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Role of Nickel in animal performance: A review

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Abstract
Nickel is an emerging probable essential trace element. Nickel is poorly absorbed by the body and is eliminated mainly in the faeces, but absorption increases during pregnancy, lactation and iron deprivation. Ni is highly mobile under acidic and oxidizing conditions. In general, plant foods are higher in Ni than foods of animal origin. Ni is an essential trace element and their deficiency has been associated with depressed growth, alterations in carbohydrate and lipid metabolism, delayed gestation period, anaemia, reduced haemoglobin and hematocrit values and alterations in the content of Fe, Cu, and Zn in liver. Ni supplementation in ruminant diets has improved growth performance and feed conversion efficiency. Ni may aid in prolactin production, and thus be involved in milk production.

Keywords: Nickel, growth, performance

Introduction
Optimum production, reproduction and normal health of livestock can only be maintained by providing essential nutrients in appropriate proportion (Garg *et al*., 2000) [9]. Unlike protein and energy, micronutrients though required in small amounts, plays an important role in various body functions. Balanced supply of minerals should be necessary to get optimum performance from livestock. Minerals provide the essential nutrients animals need for growth and development, as essential part of many enzymes, hormones or functions as cofactors or bio-ligand in metabolism, catalysts and enzyme activation. Even moderate deficiencies of minerals can adversely impact animal health and performance. Until 1950, mineral elements were classified as essential: these comprised the major elements and the micro or trace elements. By 1970, molybdenum, selenium, chromium and fluorine had been added to the list of trace elements. Role of major and trace minerals in performance of livestock is well established. Recently some other trace elements like Ni has been identified which also has certain beneficial role in animals. These elements are grouped as newer essential trace elements because deprived animals were unhealthy and showed physiological responses to the supplementation (Nielsen, 2000) [13]. Hence, the literature pertaining to the supplementation of Ni in growing cattle has been reviewed under following subheadings:

1. Chemical properties of Nickel
2. Metabolism of Nickel
3. Level of Nickel in feedstuffs
4. Role of Nickel in animal performance
   4.1. Role of Nickel in growth performance
   4.2. Role of Nickel in milk production

Chemical properties of Nickel
The name Ni comes from the German word KupferNickel, meaning "Old Nick's copper," a term used by German miners. Swedish mineralogist Axel Fredrik Cronstedt (1722-65) was the first person to realize that Ni was a new element. He found something in the mineral that did not act like cobalt, copper, or any other known element. He used a shortened version of KupferNickel for the name of the new element and called it as Ni. Ni has an atomic number of 28, an atomic mass of 58.69 and exists in two oxidation states (+2 and +3) and five naturally occurring isotopes (^{58}Ni, ^{60}Ni, ^{61}Ni, ^{62}Ni and ^{64}Ni). It is a silvery-white siderophile metallic element with chalcophilic and lithophilic affinities and forms several minerals, including pentlandite, Niine and ullmannite. Ni forms compounds in several oxidation states, the divalent ion seems to be the most important for both organic and inorganic substances, but the trivalent form may be generated by redox reactions in the cell. Divalent (Ni^{2+}) ion is intermediate in size (69 pm) between Mg^{2+} and Ni^{2+} (72 and 61 pm respectively), for which it

substitutes during fractionation, and it is partitioned into ferromagnesian minerals such as olivine, orthopyroxene and spinel. Ni is highly mobile under acidic and oxidizing conditions. In natural water, Ni may exist in one of three oxidation states (+2, +3 and +4), although the free ion Ni predominates. Chloride, nitrate and sulphate compounds of Ni are very soluble in water, but Nickel carbonate ($NiCO_3$) and, in particular, Nickel hydroxide {$Ni(OH)_2$} and Nickel phosphate {$Ni_3(PO4)_2$} are insoluble. Colloidal Nickel hydroxide is present above pH 8 and under reducing conditions, Ni is incorporated into sulphides, such as millerite (NiS), also lowering its mobility (McBride, 1994). Ni forms complexes with adenosine triphosphate (ATP), amino acids, peptides, proteins and deoxyribonucleic acid in biological system.

Metabolism of Nickel

Nickel is poorly absorbed by the body and is eliminated mainly in the faeces, but absorption increases during pregnancy, lactation and iron deprivation, suggesting the involvement of active transport mechanisms shared with Fe (NRC, 2005) [14]. Limited studies suggest that typically less than 10% of ingested Ni is absorbed. Absorbed Ni is rapidly cleared from serum and excreted in urine. Ni, which enters the blood stream, is excreted in the urine, and if it is entered by the food it is excreted in the feces. Concentrations of Ni in plasma are low (<0.017 µmol/L) and it is bound chiefly to albumin, but it is histidine-bound Ni that may facilitate the uptake of Ni by cells. When Ni enters into the body it is distributed to all organs. The mechanism for intestinal absorption of Ni is not clear. In short and long-term studies of animal administered various soluble Ni salts orally, Ni was found primarily in the kidneys followed by lungs, liver, heart and testes (Ambrose *et al*., 1976; Dieter *et al*., 1988) [1, 7]. Supplementation of a cow's ration with 365 or 1835 mg Ni/day as Ni carbonate ($NiCO_3$) caused no increase in milk Ni content (O'Dell *et al*., 1970a) [15] but excess absorbed Ni is excreted via the urine rather the faeces (NRC, 2005) [14]. Small Ni supplements (5 mg Ni/ kg DM) can cause six fold increases in bovine kidney Ni to 0.3 mg Ni /kg DM, suggesting a gross dietary excess (Spears *et al*., 1986) [21]. The Ni concentrations in body fluids or tissues are not significantly influenced by age, sex, or pregnancy. The chemical form and its deposition site as determined by size, shape, density, and electrical charge of the Ni particles will affect the extent of absorption in the lungs (ATSDR, 1988) [5]. Ni may undergo redox reaction generating the trivalent form thus forming reactive oxygen species (ROS). The intracellular release of Ni following phagocytosis of particles of oxidic and sulfidic Ni is an important metabolic pathway. Minute particles containing Ni have been demonstrated close to the nuclear membrane. The biological half-time of Ni depends on the species studied. For soluble compounds, the half-time of plasma Ni is 11 to 39 hours in humans have been recorded (Sunderman *et al*., 1986) [25]. A urinary elimination half-time of 17 to 48 hours has been reported for the absorbed dose following experimental oral exposure in humans (Sunderman *et al*., 1986) [25]. Results based on single-injection, continuous infusion and multiple-dosing experiments using Ni chloride in rats and rabbits showed a typical two compartment distribution and an elimination pattern comprising a rapid and a slow clearance phase Onkelinx and Sunderman (1980) [18]. At a steady state situation with continued intravenous injection, the highest Ni concentration was found in the kidney followed by the lung (ratio about 17:1).

Ni is known to bind to specific proteins and/or amino acids in the blood serum and the placenta. These ligands are instrumental in the transport and distribution of Ni in the body. Ni increased the absorption of Fe from the diet in Fe deficient rats, but only when dietary Fe was in the unavailable ferric form, whereas a mixture of ferrous and ferric sulphates as a supplement to the diet did not elicit any effect (Nielsen, 1980) [12]. Fe deficiency increased intestinal Ni absorption and indicating that Ni is partially absorbed by the active transport system for Fe absorption in the intestinal mucosal cells. Thus, when dietary Fe is absorbed as the divalent cation, competition probably occurs between Fe and the Ni^{2+} ion for the active transport system.

Level of Nickel in feedstuffs

Ni concentrations in plants can be influenced by a number of factors such as 1) plant species, 2) stage of maturity, 3) soil Ni concentration, and 4) availability of Ni in the soil. Ni is fairly evenly distributed throughout the various food groups but highest concentrations (1 to 10 mg Ni/kg fresh weights) are found in roots and vegetables, soybeans, oatmeal, and cereals food. The Ni content of the feeds analyzed varied widely, ranging from 0.04 to 3.91 ppm. In general, plant foods are higher in Ni than foods of animal origin. Pasture plants have been reported to contain 0.5 to 3.5 ppm Ni (Underwood, 1977) [26]. Concentrations of Ni in grasses are generally lower than those in soils but legumes such as Alfalfa contain more Ni (Sapek and Sapek, 1980) [20]. Wheat grains have been reported to have Ni levels ranging from 0.08 to 0.35 ppm (Welch and Cary, 1975) [28]. Ni in forages decreases with advancing maturity. The availability of soil Ni for plant uptake is highly dependent on soil pH (Rencz and Shilts, 1980) [19]. Ni forms stable complexes with Fe and manganese hydrous oxides at a neutral pH. However, at pH lower than 6.5, Ni is released from these compounds and increased movement, into plants (Rencz and Shilts, 1980) [19]. The addition of calcium carbonate to increase soil pH from 5.4 to 6.4 reduced the Ni content of red clover and ryegrass from 1.98 to 1.10 and 1.95 to 0.92 ppm, respectively (Mitchell, 1957) [11]. Ni content of different feeds and fodders is presented in Table 1 (Spears, 1984) [24].

Table 1: Ni content of feedstuffs

Ingredient	Ni level (ppm)	Ingredient	Ni level (ppm)
Corn	0.36-0.90	Cottonseed hulls	0.26
Oat	1.00	Soybean meal	3.91
Barley	0.04	Corn gluten meal	1.65
Wheat	0.56	Feather meal	0.77
Corn silage	1.28	Blood meal	0.66
Alfalfa pellets	3.69	Urea	1.52
Bermuda grass pellets	0.44		

Role of Nickel in animal performance

Ni is an essential trace element and their deficiency has been associated with depressed growth, alterations in carbohydrate and lipid metabolism, delayed gestation period, anaemia, reduced haemoglobin and hematocrit values and alterations in the content of Fe, Cu, and Zn in liver.

Role of Ni in growth performance

Ni supplementation in ruminant diets has improved growth performance and feed conversion efficiency (Spears, 1984)

[24]. In long term experiments, swine and goats maintained on low Ni diets gained at a slower rate than control animals receiving supplemental Ni (Anke *et al*., 1977) [3]. Early weaned lambs fed a low Ni diet (0.065 ppm) gained similarly to control animals receiving 5 ppm of supplemental Ni during a 97 days study (Spears *et al*., 1978a). In a later study, lambs born as twins or triplets were allotted within a pair shortly after birth to a synthetic, low Ni milk diet (0.03 ppm) or the basal diet plus 5 ppm of Ni (Spears *et al*., 1978b) [23]. When compared to the Ni- supplemented group, lambs fed the Ni deficient diet showed an increased mortality, decreased weight gain and changes in various blood and tissue parameters. Spears *et al*. (1978a) reported that when lambs were fed the adequate protein diet after receiving the low protein diet for 28 days and the tendency for increased gains in the Ni supplemented lambs may have reflected the differences noted in gain during the first period. Steers when fed the adequate protein diet gained similarly, but feed efficiency was higher in the Ni supplemented animals (Spears *et al*., 1978a). Chung *et al*. (1976) [6] reported that Ni (27 ppm) increased gain and feed efficiency in growing finishing swine fed corn soybean meal diets low in Zn. Ni deficiency in chicks growing under suboptimal conditions has resulted in leg abnormalities, skin dermatitis and changes in total liver lipids. Anke *et al*. (1974) [2] reported that when miniature pigs fed a diet containing 0.1 ppm Ni gained less than animals supplemented with 10 ppm Ni. Ni deprived pigs had delayed estrus and progeny of Ni deficient sows had an increased neonatal mortality and a decreased growth rate (Anke *et al*., 1977) [3]. Ni supplementation to pig starter and rearing diets at levels of 125, 250 or 375 ppm does not significantly effect on performance. But, 500 ppm added Ni depressed feed intake and rate of gain (Kirchgessner and Roth, 1977) [10]. In long-term studies, Anke *et al*. (1977) [3] found that goats receiving a diet containing 1 ppm Ni gained 21% slower than animals fed the basal diet supplemented along with 10 ppm Ni. Addition of Ni, 500 ppm or greater as Ni sulfate or Ni acetate to a corn-soy- bean meal-based diet resulted in a decreased rate of gain, feed intake and N retention in chicks (Weber and Reid, 1968) [27]. O'Dell *et al*. (1970b, 1971) [16] studied Ni toxicity and accumulation in young male calves fed 0, 62.5, 250 or 1,000 ppm Ni level as Ni carbonate. In animals fed 250 ppm Ni, feed intake was slightly reduced, but rate of gain was not affected. Feed intake was reduced in animals receiving 1,000 ppm Ni level and animals in this group lost weight and had higher concentrations of Ni in many tissues. The high level of Ni was also associated with decreased N retention and a shift in volatile fatty acids toward a higher molar percentage of propionic and a lower molar proportion of butyric acid. In short-term studies, Ni in the form of Nickel chloride was approximately five times more potent than the carbonate form in reducing feed consumption of cattle (O'Dell *et al*., 1970c) [17].

Role of Nickel in milk production

Ni may aid in prolactin production, and thus be involved in milk production. The Ni content of normal milk and colostrum were not reduced during Ni deficiency. However, lactating goats deficient in Ni had lower concentrations of Ni in ribs, carpals, kidneys, cerebrum, liver and cardiac muscle and frequently died from Ni deficiency. The metal can be transferred from the mother to an infant in breast milk and can cross the placenta. High doses of Ni led to the excretion of Ni into milk and changes in milk quality and production. Reductions in liver weight in the suckling pups were also observed which may have been due to Ni exposure or to changes in milk composition (Dostal *et al*., 1989) [8]. Significant alterations in milk composition included increased milk solids (42%) and lipid (110%), and decreased milk protein (29%) and lactose (61%). Dietary Ni levels of up to 250 ppm as Ni carbonate (O'Dell *et al*., 1970a) [15] or 145 mg/d as Ni chloride (Archibald, 1949) [4] does not increase the Ni content of milk or have any harmful effects in lactating dairy animals.

Conclusion

The trace element like Nickel may be added to the diets, although until today, there is no clear evidence that Nickel is essential for any metabolic process. Various research have shown that it may interact with other nutrients under various conditions to give beneficial effects. At the same time, we have to take into account the harmful effects. Nickel may accumulate and disrupt functions of vital organs thereby affecting health of animals. It affects urease activity thus increase protein utilization. In this context, the study of effects of Nickel on nutrition utilization and growth performance has become an upcoming aspect of nutritional research.

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