Original Article

Fluctuations in Seminal Quality throughout the Year: How do Temperature, Humidity and Atmospheric Pressure Impact on Human Sperm Quality?

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Abstract

Background: Most studies evaluating the possible seasonal variation of semen quality have considered temperature as the only causal factor. **Aims:** To assess possible seasonality in sperm quality and associations between semen parameters and several meteorological variables (temperature, humidity, apparent temperature and atmospheric pressure) in a large cohort of andrological patients. **Settings and Design:** This was a retrospective, cross-sectional and correlational/descriptive study. **Materials and Methods:** Patients (n: 15665) were categorised into four groups (summer, winter, spring and autumn) according to the date of assistance at the fertility centre. Daily values of temperature, apparent temperature, humidity and atmospheric pressure were provided by the National Weather System and were calculated as the average of the 74 days previous to semen collection (spermatogenic cycle). **Statistical Analysis Used:** As appropriate, the results were analysed by analysis of variance/Kruskal–Wallis, Chi-square test, *t*-test/Mann–Whitney, forward conditional regression model and Spearman/Pearson's correlations. **Results:** We detected seasonality effects on sperm count, total sperm count and total motile sperm count, with the highest values in winter and the lowest in summer. Correlation analysis showed that temperature, apparent temperature and humidity negatively correlated with semen parameters, being humidity the most powerful predictive meteorological variable. **Conclusion:** Sperm quality is influenced by seasons; increased environmental temperature and humidity negatively affect semen quality.

Keywords: *Apparent temperature, nuclear maturation, sperm count*

Introduction

Infertility, which affects around 15% of the couples worldwide, is defined as the incapacity to conceive after 1 year of regular sexual intercourse without protection.[1,2] 20%–50% of all the cases of infertility are attributed to male factors.[2] Intrinsic and extrinsic causes might affect male fertility status. While intrinsic causes include unmodifiable factors such as age or genetic background, extrinsic causes are broad and encompass modifiable factors like lifestyle issues, but also unchangeable factors like weather.[3] Several studies have evaluated the possible seasonal variation in semen quality of fertile and infertile men, finding controversial results. Although most reports have shown a significant seasonal variation in seminal parameters,[4-7] others have not detected any circannual rhythm in male fertility.[8,9] Since mammalian spermatogenesis is highly sensitive to testicular temperature,[10] the majority of the studies evaluating seasonality of seminal quality have considered

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environmental temperature as the main meteorological variable; many of these studies have reported lower seminal quality in summer.[11,12] Moreover, by epidemiological studies, a seasonal distribution in human natural conception and birth rates has been demonstrated, being summer conditions linked to a decline in births 9 months later.[13] However, Levine *et al*.[14] published a study including indoor and outdoor workers during summer and found that the effect of summer on semen quality was not different between these groups, suggesting that high temperatures might not be the only meteorological variable affecting sperm quality. Unfortunately, studies including other variables such as humidity, atmospheric pressure and daylight length in humans are scarce.[15,16] Conversely, these meteorological variables are more frequently included in studies of farm animals.[17-21]

Therefore, the aim of this study was to evaluate the possible seasonality in semen quality in a sample of more than 15,000 patients attending an andrology centre in Cordoba, Argentine, intending to determine the association between some meteorological variables (temperature, humidity, apparent temperature and atmospheric pressure) and seminal parameters.

Materials and Methods

Patients

This was a retrospective, cross–sectional and correlational/descriptive study that evaluates semen quality in the male partner of couples undergoing fertility evaluation at the Andrology and Reproduction Laboratory in Cordoba, Argentine (from January 2001 to December 2020).

Patients' data were included in this study following patient`s written informed consent for use of anonymised data for research. Since no invasive procedure was performed to the patients and data were kept rigorously anonymous, approval by an institutional review board was not mandatory. Further, principles outlined in the Declaration of Helsinki (2013) were met and the andrology laboratory, the research institute and their head researchers are certified by the local authority committee (Consejo de EvaluaciónÉtica de Investigaciónen Salud–COEIS and Registro Provincial de Investigaciónen Salud–RePis-).

All the patients filled a form, providing information on age, toxic exposure, abstinence period and history of any disease that can negatively impact on the hypothalamic-pituitary-gonadal axis. Patients with incomplete data, coming from outside Cordoba city or the nearby periphery, abstinence out of range (2–7 days), age out of range (younger than 20 or older than 60 years), varicocele, azoospermia, cryptorchidism, parotitis after 13 years of age, exposure to heat or pollutants (pesticides and radiation), moderate and heavy drinking (three or more glasses/day) and heavy smoking (more than ten cigarettes/day) were excluded from this study. Finally, 15,667 semen samples (one sample per patient) were selected.

Semen samples

Semen samples were obtained by masturbation after 2–7 days of sexual abstinence and analysed after liquefaction within the hour of collection. Semen analysis was performed according to the World Health Organization (WHO),[22] with some modification for volume and motility evaluation. All the analyses were performed by two fully trained operators.

In brief, seminal volume was determined using graduated conic tube. Sperm concentration and motility were evaluated in a Makler counting chamber and the results were expressed as rapid or total progressive motility (rapid plus slow progressive).[23] Quantifications were made by triplicate (loading the chamber three times), reporting the mean value for each patient. The parameter total sperm count (TSC) was calculated as semen volume × sperm concentration, and total motile sperm count (TMSC) was calculated by multiplying the percentage of progressive motile sperm by the TSC/100.[24] To evaluate sperm viability, we employed the eosin Y staining and, for sperm nuclear maturity (chromatin condensation), the aniline blue technique.[25] Sperm morphology was assessed by strict criteria, staining semen smears with the Papanicolau technique.[26]

Meteorological variables

This study was conducted in Cordoba, Argentine (31°24′48″ S, 64°10′51″ W, altitude: 395 m), which has a moderate and temperate weather with well-defined seasons. Winter is dry and mild, and summers are hot and humid.[27]

Hourly data of temperature (°C), apparent temperature (°C), humidity (%) and atmospheric pressure (mmHg) were provided by the National Weather System (Servicio Meteorológico Nacional, Argentine) between January 2001 and December 2020. Dynamics of the monthly average meteorological variables are depicted in Figure 1. Since, in humans, spermatogenesis and spermiogenesis span 74–24 days, respectively, the meteorological variables were initially calculated as the average of the 74–24 days prior to the semen sample collection. Nevertheless, since results were comparable, data reported in this study corresponded only to the average value of the 74 days previous to semen collection.

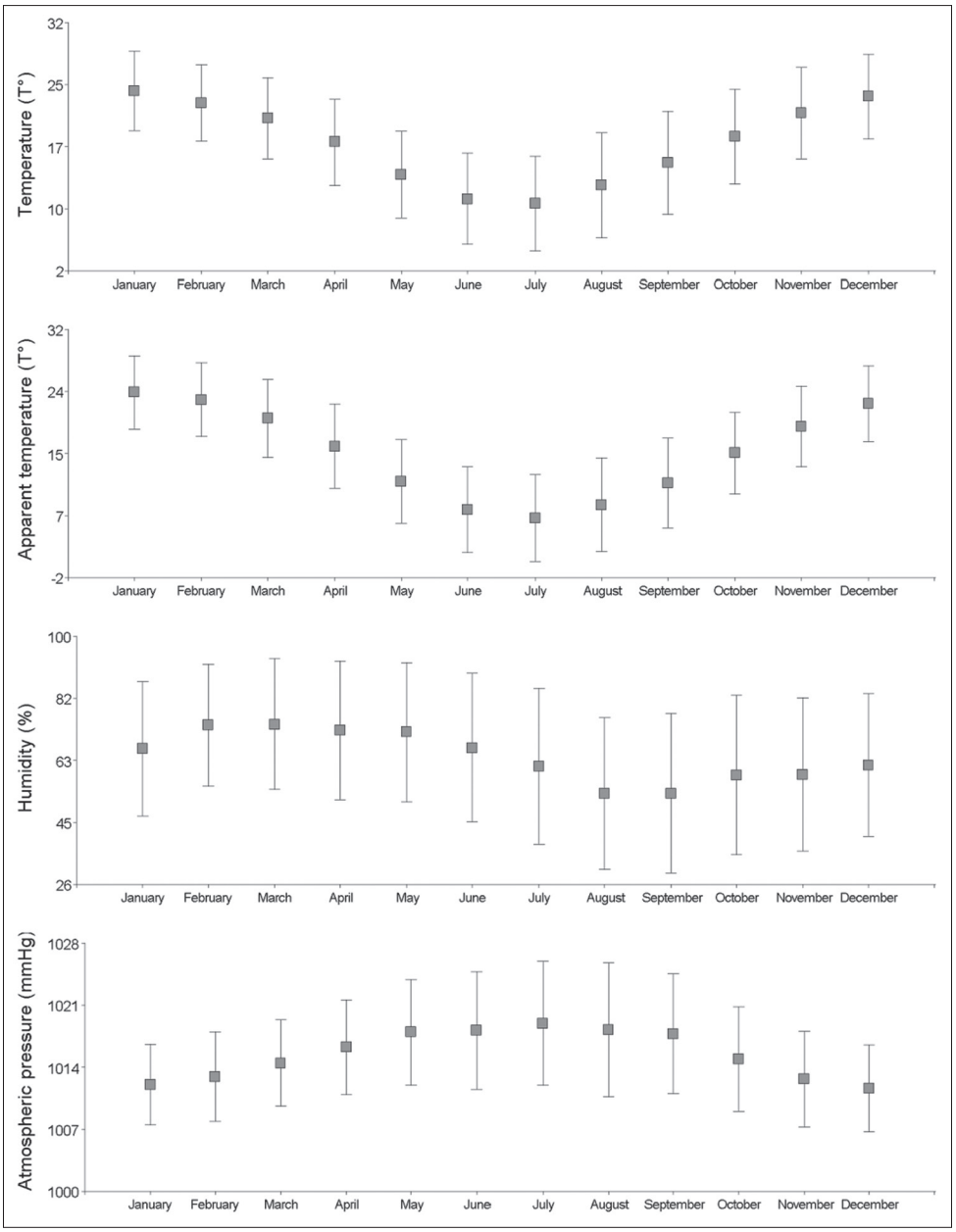

Figure 1: Average mean values (±standard deviation) of temperature (C°), apparent temperature (C°), humidity (%) and atmospheric pressure (mmHg) throughout the year in Cordoba, Argentine, from January 2001 to December 2020

Statistical analysis

Statistical analyses were performed using InfoStat 2017 (Cordoba National University, Cordoba, Argentine) and SPSS 20.0 (IBM Corp., Armonk, NY, USA). In all cases, $P < 0.05$ was considered statistically significant. The patients were grouped into seasonal periods according to the date in which they attended the andrology centre, as follows: summer = December 21st to March 20th; autumn = March 21st to June 20th; winter = June 21st to September 20th and spring = September 21st to December 20th.

First, semen variables in each season-category were summarised as the mean ± standard error of mean, and the differences between groups were evaluated using analysis of variance (ANOVA) and least significant difference or Kruskal–Wallis and Dunn test, when necessary. We also investigated month-to-month variations in semen parameters.

In addition, semen parameters of each patient were classified as either "normal" or "abnormal" in accordance with the WHO criteria. Furthermore, data of abnormalities in sperm concentration, motility and morphology were used to calculate the percentage of patients with oligo, astheno, terato or those with oligo-astheno-teratozoospermia (OAT). The differences in proportions of abnormalities were analysed using Chi-squared independence test. To identify values

that were significantly higher (marked with a [+]) or lower (marked with a [−]) than expected under independence, standardised residuals >1.96 or lower than − 1.96 were used according to Agresti.[28]

Second, Spearman or Pearson's correlation tests were applied for correlation analysis between every meteorological variable and each semen parameter. To identify the best meteorological predictors, a forward conditional regression model was performed as a variable selection method.

Third, quartiles were calculated for each meteorological variable and used to dichotomise the population in Q1 (patients exposed to the lowest values) and Q4 (patients exposed to highest values). The differences between groups were evaluated using *t*-test or Mann–Whitney.

Results

Seasonal variation

After applying the exclusion criteria, 67.77% of the 23,130 patients consulting for couple infertility were included in this study, i.e. n = 15667. To assess the possible seasonality in semen quality, and according to the date of semen collection, four groups of patients were defined: summer, n = 3279 (20.93%); autumn, n = 4013 (25.61%); winter, n = 4410 (28.15%) and spring, n = 3965 (25.31%). One way-ANOVA and Kruskal–Wallis test showed significant variations between seasons in sperm concentration, TSC and TMSC [Figure 2a-c]. As it can be seen, in all these sperm parameters, winter values were the highest and summer values the lowest ($P < 0.05$), showing a clear seasonal profile. Something similar is evident for semen abnormalities, since we found that frequencies in oligozoospermia and abnormalities in TSC and TMSC presented the highest values in summer (marked with a [+]) and the lowest in winter (marked with a [−]; P: 0.0001) [Figure 2d-f]. Furthermore, winter was the season that showed the highest mean value for motility (49.34 ± 0.28; P = 0.03 vs. summer and autumn) and the lowest percentages of abnormal nuclear maturity (24.44), teratozoospermia (30.02) and OAT (4.92) ($P < 0.01$).

When analysing semen quality variations throughout months [Figure 3], June to September showed

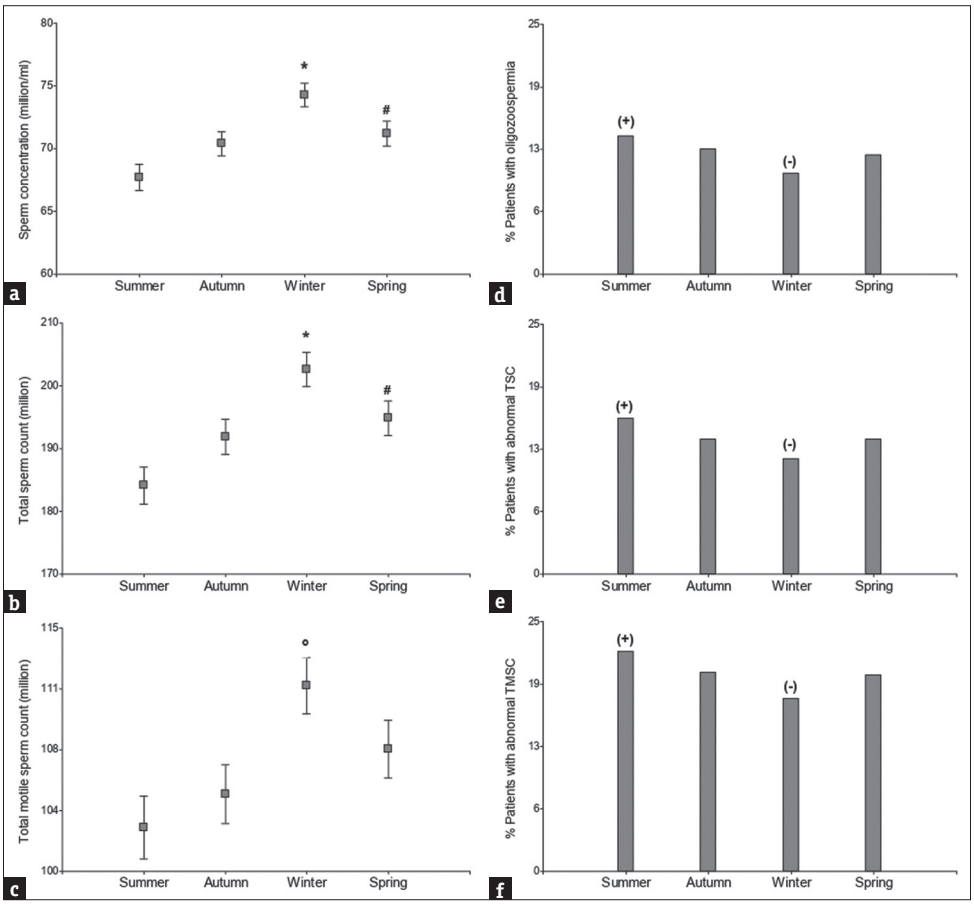

Figure 2: Sperm quality (mean ± standard error of the mean [a-c] or frequency of abnormalities [d-f] of andrology patients, grouped according to the season in which they provided the semen sample. N =15667. *: P <0.0001 winter versus all other seasons; #: P <0.0001 spring versus summer; o: P =0.0042 winter versus all other seasons. (+) and (−) identify frequencies of abnormality higher and lower than expected under independence. TSC: Total sperm count, TMSC: Total motile sperm count

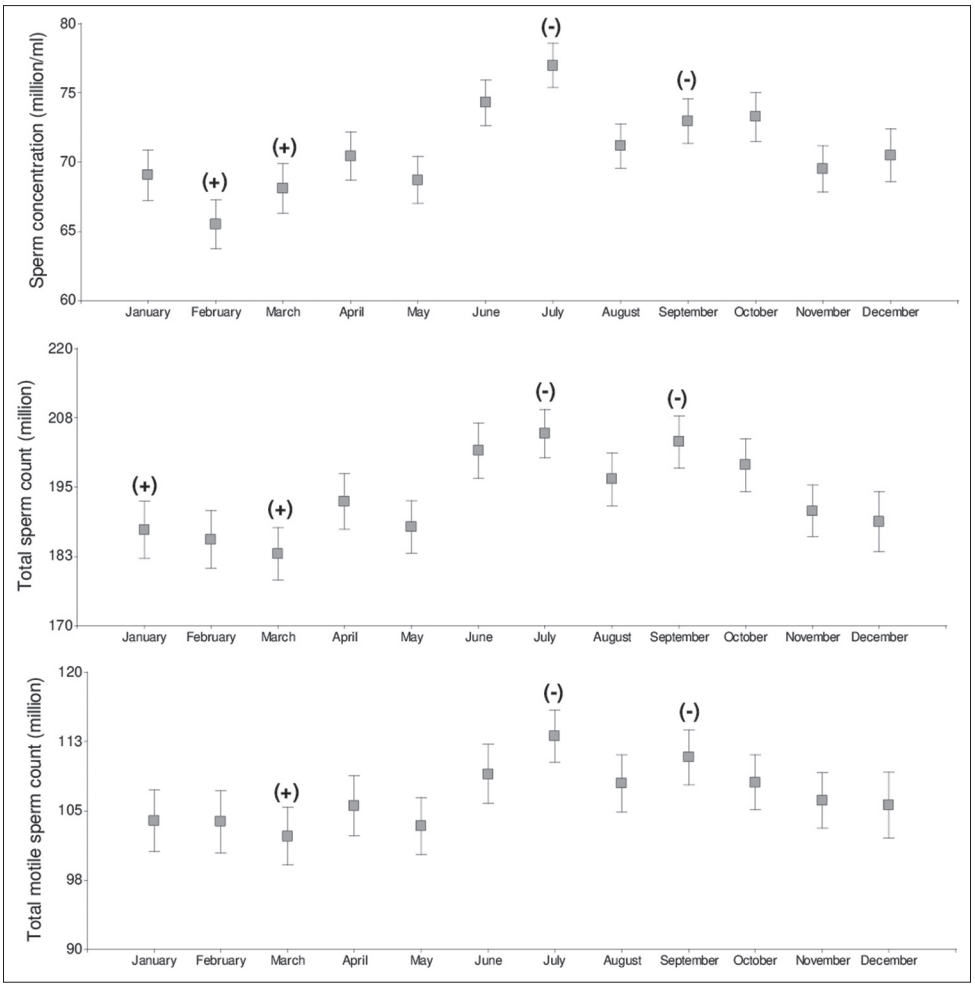

Figure 3: Sperm quality (mean ± standard error of the mean or frequency of abnormalities) of andrology patients, grouped according to the month in which they provided the semen sample. N =15667. Different letters indicate a $P < 0.05$. (+) and (−) identify frequencies of abnormality higher and lower than expected under independence

the highest values and the lowest frequencies of abnormalities (marked with a [−]) for sperm concentration, TSC and TMSC (significant values only in July and September). On the contrary, lower values for these parameters and the highest frequencies of abnormalities (marked with a [+]) were detected in January to March (P: 0.0002). The same pattern was found for patients with OAT and abnormalities in nuclear maturity; for example, the percentage of OAT was 3.93 in July and 7.73 in March (P: 0.0021).

Semen quality and meteorological variables

Correlation results between meteorological variables and seminal parameters are summarised in Table 1. Temperature and apparent temperature correlated negatively with semen quality. In contrast, a positive correlation was found between atmospheric pressure and seminal quality. Humidity correlates negatively with concentration, TSC, motility and TMSC, but positively with normal morphology, viability (expressed as percentage of dead spermatozoa) and nuclear maturity.

Since several meteorological variables simultaneously operate in defining the climate of a region, a forward conditional regression model was performed as a variable selection method, in order to identify the set of meteorological variables that better predicted each seminal parameter [Table 1, numbers in parenthesis]. Humidity was the most powerful predictive factor, since it ranked first in sperm concentration, TSC, motility, TMSC, morphology and nuclear maturity. Humidity did not rank on viability; conversely, this parameter was better predicted by apparent temperature. Atmospheric pressure was the second most powerful predictive factor, ranking second in concentration, TSC, viability and nuclear maturity.

As a complementary analysis, we calculated quartiles for each meteorological variable, and then categorised patient in Q1 and Q4, in accordance with meteorological parameters. This approach allowed us to compare both, means and frequencies of abnormalities, between the patients that were exposed to highest and lowest weather values [Tables 2-5].

Table 1: Correlation analysis between meteorological variables and patient's semen quality

Semen parameter	Temperature (°C)	Apparent temperature (°C)	Humidity (%)	Atmospheric pressure (mmHg)
Sperm concentration (×10⁶/mL)	−0.05 (4th)	−0.05 (3rd)	−0.05 (1st)	0.06 (2nd)
Total sperm count (×10⁶)	−0.04	−0.04	−0.05 (1st)	0.04 (2nd)
Motility (%)	NS	NS	−0.03 (1st)	NS
Total motile sperm count (×10⁶/mL)	−0.03	−0.03	−0.04 (1st)	0.03
Normal morphology (%)	NS	NS	0.02 (1st)	NS
Viability (percentage of dead spermatozoa)	NS	0.016 (1st)	0.017	NS (2nd)
Nuclear maturity (%)	−0.07 (3rd)	−0.06 (2nd)	0.097 (1st)	0.07

Values represent the Spearman correlation coefficients between semen parameters and meteorological data. The numbers in parentheses indicate the order of importance for each meteorological factor on semen quality, according to the forward conditional model results (*n*=15,667). NS=Not significant

Table 2: Semen quality in patients dichotomised according to their level of exposure to temperature

	Quartile 1 (*n*=2092)	Quartile 4 (*n*=2097)	*P*
Sperm concentration (×10⁶/mL)	52.346±0.827 (−)	50.468±0.898 (+)	0.001
Total sperm count (×10⁶)	152.109±2.662 (−)	146.340±2.724 (+)	0.001
Sperm motility (%)	50.860±0.412	50.828±0.411	NS
Total motile sperm count (×10⁶)	86.384±1.782 (−)	85.240±1.895 (+)	0.094
Viability (%)	17.070±0.222	17.717±0.236	NS
Normal morphology (%)	6.935±0.131	7.293±0.142	NS
Nuclear maturity (%)	71.683±0.350 (−)	68.580±0.372 (+)	0.001

Patients were dichotomised according to the level of exposure to temperature (°C) in quartile 1 (patients exposed to the lowest values) or quartile 4 (patients exposed to the highest values). Values are expressed as mean±SEM, and the P values exhibited in the table correspond to their differences. Results were also represented as frequencies of abnormalities (lower [−] or higher [+] than expected under independence), but only when statistically significant (*n*=15,667). NS=Not significant, SEM=Standard error mean

Table 3: Semen quality in patients dichotomised according to their level of exposure to apparent temperature

	Quartile 1 (*n*=2075)	Quartile 4 (*n*=2096)	*P*
Sperm concentration (×10⁶/mL)	53.100±0.844 (−)	50.167±0.900 (+)	0.001
Total sperm count (×10⁶)	154.004±2.720 (−)	146.230±2.748 (+)	0.002
Sperm motility (%)	50.801±0.411	50.540±0.417	NS
Total motile sperm count (×10⁶)	87.222±1.815 (−)	84.961±1.893 (+)	0.029
Viability (%)	16.981±0.221	17.878±0.238	0.035
Normal morphology (%)	6.839±0.129	7.457±0.143	0.019
Nuclear maturity (%)	71.795±0.348 (−)	68.493±0.375 (+)	0.001

Patients were dichotomised according to the level of exposure to apparent temperature (°C) in quartile 1 (patients exposed to the lowest values) or quartile 4 (patients exposed to the highest values). Values are expressed as mean±SEM, and the *P* values exhibited in the Table correspond to their differences. Results were also represented as frequencies of abnormalities [lower (−) or higher (+) than expected under independence], but only when statistically significant (*n*=15,667). NS=Not significant, SEM=Standard error mean

In accordance with our other results, we found that sperm concentration, TSC, TMSC and nuclear maturity were higher in patients from Q1 versus Q4 temperature and/or apparent temperature [Tables 2 and 3]. Moreover, the frequency of abnormalities in these sperm parameters, as well as OAT (Q1: 5.25 vs. Q4: 7.01), was higher in patients of Q4.

Patients exposed to the highest values of humidity [Table 4] showed lower mean values in parameters associated with sperm count and higher frequencies of oligozoospermia and asthenozoospermia. Conversely, these patients showed higher mean values of normal morphology and lower frequencies of teratozoospermia. The percentage of dead spermatozoa was also higher in these patients.

Finally, better seminal quality was found in patients of Q4 atmospheric pressure, both in terms of mean values and frequencies of abnormalities [Table 5].

Discussion

Circannual variations in conception and birth rates have drawn attention to the possible seasonal changes in sperm parameters. Although some researchers have explored these aspects, studies evaluating the association between each meteorological variable and sperm quality are scarce.

Table 4: Semen quality in patients dichotomised according to their level of exposure to humidity

	Quartile 1 (*n*=2092)	Quartile 4 (*n*=2100)	*P*
Sperm concentration (×10⁶/mL)	52.805±0.850 (−)	49.267±0.883 (+)	0.001
Total sperm count (×10⁶)	156.674±2.751 (−)	142.220±2.627	0.001
Sperm motility (%)	50.859±0.396	50.674±0.430 (+)	NS
Total motile sperm count (×10⁶)	89.181±1.832	81.949±1.782	0.001
Viability (%)	17.067±0.222	18.716±0.250	0.001
Normal morphology (%)	6.291±0.115 (+)	8.265±0.151 (−)	0.001
Nuclear maturity (%)	70.250±0.351	69.253±0.397	NS

Patients were dichotomised according to the level of exposure to humidity (%) in quartile 1 (patients exposed to the lowest values) or quartile 4 (patients exposed to the highest values). Values are expressed as mean±SEM, and the *P* values exhibited in the Table correspond to their differences. Results were also represented as frequencies of abnormalities (lower [−] or higher [+] than expected under independence), but only when statistically significant (*n*=15,667). NS=Not significant, SEM=Standard error mean

Table 5: Semen quality in patients dichotomised according to their level of exposure to atmospheric pressure

	Quartile 1 (*n*=2091)	Quartile 4 (*n*=2116)	*P*
Sperm concentration (×10⁶/mL)	49.612±0.891 (+)	52.092±0.822 (−)	0.001
Total sperm count (×10⁶)	143.894±2.751 (+)	152.731±2.780 (−)	0.001
Sperm motility (%)	50.730±0.413	50.792±0.409	NS
Total motile sperm count (×10⁶)	83.825±1.892	86.739±1.841	0.040
Viability (%)	17.787±0.232	17.396±0.222	NS
Normal morphology (%)	7.191±0.140	6.919±0.131	NS
Nuclear maturity (%)	68.548±0.382 (+)	72.033±0.352 (−)	0.001

Patients were dichotomised according to the level of exposure to atmospheric pressure (mmHg) in quartile 1 (patients exposed to the lowest values) or quartile 4 (patients exposed to the highest values). Values are expressed as mean±SEM, and the *P* values exhibited in the table correspond to their differences. Results were also represented as frequencies of abnormalities (lower [−] or higher [+] than expected under independence), but only when statistically significant (*n*=15,667). NS=Not significant, SEM=Standard error of mean

Therefore, the current study evaluated semen samples of a large cohort of men consulting for fertility problems in Cordoba, Argentine (between 2001 and 2020), in order to explore a possible seasonal variation in semen quality, taking advantage that Argentine is a country with very distinct climatic conditions between seasons and has not been well represented in the literature on the topic. Furthermore, we also evaluated the possible association between each meteorological variable and sperm parameters.

Regarding seasonality, we found a significant increase in sperm number, TSC and TMSC in winter. In addition, when comparing the frequency of abnormalities, the rates were higher in summer and lower in winter. These results are in agreement with previous studies, both in humans and animal models.[4,6,7,17,18] Of note, as reported by Carlsen,[29] ejaculatory frequency varies through the year and significantly affects semen quality; therefore, we compared abstinence between seasons and found no statistical differences (results not shown). Thus, the patterns in seminal quality detected in this study do not depend on abstinence time.

Considering that human spermatogenesis lasts 74 days, our findings might be related to the weather of spring and autumn, when the spermatozoa actually formed and matured. This is the reason why, for the subsequent analyses of this study, we evaluated the mean values of temperature, apparent temperature, humidity and atmospheric pressure of the 74 days previous to semen collection. We also assessed the mean values of 24 days previous (i.e. the length of spermiogenesis), but since the results were very similar, we only inform values of the 74 days previous.[30]

In the literature, temperature has been pointed out as a possible explanatory variable behind the seasonality of semen quality; hence, several studies have evaluated the association between this variable and semen parameters.[4,12,31-33] Nevertheless, information regarding the impact of other relevant meteorological variables upon semen quality are scarce and mainly reported in animal models.[19,20] Therefore, we thoroughly assessed the association between temperature, apparent temperature, humidity and atmospheric pressure with several routine semen parameters. We found that temperature and apparent temperature correlated negatively with semen quality, what is in line with previous results.[15,34] Moreover, for sperm concentration, TSC and TMSC, an increase in the rates of abnormalities and a decrease in the mean values were found in summer, in comparison to winter. In addition,

patients exposed to the highest values of temperature and apparent temperature (Q4 group) showed a poorer semen quality.

Mammalian spermatogenesis is a temperature-sensitive process. Indeed, it is well known that a temperature of 2°C–7°C below the core body temperature is required for normal spermatogenesis.[35] Testes have high metabolic activity and produce high amounts of heat that must be appropriately dissipated to maintain the thermal equilibrium needed for spermatogenesis.[36] Several strategies of testicular thermoregulation have been described, including a very efficient system of current heat exchange and the muscular response, which encompass contractions or relaxations that allow the testis to be drawn toward the abdomen or to hang away from the body.[37] In addition, a considerable amount of heat produced during spermatogenesis is released by evaporative cooling through the scrotum, which has a highly vascularised skin, scanty hair, abundant sweat glands and absence of subcutaneous fat.[38]

Testis hyperthermia can be induced by a wide range of issues in daily life, including environmental factors. In fact, in men, each 1°C elevation in ambient temperature triggers a 0.1°C increase in scrotal temperature.[39] Hjollund *et al*. found a 40% decline in sperm output for each 1°C increase in median daytime scrotal temperature in healthy men.[40] This could be explained by a defective evaporative cooling from the scrotal surface as temperature increases.[37] Of note, relative humidity varies as a function of both, water vapour content and air temperature and evaporative heat loss decreases with increasing relative humidity. Hence, an increase in relative humidity in addition to an increase in temperature, suppresses evaporative cooling from the skin surface.[41] In line with these observations, we found that humidity correlated negatively with most seminal parameters. In fact, when applying a regression model as a variable method selection, we found that humidity was the most important predictive variable. This was also reported in a previous study.[15]

Finally, we found a positive correlation between atmospheric pressure and semen quality. This was expected, as the increase in temperature is correlated with a decrease in atmospheric pressure. In fact, the variables that negatively correlated with temperature and apparent temperature were the same that positively correlated with atmospheric pressure; patients exposed to the highest values of atmospheric pressure showed better seminal quality, both in terms of mean values and rates of abnormalities. Similar findings have already been reported.[16] Thus, the previously mentioned correlation is subrogated to that link between temperature and semen quality. As indicated by Lv *et al*., temperature, humidity and atmospheric pressure are "inseparable variables."[16]

Noteworthy, even in cooler climates, significant reductions in sperm concentrations, count and motility have been reported in summer.[9,42,43] In addition, Levine *et al*. demonstrated that the air conditioning system used by indoor workers does not mitigate the summertime reduction in semen quality, suggesting that heat only cannot sustain the seasonal variations.[14] This is why some studies have speculated that the photoperiod (length of daylight) may be a more powerful predictive factor,[14,44] although this idea is still controversial.[41,45]

As reported by Malm *et al*., sunshine duration has a slight, but significant, impact on hormonal markers of human spermatogenesis.[46] In fact, testis volume and testosterone levels peak in shorter sunshine periods.[47,48] These variations in the testicular activity might be related to melatonin secretion by the pineal gland, which in many mammals varies according to the length of daylight, exerting neuroendocrine regulation in reproductive physiology.[49] Unfortunately, we were not able to evaluate daylight duration in our study. At this point, it is important to mention that humans are not seasonal breeders but sexually active all year long. The observed fluctuation in semen analysis may be a direct result of lifestyle and environmental changes, along with seasonal temperature and photoperiods, but the phenomenon may merely be an evolutionary remnant from times when breeding was restricted to some seasons rather than a genuine effect of current environmental conditions.

The major strength of our study is the large sample size. In addition, the fact that we included 20-year semen data and such an extended period minimises the potential impact of seasonal diversity over the years. Moreover, to the best of our knowledge, this is the first time in which meteorological variables were calculated, not only as an average value for the 74 days prior to semen collection (spermatogenesis), but also for the time that encompasses spermiogenesis. However, this study has some limitations, which have to be pointed out. First, we studied men attending a fertility clinic; therefore, our results are limited to this population. Second, since this is a retrospective study, we lack any data of patients' hormone levels; consequently, we were not able to analyse the association between seasonal hormone changes and semen parameters.

However, despite these flaws, our study in a large cohort of infertile men indicates that seasonality alters semen parameters, in agreement with current publications. Specifically, meteorological conditions of the autumn in Cordoba are associated with better semen quality in winter. Despite a measurable effect of several meteorological variables on semen quality, a definitive statement about the underlying cause for the seasonality in male fertility remains to be determined.

Finally, these results have implications for clinical practice, since defining a pattern of seasonal sperm quality may help determine the optimal time frame for initiating infertility treatment to increase the chances of conception, as suggested by previous studies.[7,50] On the other hand, during the past 100 years, the global average temperature has risen by 0.74°C, and this global warming is associated with pronounced climate changes that will continue for the next several decades.[51] Consequently, these kinds of studies highlight the relevance of environmental research to predict/treat its impact on reproductive health.

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Nil.

Conflicts of interest

There are no conflicts of interest.

Data availability statement

The data set used in the current study is available on request from Martini AC (acmartini2000@fcm.unc.edu.ar)

References

1. Balhara K, Singh S, Sharma S. Seasonal variation in semen quality: Effect of temperature: A study in North India. Int J Reprod Contracept Obstet Gynecol 2022;11:547-52.
2. Agarwal A, Baskaran S, Parekh N, Cho CL, Henkel R, Vij S, *et al.* Male infertility. Lancet 2021;397:319-33.
3. Ramírez N, Estofán G, Tissera A, Molina R, Luque EM, Torres PJ, *et al*. Do aging, drinking, and having unhealthy weight have a synergistic impact on semen quality? J Assist Reprod Genet 2021;38:2985-94.
4. Gyllenborg J, Skakkebaek NE, Nielsen NC, Keiding N, Giwercman A. Secular and seasonal changes in semen quality among young Danish men: A statistical analysis of semen samples from 1927 donor candidates during 1977-1995. Int J Androl 1999;22:28-36.
5. Proctor JG, Blackhurst DW, Boone WR. Does seasonality alter intrauterine insemination outcomes: A 5-year study. J Assist Reprod Genet 2004;21:263-70.
6. Sobreiro BP, Lucon AM, Pasqualotto FF, Hallak J, Athayde KS, Arap S. Semen analysis in fertile patients undergoing vasectomy: Reference values and variations according to age, length of sexual abstinence, seasonality, smoking habits and caffeine intake. Sao Paulo Med J 2005;123:161-6.
7. Mehrafza M, Asgharnia M, Raoufi A, Hosseinzadeh E, Samadnia S, Roushan ZA. The effect of seasonality on reproductive outcome of patients undergoing intracytoplasmic sperm injection: A descriptive cross-sectional study. Int J Reprod Biomed 2020;18:989-94.
8. Ombelet W, Maes M, Vandeput H, Cox A, Janssen M, Pollet H, *et al.* Chronobiological fluctuations in semen parameters with a constant abstinence period. Arch Androl 1996;37:91-6.
9. Mortimer D, Templeton AA, Lenton EA, Coleman RA. Annual patterns of human sperm production and semen quality. Arch Androl 1983;10:1-5.
10. Aldahhan RA, Stanton PG. Heat stress response of somatic cells in the testis. Mol Cell Endocrinol 2021;527:111216.
11. Santi D, Magnani E, Michelangeli M, Grassi R, Vecchi B, Pedroni G, *et al*. Seasonal variation of semen parameters correlates with environmental temperature and air pollution: A big data analysis over 6 years. Environ Pollut 2018;235:806-13.
12. Künzle R, Mueller MD, Huber AW, Drescher H, Bersinger NA. Seasonality in human semen quality of smokers and non-smokers: Effect of temperature. Asian J Androl 2004;6:243-7.
13. Barreca A, Deschenes O, Guldi M. Maybe next month? Temperature shocks and dynamic adjustments in birth rates. Demography 2018;55:1269-93.
14. Levine RJ, Brown MH, Bell M, Shue F, Greenberg GN, Bordson BL. Air-conditioned environments do not prevent deterioration of human semen quality during the summer. Fertil Steril 1992;57:1075-83.
15. Verón GL, Tissera AD, Bello R, Estofan GM, Hernández M, Beltramone F, *et al.* Association between meteorological variables and semen quality: A retrospective study. Int J Biometeorol 2021;65:1399-414.
16. Lv MQ, Ge P, Zhang J, Yang YQ, Zhou L, Zhou DX. Temporal trends in semen concentration and count among 327 373 Chinese healthy men from 1981 to 2019: A systematic review. Hum Reprod 2021;36:1751-75.
17. Valeanu S, Johannisson A, Lundeheim N, Morrell JM. Seasonal variation in sperm quality parameters in Swedish red dairy bulls used for artificial insemination. Livest Sci 2015;173:111-8.
18. Sharma M, Yaqoob B, Singh A, Sharma N, Rawat S. Effect of temperature humidity index on semen quality of bovine bull. Int J Curr Microbiol Appl Sci 2017;6:1822-30.
19. Sabés-Alsina M, Lundeheim N, Johannisson A, López-Béjar M, Morrell JM. Relationships between climate and sperm quality in dairy bull semen: A retrospective analysis. J Dairy Sci 2019;102:5623-33.
20. Ranjan R, Singh P, Kharche SD, Gangwar C, Ramachandran N, Singh SP, *et al*. Effect of temperature humidity index on sexual behavior and semen quality in Barbari buck under Indian climatic condition. Small Rumin Res 2020;193:106263. Available from: https://www.sciencedirect.com/science/article/pii/S0921448820302121. [Last accessed on 2023 Aug 01].
21. Suriyasomboon A, Lundeheim N, Kunavongkrit A, Einarsson S. Effect of temperature and humidity on sperm production in Duroc boars under different housing systems in Thailand. Livest Prod Sci 2004;89:19-31.
22. World Health Organization. WHO Laboratory Manual for the Examination and Processing of Human Semen. Geneva: WHO Press; 2010.
23. Makler A. The improved ten-micrometer chamber for rapid sperm count and motility evaluation. Fertil Steril 1980;33:337-8.
24. Ayala C, Steinberger E, Smith DP. The influence of semen analysis parameters on the fertility potential of infertile couples. J Androl 1996;17:718-25.
25. Dadoune JP, Mayaux MJ, Guihard-Moscato ML. Correlation between defects in chromatin condensation of human spermatozoa stained by aniline blue and semen characteristics.

Andrologia 1988;20:211-7.
26. Menkveld R, Stander FS, Kotze TJ, Kruger TF, van Zyl JA. The evaluation of morphological characteristics of human spermatozoa according to stricter criteria. Hum Reprod 1990;5:586-92.
27. Peel MC, Finlayson BL, McMahon TA. Updated world map of the Koppen-Geiger climate classification. Hydrol Earth Syst Sci 2007;11:1633-44.
28. Agresti A. An introduction to categorical data analysis. 2nd ed. Wiley-Interscience, New Jersey; 2007.
29. Carlsen E, Petersen JH, Andersson AM, Skakkebaek NE. Effects of ejaculatory frequency and season on variations in semen quality. Fertil Steril 2004;82:358-66.
30. Amann RP. The cycle of the seminiferous epithelium in humans: A need to revisit? J Androl 2008;29:469-87.
31. Spira A. Seasonal variations of sperm characteristics. Arch Androl 1984;12:23-8.
32. Yogev L, Kleiman S, Shabtai E, Botchan A, Gamzu R, Paz G, *et al.* Seasonal variations in pre- and post-thaw donor sperm quality. Hum Reprod 2004;19:880-5.
33. De Giorgi A, Volpi R, Tiseo R, Pala M, Manfredini R, Fabbian F. Seasonal variation of human semen parameters: A retrospective study in Italy. Chronobiol Int 2015;32:711-6.
34. Zhang Y, Huang S, Wang X. Sperm quality and environment: A retrospective, cohort study among 21,715 semen samples in a Southern province of China. Adv Sex Med 2021;11:73-85.
35. Ivell R. Lifestyle impact and the biology of the human scrotum. Reprod Biol Endocrinol 2007;5:15.
36. Skandhan KP, Rajahariprasad A. The process of spermatogenesis liberates significant heat and the scrotum has a role in body thermoregulation. Med Hypotheses 2007;68:303-7.
37. Morrell JM. Heat stress and bull fertility. Theriogenology 2020;153:62-7.
38. Fowler DG. The relationship between air temperature, scrotal surface area and testis temperature in rams. Aust J Exp Agric 1969;9:258-61.
39. Brindley GS. Deep scrotal temperature and the effect on it of clothing, air temperature, activity, posture and paraplegia. Br J Urol 1982;54:49-55.
40. Hjollund NH, Storgaard L, Ernst E, Bonde JP, Olsen J. Impact of diurnal scrotal temperature on semen quality. Reprod Toxicol 2002;16:215-21.
41. Gebremedhin KG, Wu B. A model of evaporative cooling of wet skin surface and fur layer. J Therm Biol 2001;26:537-45.
42. Politoff L, Birkhauser M, Almendral A, Zorn A. New data confirming a circannual rhythm in spermatogenesis. Fertil Steril 1989;52:486-9.
43. Saint Pol P, Beuscart R, Leroy-Martin B, Hermand E, Jablonski W. Circannual rhythms of sperm parameters of fertile men. Fertil Steril 1989;51:1030-3.
44. Snyder PJ. Fewer sperm in the summer – It's not the heat, it's. N Engl J Med 1990;323:54-6.
45. Kabukçu C, Çil N, Turan T, Özlülerden Y, Çabuş Ü, Abban Mete G. Do seasonal variations in ambient temperature, humidity and daylight duration affect semen parameters? A retrospective analysis over eight years. Andrologia 2020;52:e13777.
46. Malm G, Haugen TB, Henrichsen T, Bjørsvik C, Grotmol T, Saether T, *et al.* Reproductive function during summer and winter in Norwegian men living North and South of the Arctic circle. J Clin Endocrinol Metab 2004;89:4397-402.
47. Levine RJ. Seasonal variation of semen quality and fertility. Scand J Work Environ Health 1999;25 Suppl 1:34-7.
48. Bellastella A, De Bellis A, Bellastella G, Esposito K. Opposite influence of light and blindness on pituitary-gonadal function. Front Endocrinol (Lausanne) 2014;4:205.
49. viviD D, Bentley GE. Seasonal reproduction in vertebrates: Melatonin synthesis, binding, and functionality using Tinbergen's four questions. Molecules 2018;23:652.
50. Ozelci R, Yılmaz S, Dilbaz B, Akpınar F, Akdag Cırık D, Dilbaz S, *et al*. Seasonal variation of human sperm cells among 4,422 semen samples: A retrospective study in Turkey. Syst Biol Reprod Med 2016;62:379-86.
51. Reay D, Sabine C, Smith P, Hymus G. Intergovernmental Panel on Climate Change. Core Writing Team. IPCC, 2007: Climate change 2007: Synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel of climate change. In: Pachauri RK, Reisinger A, editors. Geneva, Switzerland: IPCC; 2007. p. 104. Available from: https://research.usq.edu.au/item/q6wy0/climate-change-2007-synthesis-report-contribution-of-working-groups-i-ii-and-iii-to-the-fourth-assessment-report-of-the-intergovernmental-panel-on-climate-change. [Last accessed on 2023 Aug 01].