Sex ratio of offspring in pigs: farm variability and relationship with litter size and piglet birth weight

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Abstract

The purpose of this article was to analyse data available on pig sex ratio at birth to provide information on its variability and the possible factors of influence. Factors that can influence the proportion of female or male offsprings are of interest in livestock production for practical reasons. Previous works show that exhaustive and conclusive information is not available in pigs. Nowadays, data collected by computerised pig management systems, or experimental projects aimed to test other hypotheses, enables the study of sex ratio variation. As an example, a small data set from a previous project aimed to evaluate the effect of birth weight on survivability was used in this study. The sex ratio variability among farms and its relationship with litter size and birth weight were analysed and discussed. Although not free of sampling error, neither of selective reporting, results showed that variability can exist among commercial farms, and that sex ratio was not clearly affected by litter size but varied among classes of piglets with different birth weight.

Additional key words: gender distribution, sex proportion, swine.

Resumen

Proporción de sexos en porcino: variabilidad entre granjas y relación con el tamaño de camada y el peso de los lechones al nacimiento

El objetivo de este trabajo fue analizar datos disponibles sobre la proporción de sexo al nacimiento en cerdos para proporcionar información sobre su variabilidad y los posibles factores de influencia. En producción animal, el conocimiento de los factores que influyen en la proporción de animales de distinto sexo al nacimiento tiene evidente interés desde el punto de vista productivo. En porcino, los trabajos realizados hasta el momento no ofrecen información exhaustiva ni concluyente. Actualmente, la información recogida por los sistemas informáticos de gestión, o los proyectos experimentales realizados con otros objetivos, permite el estudio de la variación de la proporción de sexos en el estrato productivo. A título de ejemplo, en este trabajo se analiza un conjunto de datos procedente de un trabajo anterior, cuyo objetivo era evaluar el efecto del peso al nacimiento sobre la mortalidad de los lechones. Se analiza y discute la variabilidad existente entre granjas para la proporción de sexos, así como su relación con el tamaño de camada y el peso al nacimiento. Pese a no estar libres de errores de muestreo, ni tampoco de la publicación selectiva de resultados, estos mostraron que puede existir variabilidad entre granjas y que la proporción de sexos no estaba claramente relacionada con el tamaño de camada, aunque variaba entre grupos de lechones de distinto peso.

Palabras clave adicionales: cerdos, cociente sexual, distribución de sexos.

Introduction

Sex ratio (the proportion of offspring from one sex) has attracted the attention of numerous works for more than a century. There is an unquestionable interest in the sex ratio for evolutionary, biological and genetic reasons. In livestock production sex ratio variability is also of interest and the knowledge of conditions that influence sex ratio can be of importance considering the economic benefits of its manipulation.

This benefit is obvious if one considers the direct breeding consequences of producing preferentially either male or female offspring but, as pointed out by

Seidel (2003), there are other phenotypic consequences that should also be considered. Reproductive performances of sows have been negatively related with a high proportion of males in their birth′s litter (Lamberson *et al.,* 1988; Drickamer *et al.,* 1997, 1999; Switonski *et al.,* 2002) and the influence of sex on pig growth performances is well known, and notable from an economic point of view (Whittemore, 1993).

Different factors have been shown to be associated with birth sex ratio in mammals, such as nutrition, season of birth, diseases, stress, mother′s age and parity, social status, levels of different hormones, type and time of insemination, oestrus synchronisation before insemination, habitat quality, population demography, sex of adjacent embryos in sow′s own birth litter, etc. (Clutton-Brock and Iason, 1986; Chandler *et al.,* 1998; Rorie, 1999; James, 2001). However, reports in the literature are not consistent, making it difficult to assess which factors might contribute to an altered sex ratio (Rorie, 1999). Maybe due to the chromosomal sex determination acting as a constraint to prevent facultative adjustment, sex ratio patterns are rarely found in vertebrates (West *et al.,* 2002).

Experimental projects should be designed to analyse specific factors but there is little previous information available about the amount of sex ratio variability in pig populations. Nowadays, data collected by computerised pig management systems, or experimental projects aimed to test other hypotheses, enables the study of sex ratio variation on a commercial level.

As an example, the present study analyses a small data set of the sex ratio previously available from a sample survey research project carried out to characterise piglet birth weight and its relationship with mortality during lactation. Now, the underlying hypothesis tested is that sex follows a binomial distribution with equal probability of occurrence for both sexes with independence of farm, litter size or piglet birth weight. The first aim of the present study was to analyse available data to discuss the variability in the sex ratio among farms and explore its relationship with litter size and piglet birth weight to speculate about results reported in the literature. A second aim was to present the application of different statistical procedures that can be used to test accomplishment of the hypothesis that sex follows a binomial distribution with equal probability of occurrence for both sexes among classes of factors affecting sex ratio.

Material and Methods

Material

Data are available from a previous sample survey research project carried out by the «Instituto Técnico y de Gestión Ganadero, S.A.» (Navarra, Spain) and designed to characterise piglet birth weight and its relationship with mortality during lactation. Piglet sex was registered at birth for 1,846 piglets born alive in 168 litters produced in the same period. These data were used in this study to analyse sex distribution according to farm, litter size and birth weight.

The results of this earlier project have not been published and therefore relevant information is given below. Data were recorded in four different commercial farms with animals from the same breeding company (Gene +) and lines (sows Alfa+ and boars Défi+). The main farm characteristics are described in Table 1. This table also contains a description of the main traits controlled at each farm. Feeding was different in each farm; though no big differences were observed in feed intake and dietary composition during gestation (daily feed intake ranged 2.4 and 2.6 kg and diet composition 3.0-3.1 Mcal kg^{-1} digestible energy and 13.9-14.6% crude protein).

Statistical analysis

Assuming the null hypothesis that sex ratio follows a binomial distribution with equal probability of occurrence for both sexes with independence of farm, litter size or piglet birth weight, different statistical procedures were used to test its accomplishment.

First, binomial distribution of sex ratio within the litter was tested for overall data and within farm and litter size levels. Litter size (defined as total number of piglets born) was categorised in four levels following the criterion of a similar number of litters per level: (1) lower than 10 (n=33); (2) equal to 10 or 11 (n=44); (3) equal to 12 or 13 (n=44); (4) greater than 13 (n=47). Sex ratio variance deviation test was performed using the K-statistic employed by James (1975). This test has been later used in other similar works (for example in Krackow (1997) and Soede *et al.* (2000)) because it has the advantage of litter size effects being independent on the mean sex ratio and of any overall skew in the sex ratio. The deviation (K/I) of the sex ratio variance from

Table 1. Farms main characteristics and average (standard error) values of traits recorded in an earlier study

	Farm A	Farm B	Farm C	Farm D
Size (No. of sows)	219	102	699	170
Sow batch management (weeks)	1	3	1	3
Type of insemination[1]	AI (ext)	NS, AI (ext)	AI (own)	AI (ext)
Sow's farrowing back fat (mm)[2]	15.7(0.7)	18.5(0.9)	16.6(0.6)	17.0(0.7)
Gestation length (days)	113.9(0.3)	113.8(0.1)	114.0(0.2)	113.8(0.1)
Days farrowing-fertilization[3]	37.0(2.8)	32.7(4.7)	33.5(2.8)	36.9(4.2)
No. piglets born alive	10.9(0.4)	11.6(0.5)	10.6(0.5)	11.0(0.4)
No. piglets stillborn	0.7(0.2)	1.4(0.2)	0.8(0.2)	0.8(0.4)
Piglet birth weight (kg)	1.39(0.02)	1.30(0.01)	1.41(0.02)	1.31(0.02)
Lactation length (days)	19.3(0.1)	20.0(0.1)	20.0(0.2)	20.0(0.1)
Lactation mortality (%)	16.1	18.0	15.4	12.5

[1] AI: artificial insemination, (ext) with doses bought, (own) with doses produced at farm; NS: natural service. [2] The week before farrowing.
[3] Interval between previous farrowing and fertilization for multiparous sows.

the binomial expectation and its variance (1/I) were measured as the dispersion and the variance of the litter gender distribution and were calculated as follows:

$$K = \sum_{i=1}^{N} 0.5 \left[\frac{f_i(f_i - 1)}{q^2} + \frac{m_i(m_i - 1)}{p^2} - \frac{2 f_i m_i}{pq} \right]$$

$$I = \sum_{i=1}^{N} \frac{n_i(n_i - 1)}{2p^2 q^2}$$

where f = number of females, n = litter size, $m = n - f$, N = number of litters, q = proportion of females, $p = 1 - q$ (in the N litters). The significance of these deviations ($\alpha = 0.05$) was tested deriving the standard normal deviates $z = |(K/I)/(1/I)^{-1/2}|$.

Second, equal distribution of gender probability between farms and litter size and piglet birth weight levels, was tested by applying Fisher's exact probability test to contingency table data. Birth weight was categorised in three levels: (1) piglets with less than 1 kg of weight; (2) piglets with a weight between 1 and 1.5 kg; and (3) piglets with more than 1.5 kg of weight. Now, the criteria followed were the biological (mortality during lactation) and economical (growth performances) differences observed between these classes in the four farms analysed in the present study (Table 2) that agrees with the results obtained by Caugant and Guéblez (1993).

Thirdly, for each level of farm, litter size and piglet birth weight considered, female proportion was estimated and tested to be significantly different than the whole population female proportion by the Binomial test using the NPAR TEST SPSS procedure (SPSS Inc., 2002). The measurement interval for each female proportion estimate was established for a 90% confidence interval following Von Collani and Elart (2001) tables.

Table 2. Mortality percentage and growth performance values (mean and standard error) during lactation, according to classes of piglet birth weight

	Piglet birth weight (kg)		
	< 1	1 – 1.5	> 1.5
Mortality (%)[1]	42	13	7
Average daily gain (kg day^{-1})[2]	0.175[a] (0.004)	0.212[b] (0.002)	0.246[c] (0.002)
Weaning weight (kg)[2]	2.5[a] (0.1)	4.8[b] (0.1)	6.0[c] (0.1)

[1] Significant differences among piglet birth weight classes by chi-square analysis ($\alpha = 0.05$).
[2] Different letters indicate significant differences between means ($\alpha = 0.05$).

Finally, permutation testing was also applied to acquire more information about the probability of occurrence of observed gender proportion within farms and levels of litter size and piglet birth weight. The distribution of the number of females within a level was computed by data permutation and observed values were compared with thresholds of the 95% high probability density area. Data permutation (100,000 permutations per analysis) was done by developing a very simple FORTRAN90 program using RNPER ISML subroutine (IMSL Stat/Library, 1994). Theory details on permutation testing can be found in Good (1994).

Results

A normal dispersion of the sex ratio for the overall data analysed was found (Table 3) indicating that sex ratio variance fits the binomial expectation. Variance in sex ratio was not significantly different from that expected under the binomial model in any farm or litter size class (Table 3). It should be considered, however, that the analyses performed present a low statistical power, and large deviations must exist to be detected, especially when small data sets are analysed.

Fisher's exact probability results to test contingency tables of sex and farm, sex and litter size, and sex and piglet birth weight, were $\alpha = 0.008$, $\alpha = 0.168$ and $\alpha = 0.006$ respectively. These results indicate that equal probability gender among different sizes of litter cannot be rejected, but differences could exist between farms and piglet birth weight levels.

The estimated female proportions within farm, litter size and birth weight, shown in Table 4, offer more information about the previous result. The overall estimate of the proportion of females was 0.496. Estimates in farms B and D were no different from this value, but estimated values in farms A and C were significantly different from that value and showed measurement intervals which hardly overlapped at all. Similarly, proportions of middle weight and heavier piglets at birth were significantly different from the overall value and almost different to each other, with more and less females than expected respectively. Differences between litter size levels are not observed confirming the result of Fisher's exact probability test, but the proportion estimated in the level of small litter size (lower than 10 piglets) was significantly smaller than the overall value.

The permutation distributions of the number of females within each farm (Fig. 1), litter size (Fig. 2) and piglet birth weight (Fig. 3) classes confirm the results of Table 4, showing that the number of females observed in farm A, and classes of middle weight (between 1 and 1.5 kg) and heavier piglet (more than 1.5 kg) at birth were very unexpected under the hypothesis of random distribution across farm and birth weight. They also show that number of females observed in farm C and smaller litter size class (less than 10 piglets) were just on the threshold of the 95% high probability density region.

Table 3. Dispersion of the litter sex distribution (K/I), variance (1/I), standard normal deviate (z) and associated two-sided probabilities (P) of all data and within farm and litter size classes

	Class	n	K/I ($\times 10^2$)	1/I ($\times 10^4$)	z	P
Overall		168	−0.2513	0.0626	1.00	0.315
Farm	A	41	−0.7293	0.2543	1.45	0.148
	B	45	−0.4948	0.2104	1.08	0.281
	C	44	0.3503	0.2543	0.07	0.945
	D	38	−0.4599	0.2806	0.87	0.385
Litter size	< 10	45	0.9741	0.5287	1.34	0.180
	10 - 11	32	−0.2316	0.3939	0.37	0.712
	12 - 13	44	−0.6655	0.2076	1.46	0.144
	> 13	47	−0.372	0.1478	0.97	0.333

Table 4. Estimated proportions of females, measurement intervals, and probability (P-value) of the null hypothesis that female proportion did not differ from population's value (q = 0.496) (for farm, litter size and piglet birth weight classes)

Factor	Class	No. records	Proportion of females	Measurement interval (β=0.90)	P-value (One-tailed test)
Farm	A	447	0.564	0.506-0.623	0.002
	B	522	0.489	0.439-0.540	0.383
	C	460	0.457	0.406-0.509	0.050
	D	417	0.475	0.421-0.531	0.207
Litter size	≤ 9	226	0.434	0.380-0.489	0.035
	10 - 11	443	0.499	0.445-0.555	0.471
	12 - 13	532	0.523	0.472-0.575	0.119
	≥ 14	645	0.493	0.448-0.539	0.456
Piglet birth weight	< 1 kg	290	0.476	0.428-0.524	0.265
	≥ 1 ≤ 1.5 kg	941	0.531	0.493-0.571	0.016
	> 1.5 kg	615	0.450	0.407-0.496	0.013

Discussion

In our data no less unisexual or more sex-balanced litters were observed than expected under a binomial model as reviewed in other works (James, 1975; Brooks *et al.,* 1991). Sex probability variation within a litter from one zygote to another has been used in some interesting discussions as an argument to accommodate disparity between works with contradictory results for factors influencing sex ratio (James, 1998; Meikle *et al.,* 1998; Mendl *et al.,* 1998). In the present study, there is no evidence to accept the hypothesis that the probability that a zygote is male or female varies from zygote to zygote within a litter, independently of farm or litter size. Consequently, we can assume sex follows a binomial distribution in our data although non-parametric tests, like permutation testing, do not need this assumption.

The results indicate that sex seems to follow a binomial distribution but sex probability is not the same for all the farms. Apparently farms have similar characteristics and are quite homogeneous. Comparing reproductive performances of farm A, which showed a biased female proportion, with those of the other farms, only sow's farrowing back fat can be considered to be significantly different and only from the value of farm B (Table 1). Consequently, the lower value of farm A can not be related with a poorer nutritional state throughout gestation that some works have suggested can affect sex ratio (Mendl *et al.,* 1997). It could also be considered that the

farm sex ratio variability observed could be associated with some source of genetic variability. Sex is a genetic trait, maybe the most important, and it would be plausible to expect genetic variation for sex ratio among populations and individuals. However, animals from all the farms had the same origin and evidence of large genetic variation is limited and there is no conclusive evidence of important individual differences in pigs (Hohenboken, 1981; Clutton-Brock and Iason, 1986). Our study shows that sex ratio variability could exist among farms, although no reasonable cause can be suggested, specially taking into account that the project to which these data belong was not designed for that purpose.

The results also suggest that sex ratio is not influenced by litter size in agreement with the results of Soede *et al.* (2000). The uterus space available per embryo has been related to a differentiated sex survival with a tendency to favour females when resources available to the foetuses are limited (Chen and Dziuk, 1993). However, we have not observed sex ratio deviation in large litters, but in small size litters, presumably without limited resources, sex ratio was not 1:1, finding more males than expected. The influence of litter size is far from well known. In other domestic species such as sheep, litter size showed a significant influence (Skjervold, 1979). Clutton-Brock and Iason (1986) reviewed 20 studies in several mammalian species and only seven showed differences in sex ratio between litter sizes. Results later reported in different species are also contradictory (Vangen, 1993; Peaker and Taylor, 1996; Krackow, 1997).
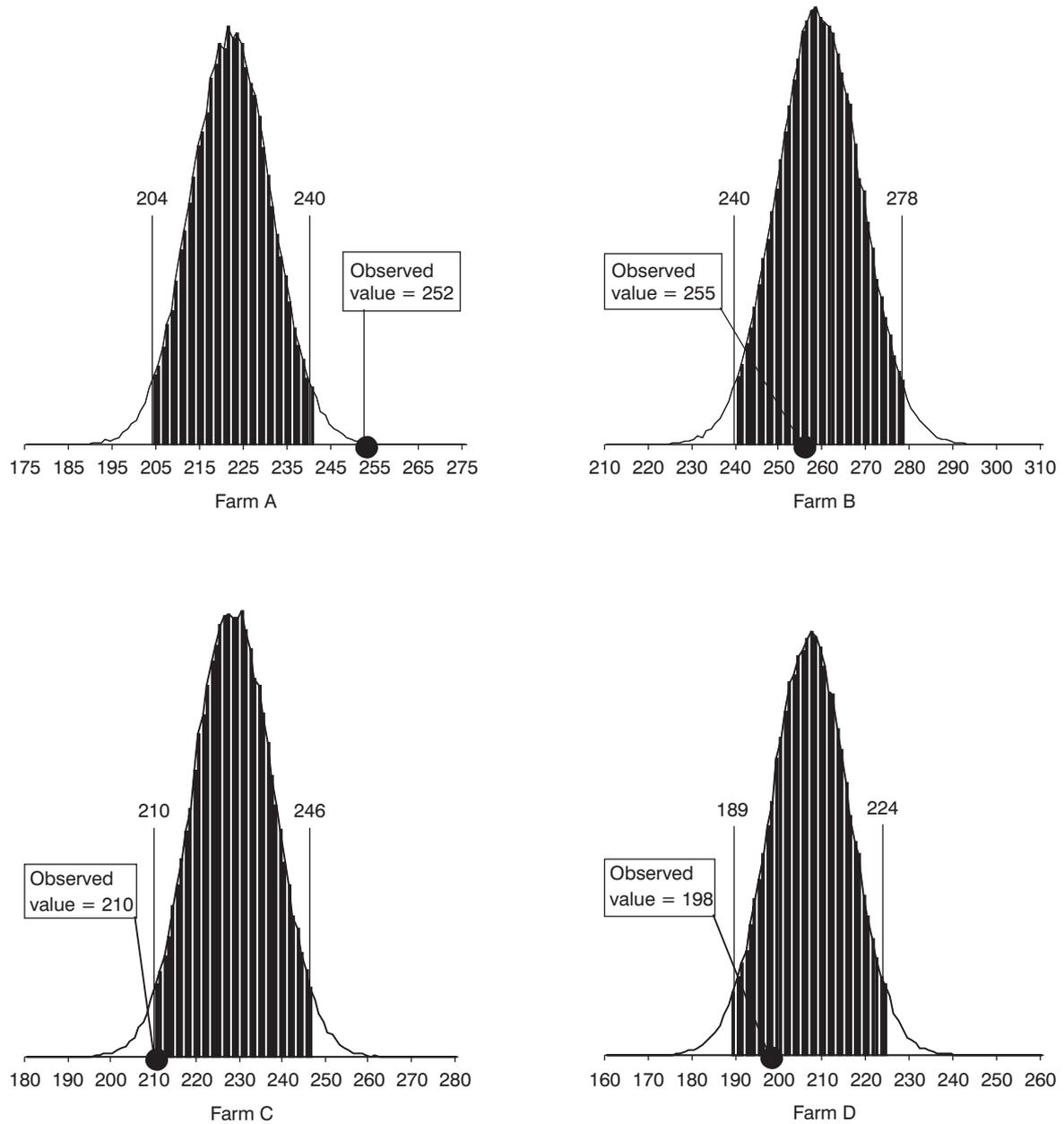
Figure 1. Permutation distribution of the number of females according to farm. Observed values are shown in boxes. Shaded regions represent the 95% density area; threshold values are indicated

Finally, sex ratio variation was observed in our study related to birth weight. A higher number of heavier males and middleweight females were found than expected under the hypothesis of equal probability. This result could be explained by the influence of sex on growth, but contradictory results for sex effect on pig embryo and foetal development have been reported in the literature (Rohde Parfet *et al.,* 1990; Caugant and Guéblez, 1993; Cassar *et al.,* 1994; Kaminsky *et al.,* 1996; Quiniou *et al.,* 2002). Our data indicate that sex ratio does not increase linearly with birth weight and that birth weight shows heterocedasticity, with variance
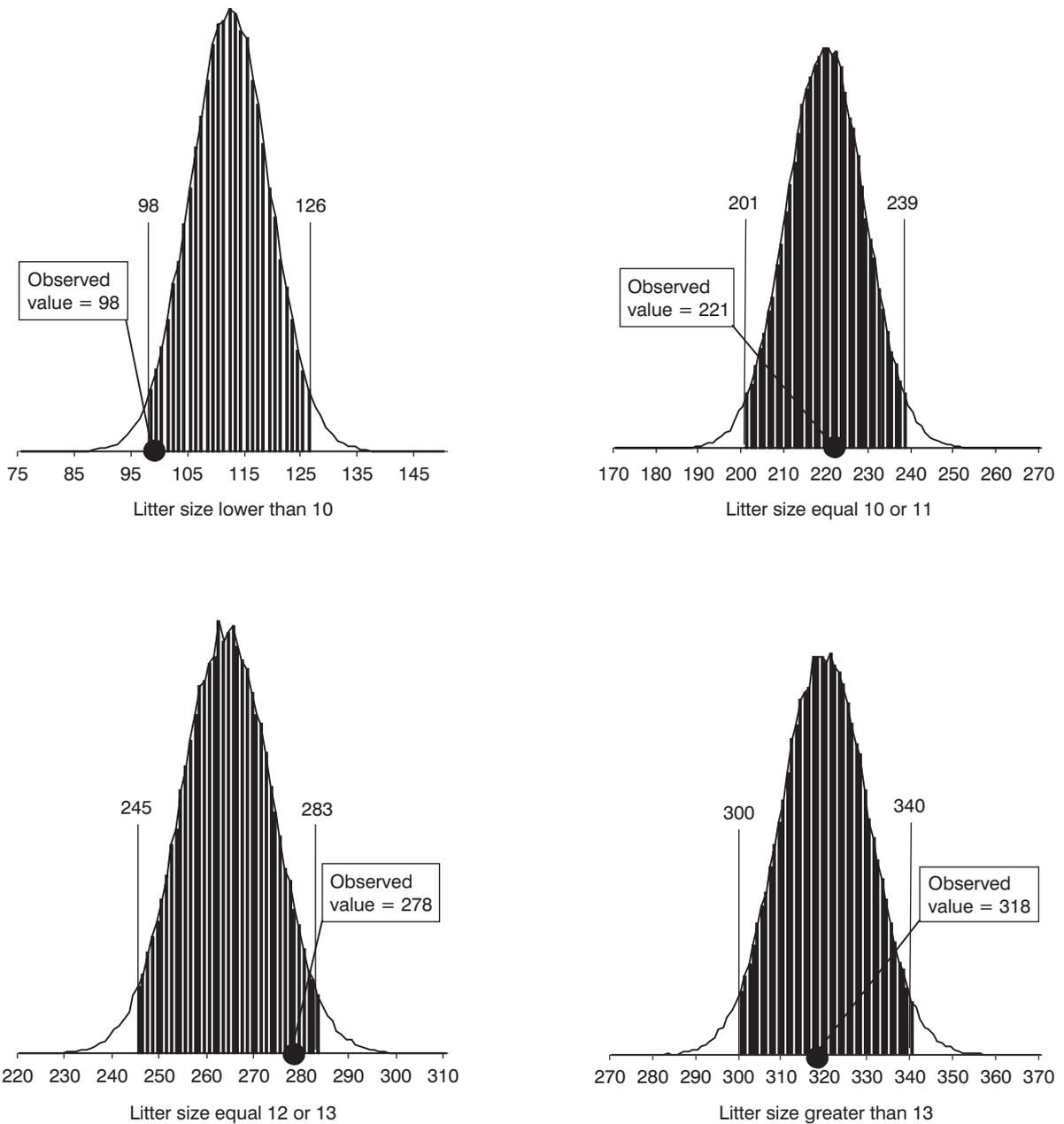
Figure 2. Permutation distribution of the number of females according to litter size classes. Observed values are shown in boxes. Shaded regions represent the 95% density area; threshold values are indicated

being significantly greater in males than in females. We can suggest therefore that a relationship between the sex ratio and birth weight ratio may exist, although this relationship should not necessarily be linear and should consider the possible heterocedasticity of the birth weight.

In summary, it is possible that sex ratio variability between farms exists in commercial pig populations. We have not found any evidence that this trait does not follow a binomial distribution but the expected equal gender probability was not always estimated. Sex probability varied significantly with a magnitude
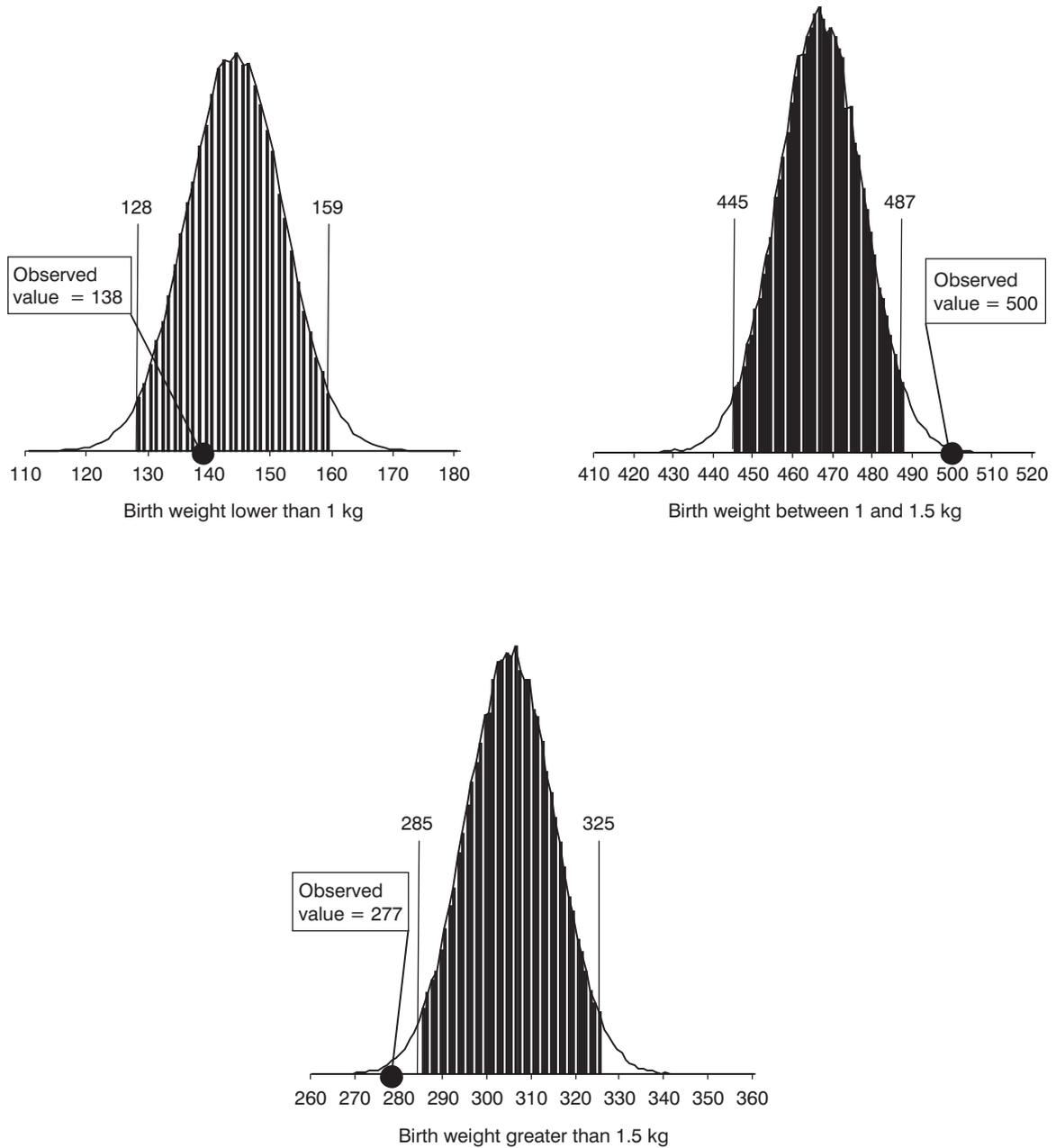
Figure 3. Permutation distribution of the number of females according to piglet birth weight classes. Observed values are shown in boxes. Shaded regions represent the 95% density area; threshold values are indicated

that could have some kind of interest if explanatory causes could be identified and subsequently manipulated. No clear association between sex ratio and litter size was observed. However, sex ratio varied among piglet birth weight classes. In conclusion, this work has shown results of pig sex ratio variability and the value of some statistical procedures to analyse data of this kind.

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