Analysis of waxy maize germplasm resources in Southwest China based on SNP markers

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Abstract Waxy maize (Zea mays L. var. ceratina Kulesh) is an important economic crop in China, most of which are distributed in Southwestern China. In this study, 30 main waxy maize inbred lines in Southwest China were used as materials, and genetic analysis of the tested waxy corn materials was carried out using high-quality single nucleotide polymorphism (SNP) marker technology. A total of 15,111 SNPs were obtained from 30 test materials, and the genetic similarity coefficient varied from 0.4568 to 0.9974. The results of population genetic structure and principal component analysis showed that the tested waxy maize materials and the commonly used common maize classification representative inbred lines (B73, ZI330, Mo17, Huangzao 4, etc.) could not be effectively clustered. The 30 waxy corn materials can be divided into five groups separately. The application of the genetic relationship between materials identified by SNP analysis will enable breeders to select different parents to develop high-yield varieties with improved quality traits.

Keywords Waxy maize · SNP · Genetic diversity · Heterotic group

Introduction

Waxy corn (Zea mays L. var. ceratina Kulesh) is a special type of corn formed by a recessive genetic mutation in common corn (Zeng 1987). Southwest China is the origin center of waxy corn (Collins 1909). The starch in waxy corn endosperm is mainly amylopectin (small molecular weight, high edible digestibility), which is a special corn with high nutritional value and economic value (Guohua et al. 2015). Single nucleotide polymorphism (SNP) genotyping has the advantages of wide distribution, dimorphism, high-throughput, strong genetic stability and easy automated analysis (Corrado et al. 2013), it has been applied to analyze the genetic diversity of crop germplasm resources (Shi et al. 2015), and research germplasm kinship (Jin-Feng et al. 2014), and provide a new idea for new crop varieties selection and genetic germplasm diversity utilization (Lu et al. 2011).

This study used SNP markers to analyze the genotypes of the main waxy maize resources in Southwestern China, and analyze the population genetic structure and genetic diversity, in order to understand the genetic relationships, population genetic structure
and evolutionary groups of waxy maize materials. It aims to provide theoretical reference for the utilization of the genetic diversity of waxy maize germplasm resources, new varieties breeding and new materials creation.

Materials and methods

Plant materials

The test materials were 30 waxy corn inbred lines, which were planted in the experimental field of the Dianjiang Scientific Research Base of Chongqing Academy of Agricultural Sciences. Each material was planted for 03 rows, 10 hills per row, two plants per hill, and self-pollination was strictly controlled. The test materials were numbered from C1 to C30, and the strain name, pedigree source and grain character were shown in Table 1.

SNP genotyping

The young leaves of the test materials were taken from the jointing stage of the plants, and the DNA of the test material was extracted by the CTAB method (Murray and Thompson 1980). The above-mentioned genetic materials were scanned for the whole genome using the Maize SNP 56K Chip (developed by Affymetrix) on the Axiom® Maize56K SNP Array platform (developed by Zhongyujin Mark (Beijing) Biotechnology Co., Ltd.) to obtain the original markers.

Table 1 Material number table of tested waxy corn inbred lines

| Sample number | Material name | Material source | Grain type | Sample number | Material name | Material source | Grain type |
|---------------|---------------|-----------------|------------|---------------|---------------|-----------------|------------|
| C01           | 03-4-1-2      | $424 \times yw2$ | White      | C16           | Y1            | landrace        | White      |
| C02           | 1107-12A      | $yw2 \times$Tropical material78599 | White      | C17           | Y2            | landrace        | White      |
| C03           | 189-2         | JingA×(1107-12A×715–12) | White      | C18           | Y8            | $yw2 \times$Tropical material78599 | White      |
| C04           | 218-2-1       | (S285×67B)×yw2  | White      | C19           | wxA8          | Selection of Landraces | White      |
| C05           | 39A           | w522×678        | White      | C20           | yw9           | self bred inbred lines | White      |
| C06           | 41A           | Yunnan introduced varieties | White      | C21           | YB4A          | self bred inbred lines | White      |
| C07           | 42A           | Yunnan introduced varieties | White      | C22           | yw2           | waxy maize Landraces×8701 | White      |
| C08           | 43B           | Yunnan local materials | White      | C23           | yw8           | Chongqing landrace×8701 | White      |
| C09           | 44A           | Guizhou local materials | White      | C24           | Guang1         | Guangxi waxy maize introduced varieties | White      |
| C10           | 46A           | Chongqing local materials | White      | C25           | Guang2D        | Guangxi waxy maize introduced varieties | White      |
| C11           | 710-8         | 9058×A47        | Purple     | C26           | JingA         | introduced varieties | White      |
| C12           | 715-10        | 9A×A81          | White      | C27           | JingB         | introduced varieties | White      |
| C13           | 8288-17       | Selection of Suyunuo 2 | White      | C28           | Mei18         | Hainan landrace | Black      |
| C14           | 8300-22       | YA9×S41         | White      | C29           | Mei8          | introduced varieties | Purple     |
| C15           | S39-6-1       | Hengbai522×698-3 | White      | C30           | Zi1           | Local purple waxy corn | Purple     |
redundant data of SNPs with minor allele frequency (MAF) < 5% and deletion rate > 20% were filtered out (Liu and Muse 2005; Zhang et al. 2016), and finally 15,111 high-quality SNP loci were obtained for subsequent analysis.

Statistical analysis

The genetic similarity coefficient was calculated by NTSYS-pc 2.11 software (Rohlf et al. 2000). Structure 2.2 was used to analyze the population genetic structure of the tested materials (Beaumont and Nichols 1996; Evanno et al. 2005). The genetic distance among strains was calculated by Nei’s algorithm (Nei et al. 1983). Based on Nei’s genetic distance, NTSYS-pc 2.11 software was used for principal component analysis (PCA), and two-dimensional space and three-dimensional space cluster graph were drawn. The NJ cluster diagram is constructed according to the neighbor joining method for cluster analysis (Tamura et al. 2013).

Results and analysis

Genetic similarity

The results of genetic similarity coefficient analysis of the tested materials were listed in Table 2, which varied from 0.4568 to 0.9974. The materials with the lowest similarity were C30 and C19, and the materials with the highest similarity were C16 and C18. The combinations with genetic similarity coefficients between 0.45 and 0.6 accounted for 68.81%, and the combinations between 0.60 and 0.75 accounted for 23.65%. Genetic similarity of materials from similar sources is relatively high, and genetic similarity analysis provided a direct basis for material classification (Fernie et al. 2006).

Population genetic structure

Population genetic structure refers to a non-random distribution of genetic variation in a species or population (Wang et al. 2008). The analysis of population structure helps to understand the evolution process, and the subgroup to which an individual belongs can be determined by the correlation study of genotype and phenotype (Inghelandt et al. 2010). The results of genetic structure analysis of the tested material population are shown in Fig. 1. The test material C10 belongs to the REID group represented by pink color; The ZI330 (ZI330 and Luda Honggu blood relationship) group represented by green color had no test materials; Material C17 belongs to LAN (Lancaster) group represented by light blue color; There was no classified representative inbred line in the blue group, which is classified into unknown group, and includes 25 test materials.

Principal component analysis

In order to reflect the genetic relationship between different groups, PCA analysis was performed on the groups of the tested materials based on SNP markers. The analysis results are shown in Figs. 2 and 3. Figure 2 is a plan view of PCA analysis, and Fig. 3 is a three-dimensional diagram made by PCA analysis. The straight-line distance between materials in the PCA diagram is proportional to the genetic distance. The genetic materials of different subgroups in the PCA analysis are marked with different colors. According to the concentration degree of each material, C09 and C10 were classified into LAN group and REID group respectively, and C17, C26 and C30 were classified into SPT group. The other materials could not cluster effectively with the existing common corn group materials, so waxy corn materials should be classified separately.

Cluster analysis

Based on the results of genetic similarity test and the test data of representative materials for common maize group classification, 30 materials were jointly mapped with specific representative materials from PB, SPT, REID, ZI330, 335FM (335 male parent blood relationship) and LAN populations, and the results were shown in Fig. 4. Among the 30 materials, 8 materials could be effectively integrated into the classification of common maize group, and 22 materials were clustered together independently, which was consistent with the results of principal component analysis.

In order to clarify the genetic relationship between waxy corn inbred lines and improve their utilization efficiency, a separate cluster analysis was performed on the tested waxy corn materials (Fig. 5). The 30
Table 2  The results of genetic similarity coefficient analysis of the tested materials

|     | C01  | C02  | C03  | C04  | C05  | C06  | C07  | C08  | C09  | C10  |
|-----|------|------|------|------|------|------|------|------|------|------|
|     |      |      |      |      |      |      |      |      |      |      |
| C01 | 1.0000 |      |      |      |      |      |      |      |      |      |
| C02 | 0.6166 | 1.0000 |      |      |      |      |      |      |      |      |
| C03 | 0.5333 | 0.5421 | 1.0000 |      |      |      |      |      |      |      |
| C04 | 0.6003 | 0.6774 | 0.5360 | 1.0000 |      |      |      |      |      |      |
| C05 | 0.5473 | 0.5610 | 0.4831 | 0.5540 | 1.0000 |      |      |      |      |      |
| C06 | 0.5595 | 0.5434 | 0.5245 | 0.5416 | 0.5641 | 1.0000 |      |      |      |      |
| C07 | 0.6207 | 0.5946 | 0.5133 | 0.5818 | 0.5964 | 0.6082 | 1.0000 |      |      |      |
| C08 | 0.5760 | 0.5923 | 0.5140 | 0.5877 | 0.5913 | 0.5743 | 0.6164 | 1.0000 |      |      |
| C09 | 0.5456 | 0.5483 | 0.4789 | 0.5552 | 0.5709 | 0.5324 | 0.5815 | 0.5773 | 1.0000 |      |
| C10 | 0.5263 | 0.5327 | 0.4801 | 0.5473 | 0.5902 | 0.5542 | 0.5698 | 0.5643 | 0.5791 | 1.0000 |
| C11 | 0.5391 | 0.5479 | 0.5153 | 0.5440 | 0.5778 | 0.5815 | 0.5788 | 0.5652 | 0.5638 | 0.5901 |
| C12 | 0.6258 | 0.7408 | 0.5663 | 0.7195 | 0.6073 | 0.5751 | 0.6303 | 0.6431 | 0.5943 | 0.5800 |
| C13 | 0.6094 | 0.5515 | 0.5299 | 0.5515 | 0.5655 | 0.6189 | 0.6849 | 0.5838 | 0.5626 | 0.5558 |
| C14 | 0.5695 | 0.5745 | 0.4978 | 0.5589 | 0.6057 | 0.5767 | 0.6356 | 0.5929 | 0.5618 | 0.5716 |
| C15 | 0.5508 | 0.5575 | 0.5265 | 0.5239 | 0.5417 | 0.5454 | 0.5615 | 0.5494 | 0.5407 | 0.5297 |
| C16 | 0.5922 | 0.5660 | 0.5149 | 0.5653 | 0.5948 | 0.6313 | 0.6966 | 0.6061 | 0.5893 | 0.5894 |
| C17 | 0.5404 | 0.5574 | 0.4787 | 0.5476 | 0.5792 | 0.5820 | 0.6004 | 0.5848 | 0.5765 | 0.5653 |
| C18 | 0.5919 | 0.5655 | 0.5155 | 0.5650 | 0.5943 | 0.6293 | 0.6955 | 0.6053 | 0.5889 | 0.5889 |
| C19 | 0.5191 | 0.6074 | 0.5067 | 0.5202 | 0.5115 | 0.5110 | 0.5290 | 0.5135 | 0.4967 | 0.5018 |
| C20 | 0.6057 | 0.6677 | 0.5712 | 0.6431 | 0.5722 | 0.5935 | 0.6205 | 0.6125 | 0.5602 | 0.5540 |
| C21 | 0.5634 | 0.6004 | 0.5205 | 0.5759 | 0.5781 | 0.5853 | 0.5893 | 0.5824 | 0.5495 | 0.5462 |
| C22 | 0.6644 | 0.8231 | 0.5858 | 0.7690 | 0.6024 | 0.5757 | 0.6428 | 0.6481 | 0.5910 | 0.5722 |
| C23 | 0.5806 | 0.6082 | 0.5581 | 0.5746 | 0.5615 | 0.6105 | 0.5947 | 0.5856 | 0.5589 | 0.5427 |
| C24 | 0.5679 | 0.5806 | 0.5186 | 0.5683 | 0.5878 | 0.5753 | 0.6260 | 0.6730 | 0.5766 | 0.5740 |
| C25 | 0.5697 | 0.5740 | 0.5710 | 0.5738 | 0.5697 | 0.5734 | 0.6091 | 0.5890 | 0.5522 | 0.5548 |
| C26 | 0.5359 | 0.5358 | 0.5379 | 0.5248 | 0.5575 | 0.5634 | 0.5794 | 0.5536 | 0.5374 | 0.5718 |
| C27 | 0.5653 | 0.5616 | 0.5104 | 0.5572 | 0.5984 | 0.6861 | 0.6370 | 0.5922 | 0.5708 | 0.5851 |
| C28 | 0.6208 | 0.5998 | 0.5166 | 0.5857 | 0.5972 | 0.6027 | 0.6027 | 0.6176 | 0.5893 | 0.5675 |
| C29 | 0.5456 | 0.5506 | 0.5117 | 0.5431 | 0.5766 | 0.5900 | 0.6082 | 0.5648 | 0.5328 | 0.5634 |
| C30 | 0.5088 | 0.5052 | 0.4693 | 0.4792 | 0.4847 | 0.5091 | 0.5529 | 0.5000 | 0.4920 | 0.4990 |

|     | C11  | C12  | C13  | C14  | C15  | C16  | C17  | C18  | C19  | C20  |
|-----|------|------|------|------|------|------|------|------|------|------|
|     |      |      |      |      |      |      |      |      |      |      |
| C11 | 1.0000 |      |      |      |      |      |      |      |      |      |
| C12 | 0.5935 | 1.0000 |      |      |      |      |      |      |      |      |
| C13 | 0.5929 | 0.5933 | 1.0000 |      |      |      |      |      |      |      |
| C14 | 0.5820 | 0.6087 | 0.5837 | 1.0000 |      |      |      |      |      |      |
|    | C11  | C12  | C13  | C14  | C15  | C16  | C17  | C18  | C19  | C20  |
|----|------|------|------|------|------|------|------|------|------|------|
| C15| 0.5633 | 0.5743 | 0.5558 | 0.5415 | 1.0000 |
| C16| 0.6012 | 0.6100 | 0.6280 | 0.6069 | 0.5653 | 1.0000 |
| C17| 0.5748 | 0.5851 | 0.6064 | 0.5803 | 0.5368 | 0.5965 | 1.0000 |
| C18| 0.5998 | 0.6094 | 0.6269 | 0.6061 | 0.5647 | 0.9974 | 0.5959 | 1.0000 |
| C19| 0.5115 | 0.5614 | 0.5004 | 0.5130 | 0.5117 | 0.5215 | 0.4918 | 0.5210 | 1.0000 |
| C20| 0.5841 | 0.7137 | 0.5926 | 0.5782 | 0.5620 | 0.6071 | 0.5740 | 0.6073 | 0.5407 | 1.0000 |
| C21| 0.5884 | 0.6430 | 0.5704 | 0.5692 | 0.5602 | 0.5900 | 0.5577 | 0.5892 | 0.5260 | 0.6242 |
| C22| 0.5914 | 0.8471 | 0.5940 | 0.6162 | 0.5677 | 0.6143 | 0.5927 | 0.6139 | 0.5917 | 0.7367 |
| C23| 0.5880 | 0.6289 | 0.6146 | 0.5631 | 0.5863 | 0.6189 | 0.5636 | 0.6187 | 0.5446 | 0.6409 |
| C24| 0.5664 | 0.6176 | 0.5911 | 0.5975 | 0.5575 | 0.6261 | 0.5720 | 0.6265 | 0.5164 | 0.6116 |
| C25| 0.5672 | 0.6101 | 0.5833 | 0.5765 | 0.5892 | 0.6102 | 0.5540 | 0.6105 | 0.5213 | 0.6120 |
| C26| 0.5681 | 0.5632 | 0.5610 | 0.5531 | 0.5200 | 0.5711 | 0.5740 | 0.5703 | 0.4865 | 0.5444 |
| C27| 0.5967 | 0.6019 | 0.6387 | 0.6046 | 0.5927 | 0.6684 | 0.6163 | 0.6681 | 0.5245 | 0.5988 |
| C28| 0.5817 | 0.6355 | 0.6782 | 0.6367 | 0.5626 | 0.6995 | 0.5999 | 0.6984 | 0.5305 | 0.6224 |
| C29| 0.5804 | 0.5847 | 0.5873 | 0.6487 | 0.5515 | 0.6159 | 0.5612 | 0.6156 | 0.5358 | 0.5751 |
| C30| 0.5147 | 0.4999 | 0.5347 | 0.4960 | 0.4762 | 0.5092 | 0.5255 | 0.5078 | 0.4568 | 0.5049 |

|    | C21  | C22  | C23  | C24  | C25  | C26  | C27  | C28  | C29  | C30  |
|----|------|------|------|------|------|------|------|------|------|------|
| C01|      |      |      |      |      |      |      |      |      |      |
| C02|      |      |      |      |      |      |      |      |      |      |
| C03|      |      |      |      |      |      |      |      |      |      |
| C04|      |      |      |      |      |      |      |      |      |      |
| C05|      |      |      |      |      |      |      |      |      |      |
| C06|      |      |      |      |      |      |      |      |      |      |
| C07|      |      |      |      |      |      |      |      |      |      |
| C08|      |      |      |      |      |      |      |      |      |      |
| C09|      |      |      |      |      |      |      |      |      |      |
| C10|      |      |      |      |      |      |      |      |      |      |
| C11|      |      |      |      |      |      |      |      |      |      |
| C12|      |      |      |      |      |      |      |      |      |      |
| C13|      |      |      |      |      |      |      |      |      |      |
| C14|      |      |      |      |      |      |      |      |      |      |
| C15|      |      |      |      |      |      |      |      |      |      |
| C16|      |      |      |      |      |      |      |      |      |      |
| C17|      |      |      |      |      |      |      |      |      |      |
| C18|      |      |      |      |      |      |      |      |      |      |
| C19|      |      |      |      |      |      |      |      |      |      |
| C20|      |      |      |      |      |      |      |      |      |      |
| C21| 1.0000 |      |      |      |      |      |      |      |      |      |
| C22| 0.6518 | 1.0000 |      |      |      |      |      |      |      |      |
| C23| 0.6233 | 0.6529 | 1.0000 |      |      |      |      |      |      |      |
| C24| 0.5904 | 0.6319 | 0.6002 | 1.0000 |      |      |      |      |      |      |
| C25| 0.5952 | 0.6265 | 0.6387 | 0.6201 | 1.0000 |      |      |      |      |      |
| C26| 0.5364 | 0.5585 | 0.5315 | 0.5462 | 0.5321 | 1.0000 |      |      |      |      |
| C27| 0.5837 | 0.6032 | 0.6080 | 0.5972 | 0.6025 | 0.5833 | 1.0000 |      |      |      |
| C28| 0.5925 | 0.6499 | 0.5940 | 0.6242 | 0.6109 | 0.5764 | 0.6391 | 1.0000 |      |      |

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waxy corn materials can be divided into five major groups, namely, Hengbai, YA, YB, YW and tropical material groups. The groups are named after the material sources or representative inbred lines. C11, C15, C21, C23 and C25 belong to Hengbai group; C01, C02, C04, C08, C12, C20, C22 and C24 belong to YW group; C03, C17, C26 and C30 belong to YA group; C05, C09 and C10 belong to YB group; C06, C17, C26 and C30 belong to tropical groups.

### Table 2 (continued)

|    | C21  | C22  | C23  | C24  | C25  | C26  | C27  | C28  | C29  | C30  |
|----|------|------|------|------|------|------|------|------|------|------|
| C29| 0.5710 | 0.5988 | 0.6017 | 0.5845 | 0.5773 | 0.5430 | 0.6383 | 0.6072 | 1.0000 |
| C30| 0.4896 | 0.5049 | 0.4843 | 0.5066 | 0.4994 | 0.5015 | 0.5022 | 0.5534 | 0.4856 | 1.0000 |

**Fig. 1** The results of genetic structure analysis of the tested material population. Pink represents improved REID blood relationship; Green was ZI 330 and Luda Honggu blood relationship; Light green was the Lancaster (LAN) group; Light blue represents the blood relationship of Tang-Si-Ping-Tou (SPT)

**Fig. 2** Two dimensional PCA analysis of Waxy Maize Inbred Lines. Yellow indicates the REID population and Improved REID blood related materials in the germplasm resource bank; Pink is ZI330 and Luda Honggu blood relationship group; Brown is the Tang-Si-Ping-Tou(SPT) group; Green is the Lancaster (LAN) group; Orange is PB group; Red is the backbone parent 335 male parent group; Blue is the 335 female parent group; Purple is the test sample in this project.
Fig. 3 Three dimensional PCA analysis of Waxy Maize Inbred Lines. Yellow indicates the REID population and Improved REID blood related materials in the germplasm resource bank; Pink is Zi330 and Luda Honggu blood relationship group; Brown is the Tang-Si-Ping-Tou (SPT) group; Green is the Lancaster (LAN) group; Orange is PB group; Red is the backbone parent 335’ male parent group; Blue is the 335’ female parent group; Purple is the test sample in this study.

Fig. 4 Phylogenetic tree of Waxy Maize Inbred Lines. The waxy maize inbred lines in this study were unmarked; Gray represents 335’ male parent blood relationship and 335’ female parent blood relationship; Blue represents Lancaster blood; Pink represents PB blood relationship; Red represents improved REID blood relationship; Green represents the blood relationship of Tang-Si-Ping-Tou (SPT); Yellow was ZI 330 and Luda Honggu blood relationship.
C07, C13, C14, C16, C18, C27, C28 and C29 belong to tropical material group, and C19 could not cluster in these five groups effectively.

**Discussion**

Southwest China is the origin center of waxy maize germplasm resources, which owns rich waxy maize germplasm resources. In this study, 30 waxy maize inbred lines commonly used in Southwest China were selected from Chongqing, Sichuan, Yunnan, Guizhou and other places, and the grain colors include white, purple and black, which were representative. SNP as the third-generation molecular marker has been applied in the fingerprint detection of common corn (Wu et al. 2014), but there are still few studies on waxy corn germplasm. Therefore, it is of great significance to use SNP molecular markers to analyze the genetic structure and diversity of waxy maize germplasm in Southwest China.

The results of this study showed that the genetic similarity coefficients between selected waxy corn germplasm resources ranged from 0.456 to 0.997, with an average value of 0.605. The materials with the lowest similarity were C30 and C19, and the materials with the highest similarity were C16 and C18. The genetic similarity coefficient of the 4.7% of the tested materials was between 0.65 and 0.89, and the genetic similarity coefficient > 0.89 accounted for 6.4% of the tested materials. In conclusion, the genetic similarity among waxy maize materials in Southwest China is low, the genetic relationships among the waxy maize materials are quite different, and the genetic basis is relatively rich, which is generally consistent with the previous results of group classification by SSR markers (Yu et al. 2012).

This study combined principal component analysis and population genetic structure analysis, and found that most of the tested materials and common maize genetic materials could not be effectively clustered together. There is a clear distinction between waxy maize genetic resources in Southwest China and representative inbred lines of commonly used maize in China. Waxy maize materials in Southwest China should be classified separately (Shi et al. 2015; Zheng et al. 2013).

There are few reports on the classification of waxy maize genetic materials, and the classification results are not the same due to different geographical and environmental conditions and test materials. Chen Jing et al. used SSR markers to divide 40 Northwest waxy maize inbred lines into 5 groups (Chen et al. 2009); Wu Yusheng et al. divided Yunnan local germplasm waxy maize materials into 3 groups and 5 subgroups (Wu et al. 2004); Chen Zhijian classified...
87 waxy maize inbred lines of Fujian into 4 groups, and the names of these groups were also different (Chen 2021). The research of Zhang Shengheng et al. showed that the main heterotic groups in Chongqing waxy maize breeding were S181 group and Hengbai group (Zhang et al. 2011).

In this study, the materials of S181 and its derivatives were unified into YW group, and most of the materials from Yunnan, Guangxi and Hainan were classified as tropical material group. Based on the results of the division of waxy maize germplasm resources, Chongqing Zhong Yi Seed Co., Ltd. using C12 (YW material 715-10) as the female parent and C14 (tropical material 8300-22) as the male parent successfully bred a new waxy corn variety ‘Q-nuo No.5’ (Lei 2020); Using C10(YB material 46A) as the female parent and C04 (YW material w218) as the male parent bred a new large ear waxy corn variety ‘Jinnuo 2’ (Zhang et al. 2021); using YW material yw2 as female parent and Hengbai material Qw101 as male parent bred a new waxy corn variety ‘Jinnuo 6’ with high quality and high yield. The main heterosis mode of these varieties was similar to S181 × Hengbai group and S181 × other groups proposed by Zhang Shengheng et al.

Conclusion

The genetic basis of waxy corn germplasm resources in southwestern China is rich, and it is clearly distinguished from the commonly used ordinary corn inbred lines. Their genetic relationship is relatively far, and could be used to create a new waxy corn hybrid dominant group classification system. In this study, 30 waxy maize inbred lines from Southwest China were divided into five groups, which provided a theoretical reference for waxy corn material utilization and new variety breeding. It not only effectively improved the waxy corn breeding, but also provided help for the utilization and innovation of germplasm resources.

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Authors’ contributions This work was carried out in collaboration among all authors. Authors C.Z. and S.W. designed the experiments and provided resources for all experiments. Authors W.Z., L.C. and T.Y. collected the tested materials and performed field management. Author C.Z. conducted the DNA extraction. Authors C.Z., S.Z. and X.C. performed the experiments, managed the data analysis and wrote the manuscripts.

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Declarations

Conflict of interests The authors declare that they have no conflict of interests.

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