New Frontiers in Mineral Nutrition

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Novus International, Inc.
Agenda

• Overview of trace minerals
  – Forms of trace minerals
• Nutrient management & the environment
• Antagonists
• Bioavailability estimation and effect on determination of dietary supply of trace minerals
• Determination of animal trace mineral status
  – Useful biomarkers of trace mineral status
  – Experimental determination of trace mineral status
• Cow/calf (pre-calving, pre-weaning and receiving programs)
• The role of minerals on responses to immunization, function of chelates on better immunity
• Antagonists and the function of chelates
• Summary
Overview of minerals in nutrition

• Structural
  – Can form important structural components in body organs and tissues
  – Ca and P in bone
  – P and S in muscle

• Physiological
  – Can occur in body fluids and tissues as electrolytes
  – Na, K, Cl, Ca in blood

• Catalytic
  – Can act as catalysts or cofactors for enzyme and hormone systems
  – Fe, Cu, Zn, Mn, Se in an enormous range of enzymes

• Regulatory
  – Can regulate cell replication and development
  – Ca with hormonal signaling
  – Zn with gene expression
Catalytic and regulatory functions of some trace minerals

<table>
<thead>
<tr>
<th>Trace mineral</th>
<th>Metalloprotein</th>
<th>Protein Role</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Copper</td>
<td>Cytochrome oxidase</td>
<td>Terminal link in the electron transport chain; permits formation of ATP</td>
<td>Energy metabolism</td>
</tr>
<tr>
<td></td>
<td>Lysyl oxidase</td>
<td>Lysine oxidation in elastin and collagen crosslinking</td>
<td>Connective tissue formation and integrity</td>
</tr>
<tr>
<td></td>
<td>Superoxide dismutase</td>
<td>Converts superoxide into oxygen and hydrogen peroxide</td>
<td>Protects against oxidative damage</td>
</tr>
<tr>
<td>Manganese</td>
<td>Glycosyl-transferase</td>
<td>Proteoglycan synthesis</td>
<td>Bone development and wound healing</td>
</tr>
<tr>
<td></td>
<td>Superoxide dismutase</td>
<td>As above</td>
<td>Protects against oxidative damage</td>
</tr>
<tr>
<td>Selenium</td>
<td>Glutathione peroxidase</td>
<td>Reduces hydrogen peroxide and lipid peroxides</td>
<td>Protects against oxidative damage</td>
</tr>
<tr>
<td></td>
<td>Thioredoxin reductase</td>
<td>Reduces thioredoxin</td>
<td>Protects against oxidative damage</td>
</tr>
<tr>
<td>Zinc</td>
<td>Collagenase</td>
<td>Breaks the peptide bond in collagen</td>
<td>Tissue remodeling, bone development and wound healing</td>
</tr>
<tr>
<td></td>
<td>Superoxide dismutase</td>
<td>As above</td>
<td>Protects against oxidative damage</td>
</tr>
<tr>
<td></td>
<td>Zinc finger transcription factors</td>
<td>Protein-DNA interactions</td>
<td>Regulate gene transcription</td>
</tr>
</tbody>
</table>
Trace minerals as components of antioxidants

- **Cu, Mn, Zn**
- **Vitamin E**
- **Vitamin C**
- **Se**
- **Carotenoid**

* = free radical or highly reactive species

# = superoxide dismutase (SOD), contains Cu and Zn
Forms of Trace Minerals

- Oxides
- Sulfates
- Proteinates
- Amino Acid Complexes
- Chelates
Nutrient management and the environment
Efficient nutrient management

• Ration balancing at a completely different level

• Estimating production of wastes and nutrient composition

• Establishing pollutant production

• Mitigating environmental issues
Role of environment on nutrient utilization

• Stress
  – Heat
  – Cold
  – Drought

• Forages
  – Maturity
  – Type
  – Utilization
Bioavailability
## Inorganic trace mineral bioavailability, %

### Absorption Coefficients (Bioavailability), %

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Feeds</th>
<th>Sulfates</th>
<th>Chlorides</th>
<th>Carbonates</th>
<th>Oxides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cu</td>
<td>4</td>
<td>5</td>
<td>5</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Mn</td>
<td>1</td>
<td>1.2</td>
<td>1.2</td>
<td>0.15</td>
<td>0.25</td>
</tr>
<tr>
<td>Zn</td>
<td>15</td>
<td>20</td>
<td>20</td>
<td>10</td>
<td>12</td>
</tr>
</tbody>
</table>

*NRC, 2001*
Dietary Antagonisms

- **Copper:**
  - S, Fe, Mo
  - High sulfate water
  - DDGS contain high and variable levels of Sulfates

- **Manganese:**
  - Ca, P, Fe

- **Zinc:**
  - Ca, P, Cu

Just feeding more inorganic trace minerals does not cure deficiencies
Biomarkers of trace mineral status

- **Zinc**
  - Plasma Zinc
  - Activity of Zinc dependent enzymes
  - Liver Zinc
  - Bone Zinc
  - Metallothionein expression

- **Copper**
  - Plasma copper
  - Plasma ceruloplasmin
  - Liver copper

- **Manganese**
  - Plasma manganese
  - Bone manganese

- **Selenium**
  - Plasma selenium
  - Whole blood selenium
  - Milk selenium
  - Plasma glutathione peroxidase
Metallothionein (MT) proteins bind to Zn and other metals.

One MT protein can bind up to 7 cations, such as Zn.

MT expression is a marker of Zn uptake by cells.

As Zn absorption increases, MT mRNA and protein increase.
Model for Mineral Delivery and Absorption
MT expression is a well-accepted biomarker of zinc absorption & status

Selected Publications

- **Chickens**

- **Pigs**

- **Sheep**

- **Rodents**

- **Humans**
HMTBa Zn bioavailability trial in broilers

- Birds were fed a common low zinc starter, and then switched to treatments (right) on day 8
- Small intestinal metallothionein (MT) measured on day 11
- Tibia zinc was measured on day 14

<table>
<thead>
<tr>
<th>Trt</th>
<th># pens</th>
<th>Source</th>
<th>Suppl. Zn (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12</td>
<td>None</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>Sulfate</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>6</td>
<td>Sulfate</td>
<td>10</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>Sulfate</td>
<td>15</td>
</tr>
<tr>
<td>5</td>
<td>6</td>
<td>Sulfate</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Sulfate</td>
<td>30</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>HMTBa</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>HMTBa</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>HMTBa</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>6</td>
<td>HMTBa</td>
<td>20</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>HMTBa</td>
<td>30</td>
</tr>
</tbody>
</table>
Tibia zinc demonstrates greater bioavailability of HMTBa Zn

\[ Y = 8.66X_1 + 13.93X_2 + 113.7 \]

\[ m_1 \text{ vs } m_2: P = 0.001 \]

Slope ratio = 161%

Zn Sulfate: linear (P<0.0001)

HMTBa Zn: quadratic (P=0.0006)

Breakpoint = 5.9mg

Novus, Data on file
MT assay also demonstrates greater bioavailability of HMTBa Zn

\[ Y = 0.92X_1 + 2.28X_2 + 1.82 \]

m₁ vs m₂: P = 0.009

Slope ratio = 248%

Novus, Data on file
Zinc Bioavailability Trial in Broilers

• Broilers on a milo-soy diet for 13 days
• Placed on corn-soy treatment diets on day 14:
  – Control 35 ppm Zn from ingredients
  – Zinc Sulfate +70 ppm Zn
  – Zinc Proteinate +70 ppm Zn
  – Zn Glycine +70 ppm Zn
  – Zn Amino Acid Complex +70 ppm Zn
  – Zn HMTBa +70 ppm Zn
• Jejunum samples collected on day 16 for MT assay
MT Assay Shows Zn Absorption

MT mRNA (relative units)

Control | Sulfate | Proteinate | Glycinate | Amino Acid Complex | Zn HMTBa

- Control: d
- Sulfate: cd
- Proteinate: bc
- Glycinate: ab
- Amino Acid Complex: cd
- Zn HMTBa: a

MT mRNA (relative units)
Effects of trace mineral sources on bioavailability and function in dairy cattle.

- 30 lactating multiparous dairy cows fed basal diet for 3 weeks
- Split into 3 groups (10 per) for 4 weeks
  - Basal control diet
  - Basal plus additional 320 mg Zn, 150 mg Cu, 130 mg Mn
    - HMTBa Chelate (14 g/d of HMTBa blend with 2g Zn, 1g Cu, 1g Mn)
      (also supplies 3.14 g HMTBa)
    - Metal specific amino acid complex blend (ZnMet, CuLys, MnMet—
      also supplies 0.93 g methionine and 0.69 g lysine)
- Basal diet: 53 ppm Zn, 11 ppm Cu, 46 ppm Mn
- Supplemented diets: 66 ppm Zn, 17 ppm Cu, 51 ppm Mn
- Collect liver for MT analysis
  - Prior to treatment diets (Week 0)
  - After one week on treatment diets (Week 1)

Thering et al., 2007
Only the cows on HMTBa OTMs had a significant increase in MT expression.

Thering et al., 2007
Delta Liver Copper—(Week 4 minus Week 0, ppm)

- Control
- AA-complex
- MINTREX

* = Diff. than zero (P < 0.1)

Thering et al., 2007
Cow/calf (pre-calving and pre-weaning)
Effect of maternal trace mineral source on cow/calf performance and the subsequent feedlot performance of beef calves from high and low marbling lines

• Objective:
  – evaluate the performance of beef calves supplemented with chelate or inorganic trace minerals as a component of a free-choice mineral supplement starting in late gestation of the dam through weaning of the calves over two years.

• Treatments:
  – Inorganic trace minerals, Zn, Cu, and Mn supplemented as sulfates at NRC levels (assuming 4 oz AF intake [113 g] per hd per d of supplement and 11 kg/d of DMI; 30 ppm Zn, 15 ppm Cu, and 40 ppm Mn) and MFP supplemented to balance the methionine provided by the HMTBa in treatment 2
  – HMTBa Zn, Cu, and Mn supplemented at an equal mineral intake to the inorganics in treatment 1
Calf weaning weight per cow exposed was greater in cows fed chelate.

<table>
<thead>
<tr>
<th>Reproductive Performance</th>
<th>Inorganic</th>
<th>Chelate</th>
<th>S.E.</th>
<th>$P$ Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calf BW, kg</td>
<td>34.4</td>
<td>34.5</td>
<td>0.4</td>
<td>0.90</td>
</tr>
<tr>
<td>Adjusted 205-d WW, kg</td>
<td>242.7</td>
<td>249.1</td>
<td>3.6</td>
<td>0.25</td>
</tr>
<tr>
<td>Calf Weaning, %</td>
<td>94.2</td>
<td>96.5</td>
<td>1.2</td>
<td>0.21</td>
</tr>
<tr>
<td>kg of Calf Weaned/cow exposed</td>
<td>228.5</td>
<td>240.1</td>
<td>2.2</td>
<td>0.008</td>
</tr>
<tr>
<td>Conception Rate, %</td>
<td>87.7</td>
<td>87.6</td>
<td>4.7</td>
<td>0.98</td>
</tr>
</tbody>
</table>

Novus, Data on file
Comparison of chelated versus inorganic trace minerals on rate and efficiency of gain and pregnancy rates in beef heifers

- **Objective:**
  - evaluate any differences in rate and efficiency of gain and conception rates in heifers supplemented with either a methionine chelated form of Cu, Zn, and Mn (chelate) or a SO$_4$ form of Cu, Zn, and Mn.

- **The trial was replicated across 3 ranches:**
  - Dillon, MT (498 Angus heifers)
  - Terry, MT (236 Red Angus x Charolais x Tarentaise heifers)
  - Ranchester, WY (1742 Angus x Composite heifers).

*Whitehurst et al., 2012*
% Bred was increased for heifers fed Chelate, particularly on Ranch 3

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Ranch 1</th>
<th>Ranch 2</th>
<th>Ranch 3</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sulfate</td>
<td>Chelate</td>
<td>Sulfate</td>
<td>Chelate</td>
<td>Sulfate</td>
</tr>
<tr>
<td>No. heifers</td>
<td>251</td>
<td>246</td>
<td>120</td>
<td>119</td>
<td>870</td>
</tr>
<tr>
<td>Days on Test</td>
<td>181</td>
<td>181</td>
<td>149</td>
<td>149</td>
<td>77</td>
</tr>
<tr>
<td>Initial BW, kg</td>
<td>250</td>
<td>251</td>
<td>269</td>
<td>270</td>
<td>289</td>
</tr>
<tr>
<td>End BW, kg</td>
<td>341</td>
<td>340</td>
<td>390</td>
<td>391</td>
<td>347</td>
</tr>
<tr>
<td>Gain, kg</td>
<td>91</td>
<td>90</td>
<td>121</td>
<td>121</td>
<td>59</td>
</tr>
<tr>
<td>ADG, kg/d</td>
<td>0.505</td>
<td>0.495</td>
<td>0.814</td>
<td>0.814</td>
<td>0.764</td>
</tr>
<tr>
<td>F:G</td>
<td>13.74</td>
<td>13.65</td>
<td>8.4</td>
<td>8.41</td>
<td>9.44</td>
</tr>
<tr>
<td>% Bred</td>
<td>85</td>
<td>86</td>
<td>92</td>
<td>91</td>
<td>59</td>
</tr>
<tr>
<td>% Bred 1st Service</td>
<td>58</td>
<td>57</td>
<td>54</td>
<td>51</td>
<td>59</td>
</tr>
</tbody>
</table>
Receiving and Immunity
The effect of chelates (Cu, Zn, Mn) on the health and growth performance of high-risk calves during a 42 day receiving study

- **Objective:**
  - To evaluate the effects of feeding Glycine Zn, Cu, Mn, Se-Yeast, MOS, and antioxidants on growth performance, feed efficiency, morbidity, mortality and drug costs in highly stressed, newly weaned calves.

- **Collaborator:** Eric Larson, Larson Nutrition Services and Apishapa Ranch
Treatments

• **Control** – calves will receive a diet with inorganic minerals as the only source of minerals and at levels defined by the feedlot nutritionist.

• **Starter Pack** - Calves will be fed chelates (Cu, Zn, Mn), Se-Yeast, MOS, and antioxidants. Supplements will be formulated to contain iso-mineral levels of Cu, Zn, Mn, and Se as the control supplement.
## Rations

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Starter Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolled Corn</td>
<td>47</td>
<td>47</td>
</tr>
<tr>
<td>Ground Sorghum Hay</td>
<td>11.6</td>
<td>11.6</td>
</tr>
<tr>
<td>Ground Alfalfa Hay</td>
<td>24.5</td>
<td>24.5</td>
</tr>
<tr>
<td>Sorghum Silage</td>
<td>8.2</td>
<td>8.2</td>
</tr>
<tr>
<td>Suspension Supplement</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Control Mineral Meal</td>
<td>3.7</td>
<td>-</td>
</tr>
<tr>
<td>Novus Mineral Meal</td>
<td>-</td>
<td>3.7</td>
</tr>
</tbody>
</table>
## Composition

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>Starter Pack</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM, %</td>
<td>74.31</td>
<td>74.66</td>
</tr>
<tr>
<td>Cu, ppm</td>
<td>27.87</td>
<td>28.17</td>
</tr>
<tr>
<td>Zn, ppm</td>
<td>99.39</td>
<td>103.54</td>
</tr>
<tr>
<td>Mn, ppm</td>
<td>62.44</td>
<td>65.73</td>
</tr>
<tr>
<td>Se, ppm</td>
<td>0.43</td>
<td>0.42</td>
</tr>
<tr>
<td>Nem, Mcal/lb</td>
<td>0.81</td>
<td>0.82</td>
</tr>
<tr>
<td>NEg, Mcal/lb</td>
<td>0.49</td>
<td>0.49</td>
</tr>
<tr>
<td>CP, %</td>
<td>12.7</td>
<td>12.27</td>
</tr>
<tr>
<td>ADF, %</td>
<td>17.51</td>
<td>17.08</td>
</tr>
</tbody>
</table>
Cattle performance did not differ

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Starter Pack</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 0</td>
<td>514</td>
<td>513</td>
<td>0.89</td>
<td>0.93</td>
</tr>
<tr>
<td>Day 14</td>
<td>547</td>
<td>548</td>
<td>1.31</td>
<td>0.67</td>
</tr>
<tr>
<td>Day 28</td>
<td>573</td>
<td>574</td>
<td>1.47</td>
<td>0.74</td>
</tr>
<tr>
<td>Day 42</td>
<td>609</td>
<td>611</td>
<td>1.8</td>
<td>0.66</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Starter Pack</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADG, lbs/d</td>
<td>2.34</td>
<td>2.37</td>
<td>0.06</td>
<td>0.73</td>
</tr>
<tr>
<td>DMI, lbs/d</td>
<td>13.17</td>
<td>13.32</td>
<td>0.14</td>
<td>0.45</td>
</tr>
<tr>
<td>Feed/Gain</td>
<td>5.67</td>
<td>5.69</td>
<td>0.12</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Times pulled did not differ

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Pens</th>
<th>Head</th>
<th>Pulled 1 Time</th>
<th>Pulled 2 Times</th>
<th>Pulled 3 Times</th>
<th>Pulled 4 times</th>
<th>Pulled 5 times</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>8</td>
<td>478</td>
<td>325</td>
<td>110</td>
<td>31</td>
<td>12</td>
<td>2</td>
</tr>
<tr>
<td>Starter</td>
<td>8</td>
<td>477</td>
<td>328</td>
<td>97</td>
<td>31</td>
<td>14</td>
<td>2</td>
</tr>
</tbody>
</table>
The starter pack did not impact morbidity, but reduced mortality.

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Starter Pack</th>
<th>SEM</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Morbidity, % of pen</td>
<td>68.08</td>
<td>68.78</td>
<td>2.56</td>
<td>.85</td>
</tr>
<tr>
<td>Pulled 1x</td>
<td>23.05</td>
<td>20.33</td>
<td>1.95</td>
<td>.36</td>
</tr>
<tr>
<td>Pulled 2x</td>
<td>6.47</td>
<td>6.49</td>
<td>.83</td>
<td>.99</td>
</tr>
<tr>
<td>Pulled 3x</td>
<td>2.51</td>
<td>2.93</td>
<td>.80</td>
<td>.72</td>
</tr>
<tr>
<td>Pulled 4x</td>
<td>6.35</td>
<td>6.26</td>
<td>.25</td>
<td>.80</td>
</tr>
<tr>
<td>Days Between Re-pulls</td>
<td>16.18</td>
<td>15.88</td>
<td>.78</td>
<td>.80</td>
</tr>
<tr>
<td>Medicine cost, $/hd</td>
<td>2.09</td>
<td>1.04</td>
<td>.31</td>
<td>.05</td>
</tr>
<tr>
<td>Deads, %</td>
<td>3.14</td>
<td>2.93</td>
<td>.61</td>
<td>.95</td>
</tr>
<tr>
<td>Total Out, %</td>
<td>3.14</td>
<td>2.93</td>
<td>.61</td>
<td>.95</td>
</tr>
<tr>
<td>(Realizers+Deads)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion

- Performance did not differ between treatments
- Morbidity did not differ between treatments
- Mortality was halved by the starter pack
Immune responses in lactating Holstein cows supplemented with Cu, Mn, and Zn as sulfates or chelates

Objective:
- compare performance, plasma and milk minerals, and measures of innate and adaptive immune function in early lactation cows fed Cu, Mn, and Zn supplied by either inorganic or chelated organic sources for 12 wk.

Materials and Methods:
- 26 Holstein cow (all parities) in early lactation
- Diets supplemented with sulfates or chelates to NRC
- Vaccinated for rabies on week 8

<table>
<thead>
<tr>
<th></th>
<th>ITM</th>
<th>Chelates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>73</td>
<td>94</td>
</tr>
<tr>
<td>Cu</td>
<td>21</td>
<td>23</td>
</tr>
<tr>
<td>Mn</td>
<td>42</td>
<td>46</td>
</tr>
</tbody>
</table>

Nemec et al., 2012
Cows fed Mintrex had a greater antibody titer to rabies than cows fed ITM

Nemec et al., 2012
Antagonists
Performance in the face of antagonists

Iowa Feedlot

- Retained Ownership/Custom Finish
- Purchased H₂O from Town
  - 6-8 cents/hd/d 16.1 ppm S
  - Morbidity 10% Mortality 2%
    (400-525# calves)
- Reduce Production Costs- Well H₂O
  - No other management changes
  - 1,700 ppm Sulfate
  - Morbidity 30% Mortality 5-7%
    (most attributed to respiratory disease)
  - ↑ Dark Cutting Carcasses

High Sulfur content in drinking water and feedstuffs causes antagonisms with Cu and other trace minerals

Cu deficiency leads to Immune Function disorders

Vázquez-Añón et al., 2007
Case study: Iowa Feedlot

• Design
  – 4 pens/trt - 80hd/pen
  – Identical handling, growth promotant, vaccination regimen, feeding phases

• Treatments:
  – Control: Standard mineral program (79 ppm Zn, 27 ppm Cu, 35 ppm Mn)
  – Chelate: Control+ Chelate (116 ppm Zn, 44 ppm Cu, 50 ppm Mn)

Vázquez-Añón et al., 2007
Sulfate Antagonism Was Alleviated with Organic Trace Minerals

Improved Health of the Herd by Reducing Mortality and Morbidity

Mortality, %
Control
Zn-, Cu-, Mn- (HMTBA)2

Cattle treated, %

Treatments
Mortality P=0.05; % First Treated P=0.06

Vázquez-Añón et al., 2007
Sulfate Antagonism Was Alleviated with Organic Trace Minerals

Reduced Dark Cutter Incidence

- Control
- Zn-, Cu-, Mn- (HMTBA)\textsubscript{2}

P = 0.02

Vázquez-Añón et al., 2007
Take home message

• Trace mineral absorption is reduced by antagonisms
• Chelated trace minerals can reduce the impact of antagonisms and are more bioavailable
• Greater bioavailability leads to improved functional benefits in immunity and reproduction
Summary

- Trace minerals are essential for wide ranging biological functions.
- Chelated minerals are more bioavailable than other ITM forms.
  - Tissue mineral experiments
  - Gene expression experiments
- This translates into a variety of benefits:
  - Immune benefits
  - Performance in the face of antagonists
  - Similar or increased performance at lower levels of supplementation
  - Oxidative balance benefits
  - Structural (bone, footpad, eggshell, intestinal breaking, etc) benefits
Thank you