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Study Review

The composition of camel milk: A meta-analysis of the literature data

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ABSTRACT

Camel milk composition from both dromedary and Bactrian species was described in several publications. Eighty-two references from scientific journals or grey literature were selected, and a meta-analysis was achieved including the gross composition of camel milk (fat matter, total protein, lactose, ash and dry matter). A high variability was observed in the published data. Two factors were specifically studied: the geographical origin of the data and the year of publication. The references from Asia gave results with higher values in all the components, except ash, probably linked to the camel species, the Bactrian camel being predominant in the area. Milk composition reported in East African references was higher in fat matter content compared to other references in Africa and Western Asia. The chronicle made it possible to distinguish four periods according to fat matter and total protein values. Personal data from Kazakhstan showed significantly higher fat matter and total protein contents, but a lower lactose content compared to other references from Central Asia.

Contents

1. Introduction

The milk composition of dairy animals has been widely studied throughout the world and thousands of references are available especially with regard to milk consumed by humans. The literature data mainly concerns cow milk, which represents 85% of the milk consumed in the world and, to a lesser extent, goat and sheep milk. Studies on other dairy animals (buffalo, yak, mare, and camel) are rather scarce, in spite of their nutritional interest. In this context, camel milk needs to be further investigated. There are only a few references on camel milk, whether they concern production (Faye, 2005) or composition aspects (Farah, 1993; Ramet, 1993). Yet camel milk is an important source of proteins for the people living in the arid lands of the world. Also, camel milk is known for its medicinal properties, which are widely exploited for human health, as in several countries from the ex-Soviet Union (Kenzhebulat et al., 2000) and developing countries (Mal et al., 2006). Camel milk is considered to have anti-cancer (Magjeed, 2005), hypo-allergic (Shabo et al., 2005) and anti-diabetic properties (Agrawal et al., 2003). A high content in unsaturated fatty acids contributes to its overall dietary quality (Karray et al., 2005; Konuspayeva et al., 2008). The low quantity of β-casein and the lack of β-lactoglobulin are linked to the

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Table 1
Exhaustive references ($n = 82$) on camel milk composition from the literature.

	Reference	FM	TP	L	DM	Ash	Country
1	Barthe (1905)	5.38	2.98	3.26	12.39	0.70	UD
2	Leese (1927)	2.90	3.70	5.80	13.00	0.60	East Africa
3	Davies (1939)	3.07	4.00	5.60	13.47	0.80	UD
4	Lampert (1947)	3.02	3.60	5.20	12.42	0.70	UD
5	Khersakov (1953)	4.47	3.50	5.00	13.67	0.70	URSS
6	Yasin and Wahid (1957)	2.90	3.70	5.80	13.30	0.70	Pakistan
7	Ohri and Joshi (1961)	3.78	3.95	4.88	13.57	0.95	India
8	El-Bahay (1962)	3.80	3.50	3.90	12.00	0.80	Egypt
9	Singh (1966)	2.90	3.90	5.40	13.00	0.80	India
10	Davies (1963)	3.00	3.90	5.50	13.20	0.80	Egypt
11	Khan and Appana (1965)	3.08	3.80	5.40	12.98	0.70	India
12	Jenness and Sloan (1969)	4.50	3.60	5.00	13.10	0.70	UD
13	Kon and Cowie (1972)	4.20	3.70	4.10	12.80	0.80	Pakistan
14	Knoess et al. (1986)	5.50	4.50	3.40	14.40	0.90	Egypt
15	Atherton and Newlander (1977)	5.38	2.98	3.26	11.62	0.70	Saudi Arabia
16	Knoess (1977)	5.50	4.50	3.40	14.30	0.90	Ethiopia
17	Knoess (1979)	4.30	4.60	4.60	14.10	0.60	Ethiopia
18	Elamin (1980)	4.00	3.60			0.80	Sudan
19	Yagil and Etzion (1980)	3.90	4.90	5.00	13.80	0.63	Israël
20	Mukasa-Mugerwa (1981)	4.33	4.02	4.21	13.36	0.79	Saudi Arabia
21	Dasai et al. (1982)	3.20	2.70	4.20	9.80	0.60	UD
22	El-Agamy (1983)	2.90	3.70	5.80	13.10	0.70	Egypt
23	Hjort af Ornas (1988)	5.40	3.00	3.30	13.70	0.70	Somalia
24	Sawaya et al. (1984)	3.60	2.95	4.40	11.74	0.79	Saudi Arabia
25	Gnan and Sherida (1986)	3.30	3.30	5.61	13.03	0.82	Lybia
26	Abdel-Rahim (1987)	3.20	4.00	4.80	13.40	0.70	Pakistan
27	Abu-Lehia (1987)	3.31	2.68	4.67	11.29	0.80	Saudi Arabia
30	Bachmann and Schulthess (1987)	4.60			15.40		Kenya (Somali)
29	Bachmann and Schulthess (1987)	3.60			11.20		Kenya (Rendille)
28	Hassan et al. (1987)	3.50	2.50	3.90	11.00	0.80	East Africa
31	Ellouze and Kamoun (1989)	3.55	2.29	4.69	11.40	0.90	Tunisia
32	Abu-Lehia et al. (1989)	3.80	4.00	5.50	14.20	0.80	East Africa
33	Farah and Rüegg (1989)	3.15	3.11	5.24	12.20	0.80	Kenya
34	Mehaia and Al-Kahnal (1989)	3.24	3.35	4.52	11.91	0.80	Saudi Arabia
35	Mohamed et al. (1989)	4.60	3.30		13.00	0.60	Somalia
36	Taha and Keilwein (1989)	5.22	3.19	5.00	14.50	0.80	Egypt
37	Abu-Lehia (1990)	3.83		4.00	13.66	0.85	Saudi Arabia
38	Bayoumi (1990)	3.60	3.27	5.53	13.20	0.80	Egypt
39	Gran et al. (1990)	2.58	2.15	4.83			Lybia
40	Jardali (1988)	3.70	3.45	4.62	12.63	0.74	East Africa
41	Elamin and Wilcox (1992)	3.15	2.81	4.16	10.95	0.83	Saudi Arabia
42	Farag and Kabary (1992)	3.90	3.10	4.47	12.36	0.80	Egypt
43	Mehaia (1993)	3.50	2.80	4.60	11.69	0.79	Saudi Arabia
44	Mehaia et al. (1995)	2.85	2.52	4.46	10.63	0.80	Saudi Arabia (Hamra)
45	Mehaia et al. (1995)	2.46	2.36	4.44	10.07	0.81	Saudi Arabia (Wadah)
46	Mehaia et al. (1995)	3.22	2.91	4.43	11.35	0.79	Saudi Arabia (Majaheim)
47	Mehaia (1996)	0.28	3.22	4.45	8.64	0.69	Saudi Arabia
48	Field et al. (1997)	5.70	3.00	2.40		0.80	Kenya
49	Abu-Lehia (1998)	3.20	3.20	4.95	12.15		Jordania
50	El-Agamy et al. (1998)	3.95	3.26	4.74	12.80	0.85	Egypt
51	Gnan et al. (1998)	2.58	2.15	4.83			Lybia
52	Indra and Erdenebaatar (1998)	6.40	4.80	4.70		0.80	Mongolia
53	Kamoun (1998)	3.76	3.43		12.13	0.81	Tunisia
54	Karue (1998)	5.60	3.42	3.65	12.14	0.86	Kenya
55	Larsson-Raznikiewicz and Mohamed (1998)	4.60	3.00		13.10	0.60	Somalia
56	Mehaia (1998)	3.90	2.54	4.71	11.94	0.79	Saudi Arabia
57	Ramdaoui and Obad (1998)	2.74	3.36	4.19	11.14	0.86	Morocco
58	Wangoh et al. (1998)	4.20	3.08	4.18	12.66	0.79	Kenya (Somali)
59	Wangoh et al. (1998)	4.81	3.31	4.28	13.44	0.83	Kenya (Turkana)
60	Wangoh et al. (1998)	4.29	3.13	4.05	12.45	0.82	Kenya (S × T)
61	Zhao (1998)	5.54	4.08	5.50	16.08	0.91	China (Bactrian)
62	Zhao (1998)	5.50	3.87	4.34	14.68	0.97	China (Bactrian)
63	Zhao (1998)	4.15	3.45	4.55	8.85	0.70	China (Dromedary)
64	Zia-Ur-Rahman and Straten (1998)	5.22	2.68	4.30	10.40	0.73	Pakistan I
65	Zia-Ur-Rahman and Straten (1998)	3.50	4.00	3.26	13.30	0.83	Pakistan II
66	Zia-Ur-Rahman and Straten (1998)	4.50	3.00	4.10	11.10	0.78	Pakistan III
67	Zia-Ur-Rahman and Straten (1998)	2.85	2.67		9.07		Pakistan
68	Dell'Orto et al. (2000)	2.56	3.19				UD
69	Guliye et al. (2000)	3.39	2.79	4.81	11.50	0.77	Kenya
70	Serikabeva and Toktamysova (2000)	5.17	4.45	4.82	15.51	0.68	Kazakhstan
71	Sharmanov and Zhangabylov (1991)		4.32	4.24	14.50		Kazakhstan
72	Urbisinov (1992)	5.10	4.26	3.84	14.35		Kazakhstan
73	Seitov (2005)	4.47	3.50	4.95	13.62		Kazakhstan
74	Attia et al. (2001)	1.20	2.81	5.40	9.61	0.99	Tunisia
75	Indra and Erdenebaatar (1998)	3.54	2.64		12.22		Mongolia Bactrian
76	Indra (2003)	5.45	4.43	4.76	15.54	0.90	Mongolie Bactrian

Table 1 (*Continued*)

	Reference	FM	TP	L	DM	Ash	Country
77	Indra (2003)	4.47	3.53	4.95	13.64	0.70	Mongolie Dromedary
78	Sela et al. (2003)	2.61	2.69	4.61		0.78	Israël
79	Wernery (2003)	3.50	3.35	4.75	10.75		Arab Emirates
80	Raghvendar et al. (2004)	2.30	2.3	4.05	9.50		India
81	Kouniba et al. (2005)	2.65	3.25	4.05	10.80	0.83	Morocco
82	El-Hatmi et al. (2006)	3.00	3.1	4.20		1.05	Tunisia

FM = fat matter; TP = total protein; L = lactose; DM = dry matter; ash = ash; UD = undetermined (within parentheses are the camel breeds or species).

Table 2
Mean and standard deviation of camel milk components in Kazakhstan for Bactrian camel, dromedary and hybrids (from after Konuspayeva, 2007).

Species	FM	TP	DM	L	Ash	*n*
Bactrian camel	6.67 ± 2.93	3.33 ± 0.74	13.07 ± 1.15	2.77 ± 0.96	–	56
Dromedary	5.94 ± 2.26	3.03 ± 0.76	$12{,}39 \pm 0.74$	3.12 ± 0.92	–	70
Hybrids	6.09 ± 1.81	3.28 ± 1.01	$11{,}91 \pm 0.74$	3.04 ± 0.60	–	20

FM: fat matter; TP: total protein; DM: dry matter; L: lactose.

hypo-allergic effect of camel milk. Other components such as lactoferrin, immunoglobulins, lysozyme or vitamin C were reported to play a central role in the determination of these properties (El-Agamy et al., 1996; Konuspayeva et al., 2007). Nevertheless, even these few references helped to achieve a comprehensive meta-analysis of the published data. The objective of the present paper was to propose a meta-analysis of the literature data concerning gross camel milk composition, by exhaustively taking into account the available data published in scientific papers in order to assess some variations especially in geographical location and according to year.

2. Materials and methods

2.1. Data origin

The references on camel milk were collected by consulting international databases and local archives of UCEC (Coordination Unit on Camel Farming) at CIRAD-France, which contained some references from the so-called "grey literature"[1]. As a whole, 82 references were reported (Table 1) and the oldest was Barthe's (1905). For each reference, the country origin was mentioned when available. When it was not, the reference was considered as undetermined (UD). One reference corresponding to our own results from Kazakhstan was added (Konuspayeva, 2007) in order to place these results among those of the literature review. This reference included the milk composition of the Bactrian camel, the dromedary and hybrids reared in similar conditions (Table 2).

2.2. Camel milk parameters

Only the main parameters of camel milk were taken into account: fat matter (FM), total protein (TP), lactose (L), dry matter (DM) and ash. In some cases, the data were missing for one or several parameters. As the number of missing data was rare, for further analysis, a value corresponding to the mean of the column was attributed.

2.3. Data analysis

The only available variation factors were the year of publication and the country where the milk analysis was performed. Other variations factors could have been taken into account, such as production rate, feeding conditions, or physiological stage. Unfortunately, these data were not generally available. The countries were grouped into wide geographical entities, namely, East Africa (EA), North Africa (NA), Western Asia (WA), Indian subcontinent (IN) and Asia (AS). Unspecified countries were grouped into the UD group. No references clearly originated from West Africa.

To take into account the year effect, changes in results based on the year of publication were reported in a chronicle for the main parameters (fat matter and total protein). A variance analysis was achieved in order to assess the geographical origin and group of years' effect.

To assess the results, a Principle Components Analysis (PCA) was applied to the table of references (Table 1) where groups of years and of countries were considered as illustrative variables. Data from Kazakhstan reported in Table 2 were added as supplementary references.

The R-software was used for all statistical analyses (Ihaka and Gentleman, 1996).

3. Results

The main composition of camel milk (in g/100 ml) according to the data in the literature was 3.82 ± 1.08 for FM, 3.35 ± 0.62 for TP, 4.46 ± 1.03 for lactose, 12.47 ± 1.53 for DM and 0.79 ± 0.09 for ash.

Globally, the number of references was balanced by group of countries (Table 3) and few references were undetermined. There was a greater number of data from East Africa. Except for ash, all the milk components were in significant higher concentration in camel milk from Asia. In the China, Mongolia, Kazakhstan and Russia group, the Bactrian double-humped camel was predominant. DM and FM were significantly higher in the East Africa group than in other African and Western Asia countries (Table 3).

As only few references were available every year, groups of years were identified by analyzing the time changing of two components (FM and TP). This analysis (Fig. 1 and Table 4) allowed identifying four main periods: a first period (from 1905 up to 1969) where FM was underestimated and TP overestimated compared to the mean; a second period (nine references between 1972 and 1982) where the published values were above the mean both for FM and TP; a third period (1983–1992) with FM and TP data corresponding to mean values; and a fourth period (1994–2006) with a high variability of the reported values but with the tendency to have underestimated data for both FM and TP. Fat matter concentrations were on average significantly higher in the second period, as well as for total protein. The dry matter content had been lower in the last period since 1994. The lactose content was significantly higher in the first and third periods. No significant differences occurred for ash content in camel milk.

The matrix correlation resulting of PCA (Table 5) and correlation circle (Fig. 2) showed a significant positive correlation between FM and TP and a negative correlation between FM and the lactose content. There is no correlation between TP and lactose. The ash content was not linked to the other parameters. The graphical representation of PCA confirmed those trends (Fig. 3): the Asian group was far away from the gravity centre of the main factorial

[1] Grey literature refers to publications (articles and other information) published outside the framework of commercial publishing houses, and without a commercial purpose; many of these publications are found on Internet.

Table 3
Mean and standard deviation of camel milk components according to the geographical origin of 82 literature references.

Zone	FM	TP	DM	L	Ash	*n*
Asia	5.07 ± 0.21**	4.02 ± 0.47**	13.86 ± 1.97**	5.33 ± 0.42*	0.79 ± 0.10	11
East Africa	4.14 ± 0.80*	3.33 ± 0.52	12.69 ± 1.11*	4.18 ± 0.72	0.76 ± 0.09	20
North Africa	3.50 ± 1.01	3.21 ± 0.60	12.53 ± 1.22	4.65 ± 0.67	0.84 ± 0.08*	16
Indian subcontinent	3.49 ± 0.85	3.36 ± 0.64	12.05 ± 1.61	4.45 ± 0.74	0.78 ± 0.07	12
Western Asia	3.31 ± 1.03	3.10 ± 0.62	11.62 ± 1.29	4.45 ± 0.40	0.78 ± 0.05	17
Undetermined	3.62 ± 0.81	3.34 ± 0.53	12.22 ± 1.22	4.49 ± 0.77	0.72 ± 0.07	6

FM: fat matter; TP: total protein; DM: dry matter; L: lactose.
* Significant level compared to the lowest value: $P < 0.05$.
** Significant level compared to the lowest value: $P < 0.01$.

Table 4
Mean and standard deviation of camel milk components according to the group of years of 82 literature references.

Year	FM	TP	DM	L	Ash	*n*
1905–1969	3.57 ± 0.83	3.68 ± 0.28**	13.01 ± 0.51**	5.06 ± 0.77*	0.75 ± 0.09	12
1972–1982	4.48 ± 0.81**	3.94 ± 0.77**	12.93 ± 1.50**	3.98 ± 0.61	0.75 ± 0.12	9
1983–1992	3.76 ± 0.74	3.22 ± 0.57	12.82 ± 1.24*	4.83 ± 0.61*	0.78 ± 0.06	23
1993–2006	3.78 ± 1.31	3.19 ± 0.60	11.98 ± 1.78	4.34 ± 0.54	0.81 ± 0.08	38

FM: fat matter; TP: total protein; DM: dry matter; L: lactose.
* Significant level compared to the lowest value: $P < 0.05$.
** Significant level compared to the lowest value: $P < 0.01$.

plan and placed at the left part of the plan, linked to high values in FM and TP; the other geographical groups were gathered except references from East Africa. The "Indian subcontinent group" was a very heterogeneous group. When the individual projections were analyzed on the main factorial plan, the references from India appeared widely separated from the references from Pakistan. These latter were in fact closer to the references from Western Asia. The references from the Western Asia group were the poorest in FM and TP which explained their projection at the right side of the factorial plan, opposite to Asian references. In the years' groups, the first period (1905–1969) was separated from the other groups and was close to references rich in TP.

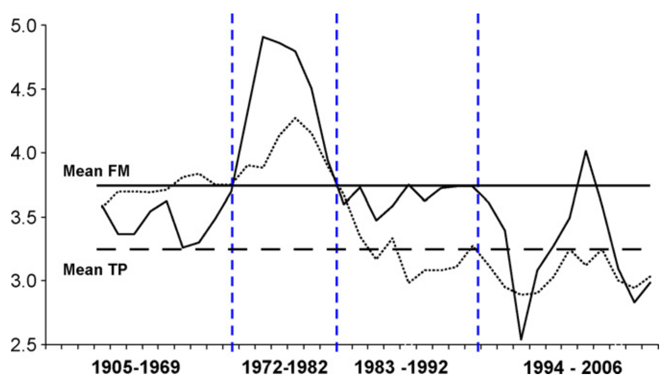

Fig. 1. Chronicle of the fat matter (____) and total protein (. . . . . .) content in camel milk according to 82 references from 1905 to 2006. The upper horizontal line represents the fat matter (FM) mean and the lower line, the total protein (TP) mean for all the references.

Table 5
Correlation matrix between the main components of camel milk according to 82 literature references (in bold, significant coefficient at $P < 0.05$).

Variables	FM	TP	L	DM	Ash
FM	**1**	**0.402**	**−0.355**	**0.565**	−0.001
TP		**1**	0.181	**0.645**	−0.060
L			**1**	0.159	−0.076
DM				**1**	0.046
Ash					**1**

FM: fat matter; TP: total protein; L: lactose; DM: dry matter.

The projection of our data from Kazakhstan was clearly far away from the gravity centre of the PCA analysis (Fig. 4). This position enlightened the peculiarity of camel milk composition in Kazakhstan which was much richer in fat matter and poorer in lactose.

4. Discussion

The variability of camel milk composition clearly depended on the geographical origin and year of publication of the published data. In most of the published data, other variation factors were not necessary mentioned, such as the physiological stage, feeding conditions, milk production, genetic or health status (Khan and Iqbal, 2001). Thus a part of the variability could have been linked to these factors.

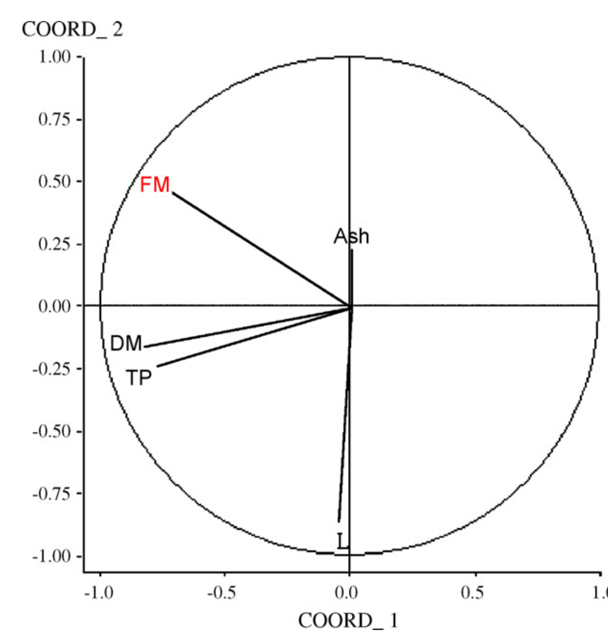

Fig. 2. Correlation circle of the variables (camel milk components: FM = fat matter; TP = total protein; L = lactose; DM = dry matter; ash) issued from 82 literature's references, on the main factorial plan (F1 and F2) resulting from Principles Components Analysis.

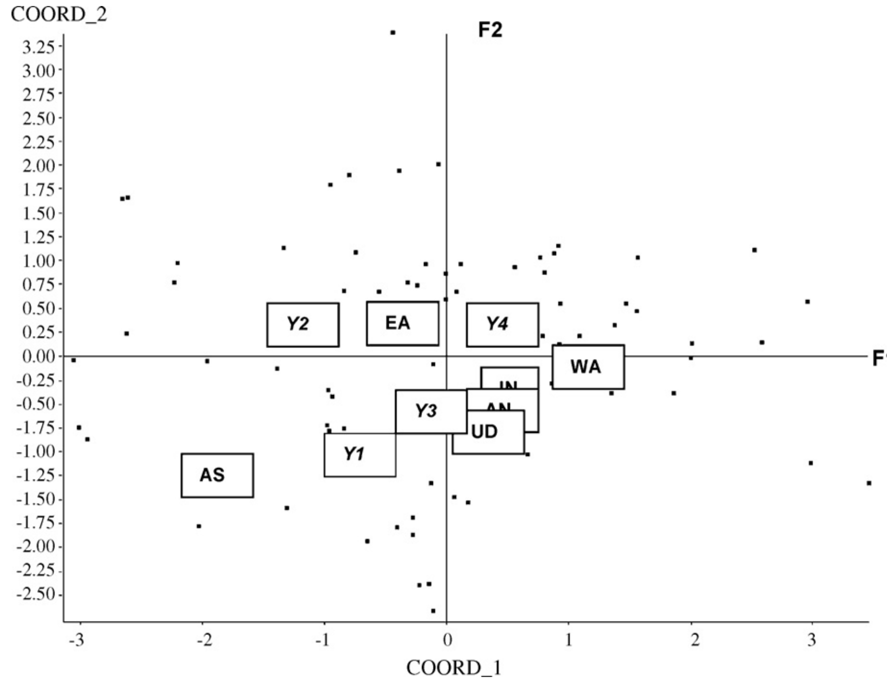

Fig. 3. Projection of the 82 references on camel milk composition, of the geographical origin (AS = Asia, EA = East Africa, AN = North Africa, IN = Indian sub-continent, WA = Western Asia and UD = undetermined) and of the group of year (Y1 = 1905–1972, Y2 = 1972–1982, Y3 = 1983–1992, and Y4 = 1994–2006) on the main factorial plan (F1 and F2) resulting of the Principal Components Analysis (explaining 67.5% of the variance).

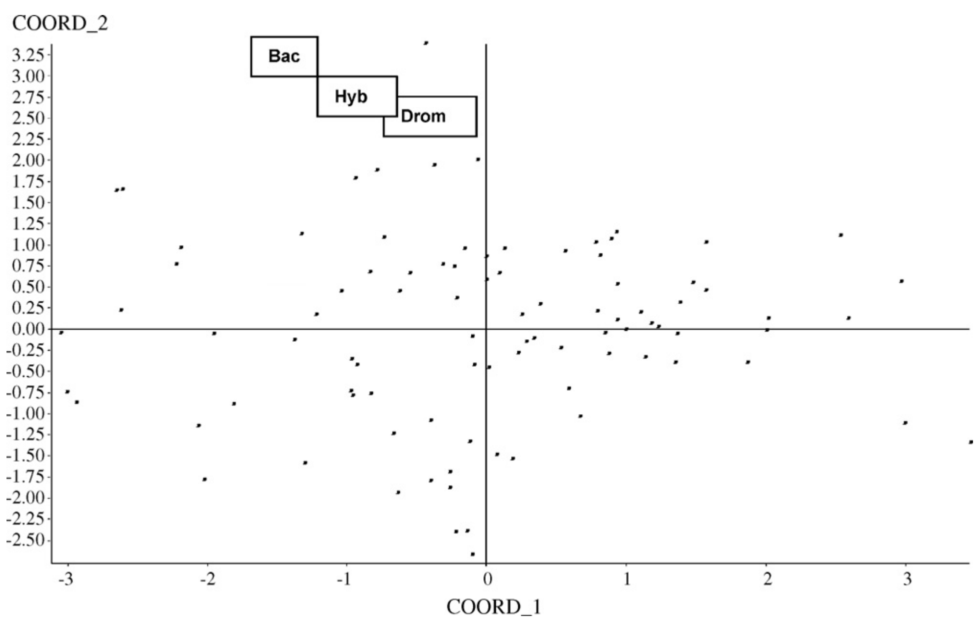

Fig. 4. Projection of the 82 references on camel milk composition, and of the data from Kazakhstan involving Bactrian (Bac), dromedary (drom) and hybrid (hyb) camels on the main factorial plan (F1 and F2) resulting of the Principal Components Analysis (explaining 67.5% of the variance).

The significant difference between references from Asian countries and the other references was linked to the species involved. Milk from the Bactrian camel was considered as having a higher fat matter content than milk from the dromedary (Zhao, 1998). Our results (Faye et al., 2008) involving both species and their hybrids under similar farming conditions showed some differences in the gross composition with a higher content of fat matter, total protein, vitamin C, calcium, phosphorus, and a lower content in lactose in Bactrian camel milk compared to dromedary milk. So, the positioning of Asian references in the multivariate analysis was linked to the predominance of double humped camels in the area. Among the references involving only the dromedary, data from East Africa showed a higher content in fat matter compared to other areas. The differences between camel breeds could play a certain role: East African camel breeds (Rendille, Somali, Turkana, and Gabbra) have been reported to be different from Western Asian and North African breeds (Jianlin et al., 2000).

The group of year effect could be linked to the analytical procedures. The oldest data could be taken into account with caution, but the highest observed values in fat matter and total protein linked to a lower value in lactose for the period 1972–1982 were difficult to interpret. The standard analytical methods for milk analysis were proposed at the beginning of the 1980s. This could explain the changes observed starting from 1983.

The place of our observations in Fig. 3 confirmed the specificity of references from Asian countries where the Bactrian camel was predominant. However, the milk composition of the dromedary from Kazakhstan was closer to the Asian references than to the Western Asian or African references. This result suggested that there were probably specific environmental conditions (notably feeding) explaining the particular richness of the camel milk in this country.

5. Conclusion

The present meta-analysis was limited to the gross composition and to the variations in geographical location, and according to year, only because the data on fine composition or on other variation factors are lacking in most of the references. However, the present results emphasize the importance of analytical procedures which explain the changes observed for one century. They also emphasize the complexity that underlies regional differences, which includes breeds (or species), feeding conditions and probably also seasonal or physiological variations. Because of the high interest of camel milk for the population in arid countries, it is expected that further studies will investigate the variations in fine composition and proceed with a similar meta-analysis with sufficient data.

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