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Original Research

The effect of replacing inorganic trace minerals with organic Bioplex® and Sel-Plex® on the performance and meat quality of broilers

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Summary

The aim of this study was to compare the performance and carcass quality of broilers fed diets containing either a commercial inorganic mineral premix (control) or organic trace minerals (OTM) (Sel-Plex® (Se) and Bioplex® copper (Cu), zinc (Zn), manganese (Mn) and iron (Fe)) in a commercial environment. Four identical houses with a total of 119,500 mixed-sex broiler chickens were used (two treatments × two replicates). Birds were fed identical corn/soybean based rations differing only in mineral form and levels. The inorganic treatment (control) provided Cu, Zn, Fe, Mn and Se at levels of 8, 44, 55, 66 and 0.2 ppm, respectively. The OTM contained 5.5, 22, 5.5, 22 and 0.3 ppm of Cu, Zn, Fe, Mn and Se respectively. Growth and feed conversion during the 35-day trial were not influenced ($P > 0.05$) by treatments. Over the entire trial period and during the first week of production, birds showed significantly lower ($P < 0.05$) mortality with the OTM treatment. Between 14 and 31 days, sudden death syndrome was lower ($P < 0.05$) with the OTM diet. OTM improved feathering at 21 days of age ($P < 0.001$) and lowered carcass skin tearing ($P < 0.05$). There was no effect of OTM on carcass yield, breast meat pH, drip loss or on meat colour (L^* and b^* values). However, birds fed organic minerals had redder breast meat (a^*) ($P < 0.05$) on days three and five after slaughter. The results showed that, under commercial conditions, using lower levels of OTM (except Se) in feed relative to inorganic controls can maintain broiler performance.

Keywords: **broiler: performance: carcass quality: Bio-plex®: Sel-Plex®: minerals: inorganic**

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Introduction

Trace minerals (Cu, I, Fe, Mn, Se, and Zn) are normally administered in the inorganic form (ITM) which has been traditionally considered as the most cost-effective application (Nollet *et al.,* 2007). Organic forms of these trace minerals (OTM) are commercially available and have a higher bioavailability than ITM (Leeson 2003, Nollet *et al.,* 2007, Zhao *et al.,* 2010). OTM allow lower dietary inclusion and cause less environmental pollution (Petrovič *et al.,* 2010). Feeding OTM has been shown to result in a similar level of performance (Perić *et al.,* 2006; Petrovič *et al.,* 2010), reduce mortality due to sudden death syndrome (Roch *et al.,* 2000), increase skin strength (Rossi *et al.,* 2007), improve feathering (Perić *et al.,* 2006, Perić *et al.,* 2009), reduce skin lesions (Edens *et al.,* 2000) and improve carcass quality (Rossi *et al.,* 2007) and meat stability by reducing drip loss and improving meat colour (Cao *et al.,* 2001; Hess *et al.,* 2007). The increased resistance of the skin, together with greater protection afforded by improved feathering,

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Table 1. Level and source of trace minerals inclusion in the two diets

Mineral (mg/kg feed)	Treatment: Control	Treatment: OTM	OTM as % of control
Selenium	0.2 (0.44 mg Na_2SeO_3)	0.3 (165 mg Selplex® 2000)	150.0
Iron	55 (166 mg $FeSO_4.H_2O$)	5.5 (37 mg Bioplex® Iron)	10.0
Copper	8.8 (34 mg $CuSO_4.5H_2O$)	5.5 (55 mg Bioplex® Copper)	62.5
Manganese	66 (85 mg MnO)	22 (146 mg Bioplex® Manganese)	33.3
Zinc	44 (55 mg ZnO)	22 (146 mg Bioplex® Zinc)	50.0

leads to a reduction in tears and damage (Edens *et al.,* 2001; Peric *et al.,* 2009), reducing carcass downgrades (Rossi *et al.,* 2007). The reduction in drip loss leads to less meat weight loss and exudative liquid in packaging, which is beneficial to retailers and consumers. A redder meat colour suggests better oxidative stability and freshness (Cao *et al.,* 2001), which can improve shelf-life. All these aspects are economically relevant (Hess *et al.,* 2007), because they contribute to better carcass quality and meat conservation, and consequently, greater consumer appeal. The aim of this study was to evaluate the effect of replacing inorganic Cu, Mn, Fe, Zn and Se with lower levels (except for Se) of organic forms of these trace minerals on the performance, mortality, feathering and carcass traits in broiler chickens.

Materials and methods

A total of 119,500 day-old mixed-sex broiler (Cobb 500 or Ross 308) chicks were equally distributed between four identical poultry houses on a commercial site in Portugal. Birds were vaccinated against infectious bronchitis (1 d) and infectious bursal disease (20 and 26 d). Continuous light for 24 h was provided until 21 d and after that at 22 h light and 2 h darkness a day until slaughter. Two treatments were applied, a control feed which was supplemented with inorganic sources of Cu, Mn, Fe, Zn and Se, and an OTM feed supplemented with organic forms of the same minerals, using Bioplex® Cu, Mn, Fe, Zn and Sel-Plex® organic selenium (Alltech Inc., Lexington, KY, USA). Mineral levels used in the two treatments are shown in Table 1.

Each treatment was fed in two, randomly selected, but identical poultry houses. Both mineral supplements were added to identical commercial starter (0-14 d) and grower rations (14-31d) (Table 2). The diets were formulated based on corn-soya, and were pelleted, giving an isonitrogenous and isoenergetic diet (Table 2). Both feed and water were provided *ad libitum.*

Body weight, feed intake, feed conversion ratio (FCR) and European production efficiency factor (EPEF) were determined for the whole growing period of 31 days. Mortality (deaths and culls) was monitored over the total growing period (31 days), and during the individual periods of 0-7, 7-14 and 14-31 days of age. The causes of mortality were determined by *post-mortem* examination. In total 35.3% of the dead birds from the ITM group and 45.6% from OTM group were necropsied. Feather score was determined at 21 d (n = 400), counting the feather germs of one side of the breast, from the peak of the breast bone towards the neck, according to the method of Perić *et al.* (2006). At 31 d, the birds were slaughtered and average carcass yield was determined per treatment group (total carcass weight/total weight of slaughtered birds; n = 4). After slaughter, 2400 carcasses (600 per treatment) were selected and examined for skin tears (lack of continuity skin areas on the back of the broiler carcasses).

After refrigeration, breast muscles (*Pectoralis major*) (n = 80) were stored at 4°C and then individually packed, sealed in plastic bags and labelled. At 0, 1, 3, 5 and 7 days after slaughter, meat pH (pH meter Hanna

Table 2. Composition of the experimental diets

Feed	Starter (0–14 days)	Grower (14–31 days)
Feedstuff %		
Corn	60	68
Soybean meal	34.5	26.5
Blended fat	2.4	2.8
Limestone	1.4	1.2
Monocalcium phosphate	1.2	1.03
Salt	0.25	0.22
Vitamin-trace Mineral premix	0.25	0.25
Nutrients (%)		
Crude protein	21	18
Lysine	1.28	1.1
Methionine + cysteine	0.94	0.92
Tryptophan	0.25	0.21
Threonine	0.9	0.77
Calcium	0.96	0.88
Total phosphorous	0.78	0.71
Available phosphorous	0.48	0.44
ME (kcal/kg)	3080	3200

Table 3. The effect of treatments on body weight, feed intake, FCR and EPEF, 0–31 days post hatch (n = 4)[1]

	Treatment			
	Control	OTM	SEM	P
Initial body weight (g)	43.1	39.4	1.24	0.14
Final Body Weight (g)	1478	1435	17.9	0.31
Daily Weight Gain (g)	46.3	45.0	0.57	0.36
Feed Intake (g/day)	73.9	72.8	0.46	0.31
FCR	1.60	1.62	0.02	0.64
EPEF	281	276	3.54	0.63

[1] Each value represents the mean of two replicates (29,875 birds per replicate).

Table 4. The effect of treatments on mortality

	Treatment		
Mortality (%)[1]	Control	OTM	P[§]
0–7 d	0.76[a]	0.41[b]	<0.001
7–14 d	0.15	0.14	0.662
14–31 d	0.29	0.33	0.204
0–31 d	1.19[a]	0.88[b]	<0.001

Means not sharing a superscript differ significantly ($P < 0.05$)
[1]results expressed as frequency number of dead birds in total birds of each treatment.
[§]probability of chi-square test.

Table 5. The effect of treatments on causes of mortality (%)[1]

Period	Cause	Control (n = 134)	OTM (n = 105)	P[§]
0–7 d	Digestive problems	0	0	0.592
	Respiratory problems (Pneumonia)	3	1.9	0.198
	Nonspecific septicaemia	12.7	7.6	0.197
	Ascites	0	1	0.127
	Dermatitis (laceration)	1.5	0	0.127
	Omphalitis	65.7[a]	78.1[b]	0.034
	Anemia	1.5	3.8	0.256
	Trauma	2.2	5.7	0.167
	Dehydration	9.7[b]	1.0[a]	0.001
	Malformations	0	1	0.061*
	Sudden death	2.2	0	0.063*
	Other	1.5	0	0.127
7–14 d	Digestive problems	0	0	–
	Respiratory problems (Pneumonia)	1.9	7.1	0.213
	Nonspecific septicaemia	53.8	38.1	0.127
	Ascites	0	2.4	0.203
	Dermatitis (laceration)	0	2.4	0.203
	Omphalitis	5.8	11.9	0.290
	Anemia	0	0	–
	Trauma	1.9	2.4	0.879
	Dehydration	3.8	0	0.121
	Malformations	1.9	2.4	0.879
	Sudden death	25	26.2	0.896
	Other	5.8	7.1	0.787
14–31 d	Digestive problems	3.1	5.4	0.493
	Respiratory problems (Pneumonia)	3.1	1.1	0.361
	Nonspecific septicaemia	12.5[a]	25.8[b]	0.037
	Ascites	14.1	11.8	0.681
	Dermatitis (laceration)	0	0	–
	Omphalitis	1.6	3.2	0.503
	Anemia	0	0	–
	Trauma	3.1	5.4	0.493
	Dehydration	1.6	2.2	0.789
	Malformations	4.7	3.2	0.642
	Sudden death	56.3[b]	37.6[a]	0.021
	Other	0[a]	4.3[b]	0.039
0–31 d	Digestive problems	0.8	2.1	0.225
	Respiratory problems (Pneumonia)	2.8	2.5	0.836
	Nonspecific septicaemia	21.2	20.0	0.743
	Ascites	3.6	5.4	0.331
	Dermatitis (laceration)	0.8	0.4	0.583
	Omphalitis	36.8	37.5	0.873
	Anemia	0.8	1.7	0.379
	Trauma	2.4	5.0	0.123
	Dehydration	6.4*	1.3*	0.002*
	Malformations	1.6	2.1	0.123
	Sudden death	20.8	19.2	0.6513
	Other	2.0	2.9	0.512

Means not sharing a superscript differ significantly ($P < 0.05$)
*Indicates strong trend ($P < 0.1$)
[1]results expressed as frequency of causes of dead in total dead birds of each treatment and each period.
[§]probability of chi-square test.

Table 6. The effects of treatments on feathering, skin tearing and carcass yield

Parameter	Treatment		SEM	P
	Control	OTM		
Number of feather germs/ bird (n = 400)	22.2[a]	24.6[b]	0.3004	<0.001
Birds with skin tearing (%) (n = 2400)	5.08[b]	3.17[a]	–	0.0182
Carcass yield (%) (n = 4)[1]	67.8	67.1	0.63	0.6748

Means not sharing a superscript differ significantly (P < 0.05)
[1] Two replicates per treatment, being each replicate the mean of all birds of each poultry house (of about 30.000 birds).

Instruments, HI 9025, Rhode Island, USA) and colour, in the CIELAB colour space, whereby lightness - L*, redness - a* and yellowness - b* were measured (colorimeter Konica Minolta CR-10, Osaka, Japan). Sample from breast muscles were weighed at the time of slaughter, suspended in a plastic bag at 4°C and weighted at 1, 3, 5 and 7 days after slaughter, removing and blotting the excess of surface fluids. The drip loss percentage of breast muscles was determined by weight loss (Honikel, 1998, cited by Petracci and Baéza, 2009).

Growth performances (body weight, feed intake, FCR and EPEF), carcass yield, breast meat pH, drip loss and colour were analysed by analysis of variance using a completely randomised method in a monofactorial experiment. Means were separated using Tukey's test. Feathering, mortality rate, causes of mortality and skin tearing were analysed by chi-square with results expressed as frequency. Statistical significance was performed using JMP5.0.1 (SAS Institute, 2003).

The trial was carried out in accordance with the Portuguese law (Portaria no. 1005/92) on animal care in experimental research.

Results

Body weight, feed intake, FCR and EPEF were not affected (P > 0.05) by the treatments (Table 3). The OTM group had lower mortality than the control (P < 0.001) during the 0-7 d and 0-31 d periods (Table 4). During other monitored periods, dietary treatments had no significant effect on mortality.

The causes of mortality are shown in Table 5. There were significant differences among treatments during 0-7 d. Occurrence of omphalitis was higher (P < 0.05) and frequency of dehydration was lower (P < 0.01) in OTM birds. From the 14-31 d period, OTM birds showed higher frequency of non-specific septicaemia (P < 0.05) and lower frequency of sudden death syndrome (SDS) (P < 0.05). For the whole growing period, there were fewer cases of dehydration in OTM birds (P < 0.05).

The effects of treatments on feathering, skin tearing and carcass yield are shown in Table 6. Birds fed OTM diets had significantly higher feather germ numbers (P < 0.001) and less skin tearing (P < 0.05). Carcass yield was not affected by treatments.

The effects of the two diets on breast meat pH and drip loss are summarised in Table 7. No significant effects (P > 0.05) were found for pH, except on the day of slaughter (P < 0.05), when pH of the OTM group (6.08) was lower than that of the ITM group (6.18). Breast meat drip loss was not different (P > 0.05) among treatments. The final drip loss (seven days after slaughter) was 4.38, and 4.54% for ITM and OTM treatments, respectively.

Table 7. The effect of treatments on breast meat pH and drip loss (n = 80).

Parameter	Days after slaughter	Treatment		SEM	P
		Control	OTM		
pH	0	6.18[b]	6.08[a]	0.023	0.0292
	1	6.10	6.12	0.025	0.6962
	3	6.13	6.12	0.026	0.9211
	5	6.11	6.15	0.023	0.3555
	7	6.06	6.11	0.024	0.3078
Drip loss (%)	1	1.16	1.30	0.056	0.2187
	3	2.14	2.31	0.119	0.4639
	5	3.39	3.58	0.169	0.5806
	7	4.38	4.54	0.190	0.6710

Means not sharing a superscript differ significantly (P < 0.05)

Table 8. The effect of treatments on breast meat colour (L*, a* and b*) (n = 80)

		Treatment			
Colour	Days after slaughter	Control	OTM	SEM	P
*L**	0	49.64	49.49	0.4246	0.8611
	3	52.59	51.35	0.3891	0.1101
	5	51.90	51.50	0.4007	0.6164
	7	50.94	51.33	0.3865	0.6170
*a**	0	0.54	0.71	0.1261	0.5039
	3	0.79[a]	1.29[b]	0.1230	0.0414
	5	0.81[a]	1.50[b]	0.1191	0.0029
	7	1.24	1.51	0.1403	0.3482
*b**	0	7.29	7.72	0.2771	0.4387
	3	9.63	9.97	0.2422	0.4862
	5	9.29	9.99	0.2529	0.1678
	7	8.85	9.61	0.2366	0.1063

Means not sharing a superscript differ significantly (P < 0.05)

As it can be seen from Table 8, *L** and *b** values of breast meat colour were similar between treatments. However, OTM broilers had higher *a** values than the control birds on days three ($P < 0.05$) and five ($P < 0.01$) after slaughter, and remained numerically higher throughout the seven day storage ($P > 0.05$).

Discussion

The growth performances of broilers met the expected commercial standards for both commercial hybrids (Cobb 500 and Ross 308) under intensive production system. The replacement of ITM by lower levels of OTM had no effect on performance, as previously observed by Perić *et al.* (2006) and Petrovič *et al.* (2010). This indicated that lower doses of Fe, Cu, Mn and Zn can be used without any loss in the performance of broilers, and with the possible advantage of reducing mineral excretion (although this was not measured in the current trial) and consequent pollution in the environment (Leeson and Caston, 2008).

Feeding OTM reduced the mortality during the growing period. This reduction could have been due to an improvement in immunocompetence, indicated by other researchers (Sunder *et al.*, 2008; Abdallah *et al.*, 2009; Mohanna and Nys, 2010). The most relevant effects were seen in the causes of mortality during the 14-31 d period. Mortality due to SDS was almost one third lower in the OTM fed birds in this period, which may have been due to a higher availability of selenium in this treatment, which is associated with improved membrane protection via antioxidant activity (Roch *et al.,* 2000). As SDS was the most frequent cause of mortality during the period when the birds were heaviest, this would represent the greatest economic impact commercially.

Improved feathering indicated that OTM were used more efficiently by the birds, particularly Se (Edens *et al.,* 2000), Zn and Cu (Scheideler, 2008). Similar results have been reported by Cao *et al.* (2001) and Perić *et al.* (2009). The reduction in skin tearing for the OTM group may be related to improved feathering (Edens *et al.,* 2000) and to a higher availability of organic Zn (Rossi *et al.,* 2007) and Cu (Zhao *et al.,* 2010) which influences skin quality. With this improvement in skin integrity, economic losses due to downgrades at slaughter could be reduced (Rossi *et al.,* 2007). There was no effect of trace mineral replacement on carcass yield, in agreement with the findings of Rossi *et al.* (2007) and Petrovič *et al.* (2010).

The difference in breast meat pH between treatments on the day of slaughter was assumed to be due to analytical variation, since in other periods no effects were observed. Peric *et al.* (2009) previously compared different dietary selenium sources (organic Se and selenite) as the sole source or in combination, and were in agreement with these current findings, i.e. treatments caused no significant differences in breast meat pH. The meat samples had normal pH values (Swatland, 2008; Garcia *et al.,* 2010; Milan and Klaus, 2010) and, as expected, this parameter slowly decreased during the storage period (Bressan *et al.,* 2004). The reduction of poultry meat pH values have been associated with an increased pro-oxidant effect (Allen *et al.,* 1998), leading to greater susceptibility of myosin denaturation, and consequentially increase drip loss (Allen *et al.,* 1998), paleness of meat (Fletcher, 1999; Swatland, 2008) and pale soft exudative (PSE) meat (Laack *et al.,* 2000; Garcia *et al.,* 2010). Drip loss results were considered normal and comparable to published values (Deniz *et al.,* 2005, Hess *et al.,* 2007, Upton *et al.,* 2003). OTM had no benefit on breast meat drip loss with, in contrast to previous reports, where a decreased drip loss was obtained with organic Se (Upton *et al.,* 2003, Deniz *et al.,* 2005, Peric *et al.*, 2009). Upton *et al.* (2008) reported that inorganic selenite may even increase drip loss, due to its pro-oxidant effects on cell membranes. As the values were similar among treatments, breast meat drip loss results from this trial were in consistent with pH results, confirming the good quality of all meat samples.

There is a paucity of studies where chicken meat colour has been evaluated during storage, especially where the use of the two sources of trace minerals (inorganic and organic) were compared. The current results showed that *L** values for breast meat were not affected by mineral source. Cao *et al.* (2001) similarly didn't see any benefit on meat lightness with the use of organic Se, in spite of the suggested pro-oxidant effect of selenite. The higher bioavailability of organic selenium (Edens *et al.,* 2000) was the most probable reason for the improvement in breast meat colour seen in the OTM group. In one of the available studies comparing meat colour of birds fed with different sources of Se, Cao *et al.* (2001) reported that, although this was not significant, meat colour in birds fed organic Se was redder than those given an inorganic source. In the trial reported by these authors, all Se treatments had higher meat *a** values than those fed the unsupplemented control, and meat colour tended to increase with Se level, suggesting less oxidation and a higher stability of meat fat and myoglobin. The current data suggests that the utilisation of organic minerals may avoid economic losses due to meat discoloration, increasing chicken meat shelf-life.

Breast meat yellowness (*b**) was not affected by the different diets, although, Cao *et al.* (2001) reported significantly lower meat yellowness of birds fed organic Se, than those fed inorganic Se ($P < 0.05$). In the same trial, meat *b** value tended to decrease with the increasing of Se level. This information suggested that organic selenium can improve antioxidant capacity and hence maintains meat colour (Cao *et al.,* 2001). Data from the current trial did not support this, as yellowness (*b**) values recorded were considered normal (Laack *et al.,* 2000; Garcia *et al.,* 2010) for both groups. The trend in this parameter with storage was as expected, as it increased during the storage, as previously observed in the studies of Petracci and Fletcher (2002) and Qiao *et al.* (2001).

Conclusions

The replacement of ITM with lower levels (except Se) of OTM did not cause any loss in productive performance, suggesting improved mineral bioavailability from OTM. The use of OTM resulted in less mortality, especially for deaths caused by SDS during 14-31 days of age. Feeding OTM resulted in an improvement in feathering, which may explain the decrease in skin tearing. Benefits in meat colour were recorded, with increased red colour in meat at days three and five of storage after slaughter. This indicates less breast meat oxidation (of fat and myoglobin) during the storage period with the use of OTM, particularly with the inclusion of organic selenium. For commercial and retailing purposes, better meat quality and oxidative stability during storage may increase poultry meat shelf-life.

The results showed that, under commercial conditions, using lower levels of OTM (except Se) in feed relative to inorganic controls can maintain broiler productive performance, whilst achieving improvements in carcass quality.

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Declarations of interests

All authors declare that the trial was financially supported by Alltech Inc, USA, however there were no financial relationships with any organisations that might have an interest in the submitted work and no other relationships or activities that could appear to have influenced the submitted work.

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