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Refining nutrition in modern livestock

L. Pinotti

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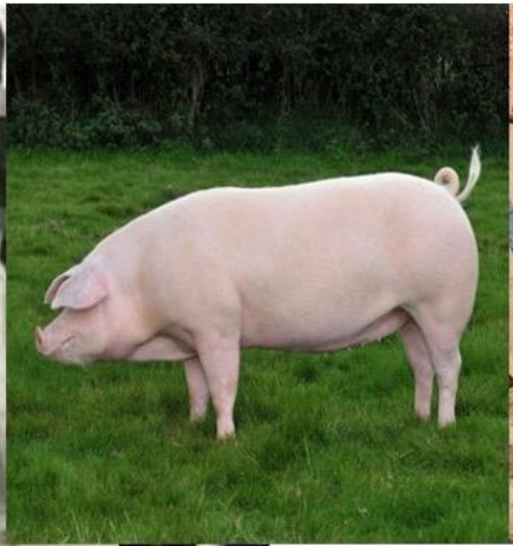

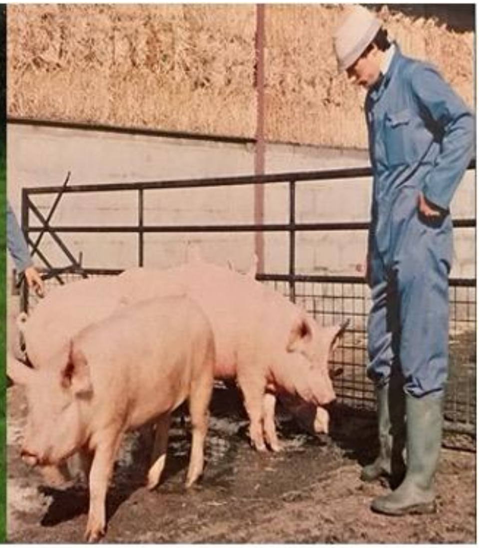

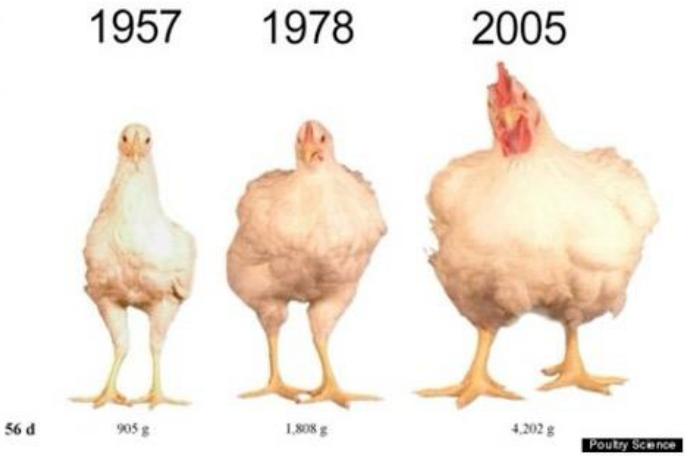

FPA: Past vs present

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Terrestrial products	FCR		Efficiency improvement
	20th Century	Today	
Poultry meat	4.5	1.9	57%
Turkey meat	6.0	2.5	58%
Eggs	4.3	2.1	51%
Milk	2.2	0.7	68%
Pork (100 kg)	4.3	2.7	37%
Beef (400 to 700 kg)	9.0	7.0	22%
Overall mean	5.05	2.81	49%
Aquaculture products			
Shrimp	2.0	1.6	20%
Salmon and trout	1.4	1.3	7.1%
Marine fish	2.0	1.7	15%
Chinese carp	2.0	1.7	15%
Tilapia	2.0	1.7	15%
Catfish	2.0	1.3	35%
Overall mean	1.9	1.55	18%
Insects			
Black soldier fly	-	1.4 to 2.6	-
Yellow mealworm	-	3.8 to 6.1	-
House cricket	-	1.3 to 10.0	-
Argentinean cockroach	-	1.5 to 2.7	-
Overall mean	-	3.68	-

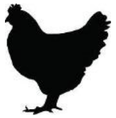
Pinotti et al 2026 in press

Contributions:

- Genetic +70%
- Nutrition+25% of the change.

Past vs present FPA: different diets

Ingredient	1957 Broiler diets[1]		2001 Broiler diets[2]			
	Starter 1 to 35 d	Grow-finisher 36 to 84 d	Starter 1 to 21 d	Grower 1 22 to 35 d	Grower 2 36 to 42 d	Finisher 43 to 84 d
	(%)					
Corn	61.00	66.50	57.60	67.95	73.25	74.30
Soybean meal (48%)	23.80	13.30	30.00	23.05	17.90	16.80
Poultry meal	0	0	5.00	5.00	5.00	5.00
Poultry fat	0	0	4.00	1.80	1.84	2.20
Meat and bone meal (50% CP)	2.50	3.00	0	0	0	0
Fish meal	2.50	2.50	0	0	0	0
Alfalfa meal (17% CP)	2.50	3.00	0	0	0	0
Wheat middlings	0	10.00	0	0	0	0
Whey	2.50	0	0	0	0	0
Distillers dried grains	2.50	0	0	0	0	0
Dicalcium-P (18.5% P)	1.65	0.55	1.25	0.25	0	0
Limestone	0.70	0.70	1.00	0.65	0.68	0.42
Salt	0.30	0.35	0.40	0.43	0.42	0.44
Mineral premix[3]	0.05	0.05	0.20	0.20	0.20	0.20
Choline Cl (60%)	0	0	0.10	0.10	0.05	0.05
DL-Met	0	0	0.11	0.15	0.17	0.18
L-Lys HCl	0	0	0	0.07	0.14	0.06
2001 vitamins[4]	0	0	0.05	0.05	0.05	0.05
1957 vitamins[4]	0.05	0.05	0	0	0	0
Se premix[5]	0	0	0.10	0.10	0.10	0.10
Hy-D[6]	0	0	0.05	0.05	0.05	0.05
Natuphos[7]	0	0	0.05	0.05	0.05	0.05
Coban 60	0	0	0.05	0.05	0.05	0.05
Baciferm	0	0	0.05	0.05	0.05	0.05
Total	100.05	100.00	100.01	100.00	100.00	100.00



Different ingredients

Higher supplemtation

11-12 items

16-17 items

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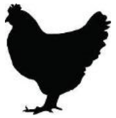
TABLE 3. Vitamin premixes and coccidiostats for the two sets of diets

Vitamin	1957 Diet	2001 Diet
	(per kg of diet)	
A, IU	8,818	6,600
Cholecalciferol, IU	3,300	2,000
E, IU	—	33
B_{12}, IU	11	19.8
Riboflavin, μg	4.17	6.6
Pantothenic acid, mg	11	—
D-Pantothentate, mg	—	11
Niacin, mg	35	55
Menadione, mg	—	2
Folic acid, mg	—	1.1
Thiamin, mg	—	2
Pyridoxine, mg	—	4
D-Biotin, μg	—	126
Se (Na_2SEO_3), mg	—	0.15
Ethoxyquin, mg	—	50
Nicarbazine, g	45	—



Reduction in selected vitamins

7 items

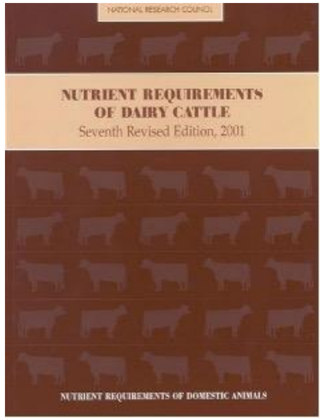
14 items

TABLE 2. Trace mineral premixes for the two sets of diets[1]

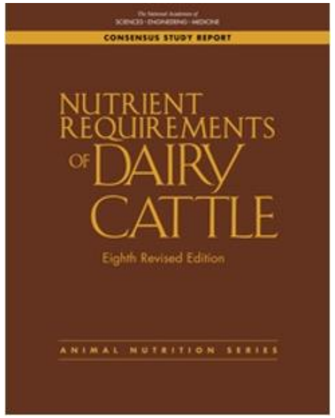
Mineral	1957 Diets	2001 Diets
	(mg/kg of diet)	
Zn	—	120 ($ZnSO_4$)
MN	32 (MnO)	120($MNSO_4$)
Fe	20 (FeCO3)	80 ($FeSO_4$)
Cu	2.5 [$Cu(OH)_2$]	10 ($CuSO_4$)
I	1.2 (KI)	2.5 ($CaIO_3$)
Co	0.2 ($CoCO_3$)	1 ($CoSO_4$)

[1]Sources are given in parentheses.

Different sources



VS



	Past system (NRC pre-2001)	**Modern system (NRC / NASEM 2021)**	**Change & reason**
Dry matter intake (kg/day)	15–18	22–28	↑ Higher production capacity and intake prediction accuracy
Net energy (NEL, Mcal/day)	28–32	35–45	↑ Higher milk yield
Crude protein (%)	15–16	16–18	↑ Milk protein synthesis
Metabolizable protein (g/day)	Not explicitly modeled	2.500–3.200	**Model-based precision replaces CP**
NDF (% DM)	≥35–40	27–33	↓ Improved rumen efficiency
Calcium (% DM)	0.6–0.7	0.6–0.8 (stage-specific)	Similar, but better timing
Phosphorus (% DM)	0.45–0.50	0.32–0.38	**↓ Reduced environmental losses**
Trace minerals, vitamins	Fixed tables	Bioavailability-adjusted	More precise, often lower amounts

$$\text{Dietary requirement (DR)} = \frac{Absorbed\ requirement\ (AR)}{Absorption\ coefficient\ (AC)}$$

Aspect	NRC (2001)	NASEM (2021)
Underlying concept	Absorbed requirement = physiologic mineral need; used to derive dietary requirement.	Same concept, but with more refined and updated biological equations.
How dietary requirement is calculated	Absorbed requirement ÷ AC	Absorbed requirement ÷ AC
Definition clarity	Implicit through factorial equations (maintenance, milk, etc.)	Explicitly stated: absorbed mineral requirement estimated first, then divided by AC.
Updates	Older AC values; less biologically accurate	Revised AC values; more accurate factorial calculations; improved understanding of absorption factors.

e.g. Ca… Absorption Coefficient (AC) change

This is one of the largest Ca differences between NRC (2001) and NASEM (2021)

Sources	NRC 2001	NASEM 2021	DIFF.%
•Ca carbonate	0,75	0,5	-33
•Limestone	0,7	0,45	-36
•Dicalcium phosphate	0,94	0,45	-52
•Ca chloride	0,95	0,6	-37
•Forages (alfalfa, corn silage)	0,3	0,4	+30

NRC (2001) Ca absorption and its AC values—especially for $CaCl_2$—were based on calf data.

NASEM (2021) corrected these using cow-relevant data

e.g. Magnesium (Mg) ≈2× higher

- **NRC (2001) Mg Absorbed Requirement**
  - Maintenance: **3 mg/kg BW**, equivalent to ~**2.0 g/day** for a 650kg cow

- **NASEM (2021) Mg Absorbed Requirement**
- New formula: **0.7 mg/kg BW + 0.3 g/kg DMI**
  - Dry cow (650kg, 10kg DMI): **4.1 g/day**
  - Lactating cow (650kg, 25kg DMI): **7.9 g/day** **(+5.9 g/day)**

Mg requirements are roughly **doubled** on average in NASEM (2021), primarily due to revised understanding of low Mg absorption and dietary antagonisms (e.g., high K in forages).

This is one of the largest mineral requirement increases from NRC → NASEM

Summary Table

Mineral	What Changed Most?	NRC (2001)	NASEM (2021)	Impact
Calcium (Ca)	Major AC revisions; new maintenance equation	Higher AC values; BW-based maintenance	Lower AC; DMI-based maintenance; updated milk Ca	Slight ↑ in dietary requirement; more accurate physiology
Magnesium (Mg)	Huge increase in absorbed requirement	Maintenance: 3 mg/kg BW	New formula multiplies requirement 2×–3×	Major ↑ in dietary Mg requirement
Phosphorus (P)	Minor updates only	Stable equations; ingredient AC	Slightly updated factorials; same AC	Minimal change in dietary requirement

Cobalt (Co): NASEM (2021)

- NASEM (2021) explicitly states that **trace minerals such as cobalt lack sufficient data** to support factorial absorbed-requirement modeling:
  - Absorption coefficients are poorly defined
  - True tissue requirements are unknown
  - Health and production responses occur above deficiency thresholds
  - Therefore, **cobalt uses Adequate Intake (AI), not Requirement**.

DEFINITION

"Adequate Intake (AI) is used when experimental data are insufficient to estimate requirements with confidence and is based on observed intakes associated with acceptable performance."

Cobalt (Co): NASEM (2021)

- **New AI Value**
  - **0.20 mg Co/kg DM**, approximately **double the NRC (2001) value**
  - This increase is one of the major changes from NRC to NASEM for trace minerals.
- **Modern cows:**
  - Higher milk yields → higher glucose demand → greater need for vitamin B_{12}
  - Greater ruminal propionate production in high-starch diets
  - Evidence of subclinical B_{12} deficiency at NRC (2001) cobalt levels

System	Expression	Recommended Value
NRC (2001)	Dietary concentration	**0.11 mg Co/kg DM**
NASEM (2021)	Adequate Intake (AI)	**0.20 mg Co/kg DM**

Mineral Comparison: NRC 2001 vs NASEM 2021

Mineral	NRC 2001	NASEM 2021	Change
Magnesium (Mg)	Older absorbed requirement (~3 mg/kg BW)	Absorbed requirement increased ~2x dry, ~1.8x lactating	Strong increase
Manganese (Mn)	Lower previous requirement	Requirements about doubled	Large increase
Zinc (Zn)	Older requirement	Increase 20–100%	Increase
Copper (Cu)	Uniform requirement	Dry cows ↑; lactating cows ↓	Dry ↑ / Lact ↓
Cobalt (Co)	Lower values	Requirement doubled	Increase
Phosphorus (P)	Stable absorbed requirement	Very small changes	Little change
Iodine (I)	Standard requirement	Minimal changes	Unchanged
Iron (Fe)	Established requirement	No change	Unchanged
Selenium (Se)	Established requirement	No change	Unchanged
Absorption Coefficients (AC)	Often ingredient-based; some values from calf studies	Many ACs revised downward (e.g., $CaCO_3$ from 0.75 → 0.50; $CaCl_2$ from 0.95 → 0.60)	Major revision

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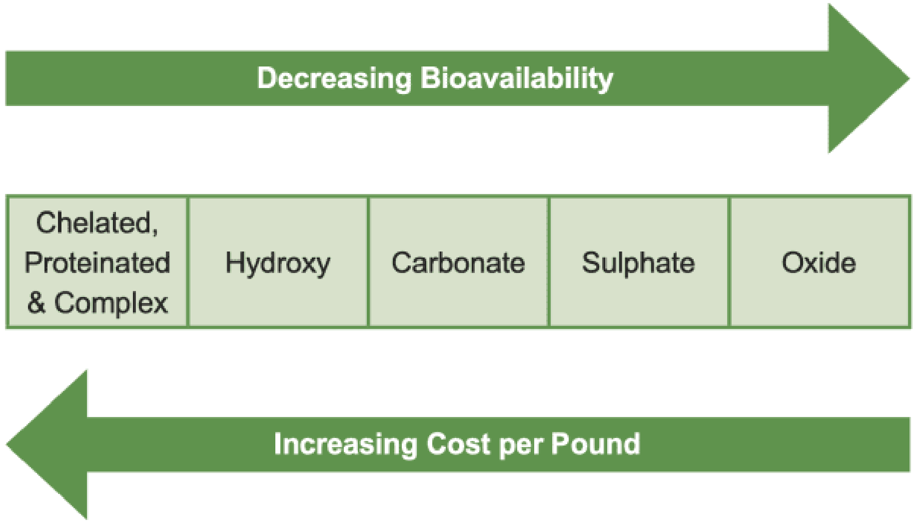
How to supply minerals

- **Inorganic form – oxides, sulfates, carbonated etc..**
- **Organic form - mineral bound to amino acids/ Hydroxy minerals**
- **Rumen-protected mineral**
- **New solutions**
- **Yeast**
- **Others**



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Inorganic form
oxides, sulfates, carbonated etc..

Popular/ common

- Provides essential macro- and micro-minerals
- Widely used in field conditions due to low cost and easy availability.
- Even oxides are still used, Sulfates forme are considered the best options

Contraindications / Limitations:

- Lower bioavailability of trace minerals (Cu, Zn, Mn, Fe)
- Mineral interactions (e.g. excess Fe reduces Cu and Zn absorption)
- Not suitable for high-producing dairy cattle with high mineral demand
- Over-supplementation may cause toxicity (esp. Cu, Se)

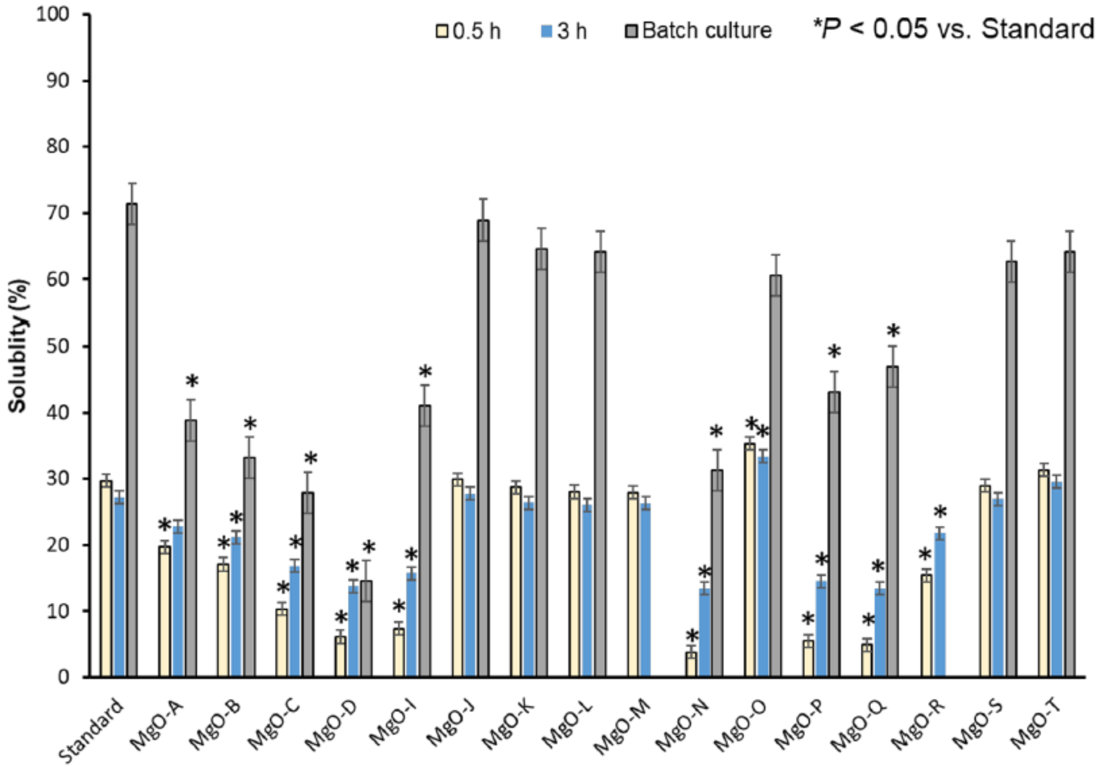
Inorganic form

Not All Magnesium Sources Are Equal

- Magnesium oxide = most common supplement

BUT:

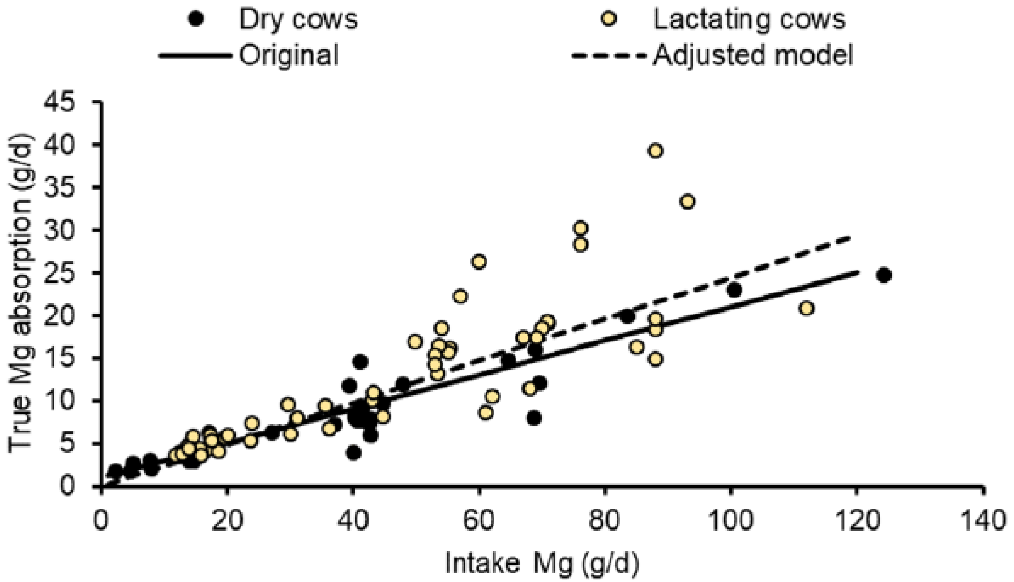
- High Mg content ≠ high availability
- Bioavailability depends on:
  - Solubility in the rumen
  - Chemical properties
- Solubility: **5–35%**
  - Large variability between Mg sources

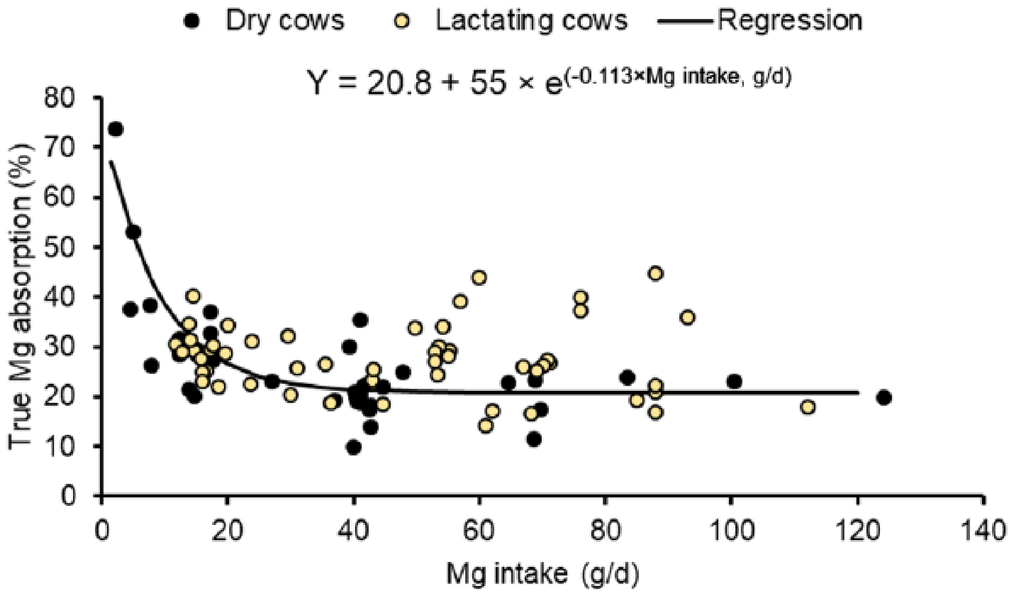


Inorganic form

Magnesium Intake vs Absorption

- Mg absorption increases with intake
- BUT efficiency is limited
- Average absorption:
  - **~20% of Mg intake**
  - Range: **10–40%**
- 👉 Not all ingested Mg is absorbed





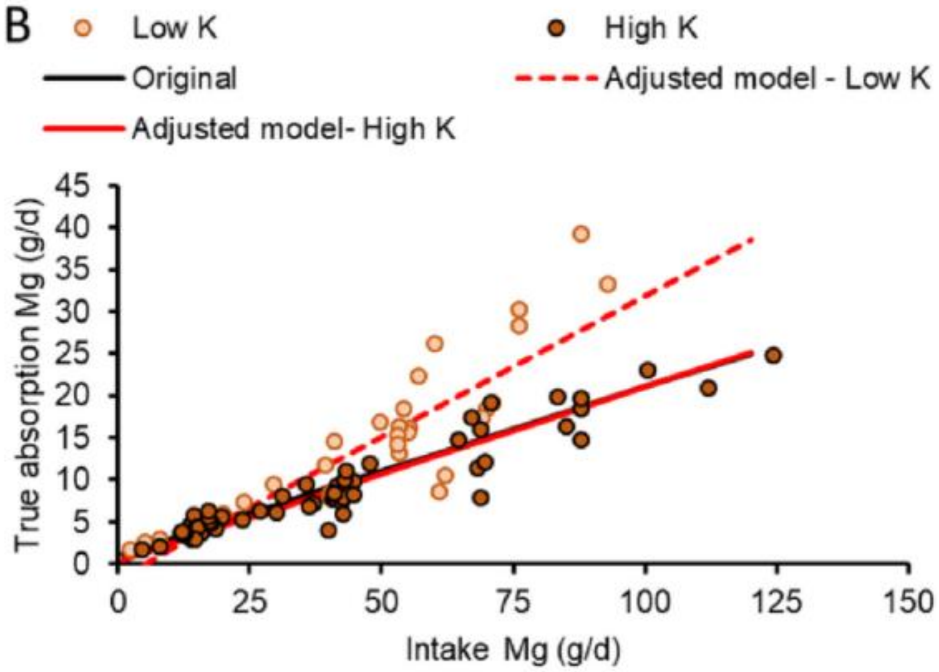
Inorganic form
Effect of Potassium on Mg Absorption

- Potassium (K) interferes with Mg absorption

Two scenarios:

- **Low K diet (≤20 g/kg DM)**
  - Higher efficiency (~34%)
- **High K diet (>20 g/kg DM)**
  - Lower efficiency (~21%)

👉 Same Mg intake ≠ absorption



High dietary K ↓ Mg absorption

Hydroxy trace minerals

Hydroxy trace minerals (HTM) – replacing sulfates

- Hydroxychloride forms of Zn, Cu, Mn are increasingly replacing sulfates. They are less soluble in the rumen, more stable in premixes, and less antagonistic
    - Better fiber digestibility and rumen health
    - Lower negative interactions with vitamins and enzymes
    - Reduced fecal mineral losses → sustainability benefit

Status

Mature, fast-growing category (mainstream in EU & North America)

Hydroxy trace minerals
Dairy cows: Different forms vs Hydroxy minerals

Types of supplemnation

- Dairy cows from 21d before expected calving through 84 d postcalving

- (1) inorganic sources based on sulfates of Zn, Cu, and Mn (ITM);
- (2) a blend (75:25) of sulfates and organic AA complexes of Zn, Cu, and Mn (ITM/OTM);
- (3) hydroxy trace minerals (HTM) of Zn, Cu, and Mn

J. Dairy Sci. 97:3728–3738
http://dx.doi.org/10.3168/jds.2013-7331

Effects of hydroxy trace minerals on oxidative metabolism, cytological endometritis, and performance of transition dairy cows

T. Yasui,* C. M. Ryan,* R. O. Gilbert,† K. R. Perryman,‡ and T. R. Overton*[1]

Results

- Overall effects of treatment on milk yield and composition were **not significant**.
- Differences between hydroxy sources and a blend of sulfates and organic complexes of Zn, Cu, and Mn were **not significant** for all outcome variables.
- Supplementation of hydroxy sources of Zn Cu, and Mn during the transition period and early lactation **modulated plasma markers** related to oxidative metabolism, resulting in **trends** for decreased TBARS concentration and decreased TAC compared with supplementation of these minerals as sulfates.

Hydroxy trace minerals

Beef Cattle: sulfate vs Hydroxy minerals

Livestock Science 245 (2021) 104425

Contents lists available at ScienceDirect

Livestock Science

journal homepage: www.elsevier.com/locate/livsci

ELSEVIER

Short communication

Effects of hydroxy trace mineral supplementation on gain and reproductive performance in beef heifers

S.A. Springman [a], M.E. Drewnoski [b], R.N. Funston [a,*]

Ingredient composition and nutrient profile of diets containing sulfate sources (SULF) or hydroxy sources (HD) of Cu and Zn of heifers during 68-d mineral trial.

Item	SULF	HD
Ingredient, kg/d (DM basis)		
Grass hay	5.5	5.5
Wet corn gluten feed	2.1	2.1
Mineral Supplement[a]	0.41	0.41
Nutrient profile (DM basis)		
CP,%	12.3	12.3
TDN,%	75.9	75.9
S,%	0.23	0.23
Cu, mg/kg	15.3	15.5
Fe, mg/kg	166.8	166.8
Mn, mg/kg	81.5	81.4
Mo, mg/kg	1.45	1.46
Zn, mg/kg	49.2	45.3

[a] Supplement contained 140 and 240 mg/kg of copper and zinc, respectively, supplying 7.2 and 12.3 mg/kg of copper and zinc to the total diet.

- Beef cattle were used.
- Animals were fed a mixed diet
- Mineral supplementation was top-dressed for 68 days.
- **low copper antagonist load**.
  - No high Sulfur Molybdenum
  - S and Mo can interact with Cu in the rumen (thiomolybdates) that reduce copper absorption.
  - The low antagonist levels in the diet increased copper bioavailability.

Hydroxy trace minerals

Beef: No differences for ADG and reproduction efficiency

- day 0: no differences in Cu and Zn
- Day 68: SULF heifers accumulated more liver Cu than HD
- The basal diet low antagonist load (S and Mo).
  - Thus, the SULF source had an absorption advantage.
- Both groups maintained an adequate mineral status.

Table 2

Liver concentrations of copper and zinc of yearling heifers assigned to receive either a sulfate (SULF) or hydroxy (HD) copper and zinc source[a] for 68 days[b].

	SULF	HD	SEM	*P*-Value
Initial	mg/kg			
Copper	183	153	20.0	0.30
Zinc	112	101	5.1	0.16
Final[c]				
Copper	208	121	6.1	<0.01
Zinc	156	130	15.0	0.40
Change[c]				
Copper	37.1	−47.0	6.0	<0.01
Zinc	44.2	29.0	15.0	0.48

[a] The supplemental mineral source added 7.2 and 12.3 mg/kg of copper and zinc to the diet resulting in total diet concentrations of 15.4 and 47.3 mg/kg of copper and zinc.

[b] There were 8 pens per treatment and three heifers were sampled per pen.

[c] Initial copper was used as a covariate ($P < 0.01$) for final copper. Initial zinc was tested as a covariate and was not significant ($P \geq 0.57$) and thus was not included in the model.

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Hydroxy minerals (HTM)

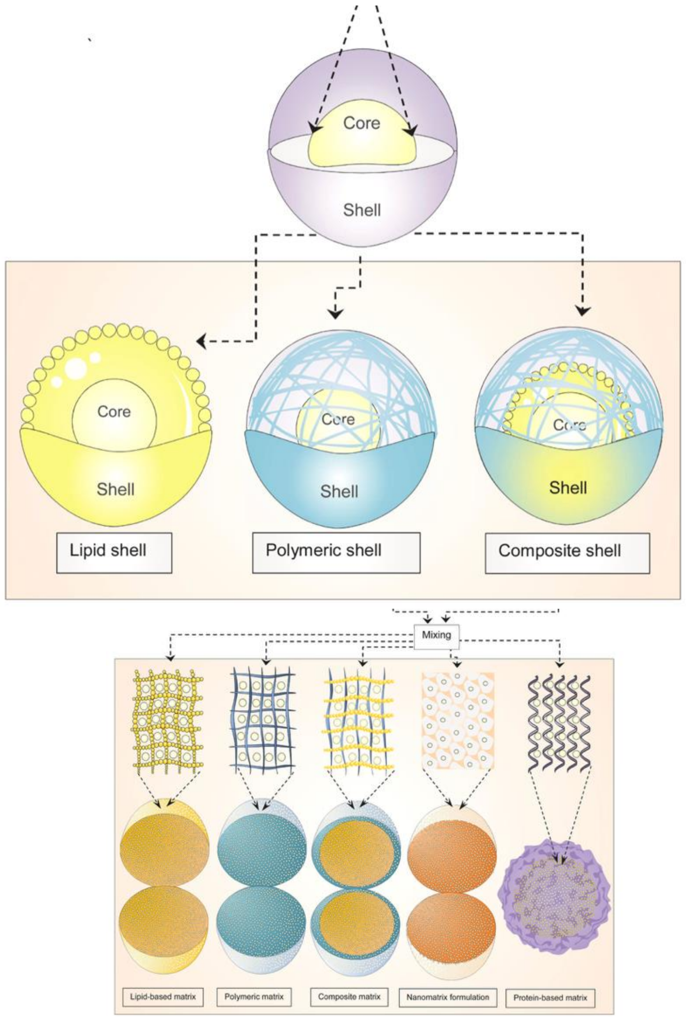
vs

- Covalent bonding within a crystalline matrix prevents premature mineral dissociation.
- Insolubility in water and neutral pH environments preserves structural integrity during storage and ingestion.
- Superior chemical stability prevents oxidation of vitamins and lipids within the feed matrix.
- Minimal rumen reactivity avoids interference with microbial fermentation and fiber digestion.
- High bioavailability is achieved through selective dissociation in the low-pH environment of the abomasum.

Sulfate minerals (SULF)

- Weak ionic bonds lead to rapid dissociation in aqueous and acidic environments.
- High solubility triggers immediate release of free metal ions in the upper digestive tract.
- Significant rumen reactivity potentially disrupts microbial microflora and fermentation efficiency.
- Free metal ions frequently form insoluble complexes with dietary antagonists, limiting intestinal uptake.
- Low feed stability promotes the degradation of sensitive nutrients through oxidative reactions.

Rumen-protected minerals
Emerging → selective adoption



- Minerals delivered postrumen using:
  - Fat-matrix protection
  - Encapsulation
  - Mineral–amino acid protected complexes
- Precision delivery during:
  - Transition period
  - Heat stress
  - High oxidative load
- **Cost-sensitive**

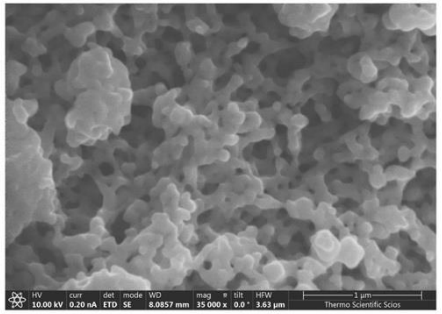
Examples

- Rumen-protected Zn–methionine
- Rumen-protected Se
- Combined RP amino acid + mineral systems

Nanominerals (R&D, not yet mainstream)

- Most studied:
  - Nano-selenium
  - Nano-zinc
- Potential advantages
  - Extremely high bioavailability
  - Strong effects on immunity and antioxidant status
  - Reduced excretion
- **Current limitations**
  - Regulatory uncertainty (EU)
  - Safety, residue, and consistency concerns

Se Form	Species/Model	Dose (mg/kg Diet)	Antioxidant Effects	Immune Effects	Reference
Various Se forms (review)	Poultry and mammals	Not specified	Selenium regulates cellular redox homeostasis through the activity of selenoproteins	Selenium participates in the regulation of both innate and adaptive immune responses	[60]
Various Se forms (review)	Poultry	Not specified	Selenium supplementation enhances antioxidant protection, particularly under stress conditions	Improved immune resilience during infection and environmental stress	[66]
Organic Se	Broilers	0–0.3	Dietary organic selenium increased glutathione peroxidase activity and reduced lipid peroxidation	Selenium supplementation stimulated lymphocyte proliferation in a dose-dependent manner	[67]
Organic Se (yeast enriched) vs. Na_2SeO_3	Broilers	0.3	Organic selenium improved antioxidant indices compared with inorganic selenium	Improved physiological condition and immune status	[68]
Nano-Se	Broilers	0.5	Selenium nanoparticles enhanced antioxidant enzyme activities and reduced oxidative stress	Increased antibody production following supplementation	[61]
Nano-Se (red)	Broilers	0.2–0.6	Selenium nanoparticles reduced malondialdehyde concentrations and increased glutathione and glutathione peroxidase levels	Not reported	[69]
Nano-Se vs. Na_2SeO_3	Broilers	0.15–1.2	Selenium nanoparticles resulted in higher glutathione concentrations than sodium selenite	Not reported	[64]
Nano-Se vs. Na_2SeO_3	Japanese quail	0.1–0.2	Selenium nanoparticles increased glutathione peroxidase activity and reduced lipid peroxidation	Selenium nanoparticles improved measured immune indices	[70]
Nano-Se	Broilers	~0.3	Selenium nanoparticles increased glutathione peroxidase and superoxide dismutase activities and reduced lipid peroxidation	Not reported	[31]
Nano-Se	Broilers	~0.9	Selenium nanoparticles improved the overall oxidative status	Enhanced immune responses and modulation of gut health	[71]
Green Nano-Se vs. Na_2SeO_3	Broilers	~0.3	Selenium nanoparticles reduced oxidative damage and increased antioxidant capacity	Improved immune competence	[72]
Nano-Se (review)	Poultry	Not specified	Selenium nanoparticles contribute to improved oxidative balance	Selenium nanoparticles enhance immune function in a form-dependent manner	[65]
Functionalized SeNPs	In vitro	Not specified	Modulation of oxidative stress was dependent on nanoparticle surface chemistry	Not reported	[73]



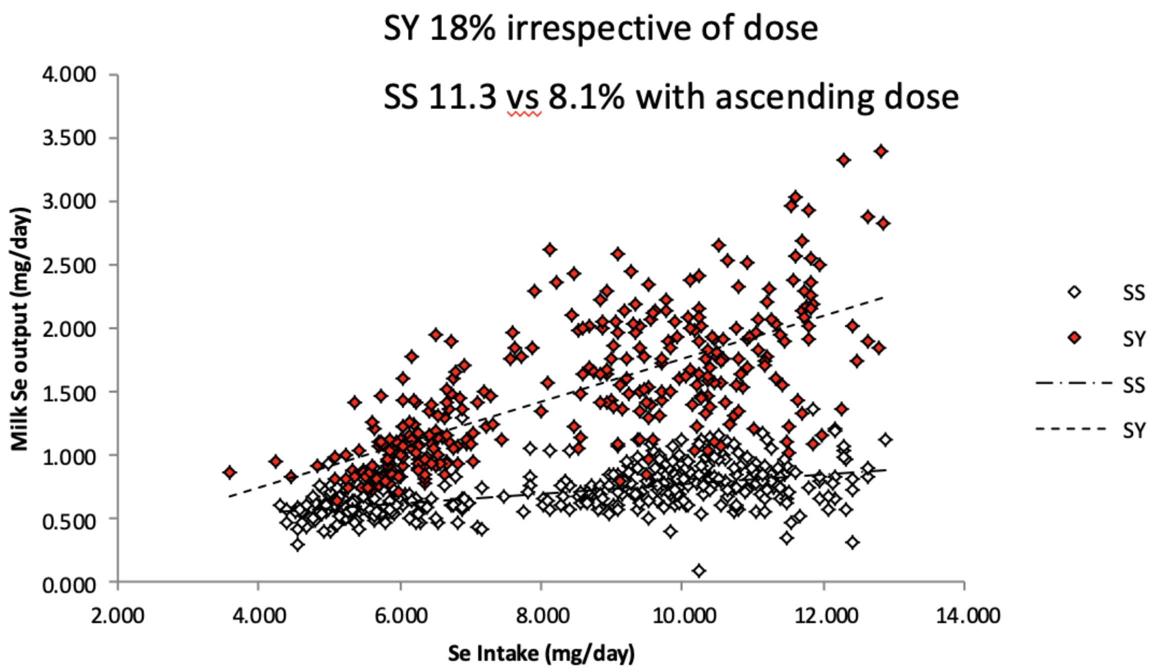
Status

Research and pilot scale, not commercial core nutrition

Yeast

Selenized enriched yeast

- Key Benefits of Selenium Yeast
- High Bioavailability:
- Organic Se (primarily selenomethionine), ensuring high absorption rates.
- Tissue/products Deposition
- Dual Effect: on Animals and on quality products



Cortesy DT Juniper, (Reading UK)

Other

Mineral enriched insects?

28 | FeedStrategy

In the early 2020s, several analysts projected the insect protein segment to boom through 2030. Strategic Market Research, a consultancy, estimated that the global insect protein market was worth US$268.7 million in 2022. The analysts expected the market to expand at an average of 31.5% per year, reaching US$4.1 billion by 2032.

The International Platform of Insects for Food and Feed (IPIFF) estimated that European insect protein output could grow from just a few thousand tons in 2020 to approximately 1 million tons of capacity by 2030, with the sector potentially creating up to 25,000 jobs across the value chain.

However, the reality has so far proven more modest.

Insect protein's reality check

High costs, failed ventures and slower-than-expected market growth temper early optimism.

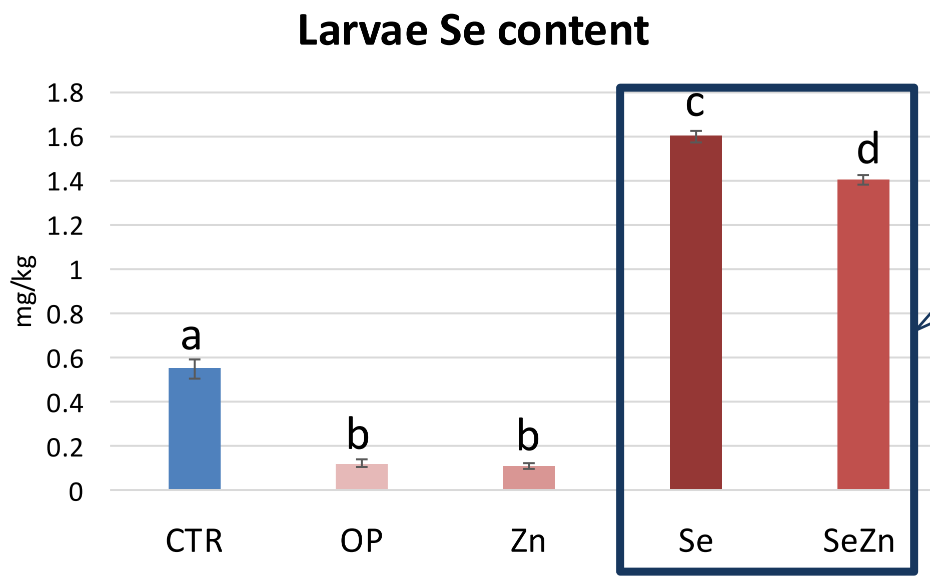
seaweed or selenium enriched substrates

L. Ferrari[1], V. Sele[2], M. Silva[2], P. Bonilauri[3], F. De Filippo[3], F. Selmin[4], R. Ørnsrud[2], L. Pinotti[1,5*] and M. Ottoboni[1]

Photo: Shutterstock

Other

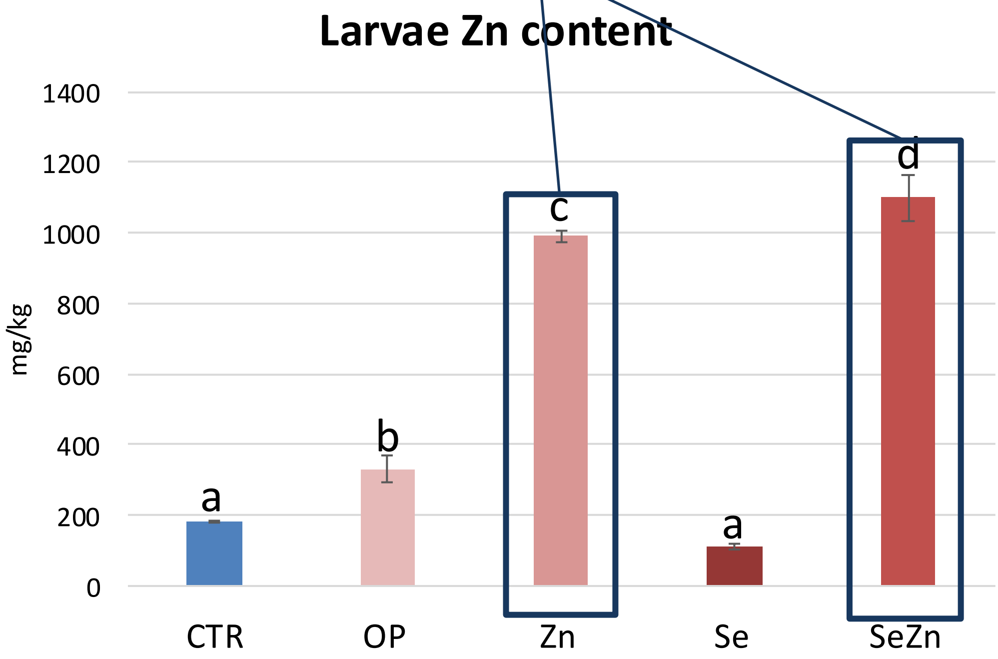
Mineral enriched insects?



Zn may share the Se transporter system, hindering the Se uptake

Zn ions in the presence of **selenite** tend to form poorly soluble Se compounds

Se compounds with Zn influenced also the Zn uptake rate, leading to a higher adsorption in SeZn group



Biofortification of zinc and selenium in black soldier fly larvae reared on fortified agro-food by-products: growth performance and micromineral composition

In: Journal of Insects as Food and Feed

Authors: A. Moradei, M. Ottoboni, C. Jucker, S. Malabusini, S. Savoldelli, A. Luciano, P. Premarajan, V. Sele, and L. Pinotti

Online Publication Date: 30 Mar 2026

Summary

Utilisation Level	Technology	Role today
1	Nanominerals	Future potential
2	Rumen-protected minerals	Precision tool
3	Chelates	Targeted performance
4	Hydroxy minerals	Modern standard
5	Sulfates / oxides	Legacy baseline

Conslusions

- **Specialty feeds:** As food animal production systems become more sophisticated, there is growing demand for **specialized feeds** tailored to specific species, production stages, and performance goals.
  - Micronutrients and feed additives play a key role in animal nutrition and feed performance.
  - Nutritional and technological quality of feed materials is essential.
- Safety and quality control: data must be available at feed mills due to the use of diverse ingredients, recipes, and formulations.
- **Regulatory compliance**: in an increasingly interconnected global market, animal feed regulations vary widely across regions, increasing complexity for trade and operations.

Acknowledgements

- Animal Nutrition Group in Milan

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EAAP European Federation of Animal Science