

Anti-Hyperglycemic Activity of Camel Milk in Rat Models of Diabetes / Insulin Resistance

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ABSTRACT:

The anti-diabetic activity of camel milk in type 1 diabetics is attributed to the significant amounts of insulin / insulin like activity present in it. However, evidence for the anti-diabetic activity of camel milk is scanty and equivocal. This study evaluated the anti-hyperglycemic effect of camel milk using drug (Streptozotocin) and diet (high sucrose) induced rat models for diabetes / insulin resistance and also assessed the heat stability / susceptibility of the effect. Diabetes / insulin resistance were induced in male, weanling WNIN rats using STZ or high sucrose diet. Camel / cow milk (raw or pasteurized or boiled) were administered to rats in the form of freeze-dried powder mixed with diet, at a dose of one gram / rat / day, for two months. Oral glucose tolerance, plasma insulin response and plasma lipid profile were determined after 30 and 60 days of feeding. At the dosage level tested, Camel milk or cow milk (raw, pasteurized or boiled) had no anti-hyperglycemic effect in the streptozotocin induced diabetes in WNIN rats. However in high sucrose diet induced rat model of insulin resistance, they had comparable anti-hyperglycemic effect and the effect was heat stable in both the milks. In conclusion, the anti-hyperglycemic effect of camel milk is not different from that of cow milk in both the models of hyperglycemia (i.e., drug or diet induced) and the effect in diet induced model is heat stable.

Keywords: Antidiabetic activity, Camel milk, Cow milk, Diabetic rat models, Hypoglycemic effect, Insulin resistance, Pasteurization, Type I Diabetes, Type II Diabetes

INTRODUCTION

Medicinal properties of camel milk are known for centuries. Traditionally, it has been used in the treatment of diabetes, asthma, ulcers, milk allergies etc. The anti-diabetic activity of camel milk has been reported recently in type 1 diabetic subjects administered 500 ml of raw camel milk per day (1-2) and it is attributed to the significant amounts of immuno-reactive insulin present in it (3). Hypoglycemic effect of camel milk has also been reported in streptozotocin-induced hyperglycemic rats (4). However, the evidence available so far, for the anti-diabetic activity of camel milk is scanty and equivocal at best. Therefore anti-hyperglycemic effect of camel milk has been evaluated in diet (high sucrose) and drug (Streptozotocin) induced models of insulin resistance / hyperglycemia in the Wistar albino rats.

Camel milk is reported to be safe even if consumed in raw form and it is reported to manifest anti-hyperglycemic effects in type 1 diabetic patients consuming raw camel milk (1-2). Similar effects if any in type 2 diabetes have not been reported till date. Cow or buffalo milk, the two most commonly consumed cattle milks are always consumed after pasteurization or boiling. Indeed, earlier studies in the Raika community of Rajasthan, the traditional camel rearing community in the country, indicated that camel milk was consumed by them mostly after boiling, in the form of tea (5). Therefore it was considered pertinent not only to assess the anti-hyperglycemic properties of camel milk but also determine whether this effect was resistant or susceptible to heat treatment. The heat stability / susceptibility of the anti-hyperglycemic effect were assessed by subjecting the camel milk to pasteurization or boiling. Appropriate controls were maintained with cow milk subjected to similar heat treatments.

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MATERIALS AND METHODS

Experimental Methods and Procedures:

A. Freeze Drying of camel and cow milk (raw, pasteurized and boiled)

Fifty liters each of camel milk and cow milk were used for this study. The milk samples were divided in to three aliquots of 17, 17 and 16 liters each. While one aliquot of each milk was freeze dried as such (raw), the other two aliquots were either pasteurized (heating at 62 °C for 30 minutes) or boiled for 10 minutes, cooled to room temperature and freeze dried. Freeze drying of the different milk samples was carried out in the industrial freeze driers at DFRL and CFTRI, Mysore, India. The freeze-dried powders were stored in vacuum-sealed pouches at 4 °C till use. Nature of diets fed to rats in different sub-groups of two experimental groups (STZ induced type 1 diabetes model versus Sucrose diet induced type 2 diabetes models) are detailed in Tables 1 & 2 respectively. The macro nutrient composition of the two milk samples was determined by standard methods and is given in table 3.

Table 1. Nature of diet fed to rats in "Streptozotocin induced model for type 1 Diabetes"

Group	Nature of diet
Con	Control diet
STZ Con	Control diet (Experimental control)*
STZ camR	Control diet + camel milk (raw)*
STZ camP	Control diet + camel milk (pasteurized)*
STZ camB	Control diet + camel milk (boiled)*
STZ cowR	Control diet + cow milk (raw)*
STZ cowP	Control diet + cow milk (pasteurized)*
STZ cowB	Control diet + cow milk (boiled)*
	(* STZ injected intra-peritoneal @ 40 mg / Kg body weight)

Table 2. Nature of diet fed to rats in "Diet induced model for type 2 Diabetes / insulin resistance"

Group	Nature of diet
Con	Control (AIN 93) diet
SUC Con	High (65 %) sucrose diet (Experimental control)
SUC camR	High (65 %) sucrose diet + camel milk (raw)
SUC camP	High (65 %) sucrose diet + camel milk (pasteurized)
SUC camB	High (65 %) sucrose diet + camel milk (boiled)
SUC cowR	High (65 %) sucrose diet + cow milk (raw)
SUC cowP	High (65 %) sucrose diet + cow milk (pasteurized)
SUC cowB	High (65 %) sucrose diet + cow milk (boiled)

B. WNIN Rat Models for Diabetes / Insulin Resistance

All animal experimental procedures were carried out in accordance with the 'principles of laboratory animal care' (6) and with the approval of the "Institute's ethical committee on animal experiments" at National Institute of Nutrition, Hyderabad, India.

Male, weanling, WNIN rats obtained from National Centre for Laboratory Animal Sciences, National Institute of Nutrition, Hyderabad, India were used in these experiments. The animals were fed *ad libitum* an AIN 93 diet and had free access to distilled water. Type 1 or Type 2 diabetes / insulin resistance was induced in these rats by administering a single intra-peritoneal dose of Streptozotocin (STZ) (@ 40 mg/kg body weight) or feeding a diet containing 65% sucrose (instead of starch) respectively.

i. Streptozotocin Induced Model for Type 1 Diabetes

Rats (n = 80) were divided in to eight groups of ten each and fed the control AIN 93 diet as mentioned in table 1 for a period of sixty days. Type 1 diabetes was induced in seven groups of rats (except controls) by a single intra-peritoneal injection of Streptozotocin (STZ @ 40 mg / Kg body weight) on day one of the experiment and the animals received their respective diets as mentioned in table 1 for sixty days from the day STZ was injected.

ii. Diet Induced Model for Type 2 Diabetes / Insulin Resistance

Rats (n = 80) were divided in to eight groups of ten each. While control rats received the AIN 93 diet, insulin resistance / type 2 diabetes was induced in the other seven groups of the rats by feeding them AIN 93 diet containing 65 % sucrose. Animals received their respective diets as mentioned in table 3 for sixty days from day one of the experiment. Various parameters were determined on day 30 and 60 of feeding, in six animals per treatment group.

iii. Administration of Camel / Cow Milk to Diabetic Rats

Camel / cow milk (raw or pasteurized or boiled) were administered to the rats in the form of freeze-dried powders mixed with diet, at a dose of one gram of powder / rat / day, starting from the day they were injected STZ or started receiving high sucrose diet. The quantity of camel / cow milk powder fed to the rats in this study corresponds approximately to the daily consumption of 500 ml of camel milk by type 1 diabetic patients, which was reported earlier to decrease their daily requirement of insulin and improve their fasting plasma glucose levels (1-3, 5).

C. Anti-Hyperglycemic / Insulin Like Effect of Camel / Cow Milk

i. Insulin Resistance / HOMA IR

The animals were fasted overnight and blood samples drawn from supra orbital sinus in accordance with NIH protocol. Plasma glucose (glucose oxidase / peroxidase kit, Biosystems, Spain) and insulin (RIA kit for rat insulin from Linco Research, U S A) were determined in these samples and the animals' insulin resistance status was assessed by computing the HOMA IR index as described by us earlier (7)

$$\text{HOMA IR} = \frac{\text{Fasting plasma glucose mmol / l} \times \text{Fasting plasma Insulin } \mu\text{U/l}}{22.5}$$

ii. Oral Glucose Tolerance Test (OGTT)

After collecting the fasting blood sample, the animals were administered a glucose solution (40 g / dl in distilled water) through an oral gavage @ 250 mg / Kg body weight and blood samples were drawn from the tail vein at 30, 60 and 120 minutes after the glucose load. Plasma glucose and insulin levels were determined in all the blood samples and the area under the curve (AUC) for glucose and insulin during the OGTT were computed using the Trapezoid formula described earlier (7, 8). While insulin AUC was used to assess the animals' capacity for insulin secretion to an acute challenge of glucose load, the ratio of glucose AUC / insulin AUC during the OGTT was used as a measure of assessing insulin resistance in the animals post-prandially.

D. Plasma Lipid Profile

The effects if any of STZ treatment / high sucrose feeding on the rats' plasma lipid profile and its modulation by feeding camel / cow milk was assessed by determining the levels of triglycerides (Glycerol phosphate oxidase/ peroxidase kit by Biosystems S.A., Barcelona, Spain,), non-esterified fatty acids (kit supplied by RANDOX Laboratories, Antrim, UK), total cholesterol and HDL-cholesterol (kits supplied by Biosystems S.A., Barcelona, Spain,) in the fasting blood plasma.

E. Heat Sensitivity / Stability of the Anti-Hyperglycemic Effect

The heat sensitivity / stability of the anti-hyperglycemic effect was assessed by determining the above parameters in STZ treated / high sucrose diet fed rats receiving pasteurized or boiled camel / cow milk along with their diet.

F. Statistical Analysis

Data was analyzed statistically SPSS version 10. All values are reported as mean \pm SE. Comparison between control (group 1) and experimental animals (group 2) in both the experiments was done by student's t-test. Comparison between Experimental controls (group 2) and other groups (groups 3-8) was done using one-way ANOVA followed by the multiple range test / least significance difference (LSD) method as appropriate. Comparisons considered were: Control (group 1) vs. Experimental control (group 2) and Experimental control (group 2) vs. rest of the groups (groups 3-8). The differences were considered significant if p was at least <0.05.

RESULTS

The nutrient composition of the camel and cow milk used in these studies is given in Table 3.

Table 3. Nutrient composition of camel milk and cow milk

Nutrient (g/100 ml)	Camel milk	Cow milk
Moisture	86.3	84.6
Protein	2.32	3.33
Fat	3.86	3.73
Ash	0.79	0.72
Crude Fiber	Nil	Nil
Carbohydrate	6.73	7.62
Energy (KCal/100 ml)	70.9	77.4

A. Effect of Camel /Cow Milk in Streptozotocin Induced / Type 1 Diabetes Model

Streptozotocin (STZ) injection, as expected significantly (compared to controls) increased blood glucose levels and decreased the body weight of the rats by 30 days of feeding and this change persisted till 60 days of feeding. It resulted in a significant increase in fasting plasma glucose and glucose AUC during OGTT and significantly decreased fasting plasma insulin and insulin AUC during OGTT. As a corollary, HOMA IR and the ratio of glucose AUC / insulin AUC during OGTT were higher in STZ treated animals compared to controls. However, plasma lipid profile was comparable among the control and STZ treated rats (Table 4).

Table 4. Effect of Streptozotocin treatment on glucose metabolism and plasma lipid profile of WNIN rats after 60 days of feeding.

Parameter	Control (Con)	STZ treated (STZ Con)
Body Weight (gms)	345 ± 14.5 ^a	158 ± 4.37 ^b
Fasting Glucose (mmol/L)	5.79 ± 0.105 ^a	11.2 ± 3.40 ^b
Fasting Insulin (pmol/L)	242 ± 15.2 ^a	123 ± 8.16 ^b
HOMA-IR	4.33 ± 0.298	8.51 ± 3.28
Glucose AUC (mmol/L/hr)	9.10 ± 0.448 ^a	34.4 ± 7.82 ^b
Insulin AUC (pmol/L/hr)	659 ± 56.1 ^a	263 ± 16.1 ^b
Glucose AUC / Insulin AUC	0.014 ± 0.001 ^a	0.132 ± 0.031 ^b
Total cholesterol (mmol/L)	1.36 ± 0.101	1.63 ± 0.280
HDL cholesterol (mmol/L)	0.095 ± 0.006	0.105 ± 0.015
Triglycerides (mmol/l)	0.419 ± 0.078	0.342 ± 0.059

Values are mean ± SE (n = 6). Values with different superscripts (in a row) are significantly different from each other by Students "t" test by at least p ≤ 0.05

Feeding camel milk (raw, pasteurized or boiled) for two months to STZ treated rats neither alleviated nor aggravated the changes in plasma glucose and insulin caused by STZ treatment. Similarly, feeding cow milk (raw, pasteurized or boiled) also had no significant effect in general, on any of the parameters mentioned above. It was however perplexing that fasting plasma insulin levels were significantly higher in STZ treated rats fed pasteurized cow milk (STZ cowP) but not in any other group of rats (Table 5).

Table 5. Effect of camel / cow milk (raw/pasteurized / boiled) on STZ induced changes in fasting plasma glucose, insulin and oral glucose tolerance in WNIN rats after 60 days of feeding.

Group	Fasting glucose (mmol/L)	Fasting Insulin (pmol/L)	HOMA IR	Glucose AUC (mmol/L/hr)	Insulin AUC (pmol/L/hr)	Glu AUC / Ins AUC
STZ Con	11.2 ± 3.40	123 ± 8.16	8.51 ± 3.28	34.4 ± 7.82	263 ± 16.1	0.132 ± 0.031
STZ camR	8.21 ± 1.64	142 ± 11.4	7.25 ± 0.954	26.7 ± 2.39	266 ± 14.4	0.101 ± 0.012
STZ camP	8.61 ± 2.30	117 ± 9.33	6.38 ± 1.48	27.0 ± 0.49	248 ± 29.4	0.107 ± 0.012
STZ camB	5.04 ± 1.33	160 ± 7.70	5.19 ± 1.35	27.7 ± 4.10	291 ± 38.8	0.102 ± 0.029
STZ cowR	7.05 ± 2.12	145 ± 11.1	6.75 ± 2.16	26.3 ± 2.92	265 ± 21.2	0.100 ± 0.014
STZ cowP	10.2 ± 2.75	193 ± 25.6 ^a	12.9 ± 4.08	32.7 ± 5.93	274 ± 26.3	0.125 ± 0.024
STZ cowB	4.77 ± 0.407	131 ± 5.25	3.99 ± 0.182	25.5 ± 1.77	257 ± 9.84	0.099 ± 0.010

Values are mean ± SE (n = 6). Values in a column with superscript 'a' are significantly different at p < 0.05 by one way ANOVA / LSD tests.

Similar to their effects on glucose metabolism, neither camel milk nor cow milk (raw, pasteurized or boiled) in general had any significant effect on the plasma lipid profile or free fatty acid levels (Table 6).

Surprisingly however, STZ treated rats receiving pasteurized cow milk (STZ cowP) had significantly higher plasma total cholesterol and free fatty acids than just STZ treated rats.

Table 6. Effect of camel / cow milk (raw/pasteurized / boiled) on STZ induced changes in plasma lipid profile in WNIN rats

Group	Total cholesterol (mmol/L)	HDL cholesterol (mmol/L)	Triglycerides (mmol/L)	Free fatty acids (mmol/L)
STZ Con	1.63 ± 0.280	0.105 ± 0.015	0.342 ± 0.059	0.257 ± 0.039
STZ camR	1.88 ± 0.124	0.101 ± 0.022	0.640 ± 0.285	0.222 ± 0.061
STZ camP	1.91 ± 0.142	0.146 ± 0.030	0.348 ± 0.066	0.365 ± 0.043
STZ camB	1.82 ± 0.258	0.100 ± 0.010	0.456 ± 0.083	0.186 ± 0.061
STZ cowR	1.91 ± 0.082	0.123 ± 0.026	0.560 ± 0.153	0.327 ± 0.093
STZ cowP	2.37 ± 0.254 ^a	0.123 ± 0.015	0.543 ± 0.168	0.543 ± 0.018 ^a
STZ cowB	1.82 ± 0.025	0.087 ± 0.017	0.514 ± 0.236	0.648 ± 0.084

Values are mean ± SE (n = 6). Values in a column with superscript 'a' are significantly different at p < 0.05 by one way ANOVA / LSD tests.

Effects of Camel / Cow Milk in High Sucrose Feeding Induced Insulin Resistance / Diabetes

Feeding 65% sucrose in the diet for two months (Suc con) had no significant effect on the body weights of the rats (Table 7). As expected, their fasting plasma glucose levels were significantly higher than those fed AIN 93 control diet, but no significant effect was seen on fasting plasma insulin levels, HOMA IR, AUC of glucose and insulin during OGTT. .

Table 7. Effect of high sucrose feeding on glucose metabolism and plasma lipid profile of WNIN rats after 60 days of feeding

Parameter	Control (Con)	High Sucrose diet (Suc con)
Body Weight (gms)	263 ± 16.2	250 ± 13.4
Fasting Glucose (mmol/L)	5.34 ± 0.146	6.29 ± 0.377 ^a
Fasting Insulin (pmol/L)	152 ± 26.1	194 ± 13.6
HOMA-IR	5.43 ± 0.972	7.80 ± 0.300
Glucose AUC (mmol/L/hr)	14.3 ± 0.810	15.5 ± 0.898
Insulin AUC (pmol/L/hr)	539 ± 75.0	459 ± 59.2
Glucose AUC / Insulin AUC	0.029 ± 0.004	0.036 ± 0.004
Total cholesterol (mmol/L)	1.71 ± 0.200	1.80 ± 0.098
HDL cholesterol (mmol/L)	1.15 ± 0.057	1.24 ± 0.096
Triglycerides (mmol/L)	0.427 ± 0.057	0.673 ± 0.145
Free fatty acids (mmol/L)	0.591 ± 0.043	0.735 ± 0.076

Values are mean ± SE (n = 6). Values in a column with superscript 'a' are significantly different at p < 0.05 by one way ANOVA / LSD tests.

Feeding raw or boiled camel milk to high sucrose diet fed rats (Suc camR and Suc camB) significantly decreased fasting plasma glucose levels (Table 8) compared to those fed high sucrose diet alone (Suc con). It was surprising that pasteurized camel milk (Suc camP) did not show any such effect in these rats. On the other hand none of the three camel milk regimes affected fasting plasma insulin levels. Interestingly, rats fed cow milk (raw, pasteurized and boiled) also showed similar anti-hyperglycemic effects. Whereas feeding camel milk (raw, pasteurized and boiled) had no significant effects on AUC glucose, AUC insulin and AUC ratio during OGTT in high sucrose diet fed rats, cow's milk decreased AUC ratio in high sucrose diet fed rats given raw and boiled but not pasteurized cow milk (Suc cowR and Suc cowB).

Table 8. Effect of camel / cow milk (raw/pasteurized / boiled) on high sucrose feeding induced changes in fasting glucose, insulin, oral glucose tolerance in WNIN rats after 60 days of feeding.

Group	Fasting glucose (mmol/L)	Fasting Insulin (pmol/L)	HOMA IR	Glu AUC (mmol/L/hr)	Ins AUC (pmol/L/hr)	Glu AUC / Ins AUC
Suc Con	6.29 ± 0.377 ^a	194 ± 13.6	7.80 ± 0.300	15.5 ± 0.898	459 ± 59.2	0.036 ± 0.004 ^a
Suc camR	4.81 ± 0.090 ^b	220 ± 33.0	7.54 ± 1.20	13.7 ± 0.323	543 ± 103	0.028 ± 0.003 ^a
Suc camP	5.82 ± 0.163 ^a	164 ± 18.4	5.28 ± 0.628	13.9 ± 1.07	452 ± 66.3	0.033 ± 0.004 ^a
Suc camB	4.51 ± 0.223 ^b	216 ± 53.2	7.58 ± 2.05	13.7 ± 0.883	245 ± 100	0.028 ± 0.005 ^a
Suc cowR	5.45 ± 0.325 ^b	227 ± 34.2	8.17 ± 1.37	14.4 ± 0.729	587 ± 52.8	0.023 ± 0.001 ^b
Suc cowP	5.68 ± 0.242 ^a	215 ± 43.3	8.05 ± 1.74	15.9 ± 0.936	546 ± 56.5	0.031 ± 0.003 ^a
Suc cowB	5.45 ± 0.161 ^b	249 ± 39.8	9.48 ± 1.68	14.1 ± 0.670	635 ± 80.5	0.024 ± 0.003 ^b

Values are mean ± SE (n = 6). Values in a column with superscript 'a' are significantly different at p < 0.05 by one way ANOVA / LSD tests.

High sucrose feeding for two months did not show any significant effects on lipid profile of rats (Table 7). Interestingly, feeding camel milk or cow milk (raw, pasteurized or boiled) to high sucrose diet fed rats for two months, significantly decreased total cholesterol levels (Table 9). However HDL cholesterol levels were also decreased in high sucrose diet fed rats given pasteurized camel milk (Suc camP) or raw cow milk (Suc cowR).

Table9. Effect of camel / cow milk (raw/pasteurized / boiled) on high sucrose feeding induced changes in plasma lipid profile in WNIN rats after 60 days of feeding

Group	Total cholesterol (mmol/L)	HDL cholesterol (mmol/L)	Triglycerides (mmol/L)	Free fatty acids (mmol/L)
Suc Con	1.80 ± 0.098 ^a	1.24 ± 0.096	0.673 ± 0.145	0.735 ± 0.076
Suc camR	1.34 ± 0.085	1.18 ± 0.092	0.415 ± 0.038	0.797 ± 0.133
Suc camP	1.28 ± 0.057	1.01 ± 0.055 ^a	0.446 ± 0.063	0.642 ± 0.036
Suc camB	1.40 ± 0.044	1.08 ± 0.033	0.449 ± 0.056	0.651 ± 0.062
Suc cowR	1.40 ± 0.020	1.00 ± 0.056 ^a	0.499 ± 0.074	0.716 ± 0.037
Suc cowP	1.36 ± 0.059	1.10 ± 0.079	0.553 ± 0.091	0.567 ± 0.045
Suc cowB	1.45 ± 0.038	1.07 ± 0.077	0.785 ± 0.174	0.615 ± 0.043

Values are mean ± SE (n = 6). Values in a column with different superscripts are significantly different at p < 0.05 by one way ANOVA / LSD tests.

DISCUSSION

The Present study evaluated and quantified the anti-hyperglycemic effect if any of camel milk using drug / diet induced rat models of diabetes / Insulin resistance. In addition the heat stability / susceptibility of the effect was also determined.

The nutrient composition of the camel and cow milk used in these studies were comparable in general excepting that cow milk had a slightly higher amount of protein and carbohydrate than camel milk. The values observed here are within the range of values reported earlier (9, 10).

Intra-peritoneal injection of STZ decreased the body weight of the rats in addition to the expected increase in fasting plasma glucose, glucose AUC during OGTT and decrease in fasting plasma insulin and insulin AUC during OGTT. In line with these findings, HOMA IR and the ratio of glucose AUC / insulin AUC during OGTT, the indicators of fasting and post prandial insulin resistance were higher in STZ treated rats than controls in general.

It was interesting that at 30 days of feeding, neither camel milk nor cow milk (raw, pasteurized or boiled) had any significant effect on any of the parameters studied, whereas the effects were observed only at 60 days of feeding

In contrast to earlier reports of a significant improvement in fasting blood glucose levels in diabetic rats given camel milk (4, 11), we observed that feeding camel milk raw, pasteurized or boiled, for a period of two months, neither alleviated nor aggravated the changes in glucose metabolism and insulin secretion caused by STZ in WNIN rats. In line with these findings, we observed that feeding cow milk (raw, pasteurized or boiled) also had no significant effect on any parameters of glucose tolerance and insulin secretion. However, it was perplexing that fasting plasma insulin levels were

increased in STZ treated rats fed pasteurized cow milk and we have no suitable explanation for this apparently discrepant finding at this time.

Our finding that feeding camel milk or cow milk (raw, pasteurized or boiled) for two months, in general had no significant effect on the plasma lipid profile or free fatty acid levels in STZ induced diabetic rats appears to be in line with similar reports of Agrawal et al (1, 2) in type 1 diabetic patients administered 500 ml of raw camel milk per day. However our observation that plasma total cholesterol and free fatty acids were significantly higher in STZ treated rats fed pasteurized cow milk (STZ cowP) than STZ treated controls, is surprising and seems inexplicable at this time point.

In contrast to previous reports showing beneficial effects of camel milk in type 1 diabetic subjects (1-2), the present results in STZ induced diabetic rat model seem to indicate that at the levels fed to rats in this study (which was reported to be effective in type 1 diabetic patients), camel or cow milk may not have any beneficial effects in terms of alleviating the changes caused by STZ treatment in glucose tolerance, insulin secretion / resistance and lipid profile in the rat model.

As expected, feeding 65% sucrose diet to rats for two months increased their fasting plasma glucose levels compared to those fed AIN 93 control diet. Although fasting plasma insulin and HOMA IR were higher in these rats than controls, the differences were not significant. Also, there was no significant effect on their oral glucose tolerance or plasma lipid profile.

Interestingly, feeding raw camel milk to high sucrose diet fed rats (Suc cam R) significantly decreased their fasting plasma glucose levels suggesting that at the level used in the study, camel milk had some anti hyperglycemic effect in high sucrose diet fed rats. The findings that pasteurization (Suc camP) did not influence this effect whereas boiling (Suc camB) affected it *albeit* partially appear to suggest the heat resistant nature of the anti-hyperglycemic effect of camel milk. That fasting plasma insulin levels were not affected by any of the camel milk regimes probably suggests that at the dose used, camel milk may not affect basal insulin secretion of the rats fed high sucrose diet. Alternately, this could mean that the anti-hyperglycemic effect of camel milk may not be due to modulation of insulin secretion in these rats.

It was of interest that high sucrose diet fed rats receiving cow milk (raw, boiled) for two months, also showed anti-hyperglycemic effect comparable to that of camel milk. These observations probably indicate that the anti-hyperglycemic effect observed was not specific to camel milk and that it was not heat labile. Indeed these observations are in line with those of Agrawal et al (4) in STZ treated rats that feeding camel milk and cattle milk *ad lib* for three weeks decreased blood glucose levels by 221 and 174 % respectively. However it is perplexing to note that Agrawal et al (4) observed a 154 % decrease in blood glucose levels of STZ induced hyperglycemic rats given water for three weeks.

In general during OGTT, glucose AUC was decreased and insulin AUC increased (except Suc camB) in high sucrose fed rats given camel milk (raw, pasteurized or boiled) compared to high sucrose fed rats (Suc con), *albeit* the differences were not significant. That almost similar effects were observed in the glucose tolerance parameters of high sucrose diet fed rats given cow milk (raw, pasteurized or boiled) appears to suggest that the anti-hyperglycemic effect observed in this study may neither be specific to camel milk nor heat labile, both in camel and cow milk. That the changes in fasting insulin and insulin AUC due to camel or cow milk were not significantly different from one another or from the high sucrose fed group seem to suggest that the anti-hyperglycemic effect of camel or cow milk may not involve modulation of insulin secretion in these rats. The differences in plasma total cholesterol, HDL cholesterol, triglycerides and free fatty acids in Wistar male rats fed high sucrose diet for two months, compared to controls, were not statistically significant.

Feeding camel or cow milk (raw, pasteurized or boiled) to high sucrose diet fed rats for two months decreased the total and HDL cholesterol levels. While the changes in total cholesterol levels were significant in all the groups, those in HDL cholesterol was significant in only the rats fed pasteurized camel milk (Suc camP) or raw cow milk (Suc cowR), *albeit* the reasons for these apparently discrepant findings are not clear to us at present. On the other hand changes in the levels of plasma triglycerides and free fatty acids in camel or cow milk fed rats were in general not significant statistically.

From these results in 65 % sucrose diet-fed WNIN rats it appears that at the dosage level used in this study, camel milk has some anti-hyperglycemic effect and the effect in general is heat resistant.

However considering that even cow milk had an anti-hyperglycemic effect of comparable magnitude in this rat model and that it also was heat resistant, it appears that camel milk may not be having any significantly higher anti-hyperglycemic effect than another commonly consumed milk like cow milk. Further, the anti-hyperglycemic effects of both camel and cow milk do not seem to be associated with modulation of insulin secretion in these rats.

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