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CHAPTER 29

ANALYSIS OF CORRELATION STRUCTURE IN BILATERAL TRAITS

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CONTENTS

ABSTRACT

When studying asymmetry of bilateral traits, it is very important to take into account their correlation structure. The assumption for quadrivariate normal distribution of traits considers possible models of equality of four correlation coefficients between traits using different criteria and approaches on the basis of two large lamina samples (N_1=500, N_2=521) of drooping birch (*Betula pendula* Roth.). This study has shown that different traits give evidence of different models of correlation structure.

29.1 INTRODUCTION

When studying morphological traits of biological objects a researcher faces an important biological phenomenon – symmetry of organism structure. Weyl defines different types of symmetry [1]; in this work we turn our attention only to bilateral symmetry – left/right symmetry. By virtue of different factors (such as heterogeneous living environment) perfect symmetry does not exist in nature, that is why the study of perfect symmetry deviation – different types of asymmetry – is an important task both from basic and applied point of views. Van Valen distinguishes fluctuating, directive asymmetry and antisymmetry [2]. After publication of Astaurov's work [3] the phenomenon of fluctuating asymmetry has become the subject of much research. One of the research courses for this phenomenon was an investigation of its quantitative estimation methods. The works of Palmer and Strobeck [4–6] contain an extensive summary. Zakharov drew attention to the influence of correlation coefficient between different parts of one trait (left/right correlation) in estimating fluctuating asymmetry [7]. In our work [8] we have suggested a new quantitative estimation index for fluctuating asymmetry – coefficient of variation – correlation $CVR = CV \cdot \left(1-\rho^2\right)$. This index based on the probability model presents left/right correlation in an explicit form as one of its components. This index has theoretical rather than practical importance as it is calculated on the basis of just one trait. Considering the symmetry of the object as a whole, usually a set of traits is used in practice. This raises the question of correlation structure between traits of the object with bilateral symmetry. This aspect is rather topical from several points of view. Firstly, it may be an additional argument when choosing traits. Secondly, according to pilot studies, it may play a significant role in estimating degree of asymmetry of bilateral objects. Thirdly, this question is important by itself, from the point of view of morphological structure of such objects. It was shown that the correlation coefficient between traits influenced fluctuating asymmetry assigning the variation range of left/right correlation (Figs. 29.1–29.6), that is, with the increase of correlation value between the traits range of possible values of left/right correlations diminished becoming a speck when correlation coefficient between traits was 1. Therefore, it becomes essential to study the correlation structure between the traits [9].

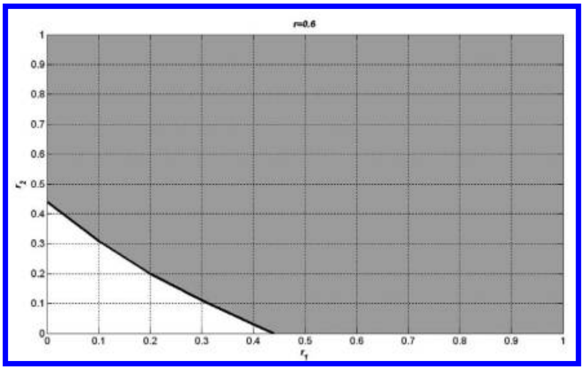

FIGURE 29.1 The range of variation of left/right correlation for two traits in case when correlation between traits is ≤0.5 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

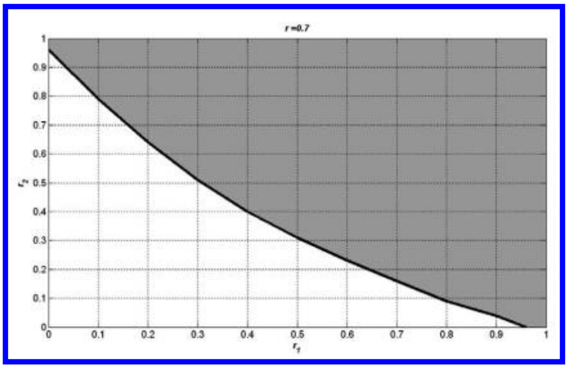

FIGURE 29.2 The range of variation of left/right correlation for two traits in case when correlation between traits is 0.6 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

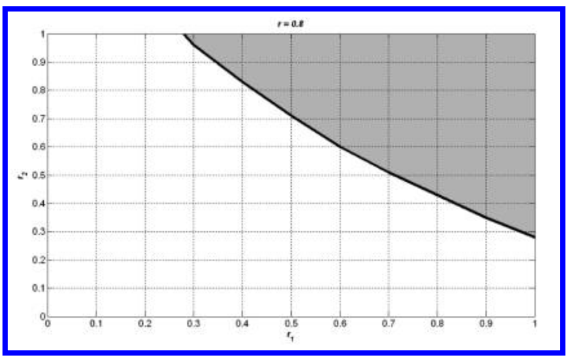

FIGURE 29.3 The range of variation of left/right correlation for two traits in case when correlation between traits is 0.7 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

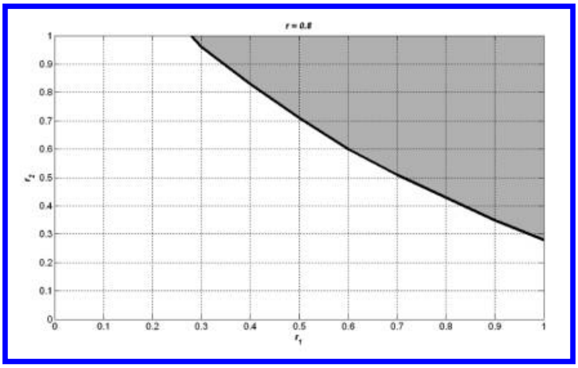

FIGURE 29.4 The range of variation of left/right correlation for two traits in case when correlation between traits is 0.8 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

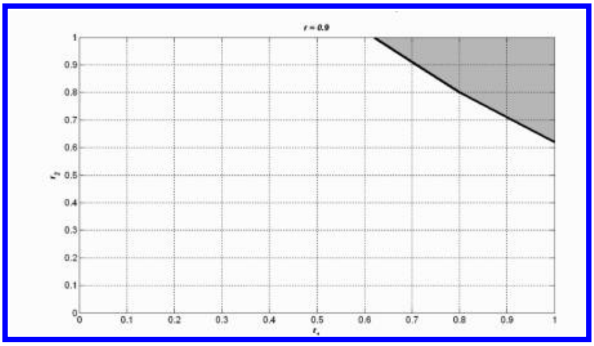

FIGURE 29.5 The range of variation of left/right correlation for two traits in case when correlation between traits is 0.9 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

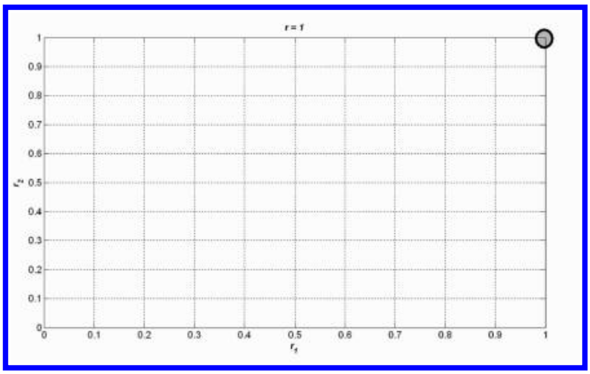

FIGURE 29.6 The range of variation of left/right correlation for two traits in case when correlation between traits is 1.0 (along abscissa axis left/right correlation is for the first trait, along ordinate axis it is for the second one).

In this chapter, we assume that data come from a multivariate normal distribution. In the case of two traits the correlation matrix contains two left/right correlation coefficients and 4 correlation coefficients between the parts of different traits (Fig. 29.7).

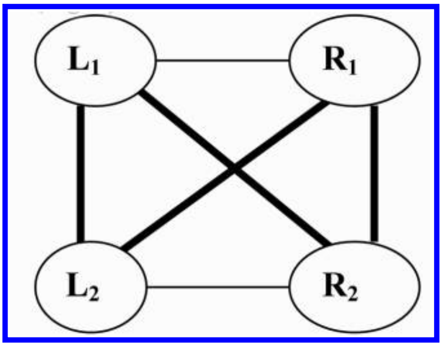

FIGURE 29.7 Correlation structure of two traits of the object with bilateral symmetry: L_1, R_1 are the values of the first trait on the left and on the right; L_2, R_2 are values of the second trait on the left and on the right.

Fine lines signify correlations between left and right parts for a separate trait, heavy lines – correlations between traits. If we assume that the traits have normal distribution, Pearson linear correlation coefficients may act as a quantitative measure of these connections. In this case there are four such correlation coefficients. The easiest estimation method for communication between traits is averaging out of these correlation coefficients or calculation of correlation coefficient between averaged value of the first trait ($(R_1 + L_1)/2$) and the second one ($(R_2 + L_2)/2$). However, this may lead to the loss of considerable part of information.

It is possible to hypothesize regarding the equality of these correlation coefficients in different ways. It is worth noting that the correlations are dependent.

29.2 MATERIALS AND METHODOLOGY

The research was carried out on the basis of materials of two independent lamina samples (V1 and V2) of drooping birch *Betula pendula* Roth. The material for the first sample was collected in the section of Nizhny Novgorod City on the other side of the Volga River in July August of 2004 in five localities (habit areas), in the quantity of 10 leaves from a separate tree. The total sample size is 500 leaves. For each lamina the values of five traits were measured on the left and on the right (Fig. 29.8). All measurements were conducted straight on the collected leaves using the protractor and the ruler. In this work we have used only first four traits.

The material for the second sample was collected in July of 2007 along the roadway of the 40th Anniversary October Revolution Street, the City of Nizhny Novgorod. The total sample size was 521 laminas. The measurements were conducted on the scanned material using electronic ruler.

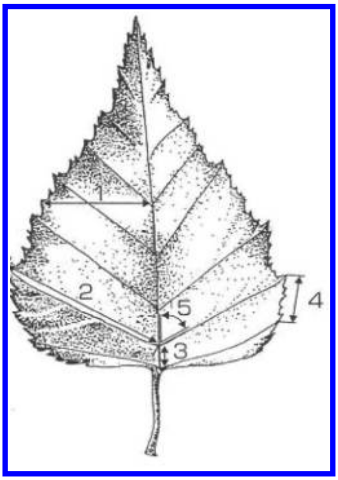

FIGURE 29.8 Measurement scheme for the leaf of drooping birch [10].

The collection methods of the first and the second samples were different. The material of the first sample was collected according to the standard method [10]: we took 10 leaves developed enough from each tree, 10 trees per each locality. The material of the second sample was collected in the following way: we cut one of the branches of each tree from every exposition at a height maximum available for the hand shears and collected all laminas; laminas collected from one branch were enumerated and then 20 laminas, which were chosen using a random number generator, were scanned.

Both samples were submitted to examination for the presence of outliers. On the basis of Rosner's test [11] 2 observations were removed from sample V1, 5 observations – from sample V2. In sample V1 the most of the observations are presented within the accuracy of integral values, however, some values (generally closer to the average ones) are presented within the accuracy of 0.5. Such values are rounded to the integral values.

The difference of traits distribution in sample V1 is statistically significant in comparison with the normal distribution (Table 29.1).

TABLE 29.1 Testing For Normality of Traits in Sample V1

Tests	L_1	R_1	L_2	R_2	L_3	R_3	L_4	R_4
χ^2 test	0.12	2.2 $\times10^{-9}$	2.4 $\times10^{-4}$	3.2 $\times10^{-5}$	8.3 $\times10^{-12}$	4.4 $\times10^{-11}$	1.2 $\times10^{-4}$	2.7 $\times10^{-5}$
Bera-Jarque test	0.67	0.38	0.04	0.08	1.3 $\times10^{-7}$	0.01	0.27	0.90
Kolmogorov–Smirnov test	0.01	0.01	3.5 $\times10^{-4}$	3.8 $\times10^{-3}$	5.9 $\times10^{-11}$	3.9 $\times10^{-10}$	1.5 $\times10^{-7}$	4.0 $\times10^{-6}$
Shapiro–Wilk test	2.0 $\times10^{-14}$	5.1 $\times10^{-14}$	6.7 $\times10^{-14}$	1.7 $\times10^{-15}$	3.8 $\times10^{-13}$	4.3 $\times10^{-14}$	1.8 $\times10^{-14}$	7.3 $\times10^{-14}$

In sample V2–5 distributions of 8 do not differ significantly from the normal ones (Table 29.2).

TABLE 29.2 Testing For Normality of Traits in Sample V2

Tests	L1	R1	L2	R2	L3	R3	L4	R4
χ^2 test	0.17	2.3 $\times10^{-4}$	0.62	0.31	0.21	0.88	0.06	6.9 $\times10^{-4}$
Bera-Jarque test	0.22	0.03	0.20	0.20	0.23	0.26	0.02	0.01
Kolmogorov–Smirnov test	0.59	0.11	0.72	0.58	0.53	0.59	0.23	0.08
Shapiro–Wilk test	0.08	1.8 $\times10^{-3}$	0.11	0.01	0.06	0.17	4.9 $\times10^{-3}$	1.0 $\times10^{-4}$

Parameters of sample V1 are presented in Tables 29.3–29.4. All correlation coefficients differ significantly from zero value ($P<10^{-2}$).

TABLE 29.3 The Means and the Variances of Sample V1

Parameters	L1	R1	L2	R2	L3	R3	L4	R4
Mean	22.11	22.36	36.06	35.97	5.22	5.22	13.30	12.57
Variance	10.49	9.99	22.23	21.65	2.53	2.54	4.00	3.75

TABLE 29.4 The Correlation Matrix of Sample V1

	L1	R1	L2	R2	L3	R3	L4	R4
L1	1	0.74	0.80	0.71	0.26	0.27	0.52	0.46
R1	0.74	1	0.71	0.77	0.21	0.16	0.44	0.52
L2	0.80	0.71	1	0.87	0.22	0.26	0.60	0.45
R2	0.71	0.77	0.87	1	0.28	0.23	0.49	0.54

TABLE 29.4 *(Continued)*

	L1	R1	L2	R2	L3	R3	L4	R4
L3	0.26	0.21	0.22	0.28	1	0.60	0.10	0.18
R3	0.27	0.16	0.26	0.23	0.60	1	0.17	0.14
L4	0.52	0.44	0.60	0.49	0.10	0.17	1	0.55
R4	0.46	0.52	0.45	0.54	0.18	0.14	0.55	1

Parameters of sample V2 are presented in Tables 29.5–29.6. All correlation coefficients differ significantly from zero value ($P<10^{-3}$).

TABLE 29.5 The Means and the Variances of Sample V2

Parameters	L1	R1	L2	R2	L3	R3	L4	R4
Mean	16.62	16.41	26.52	26.40	3.45	3.56	8.92	8.92
Variance	19.72	20.48	48.90	50.21	1.91	2.01	5.99	6.69

TABLE 29.6 The Correlation Matrix of Sample V2

	L1	R1	L2	R2	L3	R3	L4	R4
L1	1	0.93	0.95	0.93	0.14	0.14	0.85	0.83
R1	0.93	1	0.93	0.95	0.16	0.15	0.84	0.85
L2	0.95	0.93	1	0.97	0.16	0.18	0.87	0.83
R2	0.93	0.95	0.97	1	0.19	0.16	0.83	0.87
L3	0.14	0.16	0.16	0.19	1	0.72	0.11	0.14
R3	0.14	0.15	0.18	0.16	0.72	1	0.11	0.13
L4	0.85	0.84	0.87	0.83	0.11	0.11	1	0.84
R4	0.83	0.85	0.83	0.87	0.14	0.13	0.84	1

Hotelling [12] was the first who suggested the criterion for comparison the dependent correlation coefficients; he constructed an asymptotic criterion for comparison of 2 correlation coefficients of a three-dimensional normal distribution. Later on Williams [13] improved his result having increased the power of this criterion. Lawley [14] generalized Anderson's result [15] having built the criterion to compare nondiagonal elements of the correlation matrix. For these hypotheses Aitkin et al. [16] constructed the test based on the likelihood ratio. Dunn and Clark [17, 18] suggested several criteria to compare two dependent correlations; they calculated asymptotic correlations between z-values (values of correlation coefficients after Fisher's z-transformation), compared the powers of these criteria with already known Hotelling's [12] and Williams's [13] criteria. Steiger [19] suggested the solution for a more general problem – comparison of more than two dependent correlation coefficients. To solve this problem he considered two criteria that differ by estimation method of the unknown parameters: X_1 criterion uses the maximum likelihood estimates, and X_2 criterion is based on the generalized least squares method. It was shown that these estimates are equivalent [20].

In this chapter, we will use the following criteria and methods: the classical likelihood ratio test [21], the Akaike information criterion (AIC) and the Bayesian information criterion (BIC) [22–23], simulation-based criteria (model-based and nonparametric) and Steiger's X_2 criterion [19], as well as the estimation of correlation structure using partial correlation coefficients [24].

The likelihood ratio test is calculated as $-2ln\Lambda = -2ln\frac{\max_{\theta \in \Theta_0} L(\theta)}{\max_{\theta \in \Theta} L(\theta)}$, where the numerator is the maximum of likelihood function under the null hypothesis (Θ_0 parameter set), and the denominator is under the alternative, that is, the case of the difference of all 14 parameters of a 4-dimensional normal distribution (Θ parameter set). This statistic is approximately distributed as χ^2 -distribution with $(\nu - \nu_0)$ degrees of freedom, where ν is Θ dimension, and ν_0 is Θ_0 dimension.

The information criteria AIC and BIC can be written as follows

$$AIC = 2k - 2ln(L),$$

$$BIC = kln(N) - 2ln(L),$$

where k is the number of the model parameters to be estimated, L is the maximum value of likelihood function of the model, N is the sample size.

The proposed simulation criteria perform decision-making on the basis of the distribution of the differences of the compared correlation coefficients. In the first case (model-based simulation or parametric bootstrap), the specified distribution is constructed by repeated sampling from the multivariate normal distribution whose parameters are estimated from the sample. In the second case, the distribution is built by repeated sample replication by means of simple random sampling with replacement (nonparametric bootstrap analog).

The statistic of the Steiger's criterion has the following form:

$$X_2 = (N-3)[z(r) - z(\hat{p}_{GLS})]'S_{LS}^{-1}[(r) - z(\hat{p}_{GLS})],$$

where N is the sample size, $z(.)$ –is the Fisher's z-transformation, r is the vector-column of the sample correlation coefficients, $\hat{p}_{GLS}$ is the vector-column of the estimated correlation coefficients by the generalized least squares method under the null hypothesis, S_{LS}^{-1} is the estimate of the inverse covariance matrix between correlation coefficients received by the least squares method. The X_2 statistic has asymptotical χ^2 -distribution with $(k–q)$ degrees of freedom, where k is the number of upper-diagonal elements of the correlation matrix, that is, $k = (m^2 - m)/2$ for the matrix $m \times m$, q is the number of different correlation coefficients under the null hypothesis.

The variances of the traits for samples V1 and V2 differ about twofold (see Tables 29.3 and 29.5). The reason for this is different methods of material collection. In the first sample the objects were selected according to methodological recommendations [10], i.e. laminas were selected within quite small range of sizes, and in the second sample laminas were selected at random without considering their size. This led to the fact that the correlation structures of different samples are incomparably different: the traits in sample V2 are stronger correlated (see Tables 29.4 and 29.6). To compare the data of different samples we use partial correlation coefficients [24], where we choose lamina width as a conditional variable; it is calculated as the sum of the values of trait 1 on the left and on the right (denoted by *d*):

$$\rho_{L_iL_j\cdot d}=\frac{\rho_{L_iL_j}-\rho_{L_id}\rho_{L_jd}}{\sqrt{1-\rho^2_{L_id}}\sqrt{1-\rho^2_{L_jd}}},\quad \rho_{L_iR_j\cdot d}=\frac{\rho_{L_iR_j}-\rho_{L_id}\rho_{R_jd}}{\sqrt{1-\rho^2_{L_id}}\sqrt{1-\rho^2_{R_jd}}},\quad \rho_{R_iR_j\cdot d}=\frac{\rho_{R_iR_j}-\rho_{R_id}\rho_{R_jd}}{\sqrt{1-\rho^2_{R_id}}\sqrt{1-\rho^2_{R_jd}}},\quad i,j=\overline{2,4}.$$

29.3 RESULTS AND DISCUSSION

For the sake of convenience, we will denote the model when all of the four correlation coefficients between the traits are equal as 1111. If there are two different correlation coefficients, then the following models may be possible: 1112, 1121, 1122, 1211, 1212, 1221, and 1222. In case of three different correlation coefficients, the models are as follows: 1123, 1213, 1223, 1231, 1232, and 1233. Finally, if all four correlation coefficients are different, there is only one model 1234. For further details see Table 29.7.

In both samples for all pairs of traits, the likelihood ratio test accepted several different models. However, except for the pair of traits 1–2 in sample V2, in all cases model 1221 is not rejected at the 1% significance level (P = 0.02–0.94). The results for traits 1–2 in sample V1 are presented in Table 29.7. Model 1221 can be interpreted as a model in which all equal correlations between traits on one side of the lamina (left or right) differ from equal correlations between the values of the trait on different sides of the lamina.

TABLE 29.7 The Results of the Likelihood Ratio Test

Models	Interpretation	χ^2 test	Degree of freedom	P-value
1111	$\rho_{L_1L_2}=\rho_{L_1R_2}=\rho_{R_1L_2}=\rho_{R_1R_2}$	115.48	3	0.00
1112	$\rho_{L_1L_2}=\rho_{L_1R_2}=\rho_{R_1L_2}$	60.70	2	0.00
1121	$\rho_{L_1L_2}=\rho_{L_1R_2}=\rho_{R_1R_2}$	52.81	2	0.00
1122	$\rho_{L_1L_2}=\rho_{L_1R_2}\ \rho_{R_1L_2}=\rho_{R_1R_2}$	115.37	2	0.00

1211	$\rho_{L_1L_2} = \rho_{R_1L_2} = \rho_{R_1R_2}$	34.58	2	0.00
1212	$\rho_{L_1L_2} = \rho_{R_1L_2}\ \rho_{L_1R_2} = \rho_{R_1R_2}$	113.97	2	0.00
1221	$\rho_{L_1L_2} = \rho_{R_1R_2}\ \rho_{L_1R_2} = \rho_{R_1L_2}$	2.14	2	0.34
1222	$\rho_{L_1R_2} = \rho_{R_1L_2} = \rho_{R_1R_2}$	32.72	2	0.00
1123	$\rho_{L_1L_2} = \rho_{L_1R_2}$	4.82	1	0.00
1213	$\rho_{L_1L_2} = \rho_{R_1L_2}$	20.82	1	0.00
1223	$\rho_{L_1R_2} = \rho_{R_1L_2}$	0.12	1	0.72
1231	$\rho_{L_1L_2} = \rho_{R_1R_2}$	1.27	1	0.25
1232	$\rho_{L_1R_2} = \rho_{R_1R_2}$	14.55	1	0.00
1233	$\rho_{R_1L_2} = \rho_{R_1R_2}$	22.83	1	0.00
1234	All correlation coefficients are different	-	-	-

The values of the information criteria for this model are also small (see Table 29.8), which means that model 1221 is very plausible.

TABLE 29.8 The Results of the Information Criteria, AIC and BIC

Traits	Models	Rank AIC	Rank BIC
Sample V1			
	1111	13	13
1–2	1221	2	1
	1234	4	4
	1111	11	3
1–3	1221	10	6
	1234	6	14
	1111	13	13
1–4	1221	1	1
	1234	4	10
	1111	13	13
2–3	1221	1	1
	1234	6	11

	1111	14	13
2–4	1221	4	1
	1234	3	5
	1111	13	3
3–4	1221	1	1
	1234	9	15
Sample V2			
	1111	14	14
1–2	1221	4	4
	1234	2	2
	1111	10	1
1–3	1221	2	3
	1234	13	15
	1111	14	12
1–4	1221	6	2
	1234	5	8
	1111	13	13
2–3	1221	1	1
	1234	5	9
	1111	13	13
2–4	1221	1	1
	1234	4	4
	1111	6	1
3–4	1221	7	4
	1234	12	15

To test model 1221, simulation-based criteria (model-based and nonparametric) were also used (see Table 29.9).

TABLE 29.9 The Results of Simulation Study For Testing Various Hypotheses About Equality of the Correlation Coefficients (in bold – the corresponding hypothesis is rejected)

Traits	Hypotheses	Model-based simulation		Nonparametric simulation	
		2.5%-quantile	97.5%-quantile	2.5%-quantile	97.5%-quantile
Sample V1					
1–2	r1=r4	–0.0146	0.0559	–0.0214	0.0618
	r2=r3	–0.0566	0.0403	–0.0599	0.0426

1–3	r1=r4	0.0033	0.1841	0.0005	0.1817
	r2=r3	–0.0322	0.1436	–0.0322	0.1418
1–4	r1=r4	–0.0637	0.0866	–0.0716	0.0966
	r2=r3	–0.0895	0.0718	–0.0985	0.0799
2–3	r1=r4	–0.0923	0.0731	–0.0972	0.0767
	r2=r3	–0.0989	0.0601	–0.1005	0.0635
2–4	r1=r4	0.0088	0.1407	–0.0019	0.1517
	r2=r3	–0.1220	0.0317	–0.1279	0.0324
3–4	r1=r4	–0.1265	0.0710	–0.1242	0.0704
	r2=r3	–0.0949	0.1030	–0.0872	0.0950
Sample V2					
1–2	r1=r4	–0.0270	–0.0083	–0.0631	0.0077
	r2=r3	–0.0329	–0.0060	–0.0683	0.0109
1–3	r1=r4	–0.1085	0.0291	–0.1210	0.0383
	r2=r3	–0.0466	0.0900	–0.0554	0.1035
1–4	r1=r4	–0.0281	0.0191	–0.0382	0.0251
	r2=r3	–0.0551	0.0010	–0.0653	0.0077
2–3	r1=r4	–0.0955	0.0370	–0.1100	0.0455
	r2=r3	–0.0217	0.1040	–0.0403	0.1326
2–4	r1=r4	–0.0147	0.0234	–0.0193	0.0268
	r2=r3	–0.0306	0.0210	–0.0341	0.0258
3–4	r1=r4	–0.1383	0.0120	–0.1488	0.0208
	r2=r3	–0.0776	0.0718	–0.1082	0.0909

The model-based simulation criterion based on the multivariate normal distribution model rejects the hypothesis for pairs of traits 1–3 and 2–4 in the first sample as well as for pair of traits 1–2 in the second sample. The nonparametric simulation criterion is more conservative and rejects model 1221 only for pair of traits 1–3 in the first sample.

Using the Steiger's criterion, we tested models 1111 and 1221. The results are shown in Table 29.10.

TABLE 29.10 The Results of the Steiger's Criterion of Testing Models 1111 and 1221

Traits	**Model 1221**			**Model 1111**		
	χ^2	**df**	**P**	χ^2	**df**	**P**
Sample V1						
1–2	2.12	2	0.35	104.72	3	$<10^{-12}$

1–3	6.99	2	0.03	10.14	3	0.02
1–4	0.12	2	0.94	25.04	3	1.5×10^{-5}
2–3	0.62	2	0.73	25.53	3	1.2×10^{-5}
2–4	5.21	2	0.07	97.59	3	$<10^{-12}$
3–4	0.29	2	0.86	7.96	3	0.05
Sample V2						
1–2	15.55	2	4.2×10^{-4}	130.05	3	$<10^{-12}$
1–3	1.17	2	0.56	5.15	3	0.16
1–4	4.96	2	0.08	29.34	3	1.9×10^{-6}
2–3	1.73	2	0.42	58.83	3	1.0×10^{-12}
2–4	0.20	2	0.90	139.96	3	$<10^{-12}$
3–4	2.96	2	0.23	4.76	3	0.19

Except for a pair of traits 1–2 in the second sample, model 1221 is accepted everywhere. Model 1111, that is, the model of equality of all four correlation coefficients is rejected in most cases. Tables 29.11 and 29.12 show the partial correlation coefficients.

TABLE 29.11 The Partial Correlation Coefficients for Sample V1 (in bold – the corresponding hypothesis is rejected)

	L2	**R2**	**L3**	**R3**	**L4**	**R4**
L2	-					
R2	0.65	-				
L3	0.02	0.14	-			
R3	0.16	0.07	0.58	-		
L4	0.37	0.15	-0.03	0.06	-	
R4	0.06	0.24	0.06	0.02	0.39	-

TABLE 29.12 The Partial Correlation Coefficients for Sample V2 (in bold – the corresponding hypothesis is rejected)

	L2	**R2**	**L3**	**R3**	**L4**	**R4**
L2	–					
R2	0.73	–				
L3	0.09	0.16	–			
R3	0.20	0.09	0.70	–		
L4	0.33	0.12	–0.03	0.01	–	
R4	0.15	0.36	0.06	0.05	0.41	–

The analysis of the partial correlation coefficients shows that a large proportion of the correlations between traits are caused by the dependence on the size of lamina. Deliverance from this dependence leads to a situation that is very similar for both samples: traits 2 and 4 are uncorrelated, and the correlations between traits 2 and 3 are significant only when the traits located on the same side of lamina (left or right), while the correlation between the left and right sides of the same trait remains sufficiently high. Based on the values of the partial correlation coefficients, model 1221 also seems the most plausible, however, this requires a rigorous statistical analysis and this is the direction of our further research.

29.4 CONCLUSIONS

When studying asymmetry of bilateral traits one cannot but take into account their correlation structure. Based on the results received we may see that when estimating correlation between traits we cannot use the averaged values of these correlation coefficients as their equality model is one of the worst ones. It is confirmed by all criteria examined in this work. The most credible is the model in which the equal correlations between traits on one part of the lamina (left or right) differ from the equal correlations between trait values on different parts of the lamina. The examined correlation structure depends significantly on the chosen range of lamina sizes, which is struck off using partial correlation coefficients to a wide extent, at the same time communication between left and right parts of one trait stays strong enough. Based on the estimates of partial correlation coefficients we may suppose that the same model is the most probable for the correlated traits, but some traits appear to be noncorrelated.

The investigation of the influence of correlation structure between traits to the integrated indexes of asymmetry of bilateral objects seems to be the important direction of further research as for a set of traits. The selection of traits to study fluctuating asymmetry depending on their correlation is also of interest.

In order to understand the scope of generalization of the received results, it is necessary to expand the analysis conducted in this work to other objects and other traits different in structure of fluctuating asymmetry, for example, to bilateral traits of rodents skull [25].

The elaboration of this range of problems may allow understanding the mechanisms of the most important biological problem at least partially. Schmalhausen formulated it as follows: an organism as a whole in individual and historical development [26].

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KEYWORDS

- ***Betula pendula* Roth.**
- **bilateral symmetry**
- **dependent correlation coefficient**
- **fluctuating asymmetry**

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