Effects of different mineral supplementation programs on beef cattle serum Se, Zn, Cu, Mn concentration, health, growth performance and meat quality

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SUMMARY

The effects of different mineral sources (organic vs inorganic) on beef cattle serum Se, Zn, Cu, Mn concentration, health, growth performance and meat quality (hot carcass weight, dressing percentage, conformation score, fattening score and pH) were assessed in 156 intact Charolaise males. The aim of the study was to investigate a possible ameliorative action of the organic sources of those minerals compared to the inorganic ones, essential for animal welfare and productivity.

The animals were allotted to three treatment groups, receiving different sources (organic or inorganic) of minerals at different levels. H-In group received a mineral supplementation from an inorganic source according to the average mineral inclusion recommended by the European beef system. The TRT group received an organic source of minerals at the doses recommended by the producer (TRT, Total Replacement Technology, Alltech). The In group received minerals from an inorganic source, but following the same doses employed in the TRT group.

Growth performance and health status were monitored throughout the fattening period (186 days). Blood samples were evaluated in relation to mineral serum concentrations, antioxidant status and immunity reactions. After slaughtering, carcass characteristics and meat quality of Longissimus dorsi samples were evaluated.

Growth performance and health status were improved in the TRT group ($P<0.05$). The incidence of Bovine Respiratory Disease was also lower in this group. The animals in the TRT group had a better immune response ($P<0.05$) due to the higher circulating mineral concentrations which positively affected the immune function. In addition, carcass characteristics were positively affected in the TRT group because of the enhanced myogenesis ($P<0.05$). Meat quality was improved in the TRT group due to the higher level of antioxidants in the meat ($P<0.05$).

The results suggest that organic sources have a strong impact on animals' metabolism and immune function, which led to an improvement in growth performance, health and antioxidant status together with carcass and meat quality.

KEY WORDS

Cattle, minerals, performance, health, meat quality.

INTRODUCTION

Intensive beef cattle production is mainly based on fattening weaned young cattle, which have been moved from the farms of origin. In Europe, these farms are often located in other countries, which are specialized in extensive suckler cow breeding. In Italy young cattle are mainly imported from France. This procedure causes several stressors other than weaning, such as long-distance transport, group mixing, feed and water restrictions. Young cattle also have to adapt to a new environment and feeding conditions in the fattening units[1]. All these factors promote immunosuppression which can lead to pathogen colonization and proliferation, and cause various diseases. Bovine respiratory disease (BRD) is currently the most common one. In stressful situations, several nutritive substances such as minerals become essential and supplementation is recommended[1].

Mineral supplementation can help cattle recover quickly from transport fever and reactivate ruminal activity, thereby limiting oxidative stress and promoting the reactivity of their immune system[2]. Supplementation of the main micro-minerals is also required in the fattening period in order to satisfy the animals' requirements and optimize ruminal and metabolic functions; consequently, rumen efficiency and growth performance improve.

Several events can lead to pro-inflammatory conditions in fattening cattle, particularly when the diet is characterized by energy levels that enhance the risk of sub-clinical acidosis and connected pathologies[3,4]. Mineral supplementation can limit these problems and help the cattle recover quickly, reducing the negative effect of stress on animal performance and growth. Trace minerals such as zinc (Zn), copper (Cu), manganese (Mn) and cobalt (Co), as well as selenium (Se), play an important role in stress, health and growth responses in cattle[5]. Normally, they are required in very small

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amounts. However, under stressful situations and in farms with high production standards, they are needed in increasing amounts. Consequently, supplementing the diets with these minerals is necessary to avoid deficiencies.
The type of mineral sources used also has different biological effects. Minerals can in fact be provided as inorganic mineral salts or in organic forms such as chelates or enriched yeast. Due to the higher bioavailability of minerals, supplementing organic complexed minerals, such as Zn, Se, Cu, Mn, Co, may be of further benefit based on their enhanced absorption, retention and biological activity compared to inorganic sources[6].
The hypothesis was that the use of organic mineral will lead to an improvement in growth performance and health status of highly stressed cattle in contrast to inorganic supplementation at different levels, due to the higher bioavailability of organic minerals and their immune and antioxidant abilities, since little is known about the effects of organic vs inorganic sources of several basic minerals such as selenium, zinc, copper and manganese. The aim of the trial was to evaluate the effects of different dietary mineral sources (organic or inorganic) and doses on absorption, health, growth performance and meat quality.

MATERIAL AND METHODS

Animals and Farm

The study was carried out in an intensive beef fattening unit in northern Italy and involved 156 intact Charolaise males. The animals were monitored from their arrival from France throughout the entire fattening period of 186 days. Upon arrival, animals were submitted to a typical prophylaxis protocol: vaccination against respiratory diseases, antibiotic treatment if necessary, and treatment against endo- and ecto-parasites.

Animal assignment to treatment groups

Three trucks of animals arrived simultaneously. The animals from each truck were randomly allotted to the three different treatment groups in order to avoid the bias due to the batch effect. Each truck was considered as a block, the random assignment to one of the three treatment groups was performed according to the order of that the animals went into the weighing chute.

Housing and feeding

The cattle were group-fed and housed in pens of 5-6 animals each on a slatted floor. The animals from the three experimental groups were submitted to the same nutritional management and diet. During the entire fattening period two diets were administered, based on the same feedstuffs: silomais, corn meal, brewers, wheat straw, wheat bran, sunflower meal, rice bran, coconut cake, DDGS (distillers dried grains solubles) and rape cake. The first diet was formulated for the adaptation phase (0,68 Mcal/kg; 13,20 CP %DM; 34,73 Starch %DM; 4,40 EE %DM) and the second for the fattening phase (0,89 Mcal/kg; 14,66CP %DM; 46,68 Starch %DM; 4,69 EE %DM). The diets differed only for the mineral premixes employed as reported in Table 1.
Animals in the H-In group received a mineral supplementation from an inorganic source according to the average mineral inclusion recommended by the European beef system. Animals in the TRT group received an organic source of minerals at the doses recommended by the producer (TRT, Total Replacement Technology, Alltech). Animals in the inorganic (In) group received minerals from an inorganic source at the same doses employed in the TRT group the same minerals as the inorganic source but following the same amount as the TRT group.

Table 1 - Mineral and vitamin supplementation.

Nutrient	H-In	TRT	In
Mn, mg/d	550	180	180
Cu, mg/d	250	140	140
Zn, mg/d	1000	280	280
Se, mg/d	4	3	3

TRT and IN Almost in line with NCR requirements and according to manufacturing recommendations.
H-In comes from an average of several mineral mixes used in Europe and with levels of trace minerals similar to that recommended by NRC for stressed animals.

PARAMETERS

Nutritional value of the diets

Samples of the experimental diets (100 g/each) were collected every two weeks, pooled and analysed in relation to dry matter, crude protein, ether extract, starch and ash, according to the AOAC (1990) methods[6]. Neutral detergent fibre was determined according to Van Soest et al. (1991)[8].
The net energy content of the diets, was calculated using the reference values for all feed ingredients reported by NRC (2016)[2].

Minerals titration in TMR

Feed macro- and trace mineral concentrations (Zn, Se, Mn, Cu) were determined by standard wet chemistry techniques using the titration procedure.
The titration analysis consists in an inductively coupled plasma emission spectroscopy. The selenium concentration was determined using fluoro-metric methods, according to AOAC (1990)[6].

Growth performance and health

On day 0 (arrival), and at days 21, 54 and 186, before the morning feeding, the cattle were individually weighed and the average daily gain (ADG) was calculated. Once a week the average daily feed intake (ADFI) was calculated: before further feed administration, the feed intake was recorded by weighing the TMR offered and the residue in the manger 24h later. The pen feed conversion ratio (FRC) was calculated.
Animals were inspected twice a day by the farm veterinary staff for sickness, including BRD symptoms. Animals were considered affected by BRD if the rectal temperature was ≥40.0°C and if both the depression and respiratory character scores differed from the normal health status - score 0 of Baggot et al., 2011[9]. The animals diagnosed as affected by BRD were treated appropriately and registered. The mortality was also recorded.

Blood parameters

Blood samples were collected before the morning feeding from 14 animals on days 0, 21 and 105 to evaluate the immune status. Blood samples were collected by jugular venipuncture. Immunity reaction was evaluated by a BHV-1 (Bovine Herpesvirus-1) serum neutralization test, performed according to OIE (2012)[10]. The neutralizing antibody titre was measured against the homologous vaccine virus. Antibodies were titrated by the constant virus-varying serum dilution from ½ onward. The data of the neutralizing antibody titres were transformed as log(1/x), where x was the serum dilution. Serum bactericidal activity was performed according to Amadori et al. (1997)[11].

Blood samples were also collected on days 0, 21, 105 and 186 to evaluate mineral (Se, Zn, Cu and Mn) serum concentrations and antioxidant status. Blood samples were collected by jugular venipuncture into 10 ml EDTA tubes and 10 ml glass tubes and immediately cooled in ice. Two tubes were collected for each animal, one was used for serum extraction and one for the evaluation of the antioxidant condition. Serum samples were obtained by centrifugation at 3000 rpm for 10 min at 4°C and stored at -20°C. Mineral concentrations were determined in serum samples using an inductively coupled plasma source. The antioxidant condition was evaluated using glutathione peroxidase (GPx activity) titration. GPx activity was measured indirectly by a coupled reaction with glutathione reductase (GR), using the glutathione peroxidase assay kit[12].

Carcass characteristics and meat quality

The main carcass characteristics (hot carcass weight, dressing percentage, conformation score, fattening score and pH) were also evaluated at the slaughterhouse.

Hot carcass weight (HCW) was obtained after the removal of the head, hide, intestinal tract and intestinal organs.

Dressing percentage is the percentage of the animals that ends up as a carcass, and was computed from the following formula:

$$Dress\ \% = (HCW \div live\ weight) \times 100\%$$

The carcasses were classified according to the official carcass classification scheme, which includes carcass conformation and fattening score. The carcass conformation score was evaluated using the SEUROP classification. The fattening score was evaluated using a 1 to 5 scale (1 - very low, 5 - very high), according to the EU Beef Carcass Classification Scheme.

The pH was measured 24h post-mortem.

In addition, meat quality was evaluated in 10 *longissimus dorsi* samples per experimental group. 2,5 cm thick steaks were cut from the ribeye (between the 12th thoracic and 5th lumbar vertebra) to evaluate centesimal composition, meat mineral continent, drip loss, instrumental colour, thawing loss, cooking loss, tenderness and shelf life.

The samples were examined for the centesimal composition: moisture, ash, lipid and protein composition were determined, according to official methods[6].

Before analysing the meat mineral content, the muscle samples were digested using an ETHOS 900 microwave digestion system. The sample digestion procedure was performed according to the NF EN 13805 standard "Foodstuffs - Determination of trace elements -Pressure digestion"[13]. The concentration of minerals (Se, Zn, Cu, Mn) was then determined by flame atomic absorption spectrometry, using a spectrometer.

Drip loss analysis was carried out following Honikel (1998)[14]. After the meat samples were cut from the carcass, they were immediately weighed and placed in the netting and then suspended in an inflated watertight nylon bag. The meat samples were stored at chill temperatures (4°C). In the following seven days, the samples were taken out of the bags, dried by a paper towel and then weighed again. The drip loss was expressed as a percentage of the initial weight.

Every day the instrumental colour parameter, such as L (lightness), a (redness), b (yellowness) were measured for seven days, using a tristimulus colorimeter. Before each measurement, the colorimeter was standardized.

Meat cooking loss was estimated by the Shilling method[15]. The samples were weighed and cooked, achieving a temperature of 75°C inside. The samples were then weighed again. Cooking loss was expressed as a percentage of the initial weight. Thawing loss was also assessed, evaluating the difference in weight before and after thawing. The thawing loss was expressed as a percentage of the initial weight. The tenderness of the samples was also examined, using the Warner-Bratzler Shear Force procedure, which measures the force required to cut a piece of meat, according to the AMSA guidelines (1995)[16].

The shelf life of the different samples was also evaluated.

Statistical analysis

Data were analyzed with the GLM (General Linear Model) procedure of SAS. Student "t" and Tukey tests were used to compare the means of each group. The level of significance to indicate differences stated in the ANOVA model were $P<0.05$; levels of $P\leq0.1$ were considered a tendency. The d_0 values were used as a covariate in the statistical analysis. Weight at d_0 was set as a covariate for growth performance and hot carcass weight; meat samples weight at d_0 was set as a covariate for meat weight and drip loss.

RESULTS AND DISCUSSIONS

Mineral titration in TMR

Mineral titration in the different experimental TMR diets, in all the different experimental diets, are reported in Table 2. All the mineral concentrations were higher in the H-IN group, both in the adaptation and the fattening diets. In fact, the mineral quantities supplemented were higher in the H-In group.

Growth performance and health condition

The cattle growth performances are reported in Table 3. Average live weight was higher for the TRT group compared to the inorganic (In) group starting from d_{21} until the end of the fattening cycle. TRT fed cattle showed a higher live weight compared to H-In at d_{105} and d_{186}. At d_{186} a statistical difference was also found between H-In and In live weights.

During the critical moment of the adaptation phase, the administration of minerals from an organic source led to a better ADG compared to animals fed with the same amount of minerals but from an inorganic source (ADG d_{0-21} TRT vs

Table 2 - Mineral titration in TMR.

Mineral concentrations	H-In adaptation	H-In fattening	TRT adaptation	TRT fattening	IN adaptation	IN fattening
Se mg/kg DM	0.79	0.54	0.62	0.49	0.65	0.46
Zn mg/kg DM	184.24	124.52	82.39	60.12	80.94	62.45
Cu mg/kg DM	43.66	28.64	26.52	21.08	27.88	19.16
Mn mg/kg DM	111.39	68.17	57.39	34.12	58.3	36.28

Table 3 - Growth performance.

	H-In	TRT	In
n°	52	52	52
Weight, kg			
d_0	430.48	430.48	430.48
d_{21}	456.19	458.04^a	454.80^b
d_{105}	576.16^b	586.22^a	572.60^b
d_{186}	704.12^b	714.87^a	693.54^c
ADG, kg/d			
0-21	1.224	1.312^a	1.158^b
21-105	1.445^b	1.544^a	1.419^b
105-186	1.530^{a,x}	1.578^{a,y}	1.476^b
0-186	1.473^b	1.531^a	1.416^c
AFI, kg/d			
0-21	6.86^y	7.36^{a,x}	6.57^b
21-105	10.24	10.29	10.20
105-186	11.62	11.62	11.62
0-186	10.44	10.52	10.39
FCR, kg/d			
0-21	5.60	5.61	5.67
21-105	7.09	6.66	7.19
105-186	7.59	7.36	7.87
0-186	7.09	6.87	7.34

$^{a, b, c}$ on the same row: P<0.05.
$^{x, y, z}$ on the same row: P<0.1.

Table 4 - Health status.

	H-In	TRT	In
BRD first pull, % (n)	13.46 (7)	5.77^b (3)	19.23^a (10)
BRD relapses, % (n)	9.61^a (5)	0.00^b (0)	0.00^b (0)
Lameness, % (n)	1.92 (2)	1.92 (2)	1.92 (1)
Mortality, % (n)	5.77 (3)	0.00 (0)	0.00 (0)

$^{a, b, c}$ on the same raw: P<0.05.

IN; P<0.05). The same growth results were achieved only by increasing the level of inorganic supplementation. These findings could be related to the improvement in ruminal and immunity functions promoted by a higher bioavailability of some basic minerals administered such as selenium, zinc, copper and manganese[17]. In fact, the animals in the TRT group showed a better health status during adaptation. Data in Table 4 reports how animals supplemented with minerals from the inorganic source showed a higher incidence of respiratory disease (BRD first pull: In 19.23% vs TRT 5.77%; P<0.05), while those supplemented with a high level of inorganic minerals presented a higher incidence of BRD relapses (BRD relapses: H-In 9.61% vs TRT 0%; P<0.05). The higher incidence of BRD in the inorganic (In) group influenced the weight gain in the adaptation phase because of a reduction in feed intake as reported in Table 3.

During the adaptation phase, several animals incurred mild undetected forms of BRD but recovered spontaneously and efficiently through the natural immune defense. Although such animals may return to normal health quite rapidly, for several days they may reduce their feed consumption and consequently their weight gain. In fact, there is a strong relation between health condition, feed intake and ADG. This delay in growth in the first part of the fattening cycle is rarely compensated in the following weeks a statistical difference in the overall ADG was in fact found between TRT and the inorganic mineral source at the two levels examined in this study. These results are in line with Richeson and Kegley who found that highly stressed, newly received cattle treated with supplemental trace minerals had a reduced influence of BRD and an improvement in ADG[18,19].

As reported in Table 4, no difference was detected regarding the incidence of lameness which was generally low and in line with the average prevalence in this farming system in well-managed beef cattle farms[4]. On the other hand, a higher mortality was found in H-In group though even with no statistical difference. Two out of the three animals died because they failed to recover from BRD after several relapses and one because of enterotoxaemia.

Blood parameters

The better health condition shown by TRT group animals was confirmed by a better immune reaction after vaccination. Micronutrients such as Se, Zn, Cu, Mn are involved in maintaining the correct functionality of the immune system. Supplementation with these nutrients can improve the functionality of the immune system and also the production of antibodies. Arthington and Havenga found that the use of an injectable solution of trace minerals (Cu, Zn, Mn, and Se) at the same time as the vaccination, enhanced the antibody response to Bovine Herpes Virus 1[20]. In their study, the animals were vaccinated on arrival against Bovine Herpes Virus 1 of Infectious Bovine Rhinotracheitis among other pathogens. Since in France no animals are vaccinated and the virus has almost been eradicated, this parameter is a good index to evaluate the immune reaction. In our study, as expected, on arrival the animals presented no serum antibody (Figure 1). At d_{21}, the TRT animals showed a higher presence of antibodies compared to the In group, and a trend for a difference was also found at d_{105}. The activity and functionality of the

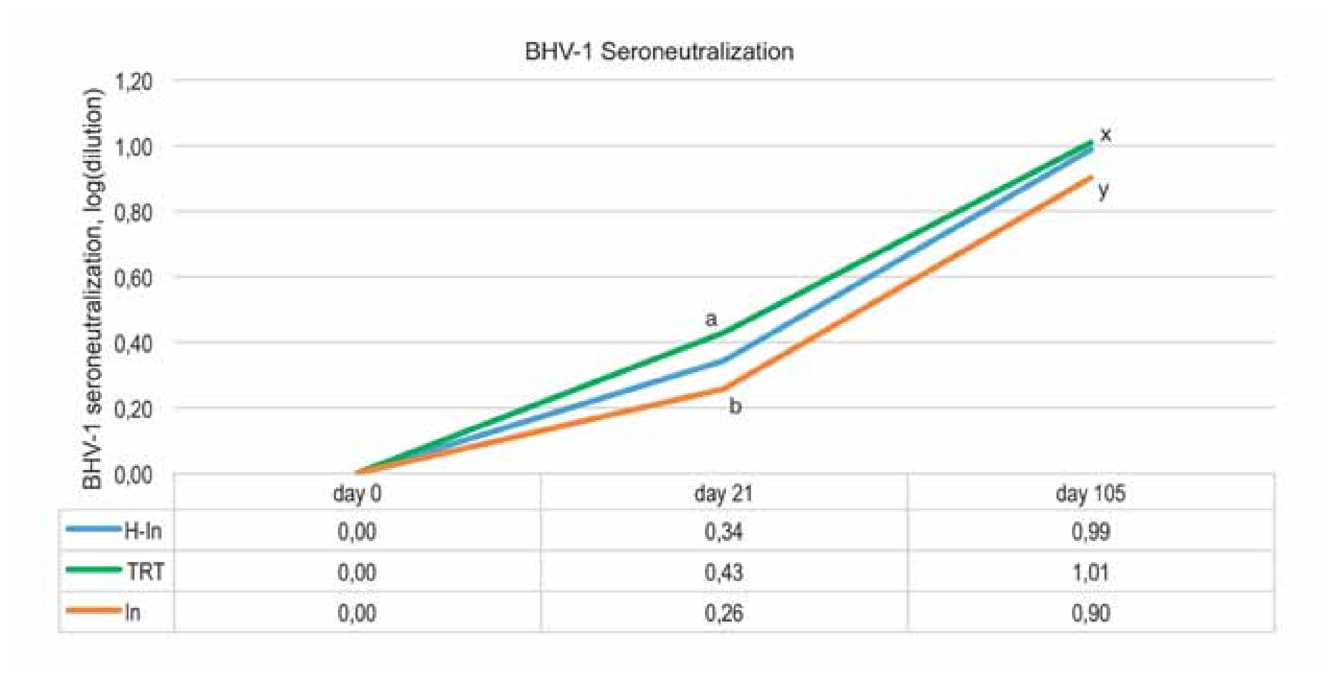

Figure 1 - Specific immunity serum indicator. a, b: P<0.05 - x, y: P<0.1.

immune system, under different mineral supplementations, was evaluated with the seroneutralization test, as reported in Figure 1. This test is used to quantify the titer of neutralizing antibodies for a virus, in this case for BHV-1. The graph shows an improvement in antibody production in the TRT group, which may reflect a higher lymphocyte B activity, due to a higher GSH-Px activity. This result could be due to the higher bioavailability of organic minerals, especially of Se, supplemented in this group.

These results agree with the findings of Nicholson et al. and Arthur et al.[21,22]. Indeed, selenium supplementation improves the antioxidant status and especially gluthatione peroxidase activity. Organic selenium sources have better effects on the antioxidant status. Calves supplemented with organic sources of selenium (Se-yeast) have been shown to have better in vitro macrophage phagocytosis compared with Na selenite supplementation[23]. As reported by Arthur et al. (2003)[20], Se improves the vitality and activity of the immune cells, including lymphocyte B. The better immune reaction after vaccination is likely due to the higher serum availability of minerals which are essential for the immune system. In fact, as reported in Table 5, starting from d_{21}, the circulating mineral concentration of selenium, zinc, copper and manganese was higher in the TRT group compared to the In and H-In groups.

These findings are in line with other studies. Chirase found that calves supplemented with Zn-methionine tend to recover from diseases more rapidly than calves supplemented with ZnO, due to the higher effect of the organic source used[24]. Also, in steers challenged with infectious bovine rhinotracheitis virus, supplementation with Zn-methionins has been shown to increase the feed intake and lower the rectal temperature, compared with the control. These are signs of a better immune function[25].

Copper levels are also involved in the immune response to bovine herpes virus 1. Arthington found that copper deficiency altered the acute-phase protein response in cattle in

Table 5 - Mineral bioavailability.

	H-In	TRT	In
n°	14	14	14
Se, g/L			
d_0	31.36	30.46	31.15
d_{21}	26.48^b	30.65^a	27.46^b
d_{105}	31.83	33.15^a	31.05^b
d_{186}	31.39	32.59^a	30.14^b
Zn, mol/L			
d_0	11.58	11.77	11.79
d_{21}	13.57^b	15.46^a	12.63^b
d_{105}	13.41^y	14.83^x	13.44^y
d_{186}	13.31^b	14.55^a	13.26^b
Cu, mol/L			
d_0	7.08	7.28	7.14
d_{21}	8.54^b	9.88^a	7.39^c
d_{105}	9.05^b	11.06^a	8.88^b
d_{186}	9.11^b	11.54^a	8.63^b
Mn, g/L			
d_0	2.57	2.50	2.52
d_{21}	2.92^b	3.34^a	2.79^b
d_{105}	3.53^b	3.93^a	3.03^c
d_{186}	3.58^b	4.08^a	3.18^c
GSH-Px, U/g Hg			
d_0	176.57	176.43	174.57
d_{21}	174.86^b	183.19^a	175.57^b
d_{105}	164.27^b	177.57^{a,x}	170.68^y
d_{186}	168.71^{b,z}	177.93^{a,x}	173.50^y

$^{a, b, c}$ on the same row: P<0.05.
$^{x, y, z}$ on the same row: P<0.1.

terms of infection[20]. Copper is a component of ceruloplasmin, one of the acute phase proteins. The average serum level was higher with the same trend also throughout the fattening cycle. Serum minerals levels of animals supplemented with high levels of inorganic minerals never reached those of the TRT group but were higher compared to the In group for Cu at d_{21} and Mn at d_{105} and d_{186}.

The body's ability to react to oxidative stress was higher in the TRT group. As reported in Table 5, glutathione peroxidase activity (GSH-Px) was higher in the TRT group starting from d_{21}, with a similar trend to the observed serum selenium concentration. This effect could be attributed to the supplementation with an organic form of selenium, which is more available and has a greater effect on the oxidant status. In fact, selenium is a component of glutathione peroxidase, an important water-soluble antioxidant. This data agrees with Juniper et al., who found higher blood glutathione peroxidase and higher glutathione peroxidase activities in beef cattle fed with organic Se, compared to those fed sodium selenites.

Selenium deficiency affects the neutrophil bactericidal activity[26]. A deficient Se status is associated with a decline in the immune response against infectious diseases, because of this decreased neutrophil bactericidal activity[17].

Carcass characteristics and meat quality

The results of slaughtering performance and meat quality seem to be related to animals' live performance, health status and blood parameters. As reported in Table 6, animals' hot carcass weight was statistically different with the same ADG trend but better results were found in the TRT group. More carcasses from the inorganic (In) group were assigned to a lower conformation category compared to the H-In and TRT groups. These findings are closely related to animal health. In fact, several authors have reported a worsening in slaughtering performance for animals with BRD[27]. Regarding the fattening score, the results are in contrast with Gardner et al. 1999[28], who reported a lower cover fat in animals with BRD. In the present study, the higher bioavailability of minerals may have improved both the metabolic and ruminal activities, enhancing myogenesis rather than adipogenesis, in agreement with the observed improved ADG. In the present experimental conditions, supplementation with organic minerals seemed to lead to leaner carcasses than the other two groups.

Meat mineral contents were consistent with the different levels of bioavailability of minerals with higher levels of Se, Zn, Cu and Mn in the TRT group compared to the inorganic supplemented animals, as reported in Table 7. H-In samples did not obtain the mineral levels of the TRT group but were higher compared to the inorganic group. The absence of an effect of mineral sources on meat centesimal composition is consistent with other studies on fattening cattle[29,30].

The potential different antioxidant action from the different supplemented minerals influenced the meat characteristics. TRT supplementation statistically improved the meat drip loss, color and overall shelf life. These findings are a consequence of the improved stability of cellular membranes due to higher antioxidant properties.

This increase in muscular antioxidant ability is consistent with the findings of several authors[30]. During ruminal degradation and intestinal digestion, organic minerals are submitted to different chemical processes from inorganic minerals, leading to higher absorption and storage at several tissue levels. The increase in muscular antioxidant activity might have reduced the extent of enzymatic and myofibrillar protein oxidation, thus promoting higher membrane stability. This results in better water holding with a lower drip loss in TRT meat samples, as reported in Table 8. This hypothesis is supported by Rowe et al.[31], who reported that dietary antioxidant supplementation in beef (vitamin E) reduced protein oxidation, and positively promoted post mortem pro-

Table 6 - Carcass characteristics.

	H-In	TRT	In
n°	49	52	52
Hot carcass weight, kg			
	419.46^{b}	426.33^{a}	411.39^{c}
Dressing percentage, %			
	59.57	59.63	59.32
Conformation, % (n°)			
S	0.00 (0)	0.00 (0)	0.00 (0)
E	93.88^{a} (46)	94.23^{a} (49)	76.92^{b} (40)
U	4.08^{b} (2)	5.77^{b} (3)	23.08^{a} (12)
R	2.04 (1)	0.00 (0)	0.00 (0)
O	0.00 (0)	0.00 (0)	0.00 (0)
P	0.00 (0)	0.00 (0)	0.00 (0)
Fattening score, % (n°)			
5	0.00 (0)	0.00 (0)	0.00 (0)
4	0.00 (0)	0.00 (0)	0.00 (0)
3	$18.37^{a,x}$ (9)	5.77^{b} (3)	$28.84^{a,y}$ (15)
2	$81.63^{b,x}$ (40)	94.23^{a} (49)	$71.15^{b,y}$ (37)
1	0.00 (0)	0.00 (0)	0.00 (0)

$^{a, b, c}$ on the same row: $P<0.05$.
$^{x, y, z}$ on the same row: $P<0.1$.

Table 7 - Meat chemical composition.

	H-In	TRT	In
n°	10	10	10
pH			
	5.74	5.71	5.74
Centesimal composition			
Humidity, %	73.35	73.05	73.44
Fat, %	2.52	2.59	2.59
Protein, %	23.14	23.39	23.01
Ash, %	0.96	0.98	0.97
Meat mineral content			
Se, mg/100 g DM	0.092^{b}	0.133^{a}	0.069^{c}
Zn, mg/100 g DM	16.41^{b}	17.95^{a}	11.90^{c}
Cu, mg/100 g DM	0.29^{a}	0.32^{a}	0.19^{b}
Mn, µ/100g DM	29.44^{b}	31.95^{a}	20.99^{c}

$^{a, b, c}$ on the same row: $P<0.05$.

Table 8 - Drip loss.

	H-In	TRT	In
n°	10	10	10
Meat weight, g			
d_0	135.32	135.32	135.32
d_1	132.78^b	133.49^a	132.64^b
d_3	131.02^b	131.96^a	130.91^b
d_5	128.50^b	129.81^a	128.68
d_7	125.05^b	126.27^a	126.04
Drip loss, %			
d_1	1.93^a	1.43^b	2.15^a
d_{1-3}	1.32	1.17	1.36
d_{3-5}	2.01	1.72	1.90
d_{5-7}	2.72^a	2.77^a	2.10^b
d_{1-7}	7.99^a	7.10^b	7.51

$^{a, b, c}$ on the same row: P<0.05.

Table 9 - Meat color.

	H-In	TRT	In
n°	10	10	10
Lightness, L*			
d_1	45.68^b	49.42^a	42.00^c
d_2	45.01^b	48.86^a	42.56^c
d_3	43.05^b	47.98^a	40.53^c
d_4	38.69^b	46.97^a	35.62^c
d_5	38.80^b	45.75^a	35.69^c
d_6	34.32^b	40.54^a	32.93^b
d_7	34.60^b	39.70^a	32.62^b
Redness, a*			
d_1	23.88^{b,y}	25.71^a	25.20^x
d_2	23.69	23.10^b	24.79^a
d_3	20.85^a	21.72^a	17.53^b
d_4	19.80	21.11^a	17.57^b
d_5	17.32^b	20.35^a	15.40^c
d_6	12.69^b	16.71^a	11.21^b
d_7	13.52^b	16.87^a	11.70^c
Yellowness, b*			
d_1	13.71^b	14.78^{a,x}	13.97^y
d_2	13.50^b	14.46^{a,x}	13.80^y
d_3	12.37^b	13.72^a	11.73^b
d_4	11.77^b	13.65^a	11.88^b
d_5	9.11^b	13.23^a	6.82^c
d_6	7.74^b	10.92^a	6.48^b
d_7	7.42^b	10.67^a	5.97^c

$^{a, b, c}$ on the same row: P<0.05.

teolysis. In our study, higher oxidant stability led to a better meat color from the first day after cutting and in the following seven days, as reported in Table 9, with a better lightness, redness and yellowness index.

An improvement in lightness due to the supplementation of organic selenium was also reported by Cozzi et al.[30], who found an increased L* value after 6 and 11 days of vacuum packaged ageing. Taylor et al. (2008)[29] also found that meat from cattle fed a selenium-enriched diet had a higher Se content and tended to have a higher average a* and b* during 12 days on the shelf, compared with animals fed an unenriched diet.

In addition, in our study TRT meat samples showed a better overall shelf life of more than one day compared to In and H-In groups (Table 10). Several statistical differences were also found between the H-In and In groups. H-In meat samples were characterized by better lightness from d_1 to d_5, redness at d_1, d_3, d_5 and d_7, yellowness at d_5 and d_7 and shelf life.

These findings demonstrate that the mineral supplementation level also improves meat quality. Some improvements with a high inorganic mineral supplementation are possible compared to a low supplementation but not as high as the level achieved with the organic supplementation.

No statistical differences were observed regarding thawing loss, cooking loss and tenderness as reported in Table 10.

Table 10 - Meat quality.

	H-In	TRT	In
n°	10	10	10
Shelf life, d			
	5.00^{b,x}	6.10^a	4.54^{b,y}
Thawing loss, %			
	1.72	1.62	1.72
Cooking loss, %			
	34.29	33.79	33.89
WBSH, kg/cm^2			
	3.36	3.32	3.31

$^{a, b, c}$ on the same row: P<0.05.
$^{x, y, z}$ on the same row: P<0.1.

CONCLUSIONS

Under our study conditions, the supplementation of minerals from an organic source to beef cattle, led to better animal health conditions and growth performance that probably relates to the high bioavailability of essential cofactors of basic metabolic and immune processes. These conditions also led to an improvement in meat quality. The administration of minerals from inorganic sources can lead to good but not excellent farming results only if administered at high concentrations.

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