental and Lifestyle Use of Chromium on Male Fertility: Focus on Antioxidant Activity and Oxidative Stress. *Antioxidants (Basel).* **10**(9):1365.

Qiao, W., Peng, Z., Wang, Z., Wei, J. and Zhou, A. (2009). Chromium improves glucose uptake and metabolism through upregulating the mRNA levels of IR, GLUT4, GS, and UCP3 in skeletal muscle cells. *Biol. Trace Elem. Res.,* **131**(2):133-142.

Qu, L., Xu, J., Dai, Z., Elyamine, A.M., Huang, W., Han, D., Dang, B., Xu, Z. and Jia, W. (2023). Selenium in soil-plant system: Transport, detoxification and bioremediation. *J. Hazard Mater.,* **452:** 131272.

Radostits, O.M., Gay, C.C., Blood, D.C. and Hinchliff, F.W. (2007). Veterinary Medicine. A textbook for the diseases of cattle, sheep, pigs, goats and horses, 10th Ed. Bailliere Tindall, London.

Ranches, J., Vendramini, J.M. and Arthington, J.D. (2017). Effects of selenium biofortification of hayfields on measures of selenium status in cows and calves consuming these forages. *J. Anim. Sci.,* **95**(1):120-128.

Schrauzer, G.N. (2001). Nutritional selenium supplements: Product types, quality, and safety. *J. Am. Coll. Nutr.,* **20:** 1–4.

Schrauzer, G.N. and Surai, P.F. (2009). Selenium in human and animal nutrition: resolved and unresolved issues. A partly historical treatise in commemoration of the fiftieth anniversary of the discovery of the biological essentiality of selenium, dedicated to the memory of Klaus Schwarz (1914–1978) on the occasion of the thirtieth anniversary of his death. *Crit. Rev. Biotechnol.,* **29**(1): 2-9.

Schwarz, F., Kirchgessner, M., and Stangl, G. (2000). Cobalt requirement of beef cattle—feed intake and growth at different levels of cobalt supply. *J. Anim. Physiol. Anim. Nutr.,* **83**: 121–131.

Sharma, M.C., Joshi, C., Pathak, N.N. and Kaur, H. (2005). Copper status and enzyme, hormone, vitamin and immune function in heifers. *Res. Vet. Sci.,* **79**(2):113-123.

Sharma, R., Singh, M., Kumar, P. and Sharma, A. (2020). Mineral profile of abandoned cows suffering from anestrus. *Indian J. Anim. Sci.,* 90(4): 581-583.

Sharma, S., Kaur, R. and Sandhu, H.S. (2004). Effect of subacute oral toxicity of molybdenum on antioxidant status in crossbred cow calves. *Indian J. Anim. Sci.,* **74**(7): 734-736.

Spears, J. W. (2000). Micronutrients and immune function in cattle. *Proc. Nutr. Soc.*, **9**(4):587-594. https://doi.org/10.1017/s0029665100000835

Spears, J.W. (2003). Trace mineral bioavailability in ruminants. *J. Nutr.,* **133**(5 Suppl 1), 1506S–9S.

Spears, J.W. and Weiss, W.P. (2008). Role of antioxidants and trace elements in health and immunity of transition dairy cows. *Vet. J.,* **176**: 70–76.

Spencer, T.E., Forde, N. and Lonergan, P. (2016). The role of progesterone and conceptus-derived factors in uterine biology during early pregnancy in ruminants. *J. Dairy Sci.,* **99**: 5941–5950.

Stangl, G., Schwarz, F., Müller, H., and Kirchgessner, M. (2000). Evaluation of the cobalt requirement of beef cattle based on vitamin B12, folate, homocysteine and methylmalonic acid. *Br. J. Nutr.,* **84**: 645–653.

Studer, J. M., Schweer, W. P., Gabler, N. K. and Ross, J. W. (2022). Functions of manganese in reproduction. *Anim. Reprod. Sci.,* **238**: 106924.

Suhajda, A., Hegoczki, J., Janzso, B., Pais, I. and Vereczkey, G. (2000). Preparation of selenium yeasts I. Preparation of selenium-enriched Saccharomyces cerevisiae. *J. Trace Elem. Med. Biol.,* **14**(1): 43-47.

Suttle, N.F. (2010). Mineral Nutrition of Livestock, 4th ed.; CABI: Oxfordshire, UK, 2010.

Tarrant, E., P Riboldi, G., McIlvin, M.R., Stevenson, J., Barwinska-Sendra, A., Stewart, L.J., Saito, M.A. and Waldron, K.J. (2019). Copper stress in Staphylococcus aureus leads to adaptive changes in central carbon metabolism. *Metallomics,* **11**(1): 183–200.

Tatemoto, H., Sakurai, N. and Muto, N. (2000). Protection of porcine oocytes against apoptotic cell death caused by oxidative stress during in vitro maturation: Role of cumulus cells. *Biol. Reprod.,* **63**: 805–810.

Trumbo, P., Yates, A.A., Schlicker, S. and Poos, M. (2001). Dietary reference intakes: Vitamin A, vitamin K, arsenic, boron, chromium, copper, iodine, iron, manganese, molybdenum, nickel, silicon, vanadium, and zinc. *J. Am. Diet. Assoc.,* **101**: 294–301.

Tumer, Z. and Moller, L.B. (2010). Menkes disease. *Eur. J. Hum. Genet.,* **18**(5):511-518.

Tuormaa, T.E. (2000). Chromium Selenium Copper and other trace minerals in health and reproduction. *J. Orthomol. Med.,* **15**: 145-157.

Tvrda, E., Peer, R., Sikka, S.C. and Agarwal, A. (2015). Iron and copper in male reproduction: A double-edged sword. *J. Assist. Reprod. Genet.,* **32**: 3–16.

Van Emon, M., Sanford, C., & McCoski, S. (2020). Impacts of Bovine Trace Mineral Supplementation on Maternal and Offspring Production and Health. *Animals: an open access journal from MDPI*, *10*(12), 2404. https://doi.org/10.3390/ani10122404

Van Emon, M., Sanford, C., and McCoski, S. (2020). Impacts of Bovine Trace Mineral Supplementation on Maternal and Offspring Production and Health. *Animals (Basel)*. **10**(12): 2404. https://doi.org/10.3390/ani10122404

Vashchenko, G. and MacGillivray, R.T.A. (2013). Multi-copper oxidases and human iron metabolism. *Nutrients,* **5**: 2289–2313.

Veldhuis, N. A., Gaeth, A. P., Pearson, R. B., Gabriel, K., and Camakaris, J. (2009). The multi-layered regulation of copper translocating P-type ATPases. *Biometals*, **22:** 177-190.

Vierboom, M.M., Engle, T.E. and Kimberling, C.V. (2003). Effects of gestational status on apparent absorption and retention of copper and zinc in mature Angus cows and Su_olk ewes. *Asian Aust. J. Anim. Sci*., **16**: 515–518.

Wada, O. (2004) "What are trace elements? Their deficiency and excess states". *Japan Medical Association Journal*, **47**(8): 351-358.

Wang, C., Han, L., Zhang, G.W., Du, H.S., Wu, Z.Z., Liu, Q., Guo, G., Huo, W.J., Zhang, J., Zhang, Y.L., Pei, C.X. and Zhang, S.L. (2021). Effects of copper sulphate and coated copper sulphate addition on lactation performance, nutrient digestibility, ruminal fermentation and blood metabolites in dairy cows. *Br. J. Nutr.,* **125**(3): 251-259.

Wang, F., Zhang, J., Xu, L., Ma, A., Zhuang, G., Huo, S., Zou, B., Qian, J., and Cui, Y. (2024). Selenium volatilization in plants, microalgae, and microorganisms. *Heliyon*, **10**(4): e26023. https://doi.org/10.1016/j.heliyon.2024.e26023

WHO. (2006). *Guidelines on Food Fortification with Micronutrients*; World Health Organization: Geneva, Switzerland.

Wood, R.J. (2009). Manganese and birth outcome. *Nutr Rev*., **67**(7):416-420.

Yasui, T., McArt, J. A. A., Ryan, C. M., Gilbert, R. O., Nydam, D. V., Valdez, F., ... and Overton, T. R. (2014). Effects of chromium propionate supplementation during the periparturient period and early lactation on metabolism, performance, and cytological endometritis in dairy cows. *J. Dairy Sci.,* **97**(10): 6400-6410).

Zhang, X., Zhang, D., Xiang L. and Wang, Q. (2022). MnSOD functions as a thermoreceptor activated by low temperature. *J. Inorg. Biochem*., **229**:111745.