

Trace-element Metabolism in Camel

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ABSTRACT

In a 195 day trial, 5 adult camels and 5 adult cows fed a similar basal diet plus mineral supplement (copper, zinc, selenium and manganese) for 3 months (days 22-112). Copper and zinc were analyzed in the plasma, liver, urine, feces and basal diet. Iron and manganese were measured in the diet and feces only. The caeruloplasmin and the erythrocyte superoxide dismutase activity were measured. The urinary excretion was negligible in both species. Camels plasma concentration of copper and zinc were (61 µg/100 ml and 38 µg/100 ml for respectively) significantly lower than that in the cows (111 and 83 respectively). The supplementation increased the plasma copper concentration and liver copper level but had no effect on plasma and liver zinc concentrations in the camels. There was a significant correlation between plasma copper and caeruloplasmin activity. However, there was no significant correlation between the plasma copper and zinc concentrations and the erythrocyte superoxide dismutase activity. Fecal excretion of all trace elements increased during supplementation period, while the apparent absorption rate decreased for iron in spite of lack of mineral supplementation. Zinc absorption stayed at lower level in camel after stopping mineral supply. Manganese apparent absorption rate was very high in camel. Results were discussed with the hypothesis of an adaptive physiology for the camels in transitory mineral under-nutrition.

Key words: Trace element, Liver, Fecal Excretion, Cow, Camel.

INTRODUCTION

It is well known that camels present some physiological particularities testifying to their adaptation to arid conditions and poor feeding resources. For example, the specific nitrogen turnover with very low urea excretion allows it to survive in spite of low quality pastures. Previous studies (Faye *et al.*, 1992; Bengoumi *et al.*, 1995a) concerning trace elements on camels have shown that there is little evidence to date of clinical deficiencies. It was concluded that camels have a particular trace element regulation (Faye and Bengoumi, 1994). However, no comparative studies with other ruminants are available in the literature, except, some results on plasma values in field conditions in different areas from Sudan (95 µg/100 ml for copper) (Tartour, 1995), Egypt (83 and 135 µg/100 ml for copper and zinc respectively) (Moty *et al.*, 1968), Ethiopia (107 and 100 µg/100 ml for copper and zinc respectively) (Faye *et al.*, 1986) and Djibouti (61 and 46 µg/100 ml for copper and zinc respectively) (Faye *et al.*, 1990).

The present study aims to compare the metabolism of the main biological trace elements (copper, zinc, manganese and iron) in cattle and camels in identical conditions. The regulation of these trace elements includes food intake, bioavailability, liver storage and fecal excretion at different mineral nutrition levels.

MATERIALS AND METHODS

The trial was carried out at the experimental station of I.A.V. Hassan II (Gharb farm), 80 km north of Rabat, Morocco.

Animals

The study included 5 to 7-year old camels originating from South Morocco, and five 4 to 6-year old multiparous, black-pied Friesian cows born at the experimental station. The approximate mean weights were 400 kg for the camels and 600 kg for the cows. The animals were treated for external and internal parasites using ivermectine (Ivomec N.D.) and were in good health during the whole experiment.

Experimental procedure

During the whole trial, the animals were kept in individual pens. Camels received a basal diet including 3 kg of wheat straw, 1.5 kg of rice meal and 1.5 kg of molasses. The composition of the basal diet for cows was similar but quantities were doubled to take account of the weight of the animals and the general food intake of each species. The diet was distributed individually. There were no refusals. The animals drank *ad libitum*. After an adaptation period of 2 weeks to equilibrate the mineral status of the animals, the experimental period (195 days) consisted of three phases:

1. A control period (days 1-21). During this stage, the animals received the basal diet. They did not receive any mineral supplementation.

2. A supplementation period with mineral additives (days 22-112). A mineral mixture including 9.5 g of copper sulphate, 44.0 g of zinc sulphate, 30.1 g of manganese sulphate, 153.5 mg of calcium iodine, 95.2 mg of cobalt sulphate and 43.6 mg of sodium selenite was prepared. This additive corresponded to a daily supply for each animal of 240 mg of copper, 1000 mg of zinc, 1000 mg of manganese, 10 mg of iodine, 2 mg of cobalt and 2 mg of selenium. These quantities were estimated to be double the requirements usually proposed for cows (McDowell, 1992) and camels (Faye *et al.*, 1992). The mineral supplementation was mixed with the molasses, then with the rice meal and distributed individually each morning. The complete consumption of the mineral supplementation was verified.

3. Post-supplementation period (days 113-195). During this last period of the experiment, supplementation was discontinued. Animals received the basal diet only.

Sampling

Blood was collected from the jugular vein with vacutainer tubes containing anticoagulant (Heparin N.D.). The blood was centrifuged immediately and the plasma was harvested. The samples were identified and kept frozen until analysis. The blood sampling was carried out in the morning before feeding. During the first

period, blood sampling was taken on days 1, 7 and 17. Twelve samplings were carried out in the second period, almost once a week: day 24, 31, 38, 48, 55, 62, 69, 80, 87, 94, 101 and 108. In the last period, blood sampling was performed once a week during the first month (day 115, 122, 129, 136), then every other week up to the end of the trial (day 150, 164, 178, 195).

Because liver storage is an important indicator of trace element status, liver biopsies were carried out on each animal. The biopsy technique used for the cow was described by Habel (1989). In the camel, the biopsy technique was adapted from that described by Cherrier et al. (1997). After biopsy, local disinfecting was performed with an antiseptic. The animals received an intramuscular injection (10 ml of Oxytetracycline, TLA N.D.). Two biopsies were carried out during the first period of the trial (days 1 and 17), then every month during the second period (day 48, 80, 108) and the third period (day 136, 164 and 195).

The feces were sampled for 24 hours on each animal with a plastic bag stuck against the anus. They were weighed and dried (at 100 °C in a oven) and stored in a plastic bag for analysis. The feces sampling days were identical to those used for blood sampling. Urine was collected in a sterile flask over 24 hours when the animal urinated. Urine sampling was performed at the same interval as feces sampling.

The elements of the basal diet were sampled at the beginning of the trial, dried and stored for analysis. The composition of the basal diet was identical all through the trial.

Laboratory analysis

In each element of the basal diet, copper, zinc, manganese and iron were measured by atomic absorption spectrophotometry according to the Bellanger method (1971). In the plasma as described by Bellanger and Lamand (1975), the atomic absorption spectrophotometer, was used to measure copper and zinc.

The liver samples were mineralized using perchloric and nitric acid according to the Bellanger method (1971). The feces samples were mineralized using a Muffle furnace (550 °C overnight). After digestion, fecal and liver samples were analyzed by atomic absorption spectrophotometer. In urine, only copper and zinc were analyzed using Bellanger et Lamand (1975).

The analytical quality of copper and zinc measurements was assured by using different reference materials. For the diet and liver analysis, two reference materials were used: meal (NIST 1567a from the National Institute of Standard and Technology) and milk (IAEA A11 from the International Atomic Energy Agency). For the plasma measurement, seronorm trace elements (Ref. 5337, NYCOMED AS., Pharma diagnostics, Oslo, Norway) were used. Fifteen replicate assays of these reference materials were used and the precision was below 5%.

Caeruloplasmin activity was measured according to its p-phenylenediamin oxidase activity as described by Chacornac *et al.*, (1986). The role of SOD is to accelerate the dismutation of the toxic superoxide radical (O_2^-), produced during oxidative energy processes, to hydrogen peroxide and molecular oxygen. The analytical method used employs xanthine and xanthine oxidase to generate superoxide radicals which react with 2-(4-iodophenyl)-3-(4-nitrophenol)-5-phenyltetrazolium chloride (INT) to form a red formazan dye. The SOD activity is then measured by the degree of inhibition of this reaction. The blood sample was centrifuged at 3000 g for 15 min and the serum discarded. Then erythrocytes were washed four times with 3 ml of 0.9% NaCl solution and centrifuged after each wash. The washed centrifuged erythrocytes should be made up to 2 ml with cold redistilled water and the lysat diluted with 0.01 M phosphate buffer pH 7.

A 50 fold dilution of lysat was recommended for bovine samples. Similar dilution was proposed for camel samples. Each prepared sample was mixed with xanthine oxidase and the final absorbance was read after 3 minutes. The precision of the results was controlled using RANSOD control (Ref: CAT. NO. SD 126, Randox Laboratories, Crumlin, North Ireland).

Statistical analysis

Variance analysis was carried out using the SYSTAT software. For each variable to be explained (copper and zinc), we tested the effect of the species (2 levels: cow or camel), the mineral supplementation period (3 levels: before, during and after) and the day sampling (23 levels for blood and feces; 8 levels for liver). Previously, normality of distribution was tested by the Skewness and

Kurtosis test (W test). Correlation between two variables were studied using the Spearman method. The multiple comparison test of the linear regression model was used to compare camels to cows.

RESULTS

Mineral composition of the basal diet is presented in Table 1. A part of the basal diet (straw) was poor in copper and zinc. Indeed, the wheat straw contained 2.9 ppm of copper and 21.3 ppm of zinc (DM expressed). The manganese content was very low in molasses (4 ppm). During period I and III, the total mineral intake was different between the two species, but it became slight during the supplementation period (Table 2). However, as the mineral supplement did not contain iron salt, iron intake was constant all through the trial and was 330 mg per day for camels and 660 mg for cows.

Table 1: Trace-element composition of the basal diet (ppm).

Trace-element	Wheat straw	Rice meal	Molasses
Copper	2.9	6.8	17.0
Zinc	21.3	53.6	14.0
Manganese	39.1	135.5	4.0
Iron	28.8	130.0	68.0

Table 2: Trace-element intake during the three periods of the experiment (mg/day/animal).

Trace-Element	Camel			Cow		
	PI	P II	P III	P I	P II	P III
Copper	35	275	35	70	310	70
Zinc	145	1145	145	290	1290	290
Manganese	293	1293	293	586	1586	586
Iron	330	330	330	660	660	660

Trace element regulation in plasma

The mean value for plasma concentration of copper was significantly higher in the cows (111 μ /100 ml) than in the camels (61 μ g/100 ml). During the three periods of the experiment, the mean copper values were 106, 111 and 113 μ g/100 ml, respectively, for cows. Camels presented lower values but with similar evolution: 44, 63 and 67 μ g/100 ml (Fig 1).

For zinc concentration in cows, the mean value was 83 μ g/100 ml. As for copper, the mean value of zinc concentration was significantly lower in the camel (38 μ g/100 ml). During the three periods of the experiment, plasma zinc concentrations were 73, 84 and 87 μ g/100 ml for cows and 35, 36 and 42 μ g/100 ml for camels. The change in plasma zinc for the whole experiment is shown in figure 1. In the two cases (plasma zinc or copper), a strong species effect ($P < 0.01$) was observed. The day of sampling for copper only ($P < 0.05$).

Caeruloplasmin and SOD activity

The mean value for caeruloplasmin activity was significantly higher in the cow (34 UO/1) than in the camel (11 UO/1). During the supplementation stage, the caeruloplasmin activity was significantly ($P < 0.05$) increased in the camel (22 UO/1). In the cow, the caeruloplasmin activity was slightly increased but not significantly (39 UO/1). The comparison of the correlation coefficient between plasma copper and caeruloplasmin activity in cows and camels, by considering the whole samples (23 x 5), showed a lower coefficient in camels (0.69) than in cows (0.87). However, in all cases the p value was below 0.01.

The SOD activity was significantly higher in cows than in camels (Fig. 2). During the 3 periods of the trial, the mean cow SOD activity was 2254 ± 205 IU/100 g Hb in period 1, 2420 ± 193 IU/100 g Hb in period 2 and 2436 ± 237 IU/100 g Hb in period 3. The camel SOD activity was 1474 ± 252 , 1720 ± 332 and 1813 ± 352 , respectively. In both species, the SOD activity slightly increased when copper-zinc supplementation occurred, but the difference was significant ($P < 0.05$) in cattle only between period 2 and period 1. During the depletion period, the mean SOD activity continued to increase slightly, but not significantly. The camel SOD activity was characterized by high individual variability.

There was no correlation between the plasma copper and SOD activity, both in camels and in cows. Considering all animals, a positive relationship was observed between the plasma zinc concentration and SOD activity in cows. The correlation was low but significant: ($r = 0.396$, $P < 0.05$). Surprisingly, this relationship was negative in camels ($r = -0.369$, $P < 0.05$). The biological relationships between zinc status and SOD activity were found to be quite different between the two species.

Trace element storage in liver

Copper concentration in liver varied from $35 \mu\text{g/g}$, (control period) to $91 \mu\text{g/g}$ (supplementation period) and $65 \mu\text{g/g}$ (post supplementation period) for cows. For camels, the mean values were 10, 26 and $18 \mu\text{g/g}$ respectively (Table 4). The ratio cow/camel indicated that the speed of copper storage was higher in cows than in

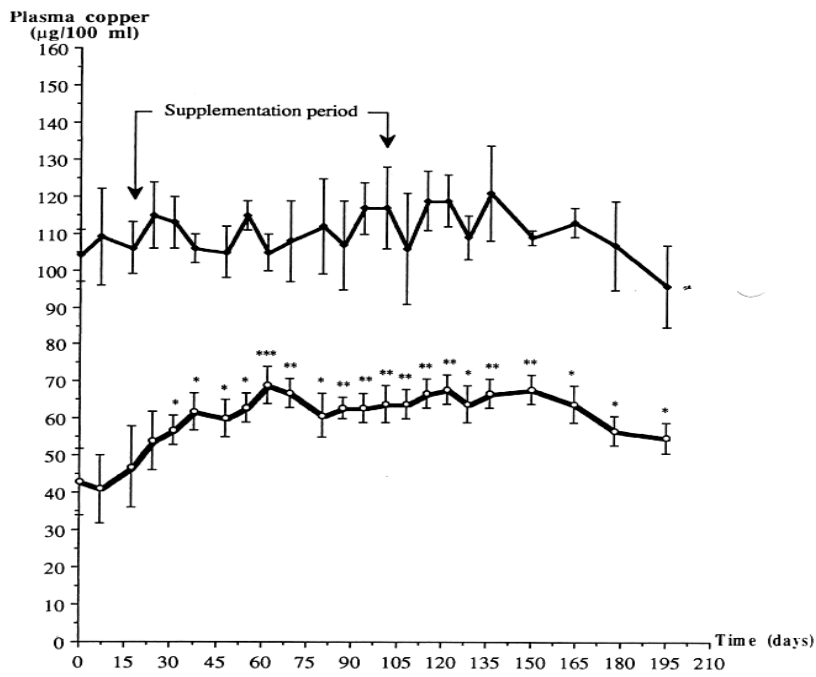
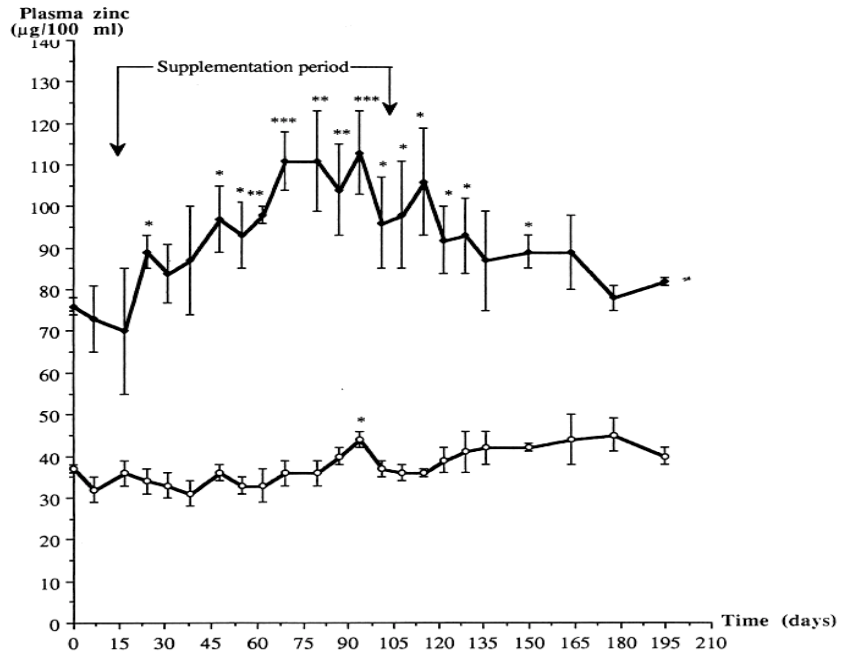


Fig. 1: Plasma concentration of zinc and copper in camels and cows

camels at the beginning of the supplementation period and the release increased rapidly in camels after the end of supplementation (Fig. 3).

Zinc concentrations in the liver were 51 µg/g at the control period 1, 41 µg/g at the second period and 42 µg/g at the last period for cows. These values were 43, 36 and 45 µg/g for camels, respectively. There were no significant differences between the two species, no significant effect of mineral supplementation and no significant change in the cow/camel ratio.

Table 3: Effect of mineral supplementation on liver copper and zinc levels (ppm) in cows and camels (Mean ± SD).

	P I		P II		P III	
	Cows	Camels	Cows	Camels	Cows	Camels
Copper	35±11	10±2	91±26	26±8	65±25	
Zinc	51±10	43±8	41±6	35±6	42±13	

Trace element fecal excretion

The importance of the increase of trace-elements intake during the supplementation period was clearly associated with the increase of fecal concentration of copper, zinc and manganese (Fig. 5) both in camels and cows. The iron fecal excretion was increased also during period II in spite of the lack of iron supplementation. From period I to period II, copper intake was multiplied by 7.8 and fecal excretion by 13.8 in camels. The values for cows were 4.4 and 11.2 respectively. When zinc intake increased 7.8 times, zinc excretion increased 7.1 times for camels. These values were only 4.5 and 3.9 for cows. In camels, the manganese intake increased 4.4 times, and fecal excretion 3.2 times. In cows, those values were 2.7 and 3.3 respectively. Concerning iron, fecal excretion in camels was multiplied by 4.3 in the second period and remained at a high level

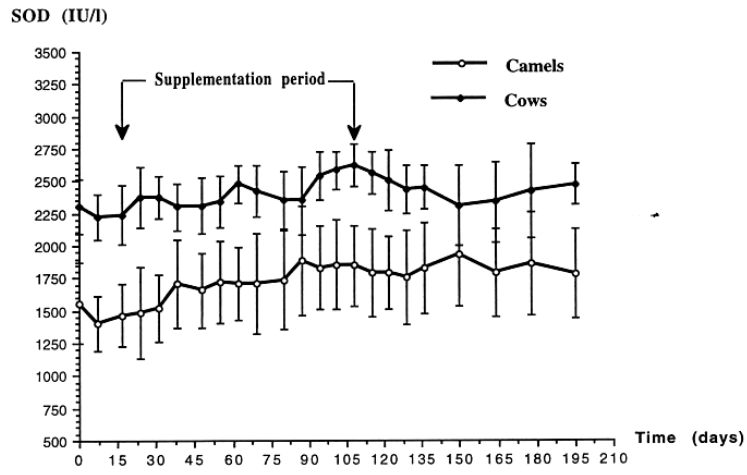


Fig. 2: Plasma concentration of SOD in camels and cows

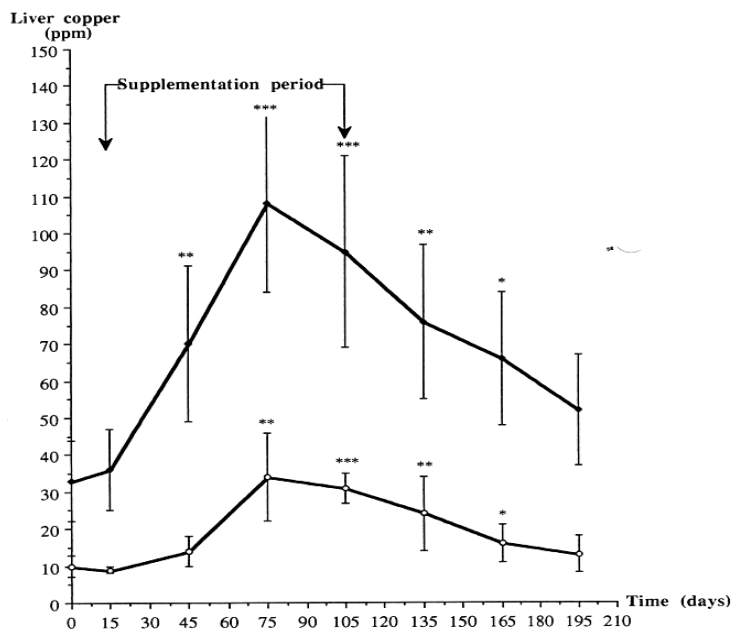


Fig. 3: Liver copper levels in camels and cows

during the post supplementation period (with an average of 145 mg/kg DM). In cows, iron excretion was multiplied by 5.9 in the same time and returned faster to previous values (Fig. 4).

Urinary excretion

The urinary excretion of copper and zinc stayed at a low level during period I, 0.06 µg/l in cows and 0.11 µg/l in camels. An increase of the urinary excretion was observed in both species during period II (an average of 2.31 and 0.82 µg/l in camel and cow respectively). The excretion in urine decreased slightly in period III: 1.13 µg/l in camels and 0.39 µg/l in cows. Concerning zinc, the urinary excretion was negligible for camels as well as for cows. Only traces were detected in the urine analysis, even during the supplementation period. As the whole, urinary excretion was not an important method of loss for these elements.

Apparent absorption

The quantity of daily excreted fecal did not change during the two first periods in camels (around 2.2 kg/d) and all through the trial in cows (3.6 kg/d). However, the camel fecal excretion decreased significantly in the post supplementation period (1.5 kg/d). The apparent absorption was significantly decreased in the two species during supplementation period (Fig. 5), except for camel zinc for which the ratio excreted/intake stayed at a low level. In camels, zinc absorption was 61% (period I), 56% (period II and 54% (period III). In cows, these values were 66, 55 and 71% respectively.

Concerning copper, no significant difference occurred between the two species but the percentage was slightly lower in camels during the post supplementation period. Indeed, the apparent absorption during the 3 periods in camels was respectively 80, 65 and 75% vs. 84.5, 61 and 86% in cows. A high significant difference ($P < 0.01$) occurred between camel and cow for manganese absorption. The apparent absorption of manganese was 78, 66 and 81% for camels during the three periods. These values were only 32.5, 43.5 and 48% in cows. Except for the supplementation period, the percentage of iron absorption in the camels (88, 62 and 81.5% for

the three periods, respectively) showed no important difference from the cows (92, 50 and 88%) (Fig. 5).

Regarding the quantity of trace-elements apparently absorbed per 100 kg of LW, it appeared that copper was better absorbed in camels than in cows when they were supplemented (Table 4). Similar results occurred for zinc. A high difference was observed between camels and cows for manganese: in any case, the quantity observed was considerably lower in the cow than in the camel. In contrast, the iron absorption reported to live weight was lower in camels than in cows, but the time-changes were similar.

Table 4: Mean trace-element absorption during the three steps of the experiment (in mg/day/100 kg LW).

Trace-element	Camel			Cow		
	P I	P II	P III	P I	P II	P III
Copper	7	45	6.5	9.8	31.4	10
Zinc	22	162	18.5	32	118	34
Manganese	128	265	139	19	97	49
Iron	256	183	228	357	216	326

DISCUSSION

Comparative copper metabolism

In contrast to previous observations (Faye and Bengoumi, 1994), copper plasma level was higher in cows than in camels. But, in these studies, the animals were managed in traditional conditions and their feeding differed from one species to another. It is known that camels graze more forage-trees than grasses (Rutagwenda *et al.*, 1990) and leaves from those trees are generally richer in copper than pasture plants which are the main diet for the cows (Tartour, 1966;

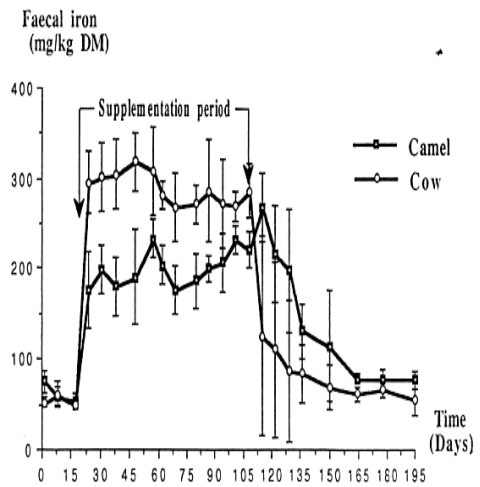
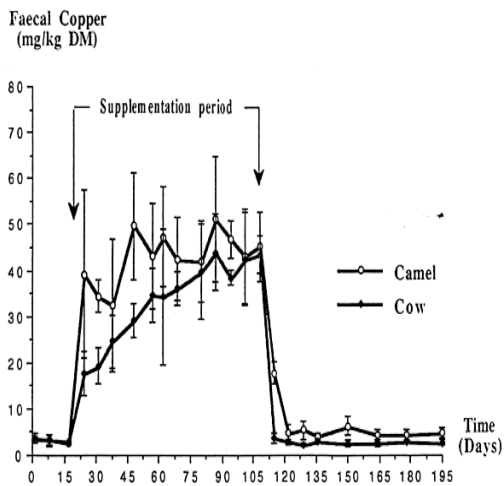
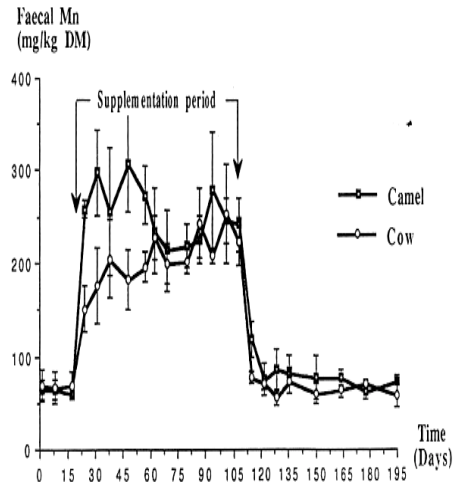
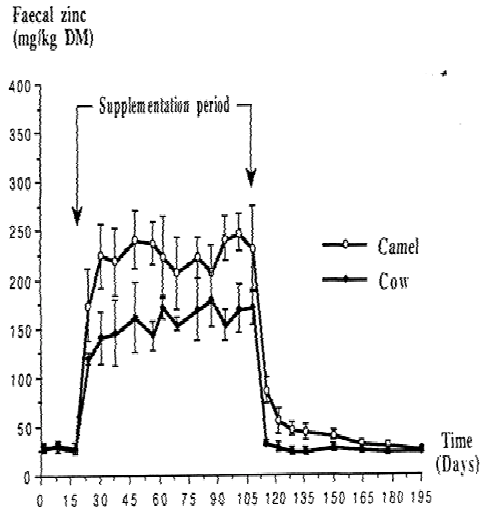


Fig. 4: Changes in faecal zinc, manganese, copper, and iron excretion in camels and cows

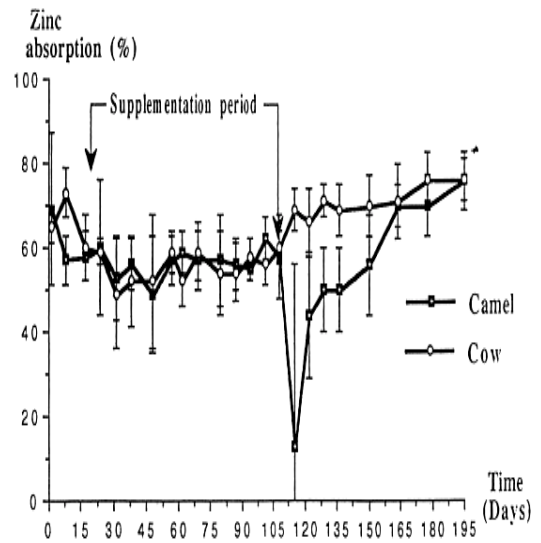
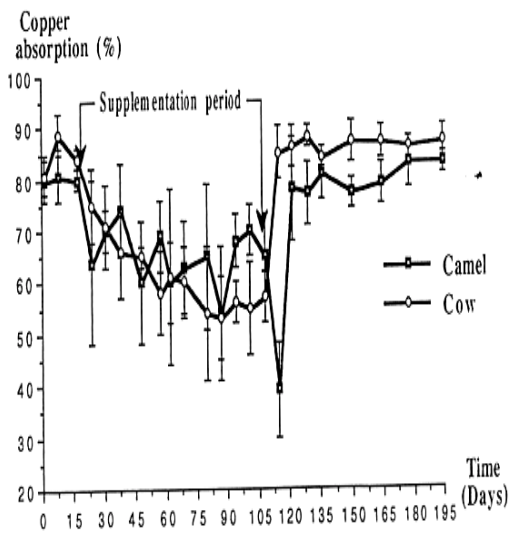
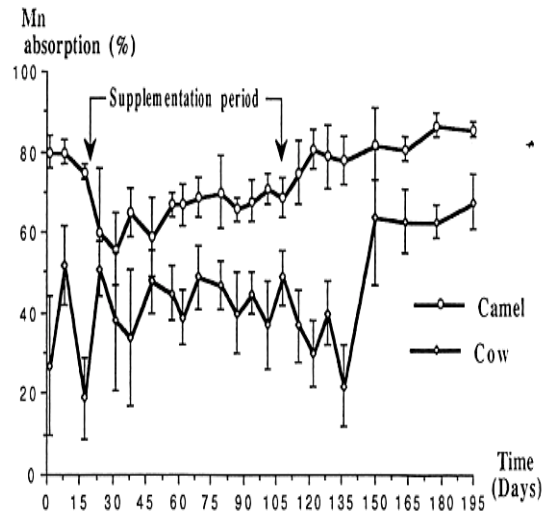
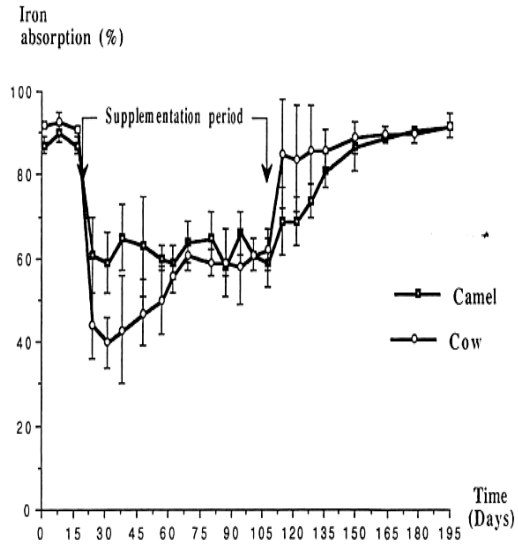


Fig. 5: Changes in iron, manganese, copper and zinc apparent absorption rate in camels and cows

Faye and Tisserand, 1989). In the present study, the basal diet was similar for camels and cows. The observed difference (on average, copper plasma level in the cow was 1.8 higher) could be attributed to a physiological difference between the two species. The plasma values for the cows were in the range generally reported in the literature (McDowell, 1992; Lamand, 1987) and widely above the deficiency threshold (70 µg/100 ml). In contrast, the plasma copper levels in the camels were just under this limit, except after several weeks of supplementation. It is very difficult to use the plasma copper concentration to appreciate the nutritional status of camels. Nevertheless, the diminution of the liver copper level, when the mineral supplementation was stopped, permit us to conclude that the camels were likely in sub deficient status at the beginning of the trial.

The values of copper concentration in camel liver were low but similar to results of the most recent studies (Faye *et al.*, 1992; Bengoumi *et al.*, 1997a). The difference between cows and camels was observed also for copper liver concentration. Camels had 2.6 lower copper concentration. The copper storage in the camel liver was slow at the beginning of the supplementation period, likely due to the sub deficient status of the animals. The copper supply sought to restore the tissue copper level first. In reverse, the copper status was normal in cows and liver storage started as soon as the mineral supplementation was given.

An important part of the copper was excreted both in camels and cows. As for all the positive ions, most of the excretion occurred by feces. This includes the non-absorbed part at the intestinal level and the endogenic part coming from previously absorbed minerals coming back in the intestinal tract. Only the difference between the intake and the excreta can be measured, i.e. a crude assessment of the apparent absorption. The quantity of copper excretion in feces was logically lower in the camel because of the lower total quantity of copper salt supplemented. The mean difference observed between the camel and the cow corresponded to the difference in copper intake. However, copper concentration was higher in camel feces than cow feces. In fact, the camel fecal excretion increased faster at the beginning of mineral supplementation in spite of sub deficient status. This could explain the low liver storage. Nevertheless, the percentage of absorbed copper was similar in the two species except at the end of the trial. The camels seemed to show a better use of copper intake in the post supplementation period by increasing the absorption and

slowing the liver release. However, setting up of these mechanisms shows a latent period, similar to those observed in cases of dehydration (Bengoumi *et al.*, 1997a).

Caeruloplasmin activity

Caeruloplasmin measured as oxidase activity is important for the functional activity in transporting copper. No inflammation process was observed during the trial. This point was important to avoid the non-physiological increase of caeruloplasmin because this metallo-enzyme is a good indicator of inflammation (Kaneko, 1989). So, the variation of the caeruloplasmin activity observed in our trial could be attributed to the feeding status. On average, the value for caeruloplasmin activity was higher in the cow than in the camel. This result is similar to that reported by Srivastava and Swarakanth (1971).

There are few references involving studies of caeruloplasmin activity in animals receiving copper supplementation. Generally, the caeruloplasmin activity and the serum or plasma copper concentration decreases with nutritional copper depletion in ruminants (McMurray, 1980; Prohaska, 1990). The normal activity of caeruloplasmin can be restored by copper supplementation (Harris and Di Silvestro, 1981). For example, in ewes, the caeruloplasmin activity increased with copper supplementation and the lambs born from these ewes had higher values in caeruloplasmin activity (Faye and Grillet, 1984). In camels, Faye *et al.* (1992) also noticed a slightly higher activity of caeruloplasmin when supplementation occurred. Similar results were observed in our study, but the increase seems more important in camels than cows. Elsewhere, the correlation caeruloplasmin/copper seems lower when no mineral supplementation occurs or when zinc supplementation competes with copper (Bengoumi *et al.*, 1995b). This could be simply attributed to a lower variability of the plasma values in such conditions.

Relationship copper-caeruloplasmin

Caeruloplasmin activity is usually well correlated to plasma copper for camels (Faye *et al.*, 1992) as well as for cows (Arnaud *et al.*, 1993). The correlation coefficient between caeruloplasmin

activity and copper concentration observed in cows is slightly higher than those observed by Blakley and Hamilton (1985) (0.60), but lower than those reported by Bingley and Anderson (1972) (0.93) and Chacornac *et al.*, 1986 (0.97). These results confirm that in the cow, the caeruloplasmin activity is usually well correlated to plasma copper concentration.

In the camel, the correlation coefficients obtained in our study between caeruloplasmin activity and plasma copper concentration were similar to those reported by Faye *et al.* (1992) (0.68) and by Faye and Mulato (1991) (0.72). It is not surprising that good relationships are observed since caeruloplasmin is reported to contain 95% of circulating copper in normal animals (Harris, 1991). However, on average, the correlation coefficient is lower in the camel than in the cow when the same analytical method is used.

The comparison between correlation figures for the camel and the cow shows a different evolution indicating that a specific difference occurred. In the camel, in the case of lower plasma copper concentration, the value of caeruloplasmin activity appears to not have been modified and the graph curve appears non linear as it was for the cow. This observation is similar to those obtained by Faye and Grillet (1984) and by Faye and Mulato (1991). This difference can be attributed to the specific copper metabolism regulation (Bengoumi *et al.*, 1997a). So, it appears that the camel, in spite of copper deficiency, can maintain normal caeruloplasmin activity. From a diagnostic perspective, caeruloplasmin activity may have applications in many animal species (Pejaudier, 1973). In the camel, it appears that caeruloplasmin is also correlated with cupremia and can be a useful indicator of nutritional copper status as indicated in cattle and sheep (Blakley and Hamilton, 1985), but a copper sub deficient situation (plasma copper concentration below 50 µg/100 ml), the caeruloplasmin does not allow one to assess the deficiency status level.

Comparative zinc metabolism

As for copper, the plasma zinc level was twice as high in cows as in camels. Bovine values were in the range of normal data (70-120 µg/100 ml) (McDowell, 1992). Present results concerning camels confirm recent observations in Djibouti (Faye *et al.*, 1992), Morocco

(Bengoumi *et al.*, 1995a) and France (Faye *et al.*, 1995). Camels have a lower normal level of the plasma zinc concentration and we can consider that the deficient threshold is below 40 µg/100 ml. Indeed, zinc supplementation did not increase the plasma zinc concentration, in comparison to the cows. Elsewhere, no liver storage was observed, either in the cows or in the camels. The supplementation period was even marked by a slight decrease of liver zinc in camels. The present observed liver concentrations are lower than those reported in the literature (Faye *et al.*, 1992; Wensvoort, 1992), except in Sudan (Abu Dhamir *et al.*, 1983).

Excretion of zinc in urine and hair being negligible, fecal excretion is the principal way for reporting endogenous and nutritional zinc. As for copper, the quantity of fecal zinc was higher in the cows due to the slight difference of mineral intake, and fecal zinc concentration was higher in the camel. As a whole, zinc excretion was higher in camels which confirms the absence of deficiency in spite of low observed plasma zinc concentration in this species. However, the percentage of absorption was similar in the two species and was not influenced by the supplementation. So, it is clear that zinc requirements are lower in camels than in cows and the supply through the basal diet is sufficient. Because of the important enzyme activities in the camel kidney than liver (Bengoumi *et al.*, 1997b), one could consider that this organ could play a particular role in the storage of this trace element.

Relationships between copper, zinc and SOD activity

Only the erythrocyte super oxide dismutase activity was measured. The extra cellular activity level is a less efficient biomarker for copper or zinc status (Olin *et al.*, 1995). Our results showed the camel SOD activity similar to that of the human (Panemangalore and Bebe, 1996) than the bovine (Kaneko, 1989).

A depressed SOD activity is considered to indicate a severe and prolonged deficiency of copper or an inflammation (Gomi and Matsuo, 1995; Mulryan and Mason, 1992; Paynter, 1987). However, the functional significance of these observations is not clear. Panemangalore and Bebe (1996) observed a significant linear relationship between dietary copper levels and SOD activity. However, in the human, a relationship between the SOD activity and

serum copper was not observed in the case of hypertension (Vivoli *et al.*, 1995).

The lack of correlation between copper or zinc and SOD cannot be attributed to the short supplementation period. Several authors have shown that copper supplementation of copper-depleted humans for 3 or 4 weeks can restore SOD activity to normal (Panemangalore and Bebe, 1996). However, a longer duration of oral copper supplementation may be needed to effectively increase erythrocyte SOD activity. In our study, the depleted period occurred after 3 months of mineral supplementation. Plasma copper level was maintained after cessation of supplementation by the mobilization of copper stored in the liver during the previous period. The variability of plasma copper was probably not sufficient in both species to observe significant change in SOD activity. Elsewhere, a possible negative interaction between copper and zinc could act in the erythrocyte (Susuki and Kuroda, 1995) as was observed for intestinal absorption in both cows (Towers *et al.*, 1981) and camels (Bengoumi *et al.*, 1995b).

A moderately high zinc diet has been shown to increase slightly SOD activity in female rats given a normal copper diet (Panemangalore and Bebe, 1996). High dietary zinc level could reduce the copper plasma concentration and thus alter the erythrocyte enzyme activity. Co-existing ionic copper level in the erythrocytes inhibits the binding of zinc to SOD. Elsewhere, ionic copper can be transferred to the zinc-binding site at a comparable efficiency (Susuki and Kuroda, 1995). Complex relationships therefore seem to exist between copper, zinc and SOD activity. In our study, the supplemented diet included both copper and zinc. The camel was characterized both by a high individual variability in SOD activity values and a negative relationship with plasma zinc concentrations, which was opposite to what we observed in the cows. In the camels, the zinc plasma levels did not change when the copper plasma levels increased. Since the competition between copper and zinc on SOD binding sites is favorable to copper, the relationship between zinc and SOD will tend to be reduced. In cows, zinc and copper plasma concentration tended to increase simultaneously. So, the competition between copper and zinc on SOD binding-sites was less efficient. However, the interaction between copper and zinc could partly explain the weak relationship with cow SOD activity.

It was noteworthy that the plasma zinc concentration in the camel was not influenced by the dietary zinc concentrations. This lack of variation in camel plasma zinc levels was previously observed in different field or experimental conditions (Bengoumi *et al.*, 1993; Bengoumi *et al.*, 1995b). It appears that the plasma zinc concentration in the camel is not a good indicator of dietary zinc status or SOD activity.

Comparative manganese metabolism

During periods I and III, the ratio excreted/intake was around 20% on average and slightly increased during supplementation period. As for copper and zinc, the apparent absorption then decreased when mineral supplementation occurred. However, the manganese absorption is low in most ruminants. According to Khalili *et al.* (1993), 95% of this element is excreted in cattle.

The camel could have a higher ability to absorb manganese than other ruminants because of a low probability of inter-spacey difference in urinary excretion. In lack of noticeable liver storage (Abu Damir *et al.*, 1983; Awad & Berschneider, 1977; Wensvoort, 1992) and kidney storage (Abu Damir *et al.*, 1983) or adipomuscular storage (Zamil-el-Faer *et al.*, 1991), other tissues such as bone tissue could be provided sufficiently by the basal diet in spite of the low well-known manganese content of molasses.

Comparative iron metabolism

Primary iron deficiency does not occur in grazing ruminants in natural conditions (Underwood, 1977). In our trial, the iron faecal concentration (most important method of excretion) highly increased during the mineral supplementation period. As the nutritional iron supply did not change, this result was due essentially to a high interaction with other elements from mineral supplementation. In other words, the trace element supplementation has modified iron absorption in the intestinal tract. An important negative interaction between trace elements occurred. Copper, zinc and manganese depressed the iron absorption as a negative interaction copper-zinc due to a competition in intestinal absorption (Bengoumi *et al.*, 1995a; Yu & Beynen, 1994). However, this depressing effect seems less important in camels than in cows.

CONCLUSION

It is doubtless that the camel regulates the main trace elements (copper and zinc) at lower levels than the cow. The observed plasma concentration and liver concentration were always around twice as important in the cow as in the camel. Such results suggest that the trace element requirements seem to be lower in the camel, especially for zinc. However, in natural conditions, camels have the capacity to choose their forages more efficiently. The trace element excretion pattern seems partially different between camel and cow. If the general trends are comparable, the absorption ability is either clearly better in camels (manganese for example), or slightly less depressed than in cows in the case of mineral supplementation (copper, zinc and iron). These results suggest lower trace elements requirements in the camel and the ability for this animal to anticipate transitory mineral under-nutrition periods. It reveals a thrifty physiology, characteristic of the desert animals.

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