Combining ability and heterosis to root-knot nematode resistance on seven genotypes of kenaf using full diallel cross analysis

Parnidi 1,2, L Soetopo 1, Damanhuri 1 and Marjani 1

1. Faculty of Agriculture, Brawijaya University, Malang, Indonesia.
2 Indonesian Sweetener and Fiber Crops Research Institute

*Author E-mail: nikicro@yahoo.co.id, lita.fp@ub.ac.id, damanhuri385@yahoo.com, marjani.balittas@gmail.com

Abstract A full diallel cross is confirmed to be able to advocate kenaf breeders to select breeding materials, such as inbred lines that produce the best combination with heterosis properties. The results of this study provided information about general combining abilities (GCA) of parents, specific combining ability (SCA), as well as heterosis values. This study aims to estimate the combining abilities and heterosis values of root-knot nematodes in kenaf originated from the full diallel cross. Semi-field research was conducted in an experimental garden located at Karangploso Balitas, from November 2018 to January 2019. The variance of GCA values was higher than SCA values for the number of root knot, reproductive factors, and number of egg mass. In contrast, the variance of GCA values was lower than SCA values for the number of second-stage juvenile (J2) and the number of egg per egg mass characters. KR4, K45, and KR15 genotypes indicated negative GCA values on all characters tested. Meanwhile, KR1, Kin2 and DS028 genotypes signified susceptibility with a positive GCA value. The crossbreeding combinations showed negative SCA values on the number of second-stage juvenile, the number of egg mass and the number of egg per egg mass characters of resistance to root-knot nematodes (M. incognita), i.e. KR6 x DS028: KR4, KR5 and KR15 genotype was quite consistent with negative GCA and SCA values, as well as heterosis values for characters of resistance to root-knot nematodes on kenaf roots on the number of second-stage juvenile (J2), the number of egg mass and the number of egg per egg mass characters tested. Genotype of KR4 x KR5 and its reciprocal have negative heterobeltiosis values on number of second-stage juvenile, egg mass, and the number of eggs per egg mass evaluated characters.

Key words: kenaf, heterosis, heterobeltiosis, resistance, nematode

1. Introduction
Kenaf is a plant producing natural fibers processed from its bark by soaking and scraping. Kenaf fibers could be utilized for the raw materials of gunny sacks, door trims, fiber grains, geotextiles, pulp, and environmentally friendly handicrafts. Indonesian kenaf productivity reaches 3-4 tons per hectare of dry fiber [1]. One of the factors influencing the low productivity of kenaf in Indonesia is the limited number of wide yielding varieties and the low resistance of common varieties to diseases caused by root-knot nematodes.
There are several cross designs that can be applied to select the parental genotypes for producing new high yielding varieties, one of it is through full diallel cross design. This type of crossing is proven to be suitable for plant breeders to determine the breeding materials, including the inbred lines that produce the best combination as well as having heterosis properties [2-3]. Diallel cross is mating schemes carried out using various genotypes, including the parental genotype and the F1 hybrids. The genetic response is an important factor for designing selection in plant breeding programs and assembling varieties with good qualities. This kind of information could be obtained through diallel cross techniques [3].

The diallel cross method has been widely used to obtain information on genetic parameters related to the number and quality of plants, as well as its resistance to pathogens [4]. Hayman method is one of the diallel analysis procedures used to investigate the genetic parameters and the heritability. This method is able to determine the breeding systems that can optimize gene actions to get the desired traits. The diallel cross design should fit several assumptions: (1) diploid segregation; (2) there is no differences between F1 and its reciprocity or no maternal effects; (3) there are no interactions between genes from different alleles (epistasis); (4) there is no multiallelism; (5) homozygous parents; and (6) genes that spread randomly among parental genotypes [5-6].

Sujiprihati et al., (2007) stated that in order to produce high yielding hybrids, therefore the parents should be originated from two or more genetically different populations, thus will produce a high level of heterosis on F1 hybrids [7]. Diallel cross provides an approach to evaluate and determine parental genotypes that can be combined in an effort to improve a population. Moreover, diallel crosses also provide information regarding general combining ability (GCA) and specific combining ability (SCA) of the parental genotypes as well as the crossing schemes. GCA and SCA are essential for the first stages of improving plant traits to identify the best strain’s combinations that are able to produce high yielding hybrids.

Several studies on heterosis and heterobeltiosis have been carried out on kenaf [8-10]. Heterobeltiosis is the F1 hybrids exhibiting better traits compared to the parental genotypes with the best-desired traits. Wide yielding varieties can be achieved if the hybrids of the crossbreeding have positive heterosis. This study aims to obtain information regarding both heterosis and heterobeltiosis from the crossbreeding of 7 kenaf parental genotypes in order to gain hybrid candidates complemented with resistanceto root-knot nematodes.

2. Research Methods

Semi-field research was conducted in an experimental garden located at elevation 515 masl, on Sweetener and Fiber Crops Research Institute-Karangploso, from November 2019 to January 2020. Seven kenaf genotypes were used in this study: Karangploso 1 (KR1), Karangploso 4 (KR4), Karangploso 5 (KR5), Karangploso 6 (KR6), Karangploso 15 (KR15), Kenafindo Agribun 2 (Kin2), and DS028, as well as 42 F1 hybrids collected from full diallel crosses. The parental genotypes were selected based on having different genotypes between one another. Crossing schemes were presented in Table 1.

Experiments were designed in a Randomized Block Design with one factor and repeated 3 times.

| Table 1. Full diallel cross schemes of 7 different kenaf genotypes |
|-------------------------|-----------------|----------------|----------------|-----------------|-----------------|-----------------|
| Genotypes               | KR1  | KR4  | KR5  | KR6  | KR15 | Kin2  | DS028 |
| KR1                     | ☒    | 1x4  | 1x5  | 1x6  | 1x15 | 1xkin | 1xds  |
| KR4                     | 4x1  | ☒    | 4x5  | 4x6  | 4x15 | 4xkin | 4xds  |
| KR5                     | 5x1  | 5x4  | ☒    | 5x6  | 5x15 | 5xkin | 5xds  |
| KR6                     | 6x1  | 6x4  | 6x4  | ☒    | 6x15 | 6xkin | 6xds  |
| KR15                    | 15x1 | 15x4 | 15x5 | 15x6 | ☒    | 15xkin| 15xds |
| Kin2                    | Kinx1| Kinx4| Kinx5| Kinx6| Kinx15| ☒    | Kinxds|
| DS028                   | Dsx1 | Dsx4 | Dsx5 | Dsx6 | Dsx15| Dsxkin| ☒    |

☒ = selfing
Kenaf was planted in a polybag of 30 x 30 cm with a spacing of 30 x 50 cm, and a distance of 100 cm between each replicate. The planting media were 55% sandy soil, 36% silt, and 17% clay. Sterilization of planting media was carried out using 4% formalin solution.

Planting was performed by putting 3-5 seeds into the planting hole with a depth of 3-5 cm. The first thinning was carried out at 7 DAPs (Day After Planting), and the next thinning was performed by sparsing into one plant per polybag at 14 DAPs. Fertilization was carried out by administering a dose of 3 g N + 1.5 g P2O5 + 1.5 g K2O to each plant or equal to 3.5 g urea +10 g Phonska per plant. Phonska fertilizer was given at 10 DAPs, meanwhile urea fertilizer at 30 DAPs. Fertilizers were administered by putting it into the hole and covering it with soil. Other maintenances, including weeding, irrigating, and controlling pests and diseases, adjusted to the plant conditions. Nematicide was not given during the experiments.

Experiments were carried out by infecting kenaf plants aged 15 DAPs with *M. incognita* nematodes in a population of 40 juvenile II/100 gr soil [11-12]. Observations on the number of root-knot nematodes and Sasser the reproduction factor were conducted at 75 days after inoculation. The amount of egg mass per 10 grams of roots and the number of eggs per egg mass were calculated, referring to the method of [3, 13].

Calculation of the number of root-knot at the root was intended to determine the number of root-knot formed during the designated time. Calculation of the number of second-stage juvenile nematodes on 100 g of soil was intended to investigate the nematode reproduction factors. The number of second-stage juvenile of nematodes on 10 g roots by extracting method use Dalmadiyo (1989) method [11]. The amount of egg mass was calculated from 10 g of root samples that were first soaked in a solution of Dioxin B (sigma) at a concentration of 0.15 g/L for 15 minutes [13]. Ten egg masses of each genotype were placed at 0.5% sodium hypochlorite (1 mL) for 1 minute and shook gently [11]. As much as 50 μL solutions from three samples were observed under a light microscope. Furthermore, the number of eggs and the average number of eggs per egg mass were calculated. Resistance characters, including the number of root-knot, reproduction factor, number of second-stage juvenile, number of egg mass, and number of egg per egg mass, were analysed in order to calculate the general combining abilities and heterosis. The collected data of resistance characters to root-knot nematode were analysed according to the method described by Singh and Chaudary (1979) [14].

3. **Result and Discussion**

3.1 **General Combining Ability (GCA), Specific Combining Ability (SCA), and Reciprocal Effects**

The results of GCA and SCA variances, as well as the reciprocal effects, are presented in Table 2, meanwhile, GCA values are presented in Table 3. Significant differences detected in GCA and SCA of kenaf resistance characters to root-knot nematodes indicated the presence of additive and non-additive gene actions that may control these characters.

The variance analysis results of combining abilities of GCA on the number of root knot, reproduction factor, and number of egg mass showed significant differences. However, there were no significant differences in number of second-stage juvenile (J2), and the number of egg per egg mass (Table 2). This indicates that kenaf resistance characters to root-knot nematode were regulated by both additive and non-additive genes. Significant effects on the number of root knot, reproduction factor, and number of egg mass indicated that there were one or more kenaf genotype combinations that have good combining abilities to root-knot nematode resistance. Kenaf resistance measured and analysed based on the number of root-knot, reproduction factor, number of second-stage juvenile (J2), number of egg mass, and the number of eggs per egg mass was expected to have negative GCA and SCA values. This is due to the fact that the smaller the resistance value, the more resistant the genotype is against root-knot nematodes.

The number of eggs per egg mass indicated a higher mean square for GCA compared to SCA ($\sigma_{GCA}/\sigma_{SCA} > 1$). This may indicate that the action of the additive gene was more dominant than
non-additive genes. The high ratio value of $\sigma^2$DGU/$\sigma^2$DGK showed that the additive variance plays a bigger role in influencing the resistance characters [7,15].

The greater effects of additive gene action than non-additive genes (dominant genes) on each character might give information that each character can be inherited to the offspring. This shows that the appearance of each character observed is influenced by the action of additive genes [16]. The effect of additive genes indicated that two alleles contribute together to the phenotypic trait. The role of additive genes in nematode resistance is also reported in red clover [17], sweet potato [18], cotton [19], and tobacco [3].

Additive genes are generally inherited to the offspring. General combining abilities means the ability of parental genotypes to produce better hybrids compared to other strains. Higher additive variances signify that selection is better to be carried out in the next/final generations.

**Table 2.** Recapitulation of GCA and SCA variances, as well as the ratio of GCA/SCA variances.

| Variabel | GCA       | SCA       | Reciprocal | $\sigma^2$GCA/$\sigma^2$SCA Rasio |
|----------|-----------|-----------|------------|----------------------------------|
| NRK      | 3442.71** | 3752.48** | 3617.44**  | 0.92                             |
| RF       | 10.86**   | 9.66**    | 7.89*      | 1.12                             |
| NJ2      | 25.99tn   | 70.71**   | 62.27tn    | 0.37                             |
| EM       | 45.94**   | 46.74**   | 38.35tn    | 0.98                             |
| NE/EM    | 6283.37tn | 5931.55tn | 8981.55tn  | 1.06                             |

Note: GCA = General Combining Abilities, SCA = Specific Combining Abilities, $\sigma^2$GCA = GCA variance, $\sigma^2$SCA = SCA variance. ** = Significant on level $\alpha$ = 1%, * = Significant on level $\alpha$ = 5%

**Table 3.** GCA values on number of root-knot, reproductive factor, number of second-stage juvenile, egg mass, and number of eggs per egg mass of *M. incognita*.

| Genotype | General Combining Abilities (GCA) |
|----------|----------------------------------|
|          | NRK    | RF   | NJ2  | EM   | NE/EM |
| KR1      | 28.66  | 1.99 | 4.96 | 2.88 | 44.26  |
| KR4      | -23.54 | -0.75| -3.10| -2.38| -31.56 |
| KR5      | -17.83 | -1.01| -2.02| -2.35| -30.05 |
| KR6      | 5.33   | 0.22 | -0.42| 1.10 | 1.06   |
| KR15     | -24.64 | -1.16| -2.61| -2.61| -24.31 |
| Kin2     | 17.93  | 0.60 | 1.27 | 1.99 | 27.76  |
| DS028    | 14.08  | 0.12 | 1.92 | 1.38 | 12.82  |

Note: Number of root-knot (NRK), Reproductive factors (RF), Number of second-stage juvenile (NJ2), Egg mass (EM),and Number of egg per egg mass (NE/EM)

Parental genotype with high GCA values on several important characters, especially those correlated with kenaf resistance to root-knot nematode, might hold a high potency to be used for the production of high-yielding hybrids. Crossing by using parental genotype with high GCA values may produce hybrids with better-desired traits. Genotypes with high GCA values could be utilized as the parental genotype for the production of synthetic variety or formation of basic populations through recurrent selection [20]. The utilization of plant characters with high GCA values correlated with good results has been previously reported by several studies. Dalimunthe et. al., (2015) reported that particular characters along with significant GCA values indicate the action of additive genes, and thus may allow the occurrence of huge genetic advances in intra-population selection [21]. Mahmood et al., (2002) suggested that parents that have high combining abilities could be utilized as donors for the studied characters [22].
In general, a general combining ability is implied by high and positive values [23-24] However, investigating the resistance characters, such as resistance to root-knot nematode, is expected to have high and negative values. This is the consequence of the resistance direction that leans toward the resistance of parental genotype. Similar results were also reported by several researchers who investigated the GCA and SCA values analysed from the resistance of papaya to anthracnose [6], chilli to anthracnose [25], and chilli to aphid infection [20]. All those studies showed negative values which are correlated with resistance characters and vice versa, in which positive values are correlated with vulnerability.

According to the analysis results of several resistance characters, KR4, KR5, and KR15 genotypes were moderately resistant to root-knot nematodes, meanwhile, KR6 and DS028 genotypes were susceptible to root-knot nematodes. KR1 and Kin2 genotypes were very susceptible to root-knot nematodes (Table 4). KR4, KR5 and KR15 are genotypes that show negative GCA values on all characters tested. In the character of number of second-stage juvenile a negative GCA value was also shown in the KR6 genotype. In the contrary, KR1 and Kin2 genotypes indicated higher susceptible as both genotypes have positive GCA values. Owolade et al. (2006) stated that negative GCA values indicate resistance to disease or pathogens, meanwhile positive GCA values indicate susceptible [3]. This result was also supported by Hafsoh (2016) and Irawati (2011) [6, 25].

Other than GCA values, SCA values may also be used to determine the potential of parental genotype for further kenaf resistance improvement programs to root-knot nematode. As many as 42 cross combinations were created with details: 24 cross combinations for investigating a number of root-knot nematodes, 20 cross combinations for investigating reproductive factor, 22 cross combinations for investigating number of second-stage juvenile, 16 cross combinations for investigating egg mass, and 17 cross combinations for investigating the number of eggs per egg mass which supported with negative SCA values. Two cross combinations showed negative SCA values on all resistance characters to root-knot nematode (M. incognita): KR1xKR4, KR1xKR5, KR1xKR15 and KR6 x DS028 (Table 4).

| Genotype       | Specific Combining Abilities (SCA) |
|----------------|------------------------------------|
|                | NRK | RF   | NJ2 | EM  | NE/EM |
| KR1xKR4        | -21.93 | -0.77  | -0.87   | -3.10  | -53.00 |
| KR1xKR5        | -17.90 | -0.37  | -0.03   | -1.75  | -51.57 |
| KR1xKR6        | 18.89  | 0.46   | 0.24    | 1.49   | 40.28  |
| KR1xKR15       | -24.42 | -1.10  | -0.62   | -3.05  | -62.76 |
| KR1xKin2       | 6.33   | 0.96   | 0.45    | 3.90   | 55.36  |
| KR1xDS028      | 49.90  | 2.37   | 8.02    | 4.58   | 101.31 |
| KR4xKR5        | 12.31  | 0.02   | -1.23   | -0.90  | 9.19   |
| KR4xKR6        | -7.21  | 1.00   | 1.32    | 1.74   | 15.74  |
| KR4xKR15       | 19.01  | 0.60   | -0.04   | 0.29   | 14.61  |
| KR4xKin2       | -14.57 | -0.23  | 2.15    | 1.04   | 2.03   |
| KR4xDS028      | -5.92  | -0.12  | -2.27   | 0.52   | -0.97  |
| KR5xKR6        | -8.74  | 0.23   | 0.12    | 0.15   | 16.60  |
| KR5xKR15       | 13.27  | 0.36   | 0.19    | 0.42   | 16.55  |
| KR5xKin2       | -14.94 | -0.45  | 0.42    | 0.77   | -5.56  |
| KR5xDS028      | 9.48   | 0.17   | 1.09    | 1.05   | -3.08  |
| KR6xKR15       | -1.65  | 0.92   | -0.90   | 1.63   | 7.31   |
| KR6xKin2       | 21.58  | -0.57  | -0.44   | -2.31  | -27.75 |
| KR6xDS028      | -1.84  | -1.14  | -0.25   | -2.08  | -30.67 |
| KR15xKin2      | -12.52 | -0.81  | 1.13    | -0.73  | 16.15  |
| KR15xDS028     | -13.89 | -0.27  | -0.04   | 1.03   | 10.26  |
| Kin2xDS028     | 6.07   | 0.36   | -0.78   | -2.71  | -28.99 |
| KR4xKR1        | -0.20  | -0.14  | -0.58   | -0.29  | -1.79  |
| KR5xKR1        | -0.30  | -0.09  | -0.15   | -0.26  | -0.60  |
A combination of crosses that have low SCA resistance values are generally produced by parent that have low GCA values, either one or both parents (Hafsoh, 2016; Irawati, 2011; Hartati and Sudarsono, 2015). Interestingly, a recent study indicated different results, as parent with low GCA values were not always produced hybrids with low SCA values. Crossing combinations in which hybrids with low SCA values were not produced by parent with low GCA values were as follows: DS028 x KR5, KR1 x KR4 and KR1 x KR5. Meanwhile, other crossing combinations showed that hybrids with low SCA values were not produced by parental genotypes with low GCA values, such as DS028 x KR1, Kin2 x DS028, and KR6 x KR1.

Similar results were also reported in other plants, such as papaya [6] and chili [25] both studies described that crossing parental genotypes with the best-desired characters does not always produce hybrids with the best SCA values on those desired characters. However, crossing parental genotypes that have medium GCA values to strain with high GCA values may produce hybrids with good SCA values. This may be the result of interaction between the positive alleles of parental strain which has medium GCA values with the negative alleles of parental genotypes which have low GCA values.

Genotypes detected to have low combining abilities and low values for the evaluated characters included KR6, Kin2, DS028, and KR1. However, crossing using those two genotypes (KR6 x DS028) produced hybrids with good SCA values on all characters evaluated. Allegedly, there was an interaction between positive alleles from parental genotypes who have medium GCA values with negative alleles from parental genotypes who have low GCA values. Similar things were also suspected to occur in other crosses. However, the values resulting from the combination of crosses between medium and low GCA values are usually less stable, which should be evaluated further, especially for the level of heterosis. On the other hand, the combination of crosses between parents with low combining abilities but producing hybrids with high character values may be resulted from over dominant and epistasis [27].

The combination of crosses that have low SCA values can be considered as potential parents to produce hybrids which are resistance against root-knot nematodes. Previous studies on various plants have focused on utilizing SCA values of parents in order to produce hybrids with better-desired phenotypes. Good hybrids are described by having resistance to pests and diseases and are generally produced by parents with low values of GCA, SCA, heterosis, and heterobeltiosis.

### 3.2 Heterosis
In kenaf plants, characters that are being evaluated for determining the resistance against root-knot nematode are as follows: the number of root-knot formed and the reproductive factors, number of second-stage juvenile [11-12] the egg mass and the number of eggs per egg mass [3, 13]. A heterosis is a form of the hybrid with superior phenotypes compared to its parental [7]. Heterosis or hybrid vigor is characterized by having better phenotypes than F1 hybrids derived from the crossing of two pure parental strains. Symptoms of heterosis are estimated from the yield, size, number of plant parts, chemical components, the resistance to pests/diseases, etc.

Referring to the heterosis values of 49 F1 hybrids, negative values were detected on 24 genotypes for the number of root-knot, 11 genotypes for reproductive factors, 7 genotypes for number of second-stage juvenile, 17 genotypes for egg mass, and 13 genotypes for the number of eggs per egg mass. In the results of this study, there were four cross-combination that had heterosis values that were negative in all the characters evaluated. Twenty-three cross combinations that have heterosis values that are negative in the three characters evaluated (Table 5).

On the other hand, negative values of heterobeltiosis were detected on 5 genotypes for the number of root-knot, 1 genotypes for reproductive characters, 4 genotypes for number of second-stage juvenile, 3 genotypes for egg mass, and 3 genotypes for the number of eggs per egg mass. Two cross combination (KR4 x KR5) produced negative heterobeltiosis values on all characters of resistance to root-knot nematodes. The heterobeltiosis values were -15.76, -45.43, -15.16, -1.99 dan -7.98 for the number of root-knot nematodes, reproductive factors, number second-stage juvenile, egg mass, and a number of eggs per egg mass, respectively. Meanwhile, the crossing of KR5 x KR4 is -11.73, -33.44, -7.20, -2.19 and -3.06 for the number of root-knot nematodes, reproductive factors, number second-stage juvenile, egg mass, and a number of eggs per egg mass, respectively.

The combination of crosses producing F1 hybrids with high heterosis was generally originated from parent with high GCA and SCA values. A recent study found that KR4, KR5 and KR15 genotypes were consistently exhibited negative values on GCA, SCA, and heterosis for number of second-stage juvenile, egg mass, and the number of eggs per egg mass evaluated characters associated with resistance to root-knot nematodes. Negative heterosis values are associated with gene actions in influencing the studied characters. Hafsoh, (2016) reported that the resistance of papaya against anthracnose which was exhibited negative heterosis might be influenced by additive genes [6]. Irawati (2011) also reported similar results on the different plants (chili) [25].

### Table 5. Heterosis and heterobeltiosis values associated with kenaf resistance to root-knot nematode.

| Genotype         | Heterosis | Heterobeltiosis |
|------------------|-----------|-----------------|
|                  | NRK       | RF   | NJ2  | EM   | NE/EM | NRK       | RF   | NJ2  | EM   | NE/EM |
| KR1xKR4          | -35.67    | 2.44 | 13.51| -16.03| -14.90| 33.69     | 102.97| 68.00| 15.55| 3.38  |
| KR1xKR5          | -22.17    | 6.28 | 29.21| -2.73 | -14.74| 63.13     | 108.61| 81.85| 34.49| 1.62  |
| KR1xKR6          | 42.79     | 33.06| 26.97| -2.00 | 20.60 | 118.95    | 83.25 | 45.55| 5.70 | 37.08 |
| KR1xKR15         | -41.24    | -12.16| 20.00| -11.12| -15.90| 22.99     | 75.93 | 73.08| 25.48| 2.18  |
| KR1xKin2         | 7.52      | 21.48| 41.35| 20.32 | 22.80 | 6.27      | 17.11| 27.89| 19.33| 20.33 |
| KR1xDST028       | 97.93     | 82.00| 107.14| 49.78 | 44.24 | 225.96    | 184.91| 148.57| 68.09| 64.86 |
| KR4xKR5          | 0.28      | 14.46| -19.23| -2.35 | -2.16 | 0.84      | 13.75 | -22.22| -1.99| -3.74 |
| KR4xKR6          | -15.38    | 62.94| 11.43 | 5.31  | 8.13  | 6.93      | 119.06| 40.40| 32.38| 14.76 |
| KR4xKR15         | 0.16      | 33.66| -17.29| -0.98 | 3.82  | 0.63      | 34.63 | -18.88| 1.04 | 3.83  |
| KR4xKin2         | -40.77    | -12.87| 31.44| 3.98  | 0.72  | 20.93     | 63.35 | 70.00| 41.56| 19.47 |
| KR4xDST028       | 12.95     | 24.86| -4.00 | 16.45 | 5.97  | 34.20     | 49.23 | 15.20| 40.20| 11.89 |
| KR5xKR6          | -3.58     | 23.33| 7.69  | -0.91 | 7.12  | 22.66     | 64.51 | 29.63| 25.12| 11.76 |
| KR5xKR15         | -0.02     | 16.41| 9.43  | 1.77  | 3.68  | -0.11     | 18.00 | 11.54| 3.46 | 5.41  |
| KR5xKin2         | -32.32    | -20.95| 21.50| 5.48  | -2.96 | 39.34     | 46.84 | 50.00| 44.29| 12.96 |
| KR5xDST028       | 70.93     | 37.38| 41.94| 15.29 | 3.92  | 104.40    | 63.00 | 62.96| 39.41| 7.86  |
| KR6xKR15         | -4.04     | 44.36| -12.50| 9.80  | 7.15  | 21.95     | 95.84 | 7.69 | 41.42| 13.73 |
| KR6xKin2         | 35.12     | -12.84| 3.00  | -3.44 | -3.89 | 103.95    | 14.54 | 5.26 | 3.23 | 6.79  |
| KR6xDST028       | 59.78     | -5.39| 17.81 | -1.40 | 1.19  | 68.55     | 4.76  | 22.86| 2.32 | 1.69  |
| KR15xKin2        | -38.04    | -52.15| 25.89| -5.80 | 7.76  | 27.40     | -39.54| 58.97| 31.57| 27.83 |
| KR15xDST028      | -6.37     | 1.16 | 24.59| 13.60| 13.37 | 11.85     | 21.93 | 46.15| 40.04| 19.70 |
| Kin2xDST028      | 31.27     | 16.83| 23.21| 2.70  | 0.28  | 112.69    | 73.94 | 31.43| 14.20| 11.41 |
4. Conclusion

The GCA variance value was greater than the SCA variance value for the number of eggs per egg mass. In the contrary, the GCA variance value was lower than SCA variance values for the number of root-knot, reproductive factors, number of second-stage juvenile and egg mass. KR4, KR5, and KR15 genotypes showed negative GCA values on all characters evaluated. Meanwhile, KR6 genotype has the negative GCA values on the reproductive factors and number of second-stage juvenile characters. KR1, Kin2 and DS028 genotypes were estimated to be susceptible to root-knot nematodes (*M. incognita*) due to the positive GCA values. The cross between KR4 and KR5 is the best combination to produce offspring that are resistant to root-knot nematodes (*M. incognita*).

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