Genetic variation of maturity groups and four \( E \) genes in the Chinese soybean mini core collection

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Abstract

The mini core collection (MCC) has been established by streamlining core collection (CC) chosen from China National Genebank including 23,587 soybean (\( Glycine max \)) accessions by morphological traits and simple sequence repeat (SSR) markers. Few studies have been focused on the maturity that has been considered as one of the most critical traits for the determination of the adaptation-growing region of the soybean. In the current study, two hundred and ninety-nine accessions of MCC planted for two years at four locations namely in Heihe, Harbin, Jining and Wuhan cities in China were used to assess the variation of maturity in MCC and identify the integrated effect of 4 \( E \) loci on flowering and maturity time in soybean. Forty-two North American varieties served as references of maturity groups (MG). Each accession in MCC was classified by comparing with the MG references in the days from VE (emergence) and physiological maturity (R7). The results showed that MCC covered a large range of MGs from MG000 to MGIX/X. Original locations and sowing types were revealed as the major affecting factors for maturity groups of the MCC accessions. The ratio of the reproductive period to the vegetative period (R/V) varied among MCC accessions. Genotyping of 4 maturity genes (i.e. \( E1, E2, E3 \) and \( E4 \)) in 228 accessions indicated that recessive alleles \( e1, e2, e3 \) and \( e4 \) promoted earlier flowering and shortened the maturity time with different effects, while the dominate alleles were always detected in accessions with longer maturity. The allelic combinations determined the diversification of soybean maturity groups and adaptation to different regions. Our results indicated that the maturity of Chinese soybean MCC showed genetic diversities in phenotype and genotype, which provided information for further MG classification, geographic adaptation analysis of Chinese soybean cultivars, as well as developing new soybean varieties with adaptation to specific regions.
Introduction

China has the richest germplasm resources of soybean in the world[1]. More than 23,587 soybean accessions had been collected from 29 provinces of China until 2007[2]. Evaluation of soybean germplasm collection is crucial for the selection of elite parents, identification of desirable alleles, as well as breeding of new varieties[3–5]. However, it is still a challenge to evaluate the genetic characterization of the accessions in the Genebank due to abundant resources of the germplasm. Frankel and Brown (1984) firstly proposed the concept of “core collection” (CC), defined as a sub-set of accessions (about 10% of the original size) selected by an optimal sampling method, to represent the maximum genetic diversity of the whole collection[6]. Afterwards, the development of CC has proven to be a reasonable approach to explore the variations from genetic resources[7–9]. Previously, a soybean CC with a rational size containing 472 accessions has been built based on the simple sequence repeat (SSR) marker data and agronomic traits[10]. As the accessions number of the CC is too large for the replicated evaluations at different locations, more manageable mini core collections (MCCs) of soybean have been developed based on further streamlining of the CC scale (10% of the CC), which represented 94.5% of the phenotypic diversity and 63.5% of the genetic diversity of the whole collection, respectively[11–12].

Our previous data showed the soybean accessions in MCC could be used for basic studies including gene discovery, allele mining, marker–trait associated analysis, and gene functional analysis[13]. For example, 70 SSR markers were used to evaluate a set of 96 wild soybean accessions in MCC, which indicated that a total of 1,278 alleles were identified with an average of 18.2 alleles per locus[14]. In addition, backcross introgression lines developed from soybean cultivars in the MCC were used to identify QTLs related to cold and drought stress[15–16]. Moreover, Guo and Qiu (2013) developed the allele-specific marker for the selection of allelic distributions of flavonoid 3'-hydroxylase (GmF3'H) and flavonoid 3', 5'-hydroxylase genes (GmF3'5'H) genes in 170 soybean accessions in MCC[17]. Furthermore, MCC also provided trait-specific resources for soybean improvement programs. For instance, resistance to soybean mosaic virus (SMV) was evaluated using inoculation of four Chinese SMV strains in soybean CC from Southern China [18]. Also, MCC contained a wider range of protein subunits of 11S and 7S than common cultivars, which were the major components of seed storage protein in soybean[19]. Moreover, in a study using the landraces of MCC for the identification of allele variations of soybean stem growth habit gene GmTFL1, the genetic diversity and geographic distribution of the four GmTfl1 alleles revealed that artificial selection for soybean determinacy occurred at early stages of landrace dissemination. Whereas, only one GmTfl1 allele was screened in the wild soybeans, indicating the effects of genetic bottlenecks created by germplasm introduction and modern breeding[20]. Therefore, such collection has been well acknowledged as an ideal candidate for the identification of trait-specific accessions, gene discovery and molecular breeding in soybean.

Length of growing period or maturity is an important trait of crops as it determines the geographical adaptation of a variety[21–24]. In North America, soybean had been classified into 13 MGs, which were designated by Roman numerals, starting with “000” MG adapted to long days in Canada, and ending with “X” MG adapted to short days in Southernmost areas of the US[25]. Zhang et al. (2007) examined the adaptation area of different MG soybean varieties in the US, which showed that soybeans of MG0 to MGVI were mainly grown in the major producing areas of the US, and MVGII and MGVIII were currently cultivated in a limited region in the southern states[26]. In Argentina, soybeans of MGII to MGIX could be grown under suitable environments from September to February each year[27]. Alliprandini et al. (2009) developed an efficient method for assigning relative MGs to the commercial cultivars based on
the evaluation of the maturity stability of 48 Mid-Western and 40 southern Brazilian commercial cultivars ranging from MGVI to MGVIII at 15 locations [28]. In China, extensive studies have also carried out to categorize soybean accessions into different MG groups based on environment and planting patterns [29–35]. For example, Hao et al. (2003) identified 12 soybean MGs (C1-C12) by planting 96 soybean varieties at 28 locations, but such classification was not linked with the MG system in North America [33]. Gai et al. (2001) analyzed the maturity time of 264 Chinese soybean landraces under natural and extended day-length conditions in Nanjing city and confirmed the presence of soybeans of MG000 to MGIX in China when comparing with the 48 varieties of 13 MGs from the US [4]. Additionally, the geographic distribution scheme of soybean MGs was proposed in China. The same classification will be beneficial for the comparison and exchange of soybean germplasm in a national and international scale.

Flowering and maturity of soybean are controlled by the major genes, and to date, at least nine maturity loci (E1-E8 and J) have been identified [36–42]. Up to now, extensive studies have been performed on the identification and characterization of E1-E4 genes at a molecular level [43–46]. The E1 gene encoded a transcription factor with a putative nuclear localization signal and a B3-related domain [46]. Allelic variations in the E1 gene included single nucleotide polymorphism (SNP) (e1-as) or single base deletion (e1-fs) at coding sequence and a null allele (e1-n1) [46]. For the E2 gene, an orthologue of Arabidopsis flowering gene GIGANTEA was found to be linked to the E2 locus, and a nonsense mutation resulted in premature stop codon was identified in the e2-ns allele [45]. The phytochrome genes GmPhyA3 and GmPhyA2 were reported to localized in the E3 and E4 loci, respectively [43, 44]. Meanwhile, at least six alleles of E3 were detected using sequencing technique, while at least five alleles were detected for E4 [47]. Genotyping by sequencing (GBS) approaches were also used to develop tools for breeders to rapidly identify alleles present in their germplasm at the recently cloned maturity loci [48]. Although four known maturity loci (i.e. E1-E4) contribute to our understanding on the mechanism of flowering and maturity, genotypes at the E loci and the relationship with maturity group in Chinese soybean MCC are still not well defined.

In this study, 299 Chinese soybean MCC and 42 MG representative cultivars from the US were tested to classify the maturity groups of MCC in China. In addition, genotyping of four maturity genes was performed in accessions of MCC. These results could enrich the understanding on the variations in MCC and contribute to the prediction of varieties adaptability in suitable geographical regions efficiently.

Materials and methods

Plant materials

The Chinese soybean MCC consisted of 299 accessions selected from the whole soybean collection of the National Genebank of China was used in this study [12]. Forty-two varieties of MGs (MG000–MGVIII) used as MG references were introduced from the United States (Table 1). Reference varieties were selected for each MG, including two early and two late accessions from each group except for MG000 with only one early and one late accessions included.

Field experiments

Field experiments were conducted at four locations: Heihe (50.15˚N) and Harbin (45.68˚N) in Heilongjiang Province, Jining (35.46˚N) in Shandong Province, and Wuhan (30.63˚N) in Hubei Province. All accessions were planted in Jining city during 2010 and 2011 with a planting date of May 4. In order to classify the MG accurately, some cultivars were planted at the locations in 2011, and finally normal maturity was achieved for each cultivar. Twelve early maturing varieties of MCC and the US varieties belonging to MG000, MG00, and MG0 were
Table 1. Traits of the MG reference varieties planted in spring in Heihe, Harbin, Jining and Wuhan in China.

| Variety (PI No.) | MG | Days from emergence (Ve) to physiological maturity (R7) |
|-----------------|----|------------------------------------------------------|
|                 |    | Jining | Harbin | Wuhan |
| Maple Presto (PI548594) | 000 | 65.3±0.67 | 81.97±0.25 |
| OAC Vision (PI567787) | 000 | 66.5±0.47 | 87.83±0.18 |
| Canatto (PI548648) | 00 | 61.3±0.71 | 92.00±0.41 |
| Maple Ridge (PI548596) | 00 | 67.4±0.36 | 96.3±0.34 |
| Jim (PI602897) | 00 | 78.0±1.86 | 95.17±0.50 |
| Glacier (PI592523) | 00 | 70.1±0.37 | 95.17±0.15 |
| MN0201 (PI629004) | 0 | 70.1±0.96 | 99.40±0.12 |
| Traill (PI596541) | 0 | 74.0±0.92 | 99.13±0.13 |
| Surge (PI599300) | 0 | 80.4±1.04 | 105.0±0.47 |
| MN0901 (PI612764) | 0 | 115.37±0.11 | 110.0±0.00 |
| Harlon (PI548571) | I | 88.3±3.33 | |
| Haroson (PI548641) | I | 78.3±1.03 | 99.0±0.00 |
| NE1900 (PI614833) | I | 91.8±0.34 | 111.5±0.50 |
| Titan (PI608438) | I | 86.2±1.15 | 107.5±0.83 |
| Holt (PI561858) | II | 97.5±0.50 | |
| OAC Talbot (PI567786) | II | 88.8±0.91 | |
| Amcor89 (PI546375) | II | 100.1±0.50 | |
| Flint (PI595843) | II | 102.2±0.59 | |
| Burlison (PI533655) | II | 100.8±0.62 | |
| Athrow (PI595926) | III | 102.0±0.48 | |
| Zane (PI548634) | III | 104.7±0.32 | |
| Macon (PI593258) | III | 106.4±0.48 | |
| Saline (PI578057) | III | 118.6±1.49 | |
| NS93-4118 (PI614155) | IV | 110.6±0.67 | |
| Flyer (PI534646) | IV | 115.1±1.65 | |
| TN4-94 (PI598222) | IV | 124.6±0.47 | |
| Manokin (PI559932) | IV | 126.6±0.24 | |
| Nathan (PI564849) | V | 120.2±1.29 | |
| Holladay (PI572239) | V | 129.9±0.25 | |
| Lonoke (PI633609) | V | 134.1±0.35 | |
| Rhodes (PI561400) | V | 133.5±0.40 | |
| Desha (PI633610) | VI | 141.9±1.23 | 141.6±0.86 |
| Dillon (PI592756) | VI | 135.0±1.22 | 142.1±0.93 |
| NC-Roy (PI617045) | VI | 152.8±0.50 | 148.0±1.64 |
| Musen (PI599333) | VI | 153.1±0.30 | 156.9±1.44 |
| Stonewall (PI531068) | VII | 154.1±0.59* | 153.6±0.89 |
| Benning (PI595645) | VII | 154.3±0.13* | 154.7±0.98 |
| Santee (PI617041) | VII | 154.0±0.22* | 156.5±0.70 |
| Hagood (PI555453) | VII | 163.7±0.13* | 161.3±0.95 |
| Motte (PI603953) | VIII | 159.0±0.00* | 163.1±0.39 |
| Foster (PI548970) | VIII | 159.0±0.00* | 158.5±1.46 |
| Crockett (PI535807) | VIII | 144.6±1.60* | |
| Dowling (PI548663) | VIII | 158.0±0.00* | 150.4±0.74 |

*Data were estimated according to soybean mature degree at harvest.*

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planted in Heihe on May 9, 2011. Fifteen relative early-maturing MCC varieties and US varieties of MG0 and MGI were planted in Harbin on May 4, 2011. Fifty-seven late-maturing MCC soybeans and US varieties of MGVI, MGVII, and MGVIII were planted in Wuhan on April 29, 2011. All accessions were bunch-planted in plots of 40 cm in diameter and 50 cm apart. Three replications were designed, and five plants were finally selected from each bunch for further analysis. Seed resource for each variety was the same for all locations, years and replications. Standard local practices for soybean production were used to manage the experimental plots. Data were collected from 15 plants of 3 bunches for each accession in each location. Number of days from the emergence (VE) to the first flowering (R1), from the VE to the physiological maturity (R7) were measured. The maturity was assessed when one pod in the main stem reached its final pod color[49].

Genotyping the maturity genes
Genomic DNA was extracted from leaf tissues of each accession using a modified Cetyltrimethyl ammonium bromide (CTAB) method[50]. The SNPs between different alleles of \( E_1 \), \( E_2 \), \( E_3 \), and \( E_4 \) genes were chosen according to the previous description by Tsubokura et al. (2014)[47]. The genotype of each allele was analyzed using the Sequenom MassARRAY iPLEX platform[51]. The resulting data was analyzed using the MassARRAY Typer 4.0 Analyzer software. The alleles of each maturity gene were identified by the SNPs.

Data analysis
Average days to maturity of the US reference varieties in each MG were used to determine the range of each group. The median of neighboring MGs was designed as the threshold of the two groups. Relative maturity of Chinese soybean MCC was classified according to the range of each group[34]. The ratio of reproductive (R) growth and the vegetative (V) growth duration time (R/V) was calculated according to the R1 and R7[52].

Results
Growth duration ranges of the maturity group reference varieties from the US
The days to maturity of soybean MG reference cultivars planted at Jining, Heihe, Harbin and Wuhan cities were summarized in Table 1. Almost all varieties planted in Jinling showed normal maturity before frost except MGVII and MGVIII varieties. Days to maturity of MG000 through MGVI cultivars ranged from 63 to 153 days. However, the very early-maturing varieties showed poor vegetative growth and low yield. The growth duration of MG000 to MG0 reference varieties planted in Heihe was longer than that in Jinling (82–115 days vs. 61–80 days). The days to physiological maturity (R7) of MG0 and MGI varieties planted in Harbin were 97–112 days. In Wuhan, late-maturing varieties of MGVI to MGVIII showed a maturity about 142 to 163 days after emergence.

Based on traits of the US soybeans, the maturity standards for the classification of the Chinese soybean MGs at different locations were established (Table 2). As the range of growth duration of varieties within each MG was defined as 10–15 days in the US[1], the classification standard of MG0 and MGI in Harbin could not be used as standard due to a range of less than 10 days. MG000 and MG00 in Jining could not be used as criteria likewise due to the narrow maturity ranges. The references of MGVII and MGVIII could not achieve normal maturity in Jining. Thus, most of the late-maturing soybean failed to be classified specifically in this location, however, normal maturity was achieved in Wuhan city. Although maturity range of the
two groups could not meet the standards of 10–15 days in Wuhan, it might also be considered to combine into one late group as a whole which may cover MGVII, MGVIII and even MGIX. The MG 0 through VI varieties could be used as references in Jining trail, since the maturity met the requirement of 10–15 days (Table 2).

**Maturity group classification of Chinese soybean MCC**

According to the defined classification criteria (Table 2), the Chinese soybean MCC was classified into different MGs as shown in Table 3. In Heihe trial, 12 varieties grown in spring showed normal maturity before the frost, and were classified into MG000, MG00 and MG0 according to the range of the references. In Wuhan, 57 Chinese MCC soybeans in the trial planted in spring matured normally, most of which were properly classified into different MGs according to the standard of the US references (Table 3). However, the varieties of MGVII and MGVIII could not be distinguished due to similar maturity time. Accessions of MG0-MGIV could be classified based on the growth duration ranges of reference varieties in Jining (Table 2). The classification results of soybeans in Harbin trail showed a consistency of up to 85.7% with that of Jining. Despite the fact that 28 late-maturing accessions could not matured normally in Jining before the frost, and the maturity time was estimated based on the maturity degree of the plants when harvested. The classification of the late-maturing accessions in Jining showed consistency with that of Wuhan, which demonstrated that the data obtained in Jining trial can serve as the main criterion and those from the other three locations can serve as the supplements for the determination of MGs of Chinese soybean MCC.

**Distribution of Chinese soybean MCC in geographic regions and maturity groups**

The Chinese soybean MCC and the MG assignments in the provinces were listed in Tables 4 and 5, respectively. MCC covered a large range of MGs from MG000 to MGIX/X. Spring-sowing soybeans were primarily distributed in MG 000 through MGV, and a few of which from south China were in late-maturing groups with rich genetic basis of maturity in the spring-sowing varieties. Soybeans of summer-sowing type were mainly distributed in the MG II

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**Table 2.** The Ve-R7 duration ranges of the MG reference varieties from the US in Heihe, Harbin, Jining and Wuhan in China.

| MG    | Days from emergence (Ve) to physiological maturity (R7) |
|-------|--------------------------------------------------------|
|       | Heihe | Harbin | Jining | Wuhan |
| 000   | 80–90 | 80–90  | <71*   | —     |
| 00    | 91–101| 91–101 | —      | —     |
| 0     | 102–112| 101–105| 71–81  | —     |
| I     | —     | 106–110| 82–92  | —     |
| II    | —     | —      | 93–103 | —     |
| III   | —     | —      | 104–114| —     |
| IV    | —     | —      | 115–125| —     |
| V     | —     | —      | 126–138| —     |
| VI    | —     | —      | 139–151| 141–151|
| VII/VIII | —    | —      | ≥152*  | 152–163|
| MGIX/X | —    | —      | —      | ≥164  |

* MG000/0MGVII/VIII and MGIX/X were merged respectively at Jining and Wuhan because the groups cannot be distinguished.

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Table 3. Maturity group classification and the genotyping of maturity genes in Chinese soybean MCC.

| Collection No. | Varieties | Province         | City or county | Sowing type | MG  | R/V     | Genotype          |
|----------------|-----------|------------------|----------------|-------------|-----|---------|-------------------|
| ZDD22659      | Heifeng37  | Heilongjiang     | Jiamusi        | Spring      | 0   | 2.13    | E1/E2/e3-1a/E4    |
| ZDD06819      | Nenfeng11  | Heilongjiang     | Renjiang       | Spring      | 0   | 1.92    | E1/e2-ns/E3/E4    |
| ZDD06822      | Hefeng24   | Heilongjiang     | Jiamusi        | Spring      | 0   | 1.96    | E1/e2-ns/E3/E4    |
| ZDD07623      | Jilinchalhua| Jilin            | Jilin          | Spring      | 0   | -       | E1/e2-ns/E3/E4    |
| ZDD03842      | Suyangchunheidouing | Jiangsu   | Shuyang       | Spring      | 0   | 0.91    | E1/e2-ns/E3/E4    |
| ZDD04429      | Taixingheidou | Jiangsu       | Taixing        | Spring      | 0   | 1.48    | E1/e2-ns/E3/E4    |
| ZDD04430      | Taixingaidjiaohong | Jiangsu   | Taixing        | Spring      | 0   | 1.61    | E1/e2-ns/E3/E4    |
| ZDD06856      | Heihexiaohuangdou | Heilongjiang | Heihe         | Spring      | 0   | 1.76    | E1/e2-ns/E3/e4-keshuang |
| ZDD06851      | Dongnong36  | Heilongjiang     | Harbin         | Spring      | 0   | 1.02    | e1-as/E2/E3/E4    |
| ZDD00326      | Fangzhengmoshidou | Heilongjiang | Fangzheng     | Spring      | 0   | 1.72    | e1-as/E2/e3-1a/E4 |
| ZDD17767      | Xiaolimoshidou | Heilongjiang   | Harbin         | Spring      | 0   | 1.72    | e1-as/E2/e3-Mo/E4 |
| ZDD00046      | Kebei1      | Heilongjiang     | Keshan         | Spring      | 0   | 1.76    | e1-as/e2-ns/E3/E4 |
| ZDD00059      | Mufeng1     | Heilongjiang     | Mudanjian      | Spring      | 0   | 1.69    | e1-as-ns/E3/E4    |
| ZDD00076      | Sinong1     | Heilongjiang     | Suihua         | Spring      | 0   | 1.83    | e1-as-ns/E3/E4    |
| ZDD26248      | Suinong14   | Heilongjiang     | Suihua         | Spring      | 0   | 2.26    | e1-as-ns/E3/E4    |
| ZDD07409      | Hengyoutai  | Jilin            | Helong         | Spring      | 0   | 1.63    | e1-as-ns/E3/E4    |
| ZDD01421      | Liushitianhuanbang | Liaoning      | Balinyouqi     | Spring      | 0   | 1.83    | e1-as-ns/E3/E4    |
| ZDD00041      | Heihe1      | Heilongjiang     | Heihe          | Spring      | 0   | 1.75    | e1-as/e2-ns/e3-1a/e4-keshuang |
| ZDD00709      | Heimoshidou | Jilin            |                | Spring      | I   | 1.69    | E1/E2/e3-1a/E4    |
| ZDD00310      | Qinganheidou | Heilongjiang   | Qingan         | Spring      | I   | 1.91    | E1/E2/e3-ns/E4    |
| ZDD06823      | Hefeng25    | Heilongjiang     | Jiamusi        | Spring      | I   | 1.83    | E1/e2-ns/E3/E4    |
| ZDD07489      | Tonghuapingdingxiang | Jilin       | Tonghua        | Spring      | I   | 1.85    | E1/e2-ns/E3/E4    |
| ZDD01629      | Baiqianwdou | Hebei            | Pingquan       | Spring      | I   | 2.22    | E1/e2-ns/E3/E4    |
| ZDD18529      | Maoyandou   | Hebei            | Weichang       | Spring      | I   | 2.18    | E1/e2-ns/E3/E4    |
| ZDD08603      | Xiaohuangdou| Shansi           | Huairen        | Spring      | I   | -       | E1/e2-ns/E3/E4    |
| ZDD08650      | Huangdou<2> | Shansi           | Wuzhai         | Spring      | I   | 1.94    | E1/e2-ns/E3/E4    |
| ZDD08124      | Yanqihuangdou| Xinjiang       | Yandi          | Spring      | I   | 2.44    | E1/e2-ns/E3/E4    |
| ZDD08125      | Changjihuangdou1 | Xinjiang   | Changji        | Spring      | I   | -       | E1/e2-ns/E3/E4    |
| ZDD06998      | Chasedou    | Jilin            | Gongzhuling    | Spring      | I   | 1.78    | e1-as/E2/E3/E4    |
| ZDD01124      | Xiaohuangdou| Liaoning         | Chifeng        | Spring      | I   | 2.22    | e1-as/E2/E3/E4    |
| ZDD00294      | Qingdu      | Heilongjiang     | Acheng         | Spring      | I   | 1.95    | e1-as-ns/E3/E4    |
| ZDD00603      | Changchunmancangjiang | Jilin       | Changchun      | Spring      | I   | 2.17    | e1-as-ns/E3/E4    |
| ZDD00638      | Bodiao      | Jilin            | Jitai          | Spring      | I   | 2.13    | e1-as-ns/E3/E4    |
| ZDD07218      | Zhiu2       | Jilin            |                | Spring      | I   | 2.28    | e1-as-ns/E3/E4    |
| ZDD01074      | Xiaobaqi    | Liaoning         | Chifeng        | Spring      | I   | 1.79    | e1-as-ns/E3/E4    |
| ZDD18277      | Chi382      | Iner Mongolia    | Chifeng        | Spring      | I   | 1.78    | e1-as-ns/E3/E4    |
| ZDD00003      | Heinong2    | Heilongjiang     | Harbin         | Spring      | I   | 2.1    | e1-as-ns/e3-1a/E4 |
| ZDD11255      | 77-391-1    | Jiangsu          | Zhenjiang      | Spring      | II  | 2.35    | E1/E2/E3/E4       |
| ZDD07088      | Longquanadou | Heilongjiang   |                | Spring      | II  | 2.39    | E1/e2-ns/E3/E4    |
| ZDD17989      | Huanggali   | Jilin            |                | Spring      | II  | 2.36    | E1/e2-ns/E3/E4    |
| ZDD00854      | Jinhzhou4-1 | Liaoning         | Jinhzhou       | Spring      | II  | 1.87    | E1/e2-ns/E3/E4    |
| ZDD00932      | Daheiqi     | Liaoning         | Chaoyang       | Spring      | II  | 1.48    | E1/e2-ns/E3/E4    |
| ZDD01060      | Huangji     | Liaoning         |                | Spring      | II  | 2.55    | E1/e2-ns/E3/E4    |
| ZDD01612      | Tueryan     | Hebei            | Pingquan       | Spring      | II  | 1.59    | E1/e2-ns/E3/E4    |
| ZDD08564      | Xiaoyuanhuangdou | Shansi     | Tianzheng      | Spring      | II  | -       | E1/e2-ns/E3/E4    |
| ZDD03776      | Suiyanchundou | Jiangsu       | Huaiyang       | Spring      | II  | 1.36    | E1/e2-ns/E3/E4    |
| ZDD05494      | Honghuliuyuebao | Hubei        | Honghu         | Spring      | II  | 1.27    | E1/e2-ns/E3/E4    |

(Continued)
| Collection No. | Varieties                  | Province     | City or counties | Sowing type | MG          | R/V         | Genotype         |
|---------------|----------------------------|--------------|------------------|-------------|-------------|-------------|-----------------|
| ZDD05502      | Nidou                      | Hubei        | Wuchang          | Spring II   | II          | 1.29        | E1/e2-ns/E3/E4  |
| ZDD11575      | Huasedou                   | Hubei        | Chongyang        | Spring II   | III         | 1.3         | E1/e2-ns/E3/E4  |
| ZDD06515      | Xiangdou4                  | Hunan        | Changsha         | Spring II   | III         | 1.23        | E1/e2-ns/E3/E4  |
| ZDD20671      | Gongdou7                   | Sichuan      | Zigong           | Spring II   | II          | 1.67        | E1/e2-ns/E3/E4  |
| ZDD14240      | Duzhengwudou               | Jiangxi      | Duzheng          | Spring II   | II          | 1.54        | E1/e2-ns/E3/E4  |
| ZDD06454      | Hengfengwudou              | Jiangxi      | Hengfeng         | Spring II   | II          | 1.49        | E1/e2-ns/E3/E4  |
| ZDD14252      | Fengchengzuowudou          | Jiangxi      | Fengcheng        | Spring II   | II          | 1.42        | E1/e2-ns/E3/E4  |
| ZDD22207      | Madeihediou-3              | Guangdong    | Lianxian         | Spring II   | II          | 1.38        | E1/e2-ns/E3/E4  |
| ZDD03026      | Pingdinghei                | Shandong     | Taian            | Summer II   | II          | 1.49        | E1/e2-ns/E3/E4  |
| ZDD18532      | Jidou7                     | Hebei        | Shijiazhuang     | Summer II   | II          | 2.31        | e1-as/e2-ns/E3/E4 |
| ZDD08190      | Yangtianxiaohuangdou       | Hebei        | Chicheng         | Spring III  | III         | 1.77        | E1/E2/E3/E4     |
| ZDD08282      | Nanguanxiaoliqiging        | Hebei        | Qianxi           | Spring III  | III         | 1.57        | E1/E2/E3/E4     |
| ZDD18524      | Xiaotaiwiloshidou          | Hebei        | Xinglong         | Spring III  | III         | 1.66        | E1/E2/E3/E4     |
| ZDD08018      | MuynGRAYoyalien            | Beijing      | Miyun            | Spring III  | III         | 1.57        | E1/E2/E3/E4     |
| ZDD08472      | Heidou                     | Hebei        | Wuyi             | Summer III  | II          | 1.35        | E1/E2/E3/E4     |
| ZDD03106      | Chadou                     | Shandong     | Qihe             | Summer III  | III         | 1.55        | E1/E2/E3/E4     |
| ZDD01402      | Dahelidou                  | Liaoning     | Bailinyouqi      | Summer III  | III         | 3.23        | E1/e2-ns/E3/E4  |
| ZDD01489      | Yushidou                   | Liaoning     | Xingcheng        | Spring III  | III         | 1.52        | E1/e2-ns/E3/E4  |
| ZDD02096      | Tianedan                   | Shanxi       | Wuxiang          | Spring III  | III         | 2.23        | E1/e2-ns/E3/E4  |
| ZDD02159      | Daheidou                   | Shanxi       | Daixian          | Spring III  | III         | 2.00        | E1/e2-ns/E3/E4  |
| ZDD08928      | Liushiribaidou             | Shanxi       | Yicheng          | Spring III  | III         | 1.61        | E1/e2-ns/E3/E4  |
| ZDD10186      | Zaoshuhuangdou             | Shaanxi      | Taibai           | Spring III  | III         | 1.74        | E1/e2-ns/E3/E4  |
| ZDD03739      | Pixianzaiahuacao           | Jiangsu      | Pixian           | Spring III  | III         | 2.18        | E1/e2-ns/E3/E4  |
| ZDD03740      | Pixianzianxianzhuangliuyexian | Jiangsu    | Pixian           | Spring III  | III         | 1.59        | E1/e2-ns/E3/E4  |
| ZDD14505      | Yizhangliuyexian           | Hunan        | Yizhang          | Spring III  | III         | 1.18        | E1/e2-ns/E3/E4  |
| ZDD12436      | Bazhongliankangdou         | Sichuan      | Bazhong          | Spring III  | III         | 1.25        | E1/e2-ns/E3/E4  |
| ZDD12527      | Pixiangxiaohuangdou        | Sichuan      | Pixian           | Spring III  | III         | 1.30        | E1/e2-ns/E3/E4  |
| ZDD06776      | Liuyuehuang                | Sichuan      | Deyang           | Spring III  | III         | 1.29        | E1/e2-ns/E3/E4  |
| ZDD21030      | Pengshanghuangkezi-3       | Sichuan      | Pengshan         | Spring III  | III         | 1.36        | E1/e2-ns/E3/E4  |
| ZDD15385      | Dahuangdong1               | Guizhou      | Zunyi            | Spring III  | III         | 1.38        | E1/e2-ns/E3/E4  |
| ZDD14228      | Wuyuehuang                 | Jiangxi      | Yongxin          | Spring III  | III         | 1.48        | E1/e2-ns/E3/E4  |
| ZDD06363      | Dalihuang                  | Fujian       | Jinhong          | Spring III  | III         | 1.58        | E1/e2-ns/E3/E4  |
| ZDD06377      | Xiamentengzidou            | Fujian       | Xiamen           | Spring III  | III         | 1.26        | E1/e2-ns/E3/E4  |
| ZDD06378      | Tonganzihongdou            | Fujian       | Tongan           | Spring III  | III         | 1.21        | E1/e2-ns/E3/E4  |
| ZDD16675      | Dabaiaomao3                | Guangdong    | Heping           | Spring III  | III         | 1.23        | E1/e2-ns/E3/E4  |
| ZDD18835      | Maoyandou                  | Hebei        | Weixian          | Summer III  | III         | 2.43        | E1/e2-ns/E3/E4  |
| ZDD01720      | Sijiaoqihuangdou           | Hebei        | Quzhou           | Summer III  | III         | 1.36        | E1/e2-ns/E3/E4  |
| ZDD08352      | Bendidahuangdou            | Hebei        | Xianxian         | Summer III  | III         | 1.33        | E1/e2-ns/E3/E4  |
| ZDD18771      | Qingdou                    | Hebei        | Lingshou         | Summer III  | III         | 1.41        | E1/e2-ns/E3/E4  |
| ZDD02526      | Shengi3                    | Shandong     | Yiyouan          | Summer III  | III         | 1.93        | E1/e2-ns/E3/E4  |
| ZDD02940      | Lücaddou                   | Shandong     | Mengyin          | Summer III  | III         | 1.39        | E1/e2-ns/E3/E4  |
| ZDD19409      | Zhenge50420-B1             | Henan        | Zhengzhou        | Summer III  | III         | 1.67        | E1/e2-ns/E3/E4  |
| ZDD03570      | Xinayangxiangdou           | Henan        | Xinyang          | Summer III  | III         | 1.43        | E1/e2-ns/E3/E4  |
| ZDD03868      | Peixianxiangdou            | Jiangsu      | Peixian          | Summer III  | III         | 1.20        | E1/e2-ns/E3/E4  |
| ZDD04959      | ZDD04959                   | Anhui        | Wanbei           | Summer III  | III         | 1.79        | E1/e2-ns/E3/E4  |
| ZDD12845      | Jiahehualianjwodou         | Sichuan      | Jiange           | Summer III  | III         | 1.27        | E1/e2-ns/E3/E4  |
| ZDD12908      | Qionglaiyoujiaheidou       | Sichuan      | Qiongli          | Summer III  | III         | 1.21        | E1/e2-ns/E3/E4  |
### Table 3. (Continued)

| Collection No. | Varieties       | Province     | City or county | Sowing type | MG  | R/V   | Genotype          |
|----------------|-----------------|--------------|----------------|-------------|-----|-------|-------------------|
| ZDD01169       | Niumaohu        | Liaoning     | Gaixian        | Spring      | III | 1.51  | e1-as/E2/E3/E4   |
| ZDD08238       | Chichenlvhuangdou| Hebei        | Chicheng       | Spring      | III | 2.33  | e1-as/E2/E3/E4   |
| ZDD08690       | Xiaohuangdou    | Shanxi       | Yuci           | Spring      | III | 2.47  | e1-as/E2/E3/E4   |
| ZDD19381       | Gaozuoxuan1     | Shandong     | Gaomi          | Summer      | III | 2.18  | e1-as/E2/E3/E4   |
| ZDD01983       | Baijihuangdou   | Shanxi       | Quiling        | Spring      | IV  | 2.53  | E1/E2/E3/E4     |
| ZDD04275       | Tongshanqingdadou| Jiangsu    | Tongshan       | Summer      | IV  | 1.38  | E1/E2/E3/E4     |
| ZDD04620       | Taixingniaoahuangyi| Jiangsu   | Taixing        | Summer      | IV  | 1.24  | E1/E2/E3/E4     |
| ZDD13666       | Lulanzi         | Sichuan      | Xichang        | Summer      | IV  | 1.18  | E1/E2/E3/E4     |
| ZDD02134       | Xiaohuangdou    | Shanxi       | Lingchuan      | Spring      | IV  | 2.46  | E1/e2-ns/E3/E4  |
| ZDD08728       | Bailudou        | Shanxi       | Heshun         | Spring      | IV  | 2.58  | E1/e2-ns/E3/E4  |
| ZDD03728       | Suiningpingdinghuang| Jiangsu     | Suining        | Spring      | IV  | -     | E1/e2-ns/E3/E4  |
| ZDD12331       | Xiaobaimao      | Sichuan      | Pixian         | Spring      | IV  | 1.4   | E1/e2-ns/E3/E4  |
| ZDD12635       | Zizhongliuyuezao| Sichuan      | Zizhong        | Spring      | IV  | 1.48  | E1/e2-ns/E3/E4  |
| ZDD12680       | Jianweiqianshidou| Sichuan     | Jianwei        | Spring      | IV  | 1.22  | E1/e2-ns/E3/E4  |
| ZDD20652       | 8307/8/1        | Sichuan      | Chengdu        | Spring      | IV  | 1.53  | E1/e2-ns/E3/E4  |
| ZDD14920       | Erijiaozou-2    | Guizhou      | Zhijin         | Spring      | IV  | 1.2   | E1/e2-ns/E3/E4  |
| ZDD15624       | Zaojiaodou      | Guizhou      | Xiwen          | Spring      | IV  | 1.35  | E1/e2-ns/E3/E4  |
| ZDD06375       | Daqingren       | Fujian       | Jinjiang       | Spring      | IV  | 1.46  | E1/e2-ns/E3/E4  |
| ZDD14125       | Budou451        | Fujian       | Putian         | Spring      | IV  | 1.37  | E1/e2-ns/E3/E4  |
| ZDD21485       | Quanbian11      | Fujian       | Quanzhou       | Spring      | IV  | 1.47  | E1/e2-ns/E3/E4  |
| ZDD06538       | Dongshanbaimadou| Fujian       | Dongshan       | Spring      | IV  | 1.55  | E1/e2-ns/E3/E4  |
| ZDD1683        | Diliuhuangsou-2 | Hebei        | Gaocheng       | Summer      | IV  | 1.45  | E1/e2-ns/E3/E4  |
| ZDD18558       | Huahelihu       | Hebei        | Hejian         | Summer      | IV  | 1.42  | E1/e2-ns/E3/E4  |
| ZDD02764       | Siliyuan        | Shandong     | Zaozhuang      | Summer      | IV  | 1.45  | E1/e2-ns/E3/E4  |
| ZDD02866       | Dabaipi        | Shandong     | Weishan        | Summer      | IV  | 1.72  | E1/e2-ns/E3/E4  |
| ZDD02913       | Xiaomidou       | Shandong     | Dongping       | Summer      | IV  | 1.53  | E1/e2-ns/E3/E4  |
| ZDD19131       | Maoudou         | Shandong     | Zhaoyuan       | Summer      | IV  | 2.12  | E1/e2-ns/E3/E4  |
| ZDD10100       | Zheng8516       | Henan        | Zhengzhou      | Summer      | IV  | 1.58  | E1/e2-ns/E3/E4  |
| ZDD04918       | ZDD04918        | Anhui        | Wanbei         | Summer      | IV  | 1.71  | E1/e2-ns/E3/E4  |
| ZDD12023       | Chihuangdou1    | Hubei        | Lichuan        | Summer      | IV  | 1.10  | E1/e2-ns/E3/E4  |
| ZDD12872       | Qionglaihuangmaoz| Sichuan     | Qiongai        | Summer      | IV  | 1.29  | E1/e2-ns/E3/E4  |
| ZDD17325       | Xuanza          | Yunnan       | Xuanwei        | Summer      | IV  | 2.10  | E1/e2-ns/E3/E4  |
| ZDD22145       | Dahuangdou-2    | Guangdong    | Jiaolong       | Spring      | IV  | 1.29  | E1/e2-ns/E3/E4  |
| ZDD08633       | Qingkeyuandou   | Shanxi       | Daixian        | Spring      | IV  | 2.01  | e1-as/E2/E3/E4  |
| ZDD19699       | Sidou2          | Jiangsu      | Siyang         | Summer      | IV  | 2.16  | e1-as/E2/E3/E4  |
| ZDD02400       | Xiaohedou       | Shanxi       | Wuxiang        | Spring      | V   | 1.91  | E1/E2/E3/E4     |
| ZDD09279       | Xiaohedou       | Shanxi       | Yixin          | Spring      | V   | 1.79  | E1/E2/E3/E4     |
| ZDD19027       | Lupihuangdou    | Shanxi       | Guijiao        | Spring      | V   | 2.73  | E1/E2/E3/E4     |
| ZDD10252       | Xiaoheidou      | Shaanxi      | Fugu           | Spring      | V   | 1.52  | E1/E2/E3/E4     |
| ZDD10270       | Xiaoheidou      | Shaanxi      | Dingbian       | Spring      | V   | 2.15  | E1/E2/E3/E4     |
| ZDD08120       | Nidinghuameidou | Ningxia      | Zhongning      | Spring      | V   | 1.81  | E1/E2/E3/E4     |
| ZDD14911       | Xihuangdou-9    | Guizhou      | Zhijin         | Spring      | V   | 0.94  | E1/E2/E3/E4     |
| ZDD16743       | Lianjiangpouhuangdou| Guangdong  | Lianjiang      | Spring      | V   | 0.88  | E1/E2/E3/E4     |
| ZDD19293       | Zaoshuheidou    | Shandong     | Rushan         | Summer      | V   | 3.07  | E1/E2/E3/E4     |
| ZDD03540       | Boaihongpizaojiazi| Henan       | Boai           | Summer      | V   | 2.74  | E1/E2/E3/E4     |
| ZDD11586       | 82–16           | Hubei        | Wuhan          | Summer      | V   | 1.16  | E1/E2/E3/E4     |
| ZDD17457       | Yangyandou      | Yunnan       | Yongde         | Summer      | V   | 1.31  | E1/E2/E3/E4     |

(Continued)
| Collection No. | Varieties          | Province | City or counties | Sowing type | MG | R/V | Genotype |
|----------------|--------------------|----------|------------------|-------------|----|-----|----------|
| ZDD11092       | Youhuang dou       | Gansu    | Xihe             | Spring      | V  | 2.27| E1/E2/E3/E4 |
| ZDD00921       | Tianedan           | Liaoning | Jinhua           | Spring      | V  | 2.12| E1/e2-ns/E3/E4 |
| ZDD02114       | Tianedan           | Shanxi   | Tunliu           | Spring      | V  | 2.92| E1/e2-ns/E3/E4 |
| ZDD08697       | Yuxuan13           | Shanxi   | Yuci             | Spring      | V  | 2.39| E1/e2-ns/E3/E4 |
| ZDD09136       | Xiaqiong dou       | Shanxi   | Hongdong         | Spring      | V  | 2.08| E1/e2-ns/E3/E4 |
| ZDD10359       | Laohedou           | Shaanxi  | Zhiou            | Spring      | V  | 2.56| E1/e2-ns/E3/E4 |
| ZDD03733       | Pixianhongmaoyou   | Jiangsu  | Pixian           | Spring      | V  | 1.90| E1/e2-ns/E3/E4 |
| ZDD03741       | Pixiansiyuecao     | Jiangsu  | Pixian           | Spring      | V  | 1.39| E1/e2-ns/E3/E4 |
| ZDD06562       | Baimao dou         | Guzhuou  | Xingyi           | Spring      | V  | 1.5 | E1/e2-ns/E3/E4 |
| ZDD10430       | Huichaxiaohuang dou| Shaanxi  | Luonan           | Summer      | V  | 1.55| E1/e2-ns/E3/E4 |
| ZDD10812       | Jianghuang dou     | Shaanxi  | Lantian          | Summer      | V  | 1.7 | E1/e2-ns/E3/E4 |
| ZDD02864       | Pingdianhuang dou  | Shandong | Weishan          | Summer      | V  | 1.86| E1/e2-ns/E3/E4 |
| ZDD02891       | Dahuang dou        | Shandong | Liangshan        | Summer      | V  | 1.82| E1/e2-ns/E3/E4 |
| ZDD02892       | Datianedan         | Shandong | Liangshan        | Summer      | V  | 1.84| E1/e2-ns/E3/E4 |
| ZDD02921       | Qing6              | Shandong | Taian            | Summer      | V  | 1.97| E1/e2-ns/E3/E4 |
| ZDD19144       | Qisiwa             | Shandong | Wendeng          | Summer      | V  | 1.93| E1/e2-ns/E3/E4 |
| ZDD03153       | Miyangxiaohuang    | Henan    | Miyang           | Summer      | V  | 1.39| E1/e2-ns/E3/E4 |
| ZDD03237       | Xichuanjiwuhuang   | Henan    | Xichuan          | Summer      | V  | 1.53| E1/e2-ns/E3/E4 |
| ZDD03293       | Miyangniuahuang    | Henan    | Miyang           | Summer      | V  | 1.18| E1/e2-ns/E3/E4 |
| ZDD03533       | Zhechengxiaoahong dou| Henan | Zhecheng        | Summer      | V  | 2.01| E1/e2-ns/E3/E4 |
| ZDD11581       | 82–24              | Hubei    | Wuhan            | Summer      | V  | 1.46| E1/e2-ns/E3/E4 |
| ZDD11588       | 74–424             | Hubei    | Wuhan            | Summer      | V  | 1.56| E1/e2-ns/E3/E4 |
| ZDD11703       | Shuanghuang dou    | Hubei    | Dadangyang       | Summer      | V  | 1.12| E1/e2-ns/E3/E4 |
| ZDD12386       | Dahuang dou        | Sichuan  | Dayi             | Summer      | V  | 1.18| E1/e2-ns/E3/E4 |
| ZDD13560       | Baimaozaodouzi     | Sichuan  | Ningnan          | Summer      | V  | 0.87| E1/e2-ns/E3/E4 |
| ZDD17622       | Malanzaochadou     | Yunnan   | Zhaotong         | Summer      | V  | 2.08| E1/e2-ns/E3/E4 |
| ZDD18870       | Dongshan69         | Shanxi   | Taiyuan          | Spring      | V  | 2.92| e1-as/E2/E3/E4 |
| ZDD02315       | Huipizhiheidou     | Shanxi   | Xingxian         | Spring      | VI | 1.47| E1/E2/E3/E4 |
| ZDD16954       | Bozhidou           | Guangxi  | Lingshan         | Summer      | VI | 0.60| E1/E2/E3/E4 |
| ZDD16771       | Qingyuan daqing dou| Guangdong | Qingyuan        | Spring      | VI | 0.71| E1/E2/E3/E4 |
| ZDD04572       | Wuijuangwu yueniahuang | Jiangsu | Wujian          | VI | 1.49| E1/E2/E3/E4 |
| ZDD04604       | Yizhengdali huangdou| Jiangsu | Yizheng         | VI | 0.84| E1/E2/E3/E4 |
| ZDD11323       | Dantu xiao wu jia  | Jiangsu  | Dantu            | Summer      | VI | 0.69| E1/E2/E3/E4 |
| ZDD17375       | Huang dou          | Yunnan   | Yongli           | Summer      | VI | 1.43| E1/E2/E3/E4 |
| ZDD21907       | Xinyudali qing     | Jiangxi  | Xinyu            | Autumn      | VI | 1.49| E1/E2/E3/E4 |
| ZDD14190       | Baiqiu1            | Fujian   | Samming          | Autumn      | VI | -   | E1/E2/E3/E4 |
| ZDD08986       | Xiaobaidou<2>      | Shanxi   | Wenxi            | Spring      | VI | 1.11| E1/e2-ns/E3/E4 |
| ZDD12828       | Suining taise jiang  | Sichuan | Suining         | VI | 1.40| E1/e2-ns/E3/E4 |
| ZDD03603       | Niumaohuang        | Shaanxi  | Zhenan           | Summer      | VI | 1.29| E1/e2-ns/E3/E4 |
| ZDD11159       | Hualhuang dou      | Gansu    | Liangyang        | Summer      | VI | 1.26| E1/e2-ns/E3/E4 |
| ZDD03969       | Pixian layhuang    | Jiangsu  | Pixian           | Summer      | VI | 1.07| E1/e2-ns/E3/E4 |
| ZDD04092       | Bin hai dahuangkezjia | Jiangsu | Bin hai         | Summer      | VI | 1.49| E1/e2-ns/E3/E4 |
| ZDD11226       | Guanyun haihualia  | Jiangsu  | Guanyun          | Summer      | VI | 1.08| E1/e2-ns/E3/E4 |
| ZDD05920       | Daimidou           | Hubei    | Huie            | Summer      | VI | 1.10| E1/e2-ns/E3/E4 |
| ZDD11624       | Chihuang dou 2     | Hubei    | Luotian          | Summer      | VI | 0.93| E1/e2-ns/E3/E4 |
| ZDD11951       | Shanzhai huang dou | Hubei    | Yunxi            | Summer      | VI | 1.15| E1/e2-ns/E3/E4 |
| ZDD13401       | Liuyue bao -2      | Sichuan  | Yaan             | Summer      | VI | 1.87| E1/e2-ns/E3/E4 |

(Continued)
through MGIX/X, whereas the autumn-sowing varieties were sorted into MGVI or later. This indicated the MG range of these accessions was narrow. MG000 and MG00 MCC were only distributed in Northern Heilongjiang, and MGIX and MGX were only found in the accessions from south China. MGIII contained the largest number of accessions which were collected from different regions. Fifty-five accessions in MGIII originated from 16 provinces were mainly spring-sowing or summer-sowing types. Soybeans of MGVII/VIII included spring-

| Collection No. | Varieties | Province     | City or county | Sowing type | MG   | R/V          | Genotype     |
|----------------|-----------|--------------|----------------|-------------|------|--------------|--------------|
| ZDD19579       | Lühuangdou | Gansu        | Chongxin       | Spring      | VII/VIII | 2.06         | E1/E2/E3/E4  |
| ZDD16756       | Yangshangqindou | Guangdong     | Yangshan       | Spring      | VII/VIII | 0.79         | E1/E2/E3/E4  |
| ZDD20340       | Lüouheipidou | Anhui        | Yuxi           | Summer      | VII/VIII | 1.64         | E1/E2/E3/E4  |
| ZDD12322       | Huaimeidou  | Hebei        | Wufeng         | Summer      | VII/VIII | 1.02         | E1/E2/E3/E4  |
| ZDD20532       | Xiaolhuangdou | Hebei        | Zhuxi          | Summer      | VII/VIII | 0.84         | E1/E2/E3/E4  |
| ZDD12389       | Wuyanwo     | Sichuan      | Beichuan       | Summer      | VII/VIII | 1.4          | E1/E2/E3/E4  |
| ZDD12407       | Zhengjialhuangdou | Sichuan     | Guangyuan      | Summer      | VII/VIII | 1.31         | E1/E2/E3/E4  |
| ZDD12415       | Mayibo      | Sichuan      | Yunyang        | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD06475       | Yantiaoqipidou | Jiangxi      | Wuyuan         | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD06067       | Cudou       | Zhejiang     | Pinghu         | Summer      | VII/VIII | 0.60         | E1/E2/E3/E4  |
| ZDD06501       | Rujinpingdou | Jiangxi      | Rujin          | Autumn      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD21440       | Zaozhumaopengqiang | Zhejiang     | Quzhou         | Autumn      | VII/VIII | 1.24         | E1/E2/E3/E4  |
| ZDD14409       | Dahuangzhu  | Jiangxi      | Qianshan       | Autumn      | VII/VIII | 0.61         | E1/E2/E3/E4  |
| ZDD10539       | Dahuangdou  | Shaanxi      | Zhenba         | Summer      | VII/VIII | 1.45         | E1/e2-ns/E3/E4 |
| ZDD13636       | Lvdouzi     | Sichuan      | Mingshan       | Summer      | VII/VIII | 1.19         | E1/e2-ns/E3/E4 |
| ZDD13341       | Qiuyehuang  | Sichuan      | Mianyang       | Summer      | VII/VIII | E1/E2/E3/E4  |
| ZDD16846       | Yingdehedou | Guangdong    | Yingde         | Spring      | VII/VIII | 0.71         | E1/E2/E3/E4  |
| ZDD19464       | Baomuji     | Shaanxi      | Zhenan         | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD10572       | Niuphuangdou | Shaanxi      | Pingli         | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD05572       | Jinghuang35yi | Hebei         | -              | Summer      | VII/VIII | 0.68         | E1/E2/E3/E4  |
| ZDD11866       | Chahuangdaiyoudou | Hebei       | Nanzhang       | Summer      | VII/VIII | 0.88         | E1/E2/E3/E4  |
| ZDD17233       | Mashanrenfenghuangdou | Guangxi | Mashan         | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD16874       | Heikewudou  | Hainan       | Chengmai       | Summer      | VII/VIII | -            | E1/E2/E3/E4  |
| ZDD12836       | Shifanguosidou | Sichuan     | Shifang        | Spring      | VII/VIII | 1.39         | E1/e2-ns/E3/E4 |
| ZDD10615       | Laoshupi    | Shaanxi      | Ningshan       | Summer      | VII/VIII | 1.18         | E1/e2-ns/E3/E4 |
| ZDD17574       | Songzidou   | Yunnan       | Huaning        | Summer      | VII/VIII | 2.00         | E1/e2-ns/E3/E4 |
| ZDD12688       | Changshouxiyuehuang | Sichuan     | Changshou      | Spring      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD12910       | Hanyuanbalixiaoheidou | Sichuan   | Hanyuan        | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD13233       | Donghuangdou1 | Sichuan    | Shizhu         | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD13441       | Zaohuangdou-4 | Sichuan     | Xingjing       | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD12400       | Shiyuehuang  | Sichuan      | Xichang        | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06461       | Shangraoyuebauabei | Jiangxi  | Shangrao       | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06803       | Dawudo      | Guangxi      | Hepu           | Summer      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06528       | Huangmaodou  | Hunan        | Ningyuan       | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06543       | Hong2hudou  | Hunan        | Hengshan       | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD14782       | Changshandou | Hunan        | Changsha       | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD14783       | Aishengnidou | Hunan        | Liuyang        | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06494       | Shaxindou   | Jiangxi      | Shicheng       | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06410       | Zhaoanquidadou | Fujian     | Zhaoan         | Autumn      | IX/X    | -            | E1/E2/E3/E4  |
| ZDD06438       | Shaxianwudou | Fujian       | Shaxian        | Autumn      | IX/X    | -            | E1/E2/E3/E4  |

Table 3. (Continued)

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Genetic variation of maturity group and E genes in the Chinese soybean mini core collection
## Table 4. Maturity group assignments of the Chinese soybean MCC.

| MG       | Variety                                                                 |
|----------|-------------------------------------------------------------------------|
| 000      | **Spring-sowing**: Dongnong36, Wilenskabaranatrall-2-184, Pojobaran 856–3, Heihexiaohuangdou |
| 00       | **Spring-sowing**: Heihe1, Hefeng37                                      |
| 0        | **Spring-sowing**: mufeng1, hengfeng24, helongyoujia, shuyangchunheidoubing, baichengmoshidou, Boige du lot et geronne, fangzhengmoshidou, dongmeng434, kebei1, liushishihanhuang, suinong6, suinong1, Dunajka, taixingjiaohong, jilinchalihu, zhengguang1, Flora, xiaolishimidou, nenfeng11, taixingheidou, suinong14, dongmeng163 |
| I        | **Spring-sowing**: hefeig25, Huangdou<2<, chasedou, qingdou, yanghuangdou, yapoche, chi382, qinganheidou, zhuau2, changchunmancangji, maoyandou(Jinlin), xiaohuangdou, heinong2, bodiaoj, xiaobaqi, heimoshidou, tonghuapingdingxiang, lcar 166, jinshanchamoshidou, xiaohuangdou, maoyandou(Liaoning), datunxiaoheidou, jinlin30, changjiuhuangdou1 |
| II       | 1. **Spring-sowing**: nidou, hengfengwudou, jinzhou2, 60 CMS superspecial, 77-391-1, duchangwudou, zhechun2, Domaka tolisa, huangqi, xiaoyuanhuangdou, hongfeng11, gongdou7, xiangdou4, longguandadou, Harosoy, daheiqi, tueryan, zhechun3, Harosoy2, huasedou, fengchengzaowudou, huangda li, honghuliu yuebao, huaiyangchundou, madaiheidou3 2. **Summer-sowing**: jidou12, jidou7, pingdinghei, ludo4, erliheidou, zaoshui18, zhongdou27 |
| III      | 1. **Spring-sowing**: Nova, wuyuehuang, bazhongliankandou, tianedan, pixianxianhuangliuyuexiang, dabaimao, pixianzhuzihuaocao, xiaohuangdou(Shanxi), xiamentengzidou, longchuanhuangniumao, dalheiheidou, zhiyangliuyuehuangdou, xiaohuangdou(Liaoning), xitaiximoshidou, damingbaidou1, suinong6, suinong1, Dunajka, taixingai jiaohong, jilinchalihua, zhengguang1, Flora, xiaolishimidou, nenfeng11, taixingheidou, suinong14, dongmeng163 |
| IV       | 1. **Spring-sowing**: dongshанbaimaodou, poudou451, zhihongliuyuezao, dongguanwuyuehuang, chamoshidou, dahuangdou2(Guangdong), zaojiaodou, erjiaodou2, daqingren, 8307-8-1, Shinpaldal kong2, baipihuangdou, jianweimaiboudou<2<, tongzanghongfeng, fengjiao66-22, pixianxianhuangdou, liuyuehuang, panshidou, liushiribaidou, chichengyuhuangdou, niukmaohang, nanguanxiqiping, yushidou, tianedan, zhuangdou1, yangtianxiangdou, dalihuanghai, miyuanlaiyan, pengshanghuangkezi3, zaoshuqiangdou, dalihuanghai, tieheidou 2. **Summer-sowing**: chadou, bendidahuangdou, jingehual injiwodou, zhonghuang4, lyucaodou, yushidou, Williams, tianedan, dahuangdou-1, yangtianxiao huangdou, dalihuanghai, miyuanlaiyan, pengshanghuangkezi3, zaoshuqiangdou, dalihuanghai, tieheidou |
| V        | 1. **Spring-sowing**: pixianxianmaoyou, xiaoheidou, pixiansiliao, xiaojingdou, ridinghuameidou, tianedan, cansidou, Hartwig, tianedan(Shanxi), dongshang69, lianjiangpoqisadou, heheidou, xihuangdou9, xiaoheidou(Shaan xi), baimao, luoyipihuang, shoulderhuang, hongfeng11, gongfeng11, gongfeng7, maodou, maodou, yantianqing, piqihua, suqiyuan, xiaomiao, dabaip |
| VI       | 1. **Spring-sowing**: qionglaihuangmaoyou, luyanlu, huaihehu, shuanghuangdou2, zheng8516, tongshihuangdou, xuanzhu, chihuangdou1, suqiyuangdou, ZDD04918, taixingniumaohuangyi, sidou2, 7651–1, wenfeng7, maodou, maodou, yantianqing, piqihua, suqiyuan, xiaomiao, dabaip |
| VII/VIII | 1. **Spring-sowing**: jingdeihedou, shifangluosidou, lyuqihuangdou, yangshangqingdou 2. **Summer-sowing**: lyuqihua, jinghuang35, wuyaow, mochadaidou1, dahuangdou(Shanxi), lyuweidou, yangshangqingdou, gisiwa, zhongguanghong, dahuangdou, qing6, shuanghuangdou, zaoshuhua, xianpiwudou, baimai, heikewu dou, mayibao, qiyuehuang, mashanrenfenghuangdou |

(Continued)
summer- and autumn-sowing types. Soybean cultivars in Sichuan Province showed the largest number of 30 accessions, while those of the Heilongjiang, Shanxi, Shandong and Jiangsu provinces were more than 20 accessions. However, there was no MCC accession from Tibet Autonomous Region, Qinghai province, and Tianjin, Shanghai and Chongqing Municipalities, respectively.

Twenty MCC accessions originated from 16 foreign countries also showed large range from MG000 to MGIX/X except the MGVI. All the 15 spring-sowing soybean accessions were allocated from MG 000 to MGVI, and soybeans of summer- and autumn-sowing types were mainly distributed into the groups above MGV. MGII was the largest group which included more foreign varieties than other MGs.

### Growth period structure (R/V) variation of Chinese soybean MCC

The R/V ratio of 244 soybean varieties was calculated using the data obtained from Jining under spring-sowing conditions. There were wide variation in the ratio of reproductive (R) to vegetative (V) periods (R/V) among the MCC ranging from 0.60 to 3.23 (Table 3). The summer-sowing variety of Cudou from Zhejiang province classified into MGVII/VIII showed the minimum ratio (0.60) while the spring-sowing variety of Daliheidou of MGIII from Jilin showed the maximum value (3.23). The varieties of the same MG also showed a remarkable variation in the R/V ratio. Among the MGIII varieties, the maximum R/V ratio was up to 2.63 (Williams), but the minimum value was only 1.18 (Yizhangsiyhuang). Among the MGI accessions, the maximum R/V ratio (Yanqihuangdou) and the minimum value (Datunxiaohedou) was 2.44 and 1.51, respectively. Varieties from the same region were also diverse in the R/V ratio. For example, R/V ratio of varieties from Sichuan province ranged from 0.87 to 1.87. Compared with Chinese accessions, the foreign germplasm in the MCC also showed diversity in the R/V ratio. Significant variation of the R/V ratio which was observed among the varieties reflected the rich genetic background of MCC.

### Genotyping of the maturity genes in Chinese soybean MCC

In order to detect alleles of the maturity genes in Chinese soybean MCC, 228 soybean accessions (76.3%) were genotyped by the Sequenom MassARRAY platform at four maturity loci (i.e. E1-E4) and a total of twelve genotypes were identified in this population. Among all these groups, genotypes of E1/e2-ns/E3/E4 and E1/E2/E3/E4 were the major types, which were identified in 128 and 68 cultivars, respectively (Table 3). Seven genotypes, including E1/E2/e3-ns/E4, E1/e2-ns/E3/e4-keshuang, E1/e2-ns/e3-tr/E4, e1-as/E2/e3-la/E4, e1-ns/E2/e3-Mo/E4, e1-as/e2-ns/e3-la/E4, e1-as/e2-ns/e3-la/e4-keshuang, were identified only in one variety (Table 3). In addition, the other 3 genotypes (e.g. E1/E2/e3-1a/E4, e1-as/E2/E3/E4, e1-as/e2-ns/E3/E4) were identified in 2, 10, and 13 accessions, respectively.

To determine the effects of maturity genes on maturity and photoperiod response in MCC, the relationship between allelic constitutions and maturity groups of each kind of genotypes were analyzed (Table 6). The results showed that E1/E2/E3/E4 genotypes were always detected
Table 5. Maturity group assignment of Chinese soybean MCC in certain provinces in China.

| Origin      | Sowing type | Number of accessions | Number of accessions |
|-------------|-------------|---------------------|----------------------|
|             |             |                     | 000 | 00 | 0 | I | II | III | IV | V | VI | VII/VIII | IX/X |
| Heilongjiang| Sp          | 22                  | 2   | 2  | 11| 5  | 2  |     |    |    |    |    |       |
| Jilin       | Sp          | 15                  | 4   | 8  | 1 | 1  | 1  |     |    |    |    |    |       |
| Liaoning    | Sp          | 14                  | 1   | 3  | 3 | 6  | 1  |     |    |    |    |    |       |
| Inner Mongolia| Sp  | 1                   |     |    | 1 |     |    |    |    |    |    |    |       |
| Xinjiang    | Sp          | 2                   |     |    | 1 |     |    |    |    |    |    |    |       |
| Ningxia     | Sp          | 1                   |     |    | 1 |     |    |    |    |    |    |    |       |
| Gansu       | Sp, Su      | 4                   |     |    | 1 | 1  | 1  | 1  |    |    |    |    |       |
| Shaanxi     | Sp, Su      | 13                  |     |    | 1 | 5  | 3  | 4  |    |    |    |    |       |
| Shanxi      | Sp          | 24                  |     |    | 2 | 1  | 5  | 4  | 3  |    |    |    |       |
| Hebei       | Sp, Su      | 19                  |     |    | 3 | 3  | 9  | 4  |    |    |    |    |       |
| Beijing     | Sp, Su      | 3                   |     |    | 1 | 2  |    |    |    |    |    |    |       |
| Shandong    | Su          | 20                  |     |    | 3 | 5  | 5  | 7  |    |    |    |    |       |
| Henan       | Su          | 11                  |     |    | 5 | 1  | 5  |    |    |    |    |    |       |
| Jiangsu     | Sp, Su      | 22                  |     |    | 3 | 2  | 3  | 5  | 2  | 7  |    |    |       |
| Anhui       | Su          | 4                   |     |    | 1 | 1  | 1  | 1  |    |    |    |    |       |
| Hubei       | Sp, Su      | 16                  |     |    | 4 | 1  | 4  | 3  | 4  |    |    |    |       |
| Hunan       | Sp, Au      | 6                   |     |    | 1 | 1  |    |    |    |    |    |    | 4     |
| Jiangxi     | Sp, Su, Au  | 10                  |     |    | 3 | 1  | 1  | 3  | 2  |    |    |    |       |
| Sichuan     | Sp, Su      | 30                  |     |    | 1 | 6  | 7  | 2  | 2  | 6  | 6  |    |       |
| Guizhou     | Sp, Su      | 6                   |     |    | 1 | 2  | 2  |    |    |    |    |    | 1     |
| Yunnan      | Su          | 6                   |     |    | 1 | 3  | 1  | 1  |    |    |    |    |       |
| Zhejiang    | Sp, Su, Au  | 4                   |     |    | 1 |    |    |    |    |    |    |    | 3     |
| Fujian      | Sp, Au      | 10                  |     |    | 3 | 4  | 1  | 1  | 2  |    |    |    |       |
| Guangdong   | Sp          | 9                   |     |    | 1 | 2  | 2  | 1  | 1  | 2  |    |    |       |
| Guangxi     | Sp, Su      | 4                   |     |    | 1 | 1  | 1  | 1  |    |    |    |    |       |
| Hainan      | Su          | 1                   |     |    | 1 |    |    |    |    |    |    |    |       |
| North America| Sp  | 22                  |     |    | 2 | 3  | 1  | 5  | 3  | 2  | 2  | 2  | 2     |
|             |             |                     | Total| 299| 4 | 2  | 22 | 25 | 32 | 55 | 42 | 46 | 24 | 29 | 18 |

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Table 6. The distribution of allelic variation of E1, E2, E3 and E4 loci in different MGs of Chinese soybean MCC.

| MGs         | Genotypes | G1 | G2 | G3 | G4 | G5 | G6 | G7 | G8 | G9 | G10 | G11 | G12 |
|-------------|-----------|----|----|----|----|----|----|----|----|----|-----|-----|-----|
| 0           |           | 1  | 1  |    | 1  | 1  |    | 1  |    |    | 1   |     |     |
| I           |           | 1  | 1  | 1  | 1  |    | 2  | 6  | 1  |    |     |     |     |
| II          |           | 1  |    | 18 |    |    |    |    |    |    |     |     |     |
| III         |           | 6  |    |    | 31 |    |    | 4  |    |    |     |     |     |
| IV          |           | 4  |    |    |    | 24 |    | 1  | 2  |    |     |     |     |
| V           |           | 13 |    |    |    |    | 25 |    |    |    |     |     |     |
| VI          |           | 9  |    |    |    |    |    | 11 |    |    |     |     |     |
| VII/VIII    |           | 21 |    |    |    |    |    |    | 5  |    |     |     |     |
| IX/X        |           | 14 |    |    |    |    |    |    |    | 14 |     |     |     |

Note: G1: E1/E2/E3/E4; G2: E1/E2/e3-1a/E4; G3: E1/E2/e3-ns/E4; G4: E1/e2-ns/E3/E4; G5: E1/e2-ns/E3/e4-keshuang; G6: E1/e2-ns/e3-tr/E4; G7: e1-as/E2/E3/E4; G8: e1-as/E2/e3-1a/E4; G9: e1-as/E2/e3-Mo/E4; G10: e1-as/e2-ns/E3/E4; G11: e1-as/e2-ns/e3-1a/E4; G12: e1-as/e2-ns/e3-1a/e4-keshuang.

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in medium and late-maturing accessions from MGII to VIII and even MGIX/X. In contrast, the recessive allele of the $E_3$ and $E_4$ was always detected in varieties from MG0 and MGI except a variety Dahuangdou-2 belonging to MGIV with two recessive alleles in $E_2$ and $E_3$ loci originated from Guangdong province, southern coast area of China. The allele $e_4$ was detected in only two cultivars belonging to MG0, both of which were from Heihe, Heilongjiang Province with high latitude and low temperature[35].

**Discussion**

MCC is a small sub-set of the entire collection which represents most of the total genetic variation with a minimal redundancy[53](Brown, 1995). Therefore, it is an ideal choice to utilize the MCC of soybean in China as representative materials to investigate the maturity diversity among Chinese varieties[5]. As shown in Table 5, accessions of MCC originated from 26 provinces and other 16 countries spanned more than 12 MGs (MG000 to MGIX/X). Moreover, rare alleles of maturity genes were also identified in this population, despite some genotypes were only detected in a single accession. These results were consistent with a previous report about the MG scope of Chinese soybean[54], which confirmed the representation and high diversity of this collection.

Gai et al. (2001) and Wang et al. (2006) suggested that the spring-sowing soybeans from the Northeast were classified into MG000-IV, and the summer-sowing soybeans from the Huang-Huai-Hai region and the Northwest were classified into MGII-VI and MGI-III, respectively[4, 54]. In contrast, the spring-sowing and summer-sowing soybean from the Yangtze River region were classified into MG0-IV and MGIII-VIII, respectively. Our data were mostly consistent with previous studies. Unlike the previous data, 11 spring-sowing soybean varieties were classified into MGVII or even later groups in this study, implying that there was rich genetic variations among the Chinese soybean MCC.

In this study, we also classified several accessions such as Dongnong 36, Suinong 14, Jilin 30 and Taixingheidou into the same MG appeared in previous study[4]. For the varieties of Heihe 1 (MG00), Nenfeng 11 (MGI) and Hefeng 25 (MGI), similar MG was registed in United States Department of Agriculture (USDA)[55]. Moreover, MG of some US varieties such as Harosoy, Williams, Clark and Hartwig was in line with the previous study by Chang et al (1992)[56]. Aforementioned results confirmed the experimental methods and the classification of MG. Nonetheless, in this study, Honghuliuyuebao, Duchangwudou and Daqingren were classified into MGII, MGII and MGIV, respectively. However, these 3 varieties were classified into MGI-2, MGI-2, and MGIII-2 by Gai et al (2001)[4]. This might be resulted from the different test conditions and criteria, or various source of accessions.

In North America, the optimal zones for each MG soybeans were roughly parallel with latitude[26]. However, the distribution of MGs in China seems to be relatively complex because of the diversity of ecological condition and production practices. To be exact, the same MG varieties might be from different regions and multiple MGs may present in the same region, which resulted in the abundance of Chinese soybean germplasm resources. The spring-sowing soybeans were mainly classified into MGII-III, whereas, summer- and autumn-sowing soybeans were classified into MGVII-VIII in Jiangxi province.

Previous reports revealed that recessive alleles (e.g. $e_1$, $e_2$, $e_3$ and $e_4$) were associated with earlier flowering and maturity[15]. In this study, most late-maturing accessions had the same genotype at $E_1/E_2/E_3/E_4$ with 136.2 d of average growth period while most accessions with one or more recessive alleles of $E_1$, $E_2$, $E_3$ and $E_4$ were early-maturing. In line with the previous studies[15, 45, 57] (, the average growth period of accession with single recessive allele was 116.2 d for $e_2$, 105.4 d for $e_1$ and 80.6 d for $e_3$, respectively (P<0.05, data not shown).
Meanwhile, some varieties with two or more recessive alleles were late maturing. For example, two recessive alleles were identified at \( E2 \) and \( E3 \) loci (\( E1/e2-ns/e3-tr/E4 \)) in Dahuangdou-2 classified into MGIV. The growth period of Dahuangdou-2 was 116.5 d, indicating that there might be other genes controlling the flowering and maturity in soybean. These varieties could be used for the discovery of new genes. Moreover, the effects of \( E \) genes under vegetative periods varied from those under reproductive periods during the soybean development. Previous studies revealed the positive effects of \( E1 \) allele on length of soybean vegetative periods\(^{[56, 57]} \) (Chang, 1992; Wang et al. 2008). Based on the analysis of allelic variation effects on R/V in this study, we showed the presence of recessive allele in \( E1 \) locus in all thirteen accessions with higher R/V ratio (>2.0). These data revealed that \( e1 \) had a potential effect on late mature by prolonging the reproductive period during soybean growth. In the current study, most of the US reference accessions showed normal agronomic performance in Jining, Shandong province, despite the fact that a few of the early accessions showed poor growth vigor or symptoms of mosaic virus disease. However, more standard reference varieties with the resistance to lodging and disease are required in order to avoid the potential effects of disadvantageous traits on the maturity performances\(^{[58–61]} \) (). Hence, the elite accessions with desirable agronomic traits are recommended for the establishing Chinese maturity standard classification system.

### Conclusion

A large spectrum of maturity groups (MG000-MGIX/X) were found in the Chinese soybean MCC, which reflected the complex ecological conditions and planting patterns in China. The MG000 and MG00 accessions were only distributed in northern Heilongjiang, and the MGIX/X accessions were collected only from south China. Other MGs covered the accessions from different regions and sowing types. Recessive alleles of \( E \) genes were identified with higher frequency in early-maturing accessions and the dominate alleles were detected always in medium and late-maturing accessions. The diversity of maturity groups and allelic variation of maturity genes in MCC confirmed the representativeness of Chinese soybean MCC. Some accessions could be used for the discovery of new soybean maturity genes. The combination roles of \( E \) loci could be used to design maturity group for the selection of soybean parents and breeding new varieties adapted to desired cropping systems.

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