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Correlation between the relative permittivity, conductivity, and qualitative indicators of bull and boar ejaculates

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ABSTRACT

The dielectric and electric properties (specific conductivity measured by four electrodes and two electrodes, real part of relative permittivity and high-frequency specific conductivity) of 31 ejaculates from bulls and 25 ejaculates from boars used for insemination were studied on the day of sampling and after 48 h. The correlation of the results with standard indicators of the quality of the ejaculate (sperm concentration, sperm activity and volume of the ejaculate) was investigated. The average concentration of bull sperm was 1.22 ± 0.46 mld cm^{-3}, of the filtered spermatic fraction of boar sperm 581.00 mil.cm^{-3}; the average sperm activity of bulls and boars was only $68.7 \pm 6.6\%$ and $78.0 \pm 4.8\%$, respectively; the average volume of the ejaculate of bulls and boars was 12.39 ± 4.72 and 242.00 ± 111.00 cm^3, respectively.

Correlations between the concentrations of the sperm of bulls and specific and high-frequency conductivity were always negative ($r_p = -0.09$ to -0.75), between the activity and specific four-electrode conductivity the correlation was positive ($r_p = 0.48$), between the volume of the ejaculate and specific conductivity as well as relative permittivity it was again negative ($r_p = -0.17$ to -0.72). In boars the correlations between sperm activity and all of the studied dielectric and electric properties were always positive.

KEY WORDS: conductivity, permittivity, ejaculate, bulls, boars

INTRODUCTION

The searching for methods to help evaluate the quality of ejaculates from farm animals sires used both in natural breeding and in artificial insemination has continued for many years. Based on experiences from insemination stations it is evident that the quality of the ejaculate from the same breeding animal is subject to changes. It is therefore necessary to apply several tests to evaluate each ejaculate (Kozumplík, 1990).

The physical properties of the ejaculate, and/or the dielectric and electric properties of biological material in general, have long been studied. Brandt (1963) found that, in most cases, the measured substance could be considered to be an imperfect dielectric with some conductivity arising in it only in an electric field that is variable in time, and associated with oscillation of molecules of the mass, with deformation, polarization etc.

A brief explanation of two parameters the dielectric constant and dielectric loss factor, is given by Tran et al. (1984), and a more detailed discussion is available in Metaxas and Meredith (1983). An experimental method for broadband measurements of dielectric properties of biological materials is presented by Tran et al. (1984) and Kraszewski et al. (1983).

Kozumplík and Kudláč (1980) found that the range of conductivity values in the ejaculate of boars at 25^0C in reciprocal ohms was (123.3 – 134.6) x 10^4 x $S.m^{-1}$. Katkov (1985) tested the resistance of bull sperm to high-voltage electric impulses. He found a high correlation between the resistance of the sperm membrane and unfavourable effect of freezing on this sperm resistance. Tran et al. (1984), Jain and Voss (1987), Kent (1987), Tran and Stuchly (1987), and Křivánek and Buchar (1993) measured the dielectric properties of muscles of pigs, poultry, fish, and also of milk and plant organs.

MATERIAL AND METHODS

The dielectric and electric properties of the ejaculate were studied in 37 clinically healthy breeding males (18 bulls and 19 boars); 31 ejaculates from bulls and 25 ejaculates from boars housed at insemination stations were investigated. The semen was collected from bulls and boars during the entire calendar year. Immediately after collection, operational spermatological examinations of the volume of the ejaculate and concentration and activity of the sperm were carried out. The volume of the ejaculate was based on calculations after determining the weight of the ejaculate, sperm concentrations were determined photometrically, their activity was evaluated subjectively by one and the same worker.

Within 3 h of collection, and again after 48 h, the dielectric and electric properties of the ejaculate were measured at the Mendel University of Agriculture and Forestry in Brno.

The measurements included the specific conductivity of the ejaculate – measured by four-electrode and two-electrode methods, the real part of relative permittivity and the high-frequency specific conductivity.

The values of ejaculate volume, activity and concentration of sperm as well as the values of dielectric properties were evaluated statistically. The constants, where less than 8 measured values were obtained, were not evaluated for operational reasons (specific conductivity within 48 h of ejaculate collection, high-frequency conductivity in bulls).

Correlations between the respective indicators of ejaculate quality and their dielectric and electric properties were evaluated by applying the calculated phenotypic correlations.

RESULTS

The average volume of the ejaculate of the studied bulls was found to be relatively high (12.39 cm^3), also the concentration of the sperm was very good; on the other hand, the average sperm activity (68.7%) was relatively low (Table 1). The average values of specific conductivity determined on the day of collection

TABLE 1

Average values of qualitative and quantitative indicators of the quality of the ejaculate and its dielectric properties in bulls

	Unit	n	x	s_x	V_x
Volume of ejaculate	cm^{-3}	31	12.39	4.72	39.2
Sperm concentration	mld x cm^{-3}	29	1.22	0.46	37.7
Sperm activity	%	31	68.7	6.6	9.6
Specific conductivity measured by the four-electrode method on the day of ejaculate collection	S x m^{-1}	20	0.82	0.07	8.4
Specific conductivity measured by the four-electrode method two days after ejaculate collection	S x m^{-1}	14	0.97	0.19	19.7
Specific conductivity measured by the two-electrode method on the day of ejaculate collection	S x m^{-1}	20	0.82	0.46	55.6
Specific conductivity measured by the two-electrode method two days after ejaculate collection	S x m^{-1}	14	1.02	0.51	50.1
Real part of relative permittivity two days after ejaculate collection		31	53.69	11.57	21.6
Real part of relative permittivity on the day of ejaculate collection		31	53.55	12.44	23.2
High-frequency specific conductivity on the day of ejaculate collection	S x m^{-1}	8	0.60	0.04	7.1
High-frequency specific conductivity on two days after ejaculate collection	S x m^{-1}	8	0.52	0.12	23.7

TABLE 2
Average values of qualitative and quantitative indicators of the quality of the ejaculate and its dielectric properties in boars

	Unit	n	x	s_x	V_x
Volume of ejaculate	cm^{-3}	25	242.00	111.00	45.9
Sperm concentration	mld x cm^{-3}	24	581.00	237.00	40.8
Sperm activity	%	24	78.00	4.80	6.2
Specific conductivity measured by the four-electrode method on the day of ejaculate collection	S x m^{-1}	15	1.52	0.22	18.8
Specific conductivity measured by the two-electrode method on the day of ejaculate collection	S x m^{-1}	15	0.99	0.45	45.8
Real part of relative permittivity two days after ejaculate collection		25	25.09	2.19	8.8
Real part of relative permittivity on the day of ejaculate collection		25	23.22	2.37	10.2
High-frequency specific conductivity on the day of ejaculate collection	S x m^{-1}	25	0.17	0.05	28.9
High-frequency specific conductivity on two days after ejaculate collection	S x m^{-1}	25	0.15	0.07	45.0

were similar in both measurements (i.e. the four-electrode as well as two--electrode) -- (0.82 $S.m^{-1}$), two days after collection they were nearly similar (0.97 and 1.02 $S.m^{-1}$). Neither did the values in the real part of relative permittivity on the day of collection and two days after collection differ much (53.69 and 53.55, respectively), also the values of high-frequency specific conductivity were very similar after two days (0.60 and 0.52, respectively). The two-electrode measurements of specific conductivity showed a high variability (55.6 and 50.1%, respectively).

The qualitative and quantitative indicators of boar ejaculates and their dielectric and electric properties are given in Table 2. The average volume of the ejaculate was 242.00 cm^3, the average sperm concentration was 581.00 mil. cm^3 and the activity measured by the four-electrode method on the day of ejaculate collection were higher than in bulls (1.05 $S.m^{-1}$). The average value of specific conductivity measured by the two-electrode method on the day of ejaculate collection was also higher in boars (i.e. 0.99 $S.m^{-1}$). The average real part of the relative permittivity on the day of collection was only a little higher (25.09) than two days later (23.22). The values of high-frequency specific conductivity on the day of collection (0.17 $S.m^{-1}$) differed little from those measured two days later (0.15 $S.m^{-1}$). The specific conductivity measured with the two-electrode method was again highly variable (45.8%), and so was the high-frequency specific conductivity measured two days after collection (45.0%).

TABLE 3

Calculated phenotypical correlations between the indicators of the quality of the ejaculate of bulls and their dielectric and electric properties

	Ejaculate volume	Sperm concentration	Sperm activity
Specific conductivity measured by the four-electrode method on the day of ejaculate collection	* – 0.36	** – 0.74	* 0.48
Specific conductivity measured by the four-electrode method two days after ejaculate collection	* – 0.30	* – 0.41	/
Specific conductivity measured by the two-electrode method on the day of ejaculate collection	– 0.17	– 0.09	0.08
Specific conductivity measured by the two-electrode method two days after ejaculate collection	** – 0.29	– 0.14	/
Real part of relative permittivity two days after ejaculate collection	** – 0.72	– 0.21	– 0.23
Real part of relative permittivity on the day of ejaculate collection	** – 0.67	– 0.15	/
High-frequency specific conductivity on the day of ejaculate collection	0.12	* – 0.32	– 0.01
High-frequency specific conductivity on two days after ejaculate collection	** 0.52	** – 0.75	/

* significant at $P \leq 0.05$
** significant at $P \leq 0.01$

Table 3 gives the calculated phenotypic correlation coefficients between the indicators of the quality of the ejaculate of bulls and the dielectric and electric properties of the ejaculates. Five correlations of intermediate values were found: between the ejaculate volume and real part of relative permittivity on the day of ejaculate collection ($r_p = -0.72$) (Figure 1) and two days after ($r_p = -0.67$) (Figure 2), and the high-frequency specific conductivity two days after ejaculate collection ($r_p = 0.52$) (Figure 3). Similarly, also between sperm concentration and specific conductivity measured by the four-electrode method on the day of ejaculate collection ($r_p = -0.74$) (Figure 4) and the high-frequency specific conductivity two days later ($r_p = -0.75$) (Figure 5).

In six cases the correlation was weak: it was negative between the volume of the ejaculate and specific conductivity measured by the four-electrode method on the day of collection ($r_p = -0.36$), similarly as two days later ($r_p = -0.30$),

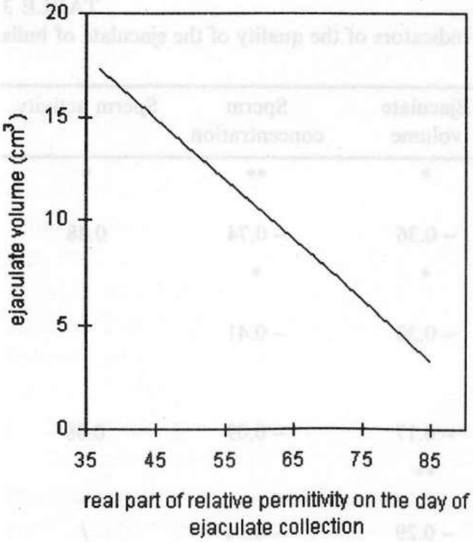

Figure 1. Relationship of the real part of relative permittivity on the day of ejaculate collection and ejaculate volume of the bulls

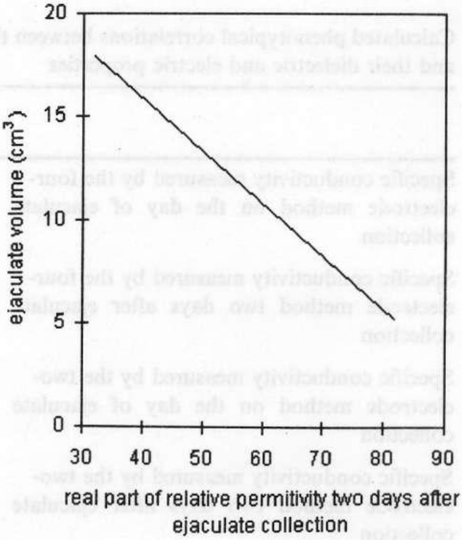

Figure 2. Relationship of the real part of relative permittivity on two days after ejaculate collection and ejaculate volume of the bulls

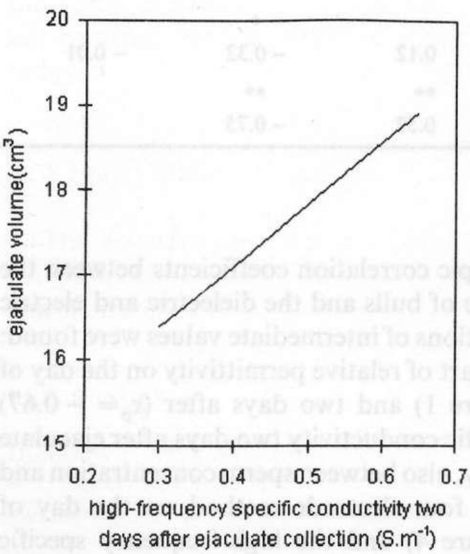

Figure 3. Relationship of the high-frequency specific conductivity on two days after ejaculate collection and ejaculate volume of the bulls

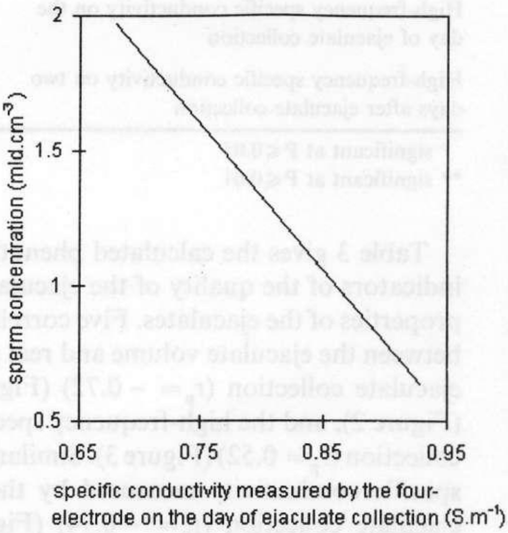

Figure 4. Relationship of the specific conductivity measured by four-electrode method on the day of ejaculate collection and sperm concentration of the bulls

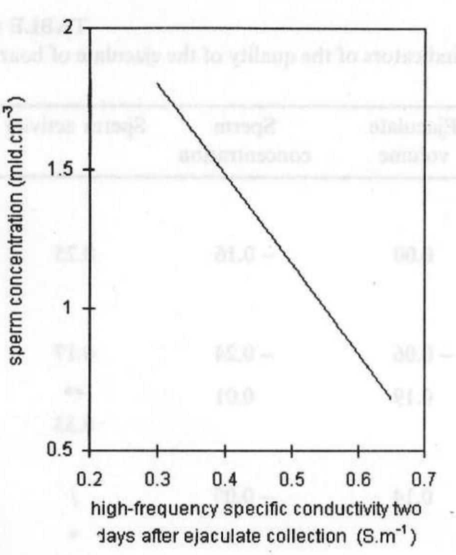

Figure 5. Relationship of the high-frequency specific conductivity on two days after ejaculate collection and sperm concentration of the bulls

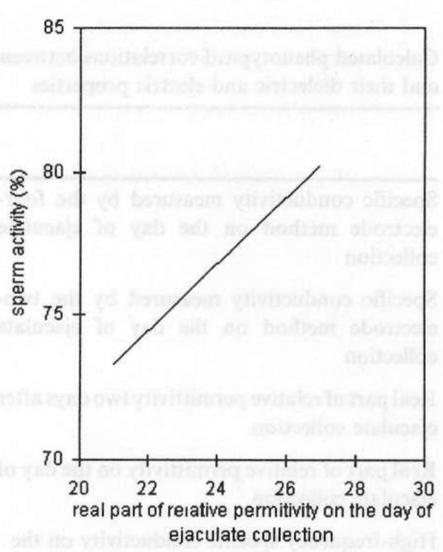

Figure 6. Relationship of real part of relative permittivity on the day of ejaculate collection and sperm activity of the boars

between sperm concentration and specific conductivity measured by the four-electrode method two days after collection ($r_p = -0.41$) and the high-frequency specific conductivity on the day of collection ($r_p = -0.32$). The correlation between sperm activity and specific conductivity measured by the four-electrode method on the day of collection was positive.

Table 4 shows the correlations between the quality of the ejaculate and the dielectric and electric properties of the ejaculate of boars. Moderate correlation was found only between the real part of relative permittivity on the day of collection and sperm activity ($r_p = 0.53$) (Figure 6), and a low one between sperm activity and high-frequency specific conductivity on the day of ejaculate collection ($r_p = 0.42$).

DISCUSSION

Sperm of good fertilizing capacity is the basic precondition for successful conception. The qualitative and quantitative indicators of ejaculates used for successive inseminations are evaluated using several special laboratory methods.

TABLE 4

Calculated phenotypical correlations between the indicators of the quality of the ejaculate of boars and their dielectric and electric properties

	Ejaculate volume	Sperm concentration	Sperm activity
Specific conductivity measured by the four-electrode method on the day of ejaculate collection	0.00	– 0.16	0.25
Specific conductivity measured by the two-electrode method on the day of ejaculate collection	– 0.06	– 0.24	0.17
Real part of relative permittivity two days after ejaculate collection	0.19	0.01	** 0.53
Real part of relative permittivity on the day of ejaculate collection	0.14	– 0.05	/
High-frequency specific conductivity on the day of ejaculate collection	0.20	0.00	* 0.42
High-frequency specific conductivity on two days after ejaculate collection	0.04	– 0.12	/

* significant at $P \leqslant 0.05$

** significant at $P \leqslant 0.01$

The high average volume of ejaculates of bulls (i.e. 12.39 ± 4.72 cm^3) found in the present study substantially exceeded the average value of – 6.00 cm^3 given, for instance, by Gamčik et al. (1992); the reason is that bulls having larger ejaculate volumes were intentionally preferred for investigations of the dielectric and electric properties of sperm. The average concentration of bull sperm considerably exceeded the demands of the Czech standard for the minimal concentration of the bull ejaculate (i.e. 0.70 mld. cm^{-3}). On the other hand, the average activity of bull sperm (68.7 ± 6.6%) was lower than required by the Czech standard (70.0%). The values found give a complete picture of the existing situation, since ejaculates both from bulls in full production and from bulls „on the waiting list", were evaluated.

In boars, the average volume of the filtered spermatic fraction of the ejaculate was 242.00 ± 111.00 cm^3 (the Czech standard requires 100.00 cm^3) and is in accordance with data given by Kozumplík and Kudláč (1988), among others. Also the average sperm concentration (581.00 ± 237.00 mil.cm^{-3}) markedly exceeded the value given in the Czech standard (i.e. 150.00 mil.cm^{-3}). The average sperm activity of the native ejaculate of boars (78.0 ± 4.8%) was also higher than that given in the Czech standard (70.0%). Negative correlations between sperm volume and concentration and the dielectric and electric properties of the ejaculate could be due to the thickness of this colloidal solution, but it also could be due to the correlation of probe efficiency and total ejaculate volume.

Evaluations of the correlation between the respective values of the quality of the ejaculate and its dielectric and electric properties were based on the following calculated phenotypic correlations:

- between the volume of bull ejaculates and all of the studied dielectric and electric properties, with the exception of high-frequency specific conductivity; negative correlations were always found, ranging between $r_p = -0.17$ and -0.72. In contrast, correlations between the volume of the ejaculate and the high-frequency specific conductivity were positive, i.e. $r_p = 0.12$ and 0.52, respectively;
- correlations between sperm concentration and the dielectric and electric properties were always negative, i.e. $r_p = -0.09$ to -0.75, with the exception of the real part of relative permittivity found two days after ejaculate collection ($r_p = 0.15$);
- correlation between sperm activity on the day of ejaculate sampling and the specific conductivity measured by the four and two electrodes method was positive ($r_p = 0.48$ and 0.08, respectively), in relation to high-frequency specific conductivity it was zero (i.e. $r_p = -0.01$), and to the real part of relative permittivity it was negative (i.e. $r_p = -0.23$).

The following data were found in boars:

- between the ejaculate volume and the real part of relative permittivity, and high-frequency specific conductivity, low positive phenotypic correlations $r_p = 0.04$ to 0.20 were found, in relation to specific conductivity they were zero $r_p = -0.06$ and 0.00;
- similarly, low negative values were found between sperm concentration and the dielectric and electric properties of the ejaculate (i.e. $r_p = -0.05$ to -0.24), between sperm concentration and real part of relative permittivity on the day of collection and high-frequency specific conductivity on the day of ejaculate collection the values were zero, i.e. $r_p = 0.01$ and 0.00, respectively;
- between sperm activity on the day of ejaculate collection and all the investigated dielectric and electric properties the correlations were positive and ranged between $r_p = 0.17$ and 0.53.

The calculated correlations, particularly where the values were intermediate, between the volume of the ejaculate and sperm concentration in bulls and boars, the dielectric and electric properties of the ejaculate showed that these properties could be used for complementary examinations of the quality of the ejaculate. Also determinations of dielectric and electric properties in separated sperm plasma and following evaluations of their effect on the studied properties of the entire ejaculate appear to be interesting for future study.

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STRESZCZENIE

Zależność między względną przepuszczalnością i elektrycznym przewodnictwem jako wskaźnikami jakości ejakulatów u buhajów i knurów

Dielektryczne i elektryczne właściwości (przewodnictwo elektryczne mierzone w układzie czterolub dwuelektrodowym) stanowią o elektrycznym przewodnictwie i wysokiej przepuszczalności spermy. Oceniano jakość 31 prób spermy od buhajów i 25 od knurów w dniu ich pobrania i po 48 godzinach przechowywania nasienia. Jakość spermy, mierzoną objętością ejakulatu, liczbą plemników i aktywnością, określano metodami standardowymi.

Średnia koncentracja plemników w nasieniu buhajów wynosiła 1,22 ± 0,46 mld.cm^{-3}, filtrowana frakcja nasienna knurów 581,00 mil.cm^{-3}. Średnia aktywnosć spermy buhajów i knurów wynosiła 68,7 ± 6,6% i 78 ± 4,8% odpowiednio, zaś średnia objętość ejakulatów buhajów 12,39 ± 4,72 cm3, a knurów 242,00 ± 111,00 cm^3.

Korelacja pomiędzy koncentracją plemników u buhajów a specyficznym wysokoczęstotliwym przewodnictwem elektrycznym była zawsze ujemna (r_p = – 0,09 do 0,75), natomiast między aktywnością spermy a specyficznym czteroelektrodowym przewodnictwem była dodatnia (r_p = 0,48). U knurów zależności pomiędzy aktywnością spermy i właściwościami elektrycznego przewodnictwa były dodatnie.