Heritability of Main Yield Traits in Red-seed Watermelon and Their Correlation Analysis

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Abstract [**Objectives**] This study was conducted to provide a reliable theoretical basis for the correct formulation of breeding programs for red-seed watermelon and the effective breeding of hybrid offspring. [**Methods**] With local varieties and inbred lines of red-seed watermelon as test materials, the generalized heritability of fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume were estimated by variance analysis; and the heritability, genetic variation coefficients, and correlation of the nine yield traits in 43 red-seed watermelon varieties were studied. [**Results**] The generalized heritability of fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume were 12.86%, 80.14%, 75.96%, 74.39%, 48.01%, 17.12%, 24.97%, 18.60%, and 37.07%, respectively. The heritability of single-fruit weight, single-fruit seed number and single-fruit seed weight was higher, and early-generation individual selection could achieve a better effect on them; and 1 000-seed weight and kernel-producing ratio had a higher coefficient of genetic variation, indicating a high selection potential. [**Conclusions**] Indirect selection could be achieved for traits such as the single-fruit seed number, single-fruit seed weight, seed kernel weight, and seed volume by selecting the single-fruit weight. In the process of red-seed watermelon breeding, traits with high heritability can be selected in early generations of hybrids, thus playing the role of early-generation orientation.
Key words Red-seed watermelon; Yield trait; Heritability; Correlation

Red-seed watermelon (*Citrullus lanatus* ssp. *vulgaris* var. *megalaspermus* Lin et Chao) is a seed-using watermelon variety[1-2] in *Citrullus lanatus* ssp. *vulgaris* of Cucurbitaceae[3-4]. It is mainly distributed in 10 provinces (regions) including Gansu, Xinjiang, Inner Mongolia, Ningxia, Guangxi, Anhui, Jiangxi, Hunan, Heilongjiang, Guangdong[5-6]. Red-seed watermelon mainly includes famous varieties (lines) such as Guangxi Xindu red-seed watermelon, Ningxia Pingluo red-seed watermelon, and Jiangxi Xinfeng red-seed watermelon. Its commodity "red watermelon seeds" is a traditional high-quality specialty for export[7-8]. In recent years, the domestic and international watermelon seeds processing industry has rapidly emerged and developed, and the demand for red-seed watermelon in the market is increasing. Therefore, there is an urgent need to cultivate new varieties of red-seed watermelon with high yield, high quality, and disease resistance.

Horticultural Research Institute, Guangxi Academy of Agricultural Sciences and other units have successively carried out the cultivation and breeding of southern ecotype red-seed watermelon[9-14], and took the lead in space mutation breeding and new functional health-care variety breeding of red-seed watermelon. Liu *et al.* [15-24] conducted long-term and systematic study on the main diseases in the production of red-seed watermelon in southern China, such as wilt and anthracnose, and proposed new solutions to solve or alleviate the diseases of red-seed watermelon in continuous cropping.

In order to effectively carry out the breeding work of red-seed watermelon, especially the combination of disease resistance breeding, quality breeding, and high-yield breeding, it is necessary to understand the heredity laws of target traits. Heritability is an important index for genetic analysis of quantitative traits and selection of hybrid offspring. In this study, the heritability and genetic correlation of nine yield traits including fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume were investigated, aiming to provide a reliable theoretical basis for the correct formulation of breeding programs for red-seed watermelon and the effective breeding of hybrid offspring.

Materials and Methods

Materials

Forty three local varieties of red-seed watermelon were collected by Horticultural Research Institute, Guangxi Academy of Agricultural Sciences from both domestic and international sources[15], with variety codes RSW01-RSW43, and were stored in the germplasm bank of Guangxi Academy of Agricultural Sciences.

Methods

The experiment was conducted within the base of Hezhou Academy of Agricultural Sciences. The seeds were sown on March 15, 2021, and plants were transplanted on April 20. Each plot

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had an area of 15 m^2 and was planted with 20 plants according to a plant spacing of 0.5 m and a row spacing of 1.2 m. Random block design was adopted, and 3 replicates were set. Seedlings were raised using soilless substrate in trays, and bagged for isolation and pollination and naturally watermelon sitting. After the seed-use watermelons were mature, 10 plants were randomly sampled from each plot to observe and record the fruit number per plant (X1, pieces), single-fruit weight (X2, g), single-fruit seed number (X3, pieces), single-fruit seed weight (X4, g), seed kernel weight (X5, g), 1 000-seed weight (X6, g), kernel-producing ratio (X7, %), seed production ratio (X8, %), and seed volume (X9, mm^3). The genotype variance, phenotype variance, generalized heritability and genetic variation coefficient of the above nine traits were estimated by using variance analysis method on a plot basis[25-26]. Relevant formulas are as follows:

Kernel-producing ratio (%) = (Single-fruit weight/Single-fruit seed weight) ×100

Seed production ratio (%) = (Single-fruit seed weight/Single-fruit weight) ×100

Seed volume (mm^3) = Seed length × Width × Thickness

Data processing

The experimental data were processed and statistically analyzed using SAS9.6 software.

Results and Analysis

Field test results of main yield traits of red-seed watermelon

The distribution range of fruit number per plant in the tested red-seed watermelon varieties was 1.1 - 2.2, with a range of 1.1. The variation range of single-fruit was relatively large, from 242 to 760 g, with a range of 518. The observed distribution of single-fruit seed number ranged from 61 to 181, with a range of 120. The measured values of single-fruit seed weight were distributed from 5.920 0 to 17.793 3 g, with a range of 11.873 3. The measured values of seed kernel weight were distributed from 3.334 3 to 10.860 0 g, with a range of 7.525 7. The distribution range of 1 000-grain weight was 88.194 8 - 131.737 2 g, with a range of 43.542 4. The measured values of kernel yield were distributed from 51.445 8% to 61.034 2%, with a range of 9.588 4. The measured values of seed production ratio ranged from 1.735 1% to 3.232 1%, with a range of 1.497 0. The measured values of seed volume were distributed from 143.50 to 234.24 mm^2, with a range of 90.74 (Table 1). In order to compare the degree of differences between intervarietal variables and error variance, F-tests were conducted on the field test results of the nine yield traits mentioned above, and the results showed that the differences between varieties all reached a significant level. It indicated that the differences in observed values among different varieties of red-seed watermelon were mainly determined by genetic factors, and relatively less affected by environmental conditions.

Heritability and genetic variation coefficients of yield traits in red-seed watermelon

The generalized heritability and genetic variation coefficients of main yield traits in red-seed watermelon were estimated by variance analysis with experimental plot as unit. The results in Table 2 showed that the generalized heritability of fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume were 12.86%, 80.14%, 75.96%, 74.39%, 48.01%, 17.12%, 24.97%, 18.60%, and 37.07%, respectively. Among them, the generalized heritability of single-fruit weight and single-fruit seed number was significantly higher than the generalized heritability of fruit number per plant, 1 000-seed weight and seed production ratio, indicating that the single-fruit weight and single-fruit seed number were more stable than the fruit number per plant and 1 000-seed weight in heritability. The heritability of single-fruit weight, single-fruit seed number and single-fruit seed weight was the highest, so early-generation individual selection could be effectively carried out for these three traits. Seed kernel weight and seed volume also had high heritability, and early-generation individual selection could also be carried out for these two traits, but the selection proportion should be appropriately expanded. Because of the low heritability of the four traits, namely, the fruit number per plant, 1 000-seed weight, kernel-producing ratio and seed production ratio, it is not suitable to select individual plants in the early generation. The high genetic variation coefficients of 1 000-seed weight and kernel-producing ratio indicated that their selection potential was high. However, the genetic variation coefficients of single-fruit weight, single-fruit seed number, single-fruit seed weight and seed production ratio were relatively small, indicating a low selection potential.

Correlation analysis of yield traits

Based on the measured data of nine quantitative traits, including fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume, correlation analysis was conducted to obtain the correlation coefficients between various quantitative traits. The phenotypic correlation of yield traits includes genetic factors and environmental conditions, while the genetic correlation is the result of the combined effects of gene linkage and gene pleiotropy, which is also the essence of inter-trait correlation. From Table 3, it could be seen that there was an extremely significant positive correlation between single-fruit weight and seed production ratio (single-fruit seed weight, single-fruit seed number), between single-fruit seed number and single-fruit seed weight, between seed kernel weight, and 1 000-seed weight, kernel-producing ratio and seed volume, and between 1 000-seed weight and seed volume. The single-fruit weight, and seed kernel weight and seed volume, as well as the single-fruit seed weight and seed kernel weight, were positively correlated, reaching a significant level. There was a negative correlation between the single-fruit weight, and kernel-producing ratio and seed production ratio, between single-fruit seed weight and kernel-producing ratio, between 1 000-seed weight, and kernel-producing ratio and fruit number per plant, between kernel-producing ratio and seed volume, between seed production ratio, and seed volume and fruit number per plant, but the correlation was not significant. It indicated that red-seed watermelon varieties with larger single-fruit weight and seed volume had higher single-fruit seed weight and single-fruit seed number; and when selecting two traits of seed production ratio, single-fruit seed weight and single-fruit seed number, the single-fruit weight could serve as a reference for indirect selection.

Table 1 Average performance of main yield traits of red-seed watermelon

Variety	X1 // pieces	X2 // g	X3 // pieces	X4 // g	X5 // g	X6 // g	X7 // %	X8 // %	X9 // mm^3
RSW01	1.8	482	123	13.086 7	7.626 0	106.395 9	58.272 9	2.715 1	183.87
RSW02	1.2	410	100	11.000 0	6.266 0	110.000 0	56.963 6	2.682 9	180.48
RSW03	2.0	650	126	14.626 7	8.147 2	116.084 9	55.700 6	2.250 3	177.58
RSW04	1.8	420	108	11.420 0	6.408 7	105.740 7	56.118 4	2.719 0	179.94
RSW05	1.6	760	106	13.186 7	6.784 0	124.402 8	51.445 8	1.735 1	218.09
RSW06	2.2	557	133	14.036 7	7.892 2	105.539 1	56.225 6	2.520 1	191.10
RSW07	1.7	747	152	17.463 3	10.336 0	114.890 1	59.187 0	2.337 8	218.87
RSW08	1.5	690	136	15.653 3	8.704 0	115.097 8	55.604 9	2.268 6	199.21
RSW09	1.3	317	69	6.846 7	3.864 0	99.227 5	56.435 9	2.159 8	163.58
RSW10	2.0	323	96	8.466 7	4.800 0	88.194 8	56.692 7	2.621 3	151.90
RSW11	2.0	438	134	14.156 7	7.772 0	105.647 0	54.899 8	3.232 1	180.17
RSW12	1.5	587	147	15.163 3	8.135 0	103.151 7	53.649 1	2.583 2	181.65
RSW13	1.6	305	62	6.670 0	3.720 0	107.580 6	55.772 1	2.186 9	196.73
RSW14	1.6	535	105	12.030 0	6.369 3	114.571 4	52.945 1	2.248 6	191.85
RSW15	1.4	533	131	15.610 0	8.297 5	119.160 3	53.155 3	2.928 7	194.56
RSW16	2.0	619	181	17.793 3	10.860 0	98.305 5	61.034 2	2.874 5	208.58
RSW17	1.2	447	82	8.430 0	5.029 9	102.804 9	59.666 4	1.885 9	203.98
RSW18	1.6	385	94	10.036 7	5.828 0	106.773 4	58.066 9	2.606 9	169.58
RSW19	1.9	562	94	11.113 3	6.454 0	118.226 6	58.074 9	1.977 5	206.65
RSW20	1.9	577	95	10.893 3	6.460 0	114.666 3	59.302 5	1.887 9	198.92
RSW21	1.8	513	126	13.853 3	8.064 0	109.946 8	58.210 0	2.700 4	208.75
RSW22	1.3	573	114	11.960 0	7.143 2	104.912 3	59.726 1	2.087 3	180.50
RSW23	1.9	673	117	12.560 0	6.863 2	107.350 4	54.643 5	1.866 3	220.95
RSW24	1.8	317	75	8.313 3	4.800 0	110.844 0	57.738 8	2.622 5	202.63
RSW25	1.8	733	135	14.763 3	8.370 0	109.357 8	56.694 6	2.014 1	234.24
RSW26	1.8	303	67	6.856 7	3.886 0	102.338 8	56.674 5	2.262 9	169.76
RSW27	2.0	503	136	12.686 7	7.254 2	93.284 6	57.179 9	2.522 2	164.67
RSW28	1.8	733	137	14.506 7	8.036 4	105.888 3	55.398 0	1.979 1	190.49
RSW29	1.5	626	125	13.863 3	7.667 5	110.906 4	55.307 9	2.214 6	172.59
RSW30	1.8	498	105	11.573 3	6.230 7	110.221 9	53.836 8	2.324 0	201.79
RSW31	1.1	416	87	9.720 0	5.451 4	111.724 1	56.084 6	2.336 5	201.98
RSW32	1.4	407	71	7.753 3	4.164 9	109.201 4	53.717 3	1.905 0	194.86
RSW33	1.7	488	106	10.383 3	5.936 0	97.955 7	57.168 7	2.127 7	143.50
RSW34	2.0	597	125	13.783 3	7.582 5	110.266 4	55.012 2	2.308 8	181.90
RSW35	1.7	570	109	11.676 7	6.175 9	107.125 7	52.891 1	2.048 5	203.61
RSW36	1.8	744	138	15.490 0	9.384 0	112.246 4	60.581 0	2.082 0	186.03
RSW37	2.0	460	94	12.383 3	6.706 0	131.737 2	54.153 3	2.692 0	232.54
RSW38	1.6	648	119	13.480 0	7.299 5	113.277 3	54.150 3	2.080 2	208.57
RSW39	1.3	423	65	7.740 0	4.117 1	119.076 9	53.192 5	1.829 8	203.30
RSW40	1.3	498	126	14.216 7	8.147 2	112.831 0	57.307 0	2.854 8	186.47
RSW41	1.9	242	61	5.920 0	3.334 3	97.049 2	56.322 0	2.446 3	171.49
RSW42	1.6	413	96	9.606 7	5.312 6	100.069 8	55.301 4	2.326 1	185.22
RSW43	1.4	427	131	13.706 7	7.684 5	104.631 3	56.063 5	3.210 0	178.07

The values in the table are averages of three replicates. Seed volume = Seed length × Width × Thickness.

Table 2 Heritability of main yield traits in red-seed watermelon

Trait	Genotypic variance (V_G)	Phenotypic variance (V_P)	Generalized heritability H^2b//%	Genetic coefficient of variation GCV//%
Fruit number per plant (X1)	0.033 367	0.259 378	12.86	15.91
Single-fruit weight (X2)	44 837.944 000	55 949.812 000	80.14	4.21
Single-fruit seed number (X3)	1 687.442 300	2 221.628 300	75.96	4.65
Single-fruit seed weight (X4)	20.169 480	27.113 243	74.39	4.61
Seed kernel weight (X5)	0.000 687	0.001 431	48.01	20.14
1 000-seed weight (X6)	10.598 340	61.902 210	17.12	57.20
Kernel-producing ratio (X7)	0.000 359	0.001 438	24.97	51.51
Seed production ratio (X8)	0.000 117	0.000 629	18.60	4.07
Seed volume (X9)	428.740 200	1 156.420 300	37.07	15.99

Table 3 Correlation coefficients between economic traits of fruit and seeds in red-seed watermelon

Trait	Single-fruit weight	Single-fruit seed number	Single-fruit seed weight	Seed kernel weight	1 000-seed weight	Kernel-producing ratio	Seed production ratio	Seed volume	Fruit number per plant
Single-fruit weight	1.000 0								
Single-fruit seed number	0.684 6**	1.000 0							
Single-fruit seed weight	0.757 1**	0.947 9**	1.000 0						
Seed kernel weight	0.321 9*	0.062 9	0.302 5*	1.000 0					
1 000-seed weight	0.299 9	0.065 2	0.289 3	0.195 3**	1.000 0				
Kernel-producing ratio	-0.022 6	0.063 1	-0.002 8	0.362 8**	-0.145 9	1.000 0			
Seed production ratio	-0.111 0	0.101 3	0.097 4	0.007 5	0.011 8	0.003 8	1.000 0		
Seed volume	0.300 9*	0.052 1	0.212 1	0.553 5**	0.419 9**	-0.030 1	-0.042 9	1.000 0	
Fruit number per plant	0.142 8	0.103 2	0.078 9	0.039 5	-0.118 3	0.152 0	-0.107 7	0.066 7	1.000 0

** indicates that the correlation coefficient reaches an extremely significant level ($F > F_{0.01}$); and * indicates that the correlation coefficient reaches a significant level ($F > F_{0.05}$).

Conclusions and Discussion

Conclusions

(1) Zhang[27] conducted a correlation analysis on the single-fruit weight of watermelon (including seed watermelon), single-fruit seed weight, number of seeds, 1 000-seed weight, and seed production ratio, as well as a significant difference analysis on self-pollinated fruit and hybrid fruit and corresponding seed traits. The results showed that there was a strong positive correlation between single-fruit weight, single-fruit seed weight and single-fruit seed number; the single-fruit seed weight, and 1 000-seed weight and seed production ratio, and the single-fruit seed number and seed production ratio, were in negative correlation, which was moderate; single-fruit weight and 1 000-seed weight, 1 000-seed weight and single-fruit seed number and seed production ratio, were in positive correlation, which was weak; and single-fruit weight was negatively correlated with seed production ratio. Li *et al.* [28] measured 11 economic traits of fruit in red-seed watermelon and explored relevant laws of inheritance of economic traits in red-seed watermelon through correlation and regression analysis between traits. The results showed that there was a significant or extremely significant positive correlation between fruit size and seed production ratio, as well as between soluble solid content in fruit flesh, and seed size and 1 000-seed weight; and kernel-producing ratio was positively correlated with seed thickness, but negatively correlated with other measured traits, although none of them reached a significant level. Multiple regression analysis showed that seed production ratio of single-fruit was positively correlated with seed weight, but negatively correlated with single-fruit weight, seed number, and 1 000-seed weight. Xie *et al.* [29] analyzed the relationship between the physiological traits of seed-harvesting watermelon plants and seed yield and quality. The physiological traits of seed-harvesting watermelon plants were related to seed yield, but not to seed quality. Among them, there was a positive correlation between female flower node position, and single-fruit seed weight and single-fruit seed number, between fruiting node position and single-fruit seed number, between the leaf number of setting fruit, and single-fruit seed weight and single-fruit seed number, and between single-fruit seed number and single-fruit seed weight. However, there was no significant relationship between female flower node position and fruiting node position, and seed yield. Fan and Li *et al.* [30-32] measured corresponding indexes of 10 quantitative traits in red-seed watermelon, and through correlation and path analysis, the results showed that single-fruit seed weight was positively correlated with six traits, namely single-fruit weight, single-fruit seed number, seed kernel weight, 1 000-seed weight, seed production ratio and seed volume, and leaf number had a significant effect with single-fruit weight; and the coefficient of determination of single-fruit seed number, 1 000-seed weight and seed volume on the seed weight of red-seed watermelon reached 99.3%, while the coefficient of determination of other six traits and unconsidered factors on single-fruit seed weight was only 0.7%. R-type cluster analysis showed that 11 quantitative traits could be divided into yield factors, seed weight factor, growth factors, seed production factors and quality factors. The two analyses

jointly revealed the trait composition of various factors in red-seed watermelon, providing a theoretical basis for variety cultivation.

(2) The expression of plant traits is the result of the combined effect of genotype and environmental conditions. Heritability is the ratio of genetic variance to total variance, reflecting the relative values of effects of genetic factors and environmental factors on phenotype. The level of heritability is directly related to the selection effect. The ultimate goal of new variety breeding is to select excellent genotypes, while conventional selection can only predict genotypes through phenotype. The level of heritability is directly related to the reliability of phenotype estimation, and the higher the heritability, the greater the proportion of genotype in phenotype. The results of this study showed that the fruit number per plant was in negative correlation with 1 000-seed weight and seed production ratio. Therefore, it is theoretically difficult to obtain high-yield red-seed watermelon varieties solely through variety selection.

(3) At present, the traits of red-seed watermelon are mostly selected according to the advantages and disadvantages of phenotype, which affects the selection effect to a certain extent. Theoretically, the traits with high heritability can be selected in individual plants in early generations, while the traits with low heritability can be mixed selected in lower generations and selected in individual plants in higher generations[27]. In this study, the single-fruit weight had high heritability, so it is effective to perform early-generation individual selection of this trait in practice.

(4) The coefficient of genetic variation reflects the genetic potential of a population's gene pool. A large coefficient of genetic variation increases the likelihood of selecting improved traits[33]. In this study, the genetic variation coefficients of 1 000-seed weight and kernel-producing ratio were relatively large, but the generalized heritability of these two traits was not high, indicating that the selection potential of these two traits was large, and it is not suitable to select individual plants in early generations, and they can be selected by selecting traits that are significantly correlated with them and have high heritability[33]. In this study, the heritability of 1 000-seed weight was the lowest, but it was significantly positively correlated with seed volume with higher heritability. Therefore, direct selection of seed volume can realize the selection of 1 000-seed weight and seed kernel weight.

(5) Heritability reveals an extremely important characteristic of biological traits, which can be divided into heritable and non-heritable parts in the variation of traits. Breeding plans can be formulated based on this characteristic, and the progress and prospects of genetic improvement in red-seed watermelon can be predicted using scientific seed selection methods. To a great extent, the theory of heritability has freed breeding workers from blindness and experience, and brought breeding work into a scientific and quantitative track.

Conclusions

Main yield traits of red-seed watermelon including fruit number per plant, single-fruit weight, single-fruit seed number, single-fruit seed weight, seed kernel weight, 1 000-seed weight, kernel-producing ratio, seed production ratio and seed volume were 12.86%, 80.14%, 75.96%, 74.39%, 48.01%, 17.12%, 24.97%, 18.60% and 37.07%, respectively. The heritability of main yield traits in red-seed watermelon was ranked from large to small as follows: single-fruit weight > single-fruit seed number > single-fruit seed weight > seed kernel weight > seed volume > kernel-producing ratio > seed production ratio > 1 000-seed weight > fruit number per plant. The heritability of single-fruit weight, single-fruit seed number and single-fruit seed weight was higher, and early-generation individual selection could achieve a better effect on them; and 1 000-seed weight and kernel-producing ratio had a higher coefficient of genetic variation, indicating a high selection potential. Indirect selection could be achieved for traits such as single-fruit seed number, single-fruit seed weight, seed kernel weight, and seed volume by selecting single-fruit weight. In the process of red-seed watermelon breeding, traits with high heritability can be selected in early generations of hybrids, thus playing the role of early-generation orientation.

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