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Influence of aperture complex indicators on pollen volume in seedless grape cultivars

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Abstract

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The influence of aperture complex indicators on the pollen volume in 70 seedless grape cultivars was studied by mathematical methods. Among the newly created seedless cultivars, Hybrid V-6 (4708.54 μm³) had the largest pollen volume, whereas Russalka 1 (1487.92 μm³) had the smallest. In the old seedless varieties, Rody (4018.27 μm³) has the maximum and Corinthian white (1605.03 μm³) has the minimum volume of pollen. In the cultivars of the first group, statistically significant positive correlations were found between pollen volume and mesocolpium and furrow length, whereas in the cultivars of the second group, significant positive correlations were found between pollen volume and mesocolpium and apocolpium. Mesocolpium and furrow length had the strongest total positive influence on pollen volume (88.55%) in the first group, whereas mesocolpium, apocolpium and furrow length had the strongest total positive influence in the second group (94.11%). The produced linear regression models allow for future theoretical research related to the influence of the parameters of the elements of the pollen aperture complex on its volume.

Keywords: seedless grape cultivars; palynological indicators; pollen volume

Introduction

Information related to the micromorphological characteristics, vitality and fertility of pollen is needed in the creation and cultivation of different grape cultivars. Modern mathematical research methods allow a more in-depth analysis of the correlations and dependencies between the microstructural parameters of the aperture complex of pollen grains. Palynological observations by scanning electron microscope and classifications based on surface ornamentation and pollen grain sizes have been performed on seed and seedless cultivars and grape species by many authors (Linder and Linskens, 1978; Lombardo et al., 1976, 1978; Kasirszkaja, 1982, 1984; Slimane and Askri, 1989; Faegri and Iversen, 1989; Inceoglu et al., 2000; Marasali et al., 2005; Gökbayrak and Engin, 2022). According to Kelen and Demirtas (2003) and Sharafi and Bahmani (2011), pollination is the main factor influencing the quantity and quality of grapes in the vine. Through correlation analysis Sabir (2015) demonstrated that as a result of treatment with toxic materials – pesticides, plant biostimulants and chemical fertilizers, changes occur in the lengths of the polar and equatorial axes of pollen, reducing its viability, which negatively affects yield. After a biometric analysis of pollen from Spanish grape cultivars, Gallardo et al. (2009) found that pollen grains from male flowers were predominantly prolate spheroidal, whereas those from female flowers ranged from spheroidal to oval. A matter of particular interest is the existence of relationships between the biometric features of the individual palynological components, reflecting the microrelief on the pollen exine surface and its volume. The aim of this study was to perform a complex assessment of the palynological interdependencies

between the volume and the pollen aperture complex elements in seedless grape cultivars using several mathematical methods.

Material and Methods

In the experimental work, scanning electron microscopic biometric data were used for the dimensions of the polar axis, equatorial axis, mesocolpium, apocolpium, length, width and depth of furrows, length and width of pollen pores (μm) in 70 seedless grape cultivars determined using a JEM 1200 electron microscope with an ASID 10 scanning attachment (Roytchev et al., 1994; Roytchev, 1995; Roytchev, 1997). The studied cultivars were conditionally divided into two groups: the first one includes mainly newly established seedless cultivars and hybrid forms, and the second one – already known old seedless cultivars.

It is known from mathematical analysis that an ellipsoid is a three-dimensional surface with the equation:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1 \quad (1)$$

where: *a*, *b*, *c* are the lengths of its semi-axes relative to the Cartesian coordinate system in space. The pollen grain of grape cultivars can be considered a solid of revolution obtained by rotating an ellipse whose major and minor axes coincide with the polar and equatorial axes, respectively. The volume of this body was calculated by the formula:

$$V=\frac{4}{3}\pi abc=\frac{4}{3}\pi ab^2 \quad (2),$$

where:

$$a=\frac{polar\ axis\ lenght}{2} \quad (3),$$

$$b=\frac{equatorial\ axis\ length}{2} \quad (4).$$

Here π is known in mathematics as Ludolph's number or Archimedes' constant, which in this study is used by its numerical value $\pi=\frac{22}{7}$. Then

$$V=\frac{4}{3}.\frac{22}{7}ab^2=\frac{88}{21}ab^2 \quad (5).$$

A comparison of the cultivars from the two groups studied was made according to the volume of pollen grains by the one-way analysis of variance and Duncan's multiple range test (Duncan, 1955).

Correlation analysis was used to study the relationships between the different aperture elements and pollen volume. The correlation coefficients were calculated using Pearson's formula:

$$R=\frac{\sum_{i=1}^{n}(Y_i-\bar{Y})(X_i-\bar{X})}{\sqrt{\sum_{i=1}^{n}(Y_i-\bar{Y})^2\sum_{i=1}^{n}(X_i-\bar{X})^2}} \quad (6),$$

where: $\bar{X}$, $\bar{Y}$ are the arithmetic means of the two variables.

The study also includes path analysis as a tool for determining the direct and indirect influence on the change in pollen volume depending on the change in the size of the most important parameters of the aperture complex. Regression analysis was used to present in an analytical way the proven relationships between the different palynological indicators. Multiple linear regression was applied, modeling the influence of the elements of the pollen aperture complex on its volume. The mathematical processing of the experimental data was performed using the statistical software product IBM SPSS 24 (Sarwono, 2017).

Results and Discussion

The results of the comparative evaluation of the studied seedless cultivars in each group using one-way analysis of variance and Duncan's multiple range test showed that in the first group, the Russalka 1 cultivar (1487.92 μm^3) had the smallest volume of pollen, while the Hybrid V-6 cultivar (4708.54 μm^3) had the largest (Table 1a, Table 1b, Table 1c). The average pollen volume of the cultivars in this group was 2938.79 μm^3 and the standard deviation was 839. In the cultivars of the second group, Corinthian white (1605.03 μm^3) had the minimum pollen volume, and Rody (4018.27 μm^3) had the maximum, with an average value of 2823.07 μm^3 and a deviation of 765.46 (Table 2). In both groups the variation in the volume was within 25–26% of the average value, which made it an unstable quantitative feature. Given the palynological indicators involved in the formulas for its calculation, it should be assumed that this is mainly due to the variation of the dimensions of the polar and equatorial axes of pollen. The presence of numerous patterns among the studied seedless grape cultivars further confirms the extensive polymorphism of the surface microstructures of the pollen aperture complex.

The results of the correlation analysis in the cultivars of the first group show that there is a significant mathematically proven positive relationship between pollen volume and mesocolpium (R = 0.659**) and furrow length (R = 0.666**) (Table 3). The data from the applied correlation analysis in cultivars of the second group show a mathematically proven

Table 1a. Pollen volume in the first group of seedless grape cultivars

Cultivars	Pollen volume μm³	Cultivars	Pollen volume μm³
Russalka 2	4557.85^{a}	Hybrid 20-4	2623.58^{ijklmno}
Thompson seedless	3729.33^{bcdef}	Vita	3252.05^{fghij}
Apirena di Valetri	3465.82^{cdefgh}	Early seedless	2970.39^{hijkl}
Hybrid 5-2	3074.08^{hijk}	Perlette	2815.27^{ijklmn}
Apirena bruni	3297.40^{efghi}	Nishava	3786.11^{bcdef}
Hybrid V-6	4708.54^{a}	Hybrid 17-2	2752.12^{ijklmn}
Hybrid 1-52	3992.47^{bc}	Russalka	1974.01^{qrstu}
Rusensko bez seme	3430.01^{defgh}	Hybrid 3	3901.02^{bcd}
Kondarev 6	3776.58^{bcdef}	Italia x Sultanina	3763.81^{bcdef}
Kishmish moldavski	3247.25^{fghij}	Korint rose	2890.67^{ijklm}

Table 1b. Pollen volume in the first group of seedless grape cultivars

Cultivars	Pollen volume μm³	Cultivars	Pollen volume μm³
Kolarovets	4100.86^{b}	Flame seedless	2849.23^{ijklmn}
Kondarev 10	3245.28^{fghij}	Slavjanka	2808.92^{ijklmn}
Hybrid 23-4	4020.26^{b}	Hybrid 720-19	2512.54^{lmnopq}
Kishmish Hyshrau	2868.85^{ijklm}	Beauty seedless	3650.91^{bcdefg}
Hybrid 3-6	2377.41^{mnopq}	Kishmish luchistii	2466.11^{lmnopq}
Delight	2622.37^{klmnop}	Hybrid 21-17-41	2802.88^{ijklmn}
Jangier	3175.55^{ghij}	Gigant	2719.55^{ijklmn}
Nedelchev VI-4	1990.64^{qrst}	Hybrid 36-16	2034.69^{qrst}
Russalka 5 A	2988.74^{hijkl}	Tarnau	2311.30^{nopqr}
Trakyska perla	3777.08^{bcdef}	Focha seedless	2472.78l^{mnopq}

Table 1c. Pollen volume in the first group of seedless grape cultivars

Cultivars	Pollen volume μm³
Russalka 5B	2181.75^{pqrs}
Superior seedless	1658.39^{stu}
Early superior seedless	2114.148^{qrst}
Nimrang x Sultanina	2960.68^{hijkl}
Emerald seedless	1549.11^{tu}
Ruby seedless	1813.88^{rstu}
Korint seedless	2374.67^{mnopq}
Russalka 1	1487.92^{u}
Kishmish VIRA	2212.97^{opqr}
Russalka 3A	2781.54^{ijklmn}

a,b,…,u-significance level (p = 0.05)
Source: Authors' own elaboration

high positive relationship between the pollen volume and – mesocolpium (R = 0.817**) and apocolpium (R = 0.696**) (Table 4). Therefore, the increase in pollen volume depends on the increase in the size of these indicators.

The obtained correlation coefficients, proving the connections between the volume and the change of the parameters of the pollen aperture complex elements, are decomposed into direct and indirect influences. They were used to calculate the relative share of each of the studied indicators relative to the correlation coefficient and to the indirect coefficient. The obtained results provide information about the degree (in percentages) of the influence of the total and, respectively, of the indirect effect on the pollen volume. The data show that the mesocolpium volume (43.81%) and the furrow length (44.74%) have the strongest overall positive effect on pollen volume in the seedless cultivars of the first group (Table 5).

The significant positive relationship between the volume of pollen and mesocolpium – 66.65% is due to the direct effect of this indicator and 33.35% to its indirect effect. Simi-

Table 2. Pollen volume in the second group of seedless grape cultivars

Cultivars	Pollen volume µm^3	Cultivars	Pollen volume µm^3
Rody	4018.27^{a}	Ushaas nazely	3161.76^{cde}
Sultanina gigas	2767.71^{ef}	Sultanina	2560.19^{fg}
Rushaki	3043.74^{def}	Korintsko black	3516.21^{bc}
Askery	3828.34^{ab}	Sermanly	1842.00^{hi}
Kishmish black	2897.59^{ef}	Kishmish Tjurkmenski	1934.22^{hi}
Kara sultani	3767.50^{ab}	Kishmish early	2217.67^{gh}
Kishmish Muskatni	1721.17^{i}	Kishmish Vatkana	2585.98^{fg}
Korsa kishmish	3007.76^{def}	Korintsko white	1605.03^{i}
Raucha white	3030.03^{def}	Seedless red	3399.63^{cd}
Kishmish Irtishor	2957.54^{def}	Sultanina muscata	2599.02^{fg}

Source: Authors' own elaboration

Table 3. Correlation coefficients for cultivars of the first group

Indicator	Volume	Mesocolpium	Apocolpium	Furrow length	Furrow width	Furrow depth	Pore length	Pore width
Volume	1	0.659**	0.238	0.666**	0.098	0.070	0.127	0.162
Mesocolpium		1	0.206	0.482**	-0.048	-0.016	-0.156	-0.020
Apocolpium			1	0.204	0.045	-0.141	0.105	0.166
Furrow length				1	-0.201	-0.237	-0.053	0.094
Furrow width					1	0.744**	0.119	-0.065
Furrow depth						1	0.059	-0.197
Pore length							1	0.407**
Pore width								1

*, ** Correlation coefficient at level of evidence 0.01 and 0.05

Source: Authors' own elaboration

Table 4. Correlation coefficients for cultivars of the first group

Indicator	Volume	Mesocolpium	Apocolpium	Furrow length	Furrow width	Furrow depth	Pore length	Pore width
Volume	1	0.817**	0.696**	0.421	-0.111	0.018	-0.06	0.259
Mesocolpium		1	0.614**	0.265	-0.355	-0.154	-0.079	0.391
Apocolpium			1	0.388	0.118	0.159	0.003	0.499*
Furrow length				1	-0.348	-0.216	-0.394	-0.122
Furrow width					1	0.652**	0.323	-0.043
Furrow depth						1	0.366	-0.030
Pore length							1	0.209
Pore width								1

*, ** Correlation coefficient at level of evidence 0.01 and 0.05

Source: Authors' own elaboration

Table 5. Direct and indirect influences of the studied characteristics on the pollen volume in the first group of cultivars

Indicator	Direct coefficient (Beta)	Indirect coefficient (Path)	Relative share of indicators (%) compared to:	
			Correlation coefficient	Indirect coefficient
Mesocolpium	0.439	0.220	43.81	66.65
Apocolpium	0.030	0.208	5.71	12.62
Furrow length	0.497	0.169	44.74	74.59
Furrow width	0.109	-0.011	0.970	110.86
Furrow depth	0.112	-0.042	0.490	159.57
Pore length	0.156	-0.029	1.630	122.75
Pore width	0.079	0.083	2.650	48.46

Source: Authors' own elaboration

Table 6. Direct and indirect influences of the studied characteristics on the pollen volume in the second group of cultivars

Indicator	Direct coefficient (Beta)	Indirect coefficient (Path)	Relative share of indicators (%) compared to:	
			Correlation coefficient	Indirect coefficient
Mesocolpium	0.712	1.05	47.26	12.85
Apocolpium	0.15	0.46	34.30	78.45
Furrow length	0.293	0.128	12.55	30.40
Furrow width	0.228	-0.339	0.87	305.41
Furrow depth	-0.016	0.034	0.02	188.89
Pore length	0.131	-0.191	0.25	318.33
Pore width	-0.067	0.326	4.75	125.87

Source: Authors' own elaboration

larly, 74.59% of the dependence of the volume on the length of the furrow is explained by its direct effect on this feature. The regression equation representing the change in pollen volume (y) as a result of a change in these characteristics in seedless cultivars of the first group has the following form:

$$y = -4074.87 + 287.34x_1 + 173.99x_2,$$

where: x_1 – mesocolpium, x_2 – furrow length.

It follows from the data in Table 6 that in the second group of cultivars the high positive relationship between pollen volume and mesocolpium size is a result of the direct effects between them, as the indirect effect is minimal. The existing significant positive correlation with the apocolpium is due to the indirect effect (78.45%), several times the value of the direct effect. This means that the main indicators of the pollen aperture complex, which were positively related to the change in its volume, are mesocolpium (47.26%), apocolpium (34.30%) and furrow length (12.55%), which total impact amounts to 94.11%. In Table 5 and Table 6, some of the percentage values exceed one hundred, as they compensate the values of the indirect and direct effect when it has a negative sign. The applied multiple linear regression in this group of seedless grape cultivars allows a mathematical model to be developed representing the influence of mesocolpium (x_1) and apocolpium (x_2) on pollen volume (y) in analytical form, as the obtained regression equation is of the following form:

$$y = -2993.72 + 331.93x_1 + 403.45x_2.$$

Conclusions

1. From seedless cultivars in the first group, Hybrid V-6 (4708.54 μm^3) has the largest volume of pollen, and Russalka 1 (1487.92 μm^3) has the smallest. In the cultivars of the second group, Rody (4018.27 μm^3) has the maximum pollen volume, and Corinthian white (1605.03 μm^3) has the minimum. Pollen volume in both groups of cultivars was a biometrically unstable characteristic, which was mainly associated with variation in the sizes of the polar and equatorial axes.

2. In seedless cultivars of the first group, there is a mathematically proven significant positive correlation between pollen volume and mesocolpium (R = 0.659**) and furrow length (R = 0.666**), and in cultivars of the second group – between pollen volume and – mesocolpium (R = 0.817**) and apocolpium (R = 0.696**). An increase in pollen volume was associated with increases in these indicators. The obtained results can be used in cytoembryology, systematics and ampelographic identification of different grape cultivars.

3. There is a weak to significant mathematically proven relationship between the studied features. In seedless cultivars of the first group, mesocolpium and furrow length have the strongest total positive influence on pollen volume (88.55 %), and in seedless varieties of the second group – mesocolpium, apocolpium and furrow length (94.11 %). The produced linear regression models allow for future theoretical research related to the influence of the parameters of elements of the elements of the pollen aperture complex on its volume.

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References

Duncan, D. (1955). Multiple range and multiple F tests. *Biometrics, 11*, 1–42. https://doi.org/10.2307/3001478

Faegri, K. & Iversen, J. (1989). Textbook of pollen analysis, 327. https://doi.org/10.1002/jqs.3390050310

Gallardo, A., Ocete, R., Angeles-Lopez, M., Lara, M. & Rivera, D. (2009). Assessment of pollen dimorphism in populations of *Vitis vinifera* L. subsp. Sylvestris (Gmelin) Hegi in Spain. *Vitis*, *48*(2), 59–62. https://doi.org/10.5073/vitis.2009.48.59-62

Gökbayrak, Z. & Engin, H. (2022). Cytological and Palynobiometric Investigation in *Vitis vinifera* L.: Case Study of Cultivar

'Cardinal'. *Erwerbs-Obstbau*, *64*(Suppl. 1), 47–53. https://doi.org/10.1007/s10341-022-00658-x

Inceoglu, O., Pinar, N. & Oybak-Donmez, E. (2000). Pollen morphology of wild Vitis sylvestris Gmelin (*Vitaceae*). *Turkish Journal of Botany*, *24*(2), 147–150.

Kasirszkaja, T. A. (1982). Surface properties of pollen of North American and East Asian grape species. "Janos Lippai", Scientific conference, *Flöadas*, 315–326 (Hu).

Kasirszkaja, T. A. (1984). Scanning electron microscopic characteristics of pollen grains of infra-red interspecific grape hybrids. Faculty of Viticulture, *University of Horticulture, The University of Horticulture's grape harvest–Ztesi Tanszeke,* 129–135 (Hu).

Kelen, M. & Demirtas, I. (2003). Pollen viability, germination capability and pollen production level of some grape varieties (*Vitis vinifera* L.). *Acta Physiol Plant*, *25*(3), 229–233. https://doi.org/10.1007/s11738-003-0002-7

Linder, R. & Linskens, H. (1978). Alsatian Grapevine Pollen. Genetics and Grapevine Improvement. *2nd International Symposium on Grapevine Improvement, Bordeaux,* 75–79 (Fr).

Lombardo, G., Cargnello, G., Bassi, M., Gerol, M. & Carraro, L. (1978). Pollen ultrast-ructure in different vine cultivars with low productivity. *Vitis*, *17*, 221–228.

Lombardo, G., Carraro, L., Cargnello, G. & Bassi, M. (1976). Ultrastructure of pollen of *Vitis vinifera* L. cv. "*Picolit giallo*" and its behaviour in experiments of self- and cross-pollination. *Vitis*, *15*, 73–81.

Marasali, B., Pinar, M. & Büyükkartal, N. (2005). Palynological Study on the Pollen Grains of Selected Turkish Grape (*Vitis vinifera* L.) Cultivars. *Turkish Journal of Agricultural and Forestry*, *29*(1), 75–81. https://journals.tubitak.gov.tr/agriculture/issues/tar-05-29-1/tar-29-1-9-0404-20.pdf

Roytchev V. (1997). Palynological classification of seedless vine (*Vitis vinifera* L.) cultivars. *American journal of Enology and Viticulture*, *48*(2), 207–213.

Roytchev, V. (1995). Palynobiometric studies in vines (*Vitis vinifera* L.). *Vitis*, *34*(4), 197–200.

Roytchev, V., Terziisky, D., Dimova, D. & Karageorgiev, S. (1994). Scanning electron microscopy study of pollen morphology in Seedless grape (*Vitis vinifera* L.) cultivars. *Vitis*, *33*(3), 105–108. https://doi.org/10.5073/vitis.1994.33.105-108

Sabir, A. (2015). Improvement of the pollen quality and germination levels in grapes (*Vitis Vinifera* L.) by leaf pulverizations with nanosize and seaweed extract (*Ascophyllium nodosum*). *Journal of animal and plant sciences, 25*(6), 1599–1605. http://web.a.ebscohost.com/ehost/detail/detail?vid=0&sid=6e3fe4db-4910-4ad9-9a23-06c4955b2591%40sdc-v-sessmgr03&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#AN=113339926&db=asn

Sarwono, J. (2017). Correlation and regression: How to Use in Data Analysis Using IBM SPSS and Eviews, 55. ISBN: 9781549952678.

Sharafi, Y. & Bahmani A. (2011). Pollen germination, tube growth and longevity in some cultivars of *Vitis vinifera* L. *African Journal of Microbiology Research*, *5*(9), 1102–1107. https://academicjournals.org/journal/AJMR/article-full-text-pdf/D95E40F31584

Slimane, B. & Askri, F. (1989). Pollen size as a means of identifying Tunisian grapevine strains. *Annals of the National Institute of Agronomic Research of Tunisia, 62*(10), 3–18 (Fr).

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