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# Evaluation of nature and magnitude of heterosis in ashwagandha [*Withania somnifera* (L.) Dunal] for root quality and yield parameters

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**Abstract**
Ashwagandha is one of the important medicinal plant commercially cultivated for long period. The investigation was performed in Randomized Complete Block Design for seventeen traits of seven parental lines which were crossed and some reciprocal cross also made for the estimation of root yield and quality during *Rabi* 2018-19 were studied to assess the magnitude of heterosis in ashwagandha. The result obtained were the cross CGWS.92xCGWS.90, CGWS.92xCGWS.93, CGWS.93xCGWS.89 and CGWS.93xCGWS.92 recorded negative heterosis over better parent for days to 50% flowering, which indicates that scope for its utilization in evolving early flowering plant types. Significant and positive heterosis was found in the cross *viz.*, CGWS.89xCGWS.90, CGWS.89xCGWS.92, CGWS.93xCGWS.89, CGWS.94xCGWS.91 over better parent, and standard checks JA-20 and JA-134 for plant height. For no. of main branches/plant the significant positive heterosis was recorded in cross CGWS.89xCGWS.90, CGWS.90xCGWS.92, CGWS.90xCGWS.93, CGWS.91xCGWS.90 over better parent, standard checks JA-20, JA-134 and RVA-100. Similarly, for no. of secondary branches/plants was recorded in cross CGWS.91xCGWS.89, CGWS.94xCGWS.91, CGWS.95xCGWS.91 over better parent, standard checks JA-20, JA-134 and RVA-100. The cross CGWS.90xCGWS.93, CGWS.91xCGWS.90, CGWS.93xCGWS.92 was found significant and positive heterosis for no. of plant/plot over better parent, standard checks JA-20 and RVA-100. For root length significant and positive heterosis over better parent, standard checks JA-134 was recorded in cross CGWS.92xCGWS.90, CGWS.93xCGWS.91. Significant and positive heterosis recorded in cross CGWS.89xCGWS.91, CGWS.89xCGWS.92, CGWS.89xCGWS.93, CGWS.90xCGWS.92, CGWS.91xCGWS.89, CGWS.91xCGWS.92, CGWS.92xCGWS.89, CGWS.92xCGWS.93, CGWS.93xCGWS.89, CGWS.93xCGWS.92, CGWS.94xCGWS.90, CGWS.95xCGWS.92 over better parent, standard checks RVA-100 for fresh root weight/plant. For dry root weight/plant the significant and positive heterosis were recorded in cross CGWS.89xCGWS.90, CGWS.89xCGWS.91, CGWS.92xCGWS.90, CGWS.92xCGWS.93 over better parent, standard checks JA-20 and RVA-100. The low fiber content in root (%) of ashwagandha is preferred, significant and negative heterosis reported in the cross *viz.*, CGWS.90xCGWS.92, CGWS.91xCGWS.90, CGWS.94xCGWS.91 over better parent and standard checks (JA-20) for fiber content in root (%). The best cross out of 20 crosses, two heterotic $F_1$ with high fresh root weight per plant, high carbohydrate content (%), high protein content (%) and low fiber content in root (%), were found in cross CGWS.90 x CGWS.92 and CGWS.94 X CGWS.91 over standard check. These high root weight, carbohydrate content, protein content and low fiber content in $F_1$ hybrid may be recommended for commercial exploitation.

**Keywords:** *Withania somnifera*, heterosis, Standard heterosis

## Introduction
Ashwgandha is one of the most important medicinal herbs and have a recognized medicinal properties for crude drugs and extracts. Ashwagandha belongs to family of "solanaceae" and botanically known as *Withania somnifera* (L.) Dunal. It is a cross pollinated crop having the chromosome number 2n=48 (Nigam and Kandalkar 1995) [6]. It is originated from north-western and central India as well as Mediterranean region of Africa (Kumar *et al.*, 2020) [4]. In view of extremely rich biodiversity in the state, the government has declared Chhattisgarh as "Herbal state" on July 2001. It is known as "Indian Ginseng or "winter cherry" or "poison gooseberry". Ashwagandha is a "royal herb" because of its numerous rejuvenative effects on the human body possesses antioxidant, anxiolytic, adaptatgen, memory enhancing, antiparkinsonian, antivenom, antiinflammatory properties (Gupta and Rana 2007) [3].

Ashwagandha root contain various bioactive molecules known as with anolides. The main alkaloid found in ashwagandha are withanolide, somniferine, somniferinine, somine, with the anine, pseudowithanolides, withanonine and withasomine (Covello and Ciampa (1960) [1] and Patel and Desai (2017) [7]. The medicinal value of ashwagandha root is due to presence of various alkaloids which varied from 0.16-0.66%.

The awareness about its medicinal value, it has a consequence demand round the year among the consumers. The major objectives of ashwagandha breeding is to be developed high root-yielding varieties with earliness, desirable root size, attractive colour and low fiber content, high carbohydrate content and high biochemical content and free from various diseases. Heterosis analysis provides crucial details about the efficacy of cross combinations and how they can be used to achieve desired characteristics. The amount of heterosis in ashwagandh for dry root yield and its contributing character is determined by genetic variation, genetic base, and adaptability. The important factors restricting the large scale production and development of better cultivar is because of less information available therefore, Inclusion of more diverse parents in hybridization increases the chances of achieving better heterosis and a wider range of heterogeneity in segregating generations. This will be useful in the creation of miracle varieties with high root yield potential in the ashwagandha breeding programme. Speedy improvement can be brought about by exploiting heterosis for various root quality and yield contributing traits as well as earliness. The present study was conducted which will facilitate genetic upgradation to develop superior cultivars benefitting both cultivators and consumers.

## Materials and Methods

The experimental materials consists of seven parental lines of ashwagandha *viz.*, CGWS-89 ($P_1$), CGWS-90 ($P_2$), CGWS-91 ($P_3$), CGWS-92 ($P_4$), CGWS-93 ($P_5$), CGWS-94 ($P_6$), and CGWS-95 ($P_7$). Three checks JA-20, JA-134, RVA-100 collected from different states of India were considered for the study. This parental line were crossed in all possible combinations including reciprocal cross during *Rabi* 2017-18. Successfully 20 crosses will be obtained. The crossed seed will be carefully sown along with parents during *Rabi* 2018-19 for estimation of root yield and quality at research cum instructional farm, Department of Genetics and Plant Breeding, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur (C.G.). Emasculation of bud at pre-anthesis stage was done without damaging pistil. The other flower closed to emasculate bud will be removed and after pollination flower will be immediately covered with cotton and labelled with date and cross combination. All crosses and parents will be treated with 1% bavistin and will be sowing in RBD design with two replication. Recommended practices will be followed to fetch good harvest. Randomly five plants were selected from each treatment for recording data for following traits; days to flowering, plant height (cm), no. of main branches/plant, no. of secondary branches/plant, no. of plant/plot, fresh plant weight/plant (g), dry plant weight/plant (g), main root length (cm), root diameter (cm), root branches/plant, fresh root weight/plant (g), dry root weight/plant (g), fibre content in root (%), carbohydrate content in root (%), protein content in root (%), harvest index (%) and dry matter content (%).

## Statistical analysis

Shull (1914) coined the word "heterosis," which refers to $F_1$'s superiority over homozygous parents involved in its creation as well as the developmental stimulation arising from the union of various gametes. Hybrid vigour, on the other hand, is the product of heterosis. Heterosis can be classified into three groups based on performance of hybrids in comparison to individuals. These are:

i) **Relative heterosis**: It is increased or decreased hybrid vigour over the mid parental value.
ii) **Heterobeltiosis**: It is superiority of heterozygote with regard to the better parent (Fonseca and Patterson, 1968) [2].
iii) **Standard heterosis**: Also known as useful heterosis. Term was used by Meredith and Bridge (1972) [5]. It is increased or decreased vigour of the hybrid over check variety.

## Result and Discussion

There were significant differences were recorded among the parental lines with respect to different characters investigated including root quality and yield contributing traits. The mean performance of parental line and crosses presented in Table 1. And the mid parent, better parent, and standard heterosis, as well as the heterosis results shows in Table 2.

**Days to 50% flowering**: Among the parental line, the days to flowering ranged from CGWS.91 (100) to CGWS.90, CGWS.92, CGWS.93, CGWS.95 (103) and in cross combination it ranges from CGWS.93xCGWS.89 (101) to CGWS.90xCGWS.92, CGWS.91xCGWS.92, CGWS.94xCGWS.90 (105). Heterosis in both negative and positive direction for days to flowering has also been reported by Peng and Virmani (1991) [8]. Heterobeltiosis ranged from -0.98% (CGWS.93xCGWS.89) to 5.00% (CGWS.91xCGWS.92), significant negative heterosis showed by 4 hybrids. Standard heterosis over JA-20 ranges between 1% (CGWS.93xCGWS.89) to 5.06% (CGWS.91xCGWS.92). Standard heterosis over RVA-100 ranges from 0.00% (CGWS.93xCGWS.89) to 3.96% (CGWS.91xCGWS.920), significant and positive heterosis for this trait describe by 20 hybrids.

**Plant height (cm)**: It ranged between CGWS.93 (43.017) to CGWS.90 (65.383), among the parental line and in cross combination it ranges from CGWS.95xCGWS.91 (39.567) to CGWS.93xCGWS.92 (123.033). Heterobeltiosis for plant height range from -30.7% (CGWS.95xCGWS.91) to 159.63% (CGWS.89xCGWS.93), 5 hybrids were found significant positive heterosis. Standard heterosis over JA-20 ranges from -23.19% (CGWS.95xCGWS.91) to 138.82% (CGWS.93xCGWS.92), significant positive heterosis for plant height found in 6 hybrids Standard heterosis over JA-134 ranges between -24.27% (CGWS.95xCGWS.91) to 135.47% (CGWS.93xCGWS.92), significant positive heterosis for plant height found in 6 hybrids. Standard heterosis over check RVA-100 ranges from -37.66% (CGWS.95xCGWS.91) to 93.86% (CGWS.93xCGWS.92), significant and positive heterosis found in 6 hybrids

**No. of main branches/plant**: Among the parental line, it ranges from CGWS.94 (1.000) to CGWS.95 (2.334). In cross combination the ranges occurs between CGWS.92xCGWS.91, CGWS.92xCGWS.93, CGWS.93xCGWS.89 (1.00) to CGWS.93xCGWS.91, CGWS.93xCGWS.92, CGWS.94xCGWS.91 (4.00). Heterobeltiosis ranges from -57.14% (CGWS.95xCGWS.92) to 1667% (CGWS.94xCGWS.91), 5 hybrids showed significant positive heterosis and Standard heterosis over JA-20 varies from -50% (CGWS.95xCGWS.92) to 100% (CGWS.93xCGWS.91), significant positive heterosis were recorded in 5 hybrids. Standard heterosis over JA-134 ranges between -40% (CGWS.95X CGWS.92) to 140% (CGWS.93X CGWS.91), significant positive heterosis were recorded 5 hybrids and Standard heterosis over RVA-100 lies in between -45.45% (CGWS.95X CGWS.92) to 118.18% (CGWS.93X CGWS.91), 5 hybrids showed significant positive heterosis.

**No. of secondary branches/plant**: It ranges from CGWS.89, CGWS.94 (4.500) to CGWS.92 (14.500) among the parental line and cross combination occurs ranges between CGWS.91xCGWS.90 (5.000) to CGWS.90xCGWS.92 (16.00). For this trait Heterobeltiosis ranges from -44.83% (CGWS.92xCGWS.93) to 130.77 (CGWS.89xCGWS.91) significant positive heterosis showed by 8 hybrids and Standard heterosis over JA-20 ranges from -23.08% (CGWS.91xCGWS.90) to 146.15% (CGWS.90xCGWS.92), 11 hybrids were found significant positive heterosis. Standard heterosis over JA- 134 ranges between -9.09% (CGWS.91xCGWS.90) to 190.9% (CGWS.90xCGWS.92), significant positive heterosis showed by 7 hybrids and Standard heterosis over RVA-100 ranges from -28.57% (CGWS.91xCGWS.90) to 128.57% (CGWS.90xCGWS.92) significant and positive heterosis showed by 13 hybrids.

**No. of plant/plot**: Among the parental line, it ranges from CGWS.93 (7.00) to CGWS.95 (15.50) and in cross combination the trait ranges from CGWS.94xCGWS.91 (1.000) to CGWS.89xCGWS.93 (17.00). Heterobeltiosis ranged from -91.3% (CGWS.94xCGWS.91) to 78.95% (CGWS.89xCGWS.93) significant and positive heterosis showed by 4 hybrids. Standard heterosis over JA-20 for this trait ranges from -89.74% (CGWS.94xCGWS.91) to 78.94% (CGWS.89xCGWS.93) significant and positive heterosis showed by 12 hybrids. Standard heterosis over JA-134 ranges between -93.55% (CGWS.94xCGWS.91) to 9.68% (CGWS.89xCGWS.93) only 1 hybrid shows the positive and significant heterosis. Standard heterosis over RVA-100 ranges from -91.67% (CGWS.94xCGWS.91) to 41.67% (CGWS.89xCGWS.93) significant and positive heterosis showed by 9 hybrids.

**Fresh plant weight/plant (g)**: Among the parental line, range occurs between CGWS.89 (28.100) to CGWS.90 (64.900) and in cross combination fresh plant weight ranges occurs between CGWS.92xCGWS.93 (15.000) to CGWS.93xCGWS.92 (405.000). Heterobeltiosis for this trait ranges between -55.37% (CGWS.95xCGWS.91) to 766.31% (CGWS.93xCGWS.92), non- significant and positive heterosis found in 1 hybrid and Standard heterosis over JA-20 ranges -53.87% (CGWS.95xCGWS.91) to 647.23% (CGWS.93xCGWS.92), for this trait 5 hybrids were significant positive heterosis. Standard heterosis over JA-134 ranges from -25.7% (CGWS.95xCGWS.91) to 1103.57% (CGWS.93x CGWS.92), significant positive heterosis for the trait showed by 1 hybrid. Standard heterosis over RVA-100 ranges from -57.85% (CGWS.95xCGWS.91 to 582.78% (CGWS.93xCGWS.92), 5 hybrids were significant positive heterosis.

**Dry plant weight/plant (g)**: Among the parental line, the trait ranges between CGWS.89 (4.783) to CGWS.90 (8.633). In cross combination the ranges between CGWS.92xCGWS.93 (6.450) to CGWS.93xCGWS.92 (34.62). Heterobeltiosis for this trait ranges between -16.95% (CGWS.92xCGWS.93) to 345.75% (CGWS.93xCGWS.92) significant positive heterosis found in 13 hybrids, and Standard heterosis for JA-20 ranges -21.34% (CGWS.92xCGWS.93) to 322.19% (CGWS.93xCGWS.92) for this trait significant and positive heterosis found in 13 hybrids. Standard heterosis over JA-134 ranges from -54.18% (CGWS.92xCGWS.93) to 727.57% (CGWS.93xCGWS.92), 2 hybrids were positive and significant. Standard heterosis over RVA-100 ranges from -33.16% (CGWS.92xCGWS.93) to 258.76% (CGWS.93xCGWS.92), significant positive heterosis showed by 13 hybrids.

**Main root length (cm)**: Among the parental line, the trait ranges between CGWS.91 (16.567) to CGWS.90 (26.617). In cross combination the trait ranges between CGWS.94xCGWS.91 (9.200) to CGWS.92xCGWS.90 (30.700). Better parent heterosis for this trait comes between -52.49% (CGWS.94xCGWS.91) to 49.47% (CGWS.93xCGWS.92) positive heterosis showed by 3 hybrids were significant. Standard check over JA-20 ranges from -62.39% (CGWS.94xCGWS.91) to 25.48% (CGWS.92xCGWS.90) for this trait 7 hybrids showed the significant positive heterosis and Standard check over JA-134 comes under -59.68% (CGWS.94xCGWS.91) to 34.55% (CGWS.92xCGWS.90) for the trait significant positive heterosis found in 10 hybrids and Standard check over RVA-100 ranges from -56.78% (CGWS.94xCGWS.91) to 44.24% (CGWS.92xCGWS.90), for root length significant positive heterosis showed by 11 hybrids.

**Root diameter (cm)**: Among the parental line, the trait ranges between CGWS.92 (1.717) to CGWS.91 (2.750). In cross combination it ranges between CGWS.94xCGWS.91 (0.500) to CGWS.94xCGWS.90 (2.100). Better parent heterosis for root diameter comes between -81.83% (CGWS.94xCGWS.91) to 0.88% (CGWS.93xCGWS.92), significant positive heterosis for this trait found by 1 hybrid. Standard heterosis over JA-20 ranges from -77.27% (CGWS.94xCGWS.91) to -4.55% (CGWS.94xCGWS.90), significant negative heterosis for the root diameter were found in 16 hybrids. Standard heterosis over JA-134 ranges from -76.74% (CGWS.94xCGWS.91) to -2.33% (CGWS.94xCGWS.90), 17 hybrids shows the negative heterosis and significant. Standard heterosis over RVA-100 comes between -78.57% (CGWS.94xCGWS.91) to -9.99% (CGWS.94xCGWS.90) significant negative heterosis for this trait found in 14 hybrids.

**Root branches/plant**: Among the parental line, the trait ranges between CGWS.95 (4.667) to CGWS.90 (8.335). In cross combination the trait ranges between CGWS.94xCGWS.91 (4.333) to CGWS.93xCGWS.91 (20.000). Heterobeltiosis ranges between -44% (CGWS.89xCGWS.90) to 170.27% (CGWS.92xCGWS.93) significant and positive heterosis showed by 8 hybrids. Standard heterosis over JA-20 ranges from -39.53% (CGWS.94xCGWS.91) to 179.07% (CGWS.93xCGWS.91), significant and positive heterosis for this trait showed by 9 hybrids. Standard heterosis over JA-134 ranges between -

18.75% (CGWS.94xCGWS.91) to 275% (CGWS.93xCGWS.91) significant and positive heterosis for this trait showed by 4 hybrids. Standard heterosis for RVA-100 comes between -48% (CGWS.94xCGWS.91) to 140% (CGWS.93xCGWS.91) 7 hybrids were showed the significant and positive heterosis.

**Fresh root weight/plant (g)**: Among the parental line, the trait ranges between CGWS.94 (6.933) to CGWS.91 (13.867). In cross combination the fresh root weight was observed between CGWS.93xCGWS.91 (9.780) to CGWS.94xCGWS.90 (16.720). Heterobeltiosis ranges between -29.47% (CGWS.93xCGWS.91) to 70.02% (CGWS.92xCGWS.89), significant and positive heterosis showed by 12 hybrids and Standard heterosis over JA-20 ranges from 37.1% (CGWS.93xCGWS.91) to 134.39% (CGWS.94xCGWS.90), for this trait 14 hybrids were significant and positive heterosis. Standard heterosis over JA-134 ranges between 3.86% (CGWS.93xCGWS.91) to 77.56% (CGWS.94xCGWS.90), significant and positive heterosis for this trait showed by all 20 hybrids. Standard heterosis for check RVA-100 comes between -11.63% (CGWS.93xCGWS.91) to 51.98% (CGWS.94xCGWS.90), significant and positive heterosis showed by 10 hybrids.

**Dry root weight/plant (g)**: Among the parental line, the dry root yield ranges between CGWS.94 (1.30) to CGWS.91 (3.80). In cross combination it ranges from CGWS.93xCGWS.91 (2.000) to CGWS.94xCGWS.90 (6.500). Heterobeltiosis for dry root yield ranges between from -47.37% (CGWS.93xCGWS.91) to 160.38% (CGWS.95xCGWS.92) significant and positive heterosis showed by 14 hybrids. Standard heterosis over JA-20 ranges from 1.69% (CGWS.93xCGWS.91) to 230.51% (CGWS.94xCGWS.90) significant positive heterosis for this trait showed by 10 hybrids. Standard heterosis over JA-134 ranges between 26.32% (CGWS.93xCGWS.91) to 310.53% (CGWS.94xCGWS.90) positive heterosis for this trait showed by 3 hybrids found significant. Standard heterosis for check RVA-100 comes between -21.57% (CGWS.93xCGWS.91) to 154.9% (CGWS.94xCGWS.90), significant and positive heterosis showed by16 hybrids.

**Fiber content in root (%):** Among the parental line, the fiber content ranges between CGWS.92 (10.892) to CGWS.93 (25.992). In cross combination the ranges between CGWS.92xCGWS.89 (12.380) to CGWS.90xCGWS.93 (18.720). Heterobeltiosis for this trait comes under -41.37% (CGWS.93xCGWS.89) to 26.23% (CGWS.89xCGWS.92) and significant negative heterosis 2 hybrids. Standard heterosis over JA-20 lies between -19.19% (CGWS.92xCGWS.89) to 22.18% (CGWS.90xCGWS.93), 9 hybrids found significant and negative heterosis. Standard heterosis over JA-134 ranges from -41.1% (CGWS.92xCGWS.89) to -10.95% (CGWS.90xCGWS.93), 7 hybrids found significant and negative heterosis. Standard heterosis for RVA-100 lies between -25.25% (CGWS.92xCGWS.89) to 13.03% (CGWS.90xCGWS.93) and 14 hybrids showed significant and negative heterosis.

**Carbohydrate content in root (%)**: Among the parental line, the ranges lies between CGWS.94 (12.813) to CGWS.92 (29.865). In cross combination, the trait ranges between CGWS.94xCGWS.91 (16.820) to CGWS.90xCGWS.92 (25.160). Heterobeltiosis for this trait comes under -37.69% (CGWS.92xCGWS.91) to 5.53% (CGWS.89xCGWS.90) significant and positive heterosis found in 2 hybrids and Standard heterosis over JA-20 lies between -24.36% (CGWS.94xCGWS.91) to 13.15% (CGWS.90xCGWS.92), 8 hybrids were showed significant and positive heterosis. Standard heterosis over JA-134 ranges from 3.16% (CGWS.94xCGWS.91) to 54.32% (CGWS.90xCGWS.92), 8 hybrids were showed in significant and positive heterosis. Standard heterosis for RVA-100 lies between -24.62% (CGWS.94xCGWS.91) to 12.76% (CGWS.90xCGWS.92), 8 hybrids were showed in significant and positive heterosis.

**Protein content in root (%):** Among the parental line, it ranges between CGWS.92 (3.501) to CGWS.90 (6.975) and in cross combination the trait ranges between CGWS.93xCGWS.92 (5.710) to CGWS.89xCGWS.90, CGWS.94xCGWS.91 (7.410). Heterobeltiosis for this trait comes between -11.1% (CGWS.93xCGWS.92) to 41.12% (CGWS.94xCGWS.91) significant and positive heterosis found in 12 hybrids. Standard heterosis over JA-20 lies between 3.24% (CGWS.93xCGWS.92) to 33.97% (CGWS.94xCGWS.91), 18 hybrids were showing the significant and positive heterosis. Standard heterosis over JA-134 ranges from -11.1% (CGWS.93xCGWS.92) to 15.37% (CGWS.94xCGWS.91), 18 hybrids were showing significant and positive heterosis. Standard heterosis for RVA-100 lies between 30.51% (CGWS.93xCGWS.92) to 69.37% (CGWS.94xCGWS.91), only one hybrid were found significant and positive heterosis.

**Harvest index (%)**: Among the parental line, the harvest index ranges between CGWS.95 (16.304) to CGWS.91 (29.29). In cross combination the trait ranges between CGWS.93xCGWS.92 (2.49) to CGWS.92xCGWS.93 (70.8). Heterobeltiosis for this trait comes between -200.23% (CGWS.92xCGWS.89) to 50.35% (CGWS.95xCGWS.91) 10 hybrids were showed significant and positive heterosis and Standard heterosis over JA-20 lies between -608.9% (CGWS.95xCGWS.92) to 213.16% (CGWS.89xCGWS.91) 13 hybrids were found significant and positive heterosis. Standard heterosis over JA-134 ranges from -687.47% (CGWS.92xCGWS.89) to 38.34% (CGWS.89xCGWS.91), all 17 hybrids were showed significant and positive heterosis. Standard heterosis for RVA-100 lies between -85.31% (CGWS.92xCGWS.89) to 85.96% (CGWS.89xCGWS.91), 12 hybrid were showing significant and positive heterosis.

**Dry matter content (%)**: Among the parental line, trait ranges between CGWS.92 (17.36) to CGWS.89 (41.29). In cross combination the trait ranges between CGWS.93xCGWS.91 (20.45) to CGWS.95xCGWS.92 (43.81). Heterobeltiosis for this trait comes under -1493.39% (CGWS.95xCGWS.92) to 61.67% (CGWS.90xCGWS.92), 9 hybrids found significant and positive heterosis. Standard heterosis over JA-20 lies between -1727.61% (CGWS.95xCGWS.92) to 195.06% (CGWS.89xCGWS.91), 9 hybrids found significant and positive heterosis. Standard heterosis over JA-134 ranges from -1906.94% (CGWS.92xCGWS.89) to 392.12% (CGWS.95xCGWS.92), 15 hybrids found significant positive heterosis. Standard heterosis for RVA-100 lies between -512.04% (CGWS.95xCGWS.92) to 139.89% (CGWS.89xCGWS.91) significant and positive heterosis found in 11 hybrids.

**Table 1:** Mean performance of quantitative traits of parental line and cross

| S. no. | Entries | Days to 50% flowering | Plant height (cm) | No. of main branches/ plant | No. of sec. branches/ plant | No. of plant /plot | Fresh Plant weight/ plant(g) | Dry Plant weight/ plant (g) | Main Root length (cm) | Root Diameter (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | CGWS.89 ($P_1$) | 102 | 45.00 | 1.17 | 4.50 | 9.50 | 28.10 | 4.78 | 25.317 | 1.834 |
| 2 | CGWS.90 ($P_2$) | 103 | 65.38 | 1.67 | 12.50 | 11.00 | 64.90 | 8.63 | 26.617 | 2.283 |
| 3 | CGWS.91 ($P_3$) | 100 | 57.10 | 1.50 | 6.50 | 7.50 | 47.35 | 7.27 | 16.567 | 2.75 |
| 4 | CGWS.92 ($P_4$) | 103 | 48.98 | 1.67 | 14.50 | 12.50 | 46.75 | 7.77 | 18.85 | 1.717 |
| 5 | CGWS.93 ($P_5$) | 103 | 43.02 | 1.50 | 6.00 | 7.00 | 29.90 | 5.53 | 18.867 | 1.883 |
| 6 | CGWS.94 ($P_6$) | 101 | 43.48 | 1.00 | 4.50 | 11.50 | 32.68 | 5.18 | 19.367 | 1.783 |
| 7 | CGWS.95 ($P_7$) | 103 | 48.05 | 2.34 | 7.00 | 15.50 | 56.02 | 7.78 | 18.184 | 2.05 |
| 8 | CGWS.89X CGWS.90 | 103 | 64.80 | 2.00 | 14.00 | 3.00 | 85.30 | 10.66 | 16.933 | 2.033 |
| 9 | CGWS.89X CGWS.91 | 102 | 72.57 | 3.00 | 15.00 | 3.00 | 80.10 | 12.87 | 16.967 | 1.4 |
| 10 | CGWS.89X CGWS.92 | 103 | 60.47 | 3.00 | 12.00 | 11.00 | 90.20 | 11.24 | 22.867 | 1.133 |
| 11 | CGWS.89X CGWS.93 | 102 | 116.83 | 2.00 | 13.00 | 17.00 | 101.80 | 15.34 | 19.633 | 1.467 |
| 12 | CGWS.90X CGWS.92 | 105 | 114.27 | 2.000 | 16.00 | 11.00 | 126.80 | 14.23 | 24.467 | 1.3 |
| 13 | CGWS.90X CGWS.93 | 103 | 70.37 | 2.000 | 11.00 | 12.00 | 132.00 | 13.67 | 13.633 | 0.933 |
| 14 | CGWS.91X CGWS.89 | 102 | 110.23 | 3.000 | 10.00 | 13.00 | 120.60 | 9.45 | 25.3 | 2.033 |
| 15 | CGWS.91X CGWS.90 | 102 | 94.100 | 2.000 | 5.00 | 13.00 | 172.30 | 10.34 | 21.733 | 1.5 |
| 16 | CGWS.91X CGWS.92 | 105 | 88.167 | 1.000 | 9.00 | 10.00 | 175.10 | 15.84 | 27.133 | 1.333 |
| 17 | CGWS.92X CGWS.89 | 103 | 65.567 | 1.000 | 10.00 | 12.00 | 30.40 | 7.88 | 24.433 | 1.2 |
| 18 | CGWS.92X CGWS.90 | 102 | 99.067 | 3.000 | 12.00 | 12.00 | 210.00 | 16.36 | 30.7 | 1.5 |
| 19 | CGWS.92X CGWS.91 | 103 | 98.000 | 1.000 | 13.00 | 9.00 | 145.00 | 12.72 | 27.9 | 1.733 |
| 20 | CGWS.92X CGWS.93 | 102 | 66.667 | 1.000 | 8.00 | 10.00 | 15.00 | 6.45 | 16.867 | 1.1 |
| 21 | CGWS.93X CGWS.89 | 101 | 53.733 | 1.000 | 11.00 | 15.00 | 70.50 | 11.98 | 22.167 | 1.4 |
| 22 | CGWS.93X CGWS.91 | 102 | 102.57 | 4.000 | 15.00 | 12.00 | 365.00 | 22.48 | 23.333 | 1.5 |
| 23 | CGWS.93X CGWS.92 | 102 | 123.03 | 4.000 | 16.00 | 14.00 | 405.00 | 34.62 | 28.2 | 1.9 |
| 24 | CGWS.94X CGWS.90 | 105 | 96.500 | 1.000 | 16.000 | 11.000 | 365.000 | 21.73 | 20.733 | 2.1 |
| 25 | CGWS.94X CGWS.91 | 102 | 61.100 | 4.000 | 8.000 | 1.000 | 90.000 | 12.24 | 9.2 | 0.5 |
| 26 | CGWS.95X CGWS.91 | 103 | 39.567 | 1.000 | 8.000 | 3.000 | 25.000 | 9.22 | 10.533 | 0.667 |
| 27 | CGWS.95X CGWS.92 | 103 | 75.600 | 1.000 | 10.000 | 4.000 | 50.000 | 13.61 | 26.333 | 1.167 |

**Continued……..**

| S. no. | Entries | 10. Root Branches/ plant | 11. Fresh root weight/ plant (g) | 12. Dry Root weight/ plant (g) | 13. Fiber content in root (%) | 14. Carbohydrate content in root (%) | 15. Protein content in root (%) | 16. Harvest index (%) | 17. Dry matter content (%) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | CGWS.89 ($P_1$) | 7.499 | 7.95 | 3.283 | 12.025 | 22.941 | 6.125 | 28.292 | 41.296 |
| 2 | CGWS.90 ($P_2$) | 8.335 | 13.05 | 2.834 | 15.324 | 21.74 | 6.975 | 20.108 | 21.717 |
| 3 | CGWS.91 ($P_3$) | 7.5 | 13.867 | 3.8 | 15.542 | 25.116 | 5.251 | 29.287 | 27.403 |
| 4 | CGWS.92 ($P_4$) | 5.667 | 9.216 | 1.6 | 10.892 | 29.865 | 3.501 | 19.713 | 17.361 |
| 5 | CGWS.93 ($P_5$) | 6.167 | 8.283 | 1.8 | 25.992 | 21.74 | 6.423 | 27.702 | 21.731 |
| 6 | CGWS.94 ($P_6$) | 6 | 6.933 | 1.3 | 18.662 | 12.813 | 4.081 | 21.213 | 18.750 |
| 7 | CGWS.95 ($P_7$) | 4.667 | 9.133 | 1.767 | 19.226 | 16.418 | 5.721 | 16.304 | 19.347 |
| 8 | CGWS.89X CGWS.90 | 4.667 | 10.2 | 3.5 | 16.42 | 24.21 | 7.41 | 11.958 | 34.313 |
| 9 | CGWS.89X CGWS.91 | 5.333 | 14.4 | 3.8 | 16.47 | 22.67 | 6.72 | 17.978 | 26.388 |
| 10 | CGWS.89X CGWS.92 | 7.667 | 10.5 | 4 | 15.18 | 22.45 | 6.892 | 11.641 | 38.095 |
| 11 | CGWS.89X CGWS.93 | 13 | 12.4 | 3.5 | 15.78 | 20.21 | 7.25 | 12.181 | 28.225 |
| 12 | CGWS.90X CGWS.92 | 11 | 15.45 | 4.5 | 12.54 | 25.16 | 6.425 | 12.185 | 29.126 |
| 13 | CGWS.90X CGWS.93 | 7.333 | 12.55 | 4.2 | 18.72 | 22.72 | 6.92 | 9.508 | 33.466 |
| 14 | CGWS.91X CGWS.89 | 7.667 | 14.32 | 4.5 | 15.71 | 22.81 | 7.001 | 11.874 | 31.428 |
| 15 | CGWS.91X CGWS.90 | 8.333 | 10.4 | 4.3 | 12.62 | 21.74 | 6.92 | 6.036 | 41.346 |
| 16 | CGWS.91X CGWS.92 | 11.333 | 16.32 | 5.2 | 15.72 | 19.68 | 6.98 | 9.320 | 31.862 |
| 17 | CGWS.92X CGWS.89 | 9.667 | 15.67 | 4.5 | 12.38 | 21.42 | 7.21 | 51.546 | 28.717 |
| 18 | CGWS.92X CGWS.90 | 9.333 | 12.42 | 3.5 | 15.79 | 19.69 | 7.001 | 5.914 | 28.180 |
| 19 | CGWS.92X CGWS.91 | 18 | 10.7 | 3.5 | 16.41 | 18.61 | 7.11 | 7.379 | 32.710 |
| 20 | CGWS.92X CGWS.93 | 16.667 | 10.62 | 3.2 | 16.21 | 21.75 | 7.02 | 70.8 | 30.131 |
| 21 | CGWS.93X CGWS.89 | 10.333 | 10.2 | 3 | 15.24 | 22.27 | 6.872 | 14.468 | 29.411 |
| 22 | CGWS.93X CGWS.91 | 20 | 9.78 | 2 | 16.45 | 21.64 | 5.942 | 2.679 | 20.449 |
| 23 | CGWS.93X CGWS.92 | 13.333 | 10.1 | 2.5 | 16.81 | 22.73 | 5.71 | 2.493 | 24.752 |
| 24 | CGWS.94X CGWS.90 | 15 | 16.72 | 6.5 | 12.72 | 18.68 | 7.021 | 4.5808 | 38.875 |
| 25 | CGWS.94X CGWS.91 | 4.333 | 12.5 | 3.5 | 14.61 | 16.82 | 7.41 | 13.888 | 28 |
| 26 | CGWS.95X CGWS.91 | 5 | 10 | 4.2 | 12.98 | 19.63 | 6.92 | 40 | 42 |
| 27 | CGWS.95X CGWS.92 | 9.333 | 10.5 | 4.6 | 12.68 | 20.38 | 7.021 | 21 | 43.809 |

**Table 2:** Estimation of heterosis over better parent (BP) and standard heterosis $SH_1$, $SH_2$ and $SH_3$ (JA-20, JA-134 and RVA-100) of selected crosses of ashwagandha

| S. no. | Crosses | 1. Days to 50% flowering | | | | 2. Plant height (cm) | | | | 3. No. of main branches/plant | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | 0.98** | 3** | 4.04** | 1.98** | -0.89** | 25.78** | 24.02** | 2.1** | 0** | 20** | 9.09** | 20.01** |
| 2 | CGWS.89X CGWS.91 | 2** | 2** | 3.03** | 0.99** | 27.08** | 40.86 | 38.88 | 14.34** | 50 | 80 | 63.64 | 100 |
| 3 | CGWS.89X CGWS.92 | 0.98** | 3** | 4.04** | 1.98** | 23.44** | 17.37** | 15.73** | -4.73** | 50 | 80 | 63.64 | 80 |
| 4 | CGWS.89X CGWS.93 | 0** | 2** | 3.03** | 0.99** | 159.63 | 126.79 | 123.6 | 84.09 | 0** | 20** | 9.09** | 33.33 |
| 5 | CGWS.90X CGWS.92 | 1.94** | 5** | 6.06 | 3.96** | 74.76 | 121.8 | 118.69 | 80.04 | 0** | 20** | 9.09** | 20** |
| 6 | CGWS.90X CGWS.93 | 0** | 3** | 4.04** | 1.98** | 7.62** | 36.59 | 34.67 | 10.87** | 0** | 20** | 9.09** | 20** |
| 7 | CGWS.91X CGWS.89 | 2** | 2** | 3.03** | 0.99** | 93.05 | 113.98 | 110.97 | 73.69 | 50 | 80 | 63.64 | 100 |
| 8 | CGWS.91X CGWS.90 | 2** | 2** | 3.03** | 0.99** | 43.92 | 82.66 | 80.09 | 48.27 | 0** | 20** | 9.09** | 20** |
| 9 | CGWS.91X CGWS.92 | 5** | 5** | 6.06 | 3.96** | 54.4 | 71.14 | 68.74 | 38.92 | -50 | -40 | -45.45 | -40 |
| 10 | CGWS.92X CGWS.89 | 0.98** | 3** | 4.04** | 1.98** | 33.86 | 27.27** | 25.49** | 3.3** | -50 | -40 | -45.45 | -40 |
| 11 | CGWS.92X CGWS.90 | -0.97** | 2** | 3.03** | 0.99** | 51.52 | 92.3 | 89.6 | 56.09 | 50 | 80 | 63.64 | 80 |
| 12 | CGWS.92X CGWS.91 | 3** | 3** | 4.04** | 1.98** | 71.63 | 90.23 | 87.56 | 54.41 | -50 | -40 | -45.45 | -40 |
| 13 | CGWS.92X CGWS.93 | -0.97** | 2** | 3.03** | 0.99** | 36.1 | 29.4** | 27.59** | 5.04** | -50 | -40 | -45.45 | -40 |
| 14 | CGWS.93X CGWS.89 | -0.98** | 1** | 2.02** | 0** | 19.4** | 4.3** | 2.84** | -15.34** | -50 | -40 | -45.45 | -33.33 |
| 15 | CGWS.93X CGWS.91 | 2** | 2** | 3.03** | 0.99** | 79.63 | 99.09 | 96.29 | 61.6 | 100 | 140 | 118.18 | 166.67 |
| 16 | CGWS.93X CGWS.92 | -0.97** | 2** | 3.03** | 0.99** | 151.17 | 138.82 | 135.47 | 93.86 | 100 | 140 | 118.18 | 140 |
| 17 | CGWS.94X CGWS.90 | 3.96** | 5** | 6.06 | 3.96** | 47.59 | 87.32 | 84.69 | 52.05 | -50 | -40 | -45.45 | -40 |
| 18 | CGWS.94X CGWS.91 | 2** | 2** | 3.03** | 0.99** | 7** | 18.6** | 16.94** | -3.73** | 100 | 140 | 118.18 | 166.67 |
| 19 | CGWS.95X CGWS.91 | 3** | 3** | 4.04** | 1.98** | -30.7 | -23.19** | -24.27** | -37.66 | -50 | -40 | -45.45 | -57.14 |
| 20 | CGWS.95X CGWS.92 | 0** | 3** | 4.04** | 1.98** | 54.34 | 46.75 | 44.69 | 19.12** | -50 | -40 | -45.45 | -57.14 |

| S. No. | Crosses | 4. No. of sec. branches/plant | | | | 5. No. of plant/plot | | | | 6. Fresh Plant weight/plant (g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | 12** | 115.38 | 154.55 | 100 | -72.73 | -68.42 | -80.65 | -75 | 31.43** | 57.38** | 153.49 | 43.8** |
| 2 | CGWS.89X CGWS.91 | 130.77 | 130.77 | 172.73 | 114.29 | -68.42 | -68.42 | -80.65 | -75 | 69.17 | 47.79** | 138.04 | 35.04** |
| 3 | CGWS.89X CGWS.92 | -17.24** | 84.62** | 118.18 | 71.43** | -12** | 15.78** | -29.03** | -8.33** | 92.94 | 66.42** | 168.05 | 52.07** |
| 4 | CGWS.89X CGWS.93 | 116.67 | 100 | 136.36 | 85.71** | 78.95 | 78.94 | 9.68** | 41.67** | 240.47 | 87.82 | 202.53 | 71.62** |
| 5 | CGWS.90X CGWS.92 | 10.34** | 146.15 | 190.9 | 128.57 | -12** | 15.79** | -29.03** | -8.33** | 95.38 | 133.95 | 276.82 | 113.77 |
| 6 | CGWS.90X CGWS.93 | -12** | 69.23** | 100 | 57.14** | 9.09** | 26.32** | -22.58** | 0** | 103.39 | 143.54 | 292.27 | 122.53 |
| 7 | CGWS.91X CGWS.89 | 53.85** | 53.85** | 81.82** | 42.86** | 36.84** | 36.84** | -16.13** | 8.33** | 154.69 | 122.51 | 258.39 | 103.32 |
| 8 | CGWS.91X CGWS.90 | -60** | -23.08** | -9.09** | -28.57** | 18.18** | 36.84** | -16.13** | 8.33** | 165.49 | 217.89 | 412.04 | 190.47 |
| 9 | CGWS.91X CGWS.92 | -37.93** | 38.46** | 63.64** | 28.57** | -20** | 5.26** | -35.48** | -16.67** | 269.79 | 223.06 | 420.36 | 195.19 |
| 10 | CGWS.92X CGWS.89 | -31.03** | 53.85** | 81.82** | 42.86** | -4** | 26.32** | -22.58** | 0** | -34.97** | -43.91** | -9.66** | -48.75** |
| 11 | CGWS.92X CGWS.90 | -17.24** | 84.62** | 118.18 | 71.43** | -4** | 26.32** | -22.58** | 0** | 223.57 | 287.45 | 524.07 | 254.03 |
| 12 | CGWS.92X CGWS.91 | -10.34** | 100 | 136.36 | 85.71** | -28** | -5.26** | -41.94 | -25** | 206.23 | 167.53 | 330.9 | 144.45 |
| 13 | CGWS.92X CGWS.93 | -44.83** | 23.08** | 45.45** | 14.29** | -20** | 5.26** | -35.48** | -16.67** | -67.91** | -72.32** | -55.42** | -74.71** |
| 14 | CGWS.93X CGWS.89 | 83.33** | 69.23** | 100 | 57.14** | 57.89 | 57.89 | -3.23** | 25** | 135.79 | 30.07** | 109.5 | 18.85** |
| 15 | CGWS.93X CGWS.91 | 130.77 | 130.77 | 172.73 | 114.29 | 60 | 26.32** | -22.58** | 0** | 670.86 | 573.43 | 984.69 | 515.34 |
| 16 | CGWS.93X CGWS.92 | 10.34** | 146.15 | 190.9 | 128.57 | 12** | 47.37** | -9.68** | 16.67** | 766.31 | 647.23 | 1103.57 | 582.78 |
| 17 | CGWS.94X CGWS.90 | 28** | 146.15 | 190.9 | 128.57 | -4.35** | 15.78** | -29.03** | -8.33** | 462.4 | 573.43 | 984.69 | 515.34 |
| 18 | CGWS.94X CGWS.91 | 23.08** | 23.08** | 45.45** | 14.29** | -91.3 | -89.47 | -93.55 | -91.67 | 90.07 | 66.05** | 167.46 | 51.73 |
| 19 | CGWS.95X CGWS.91 | 14.29** | 23.08** | 45.45** | 14.29** | -80.65 | -68.42 | -80.65 | -75 | -55.37** | -53.87** | -25.7** | -57.85** |
| 20 | CGWS.95X CGWS.92 | -31.03** | 53.85** | 81.82** | 42.86** | -74.19 | -57.89 | -74.19 | -66.67 | -10.74** | -7.75** | 48.59** | -15.7** |

** represent significant levels at 1%.

**Continued…**

| S. no. | Crosses | 7. Dry Plant weight/plant (g) | | | | 8. Main Root length (cm) | | | | 9. Root Diameter (cm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | 23.47** | 29.99** | 154.82 | 10.47** | -36.38** | -30.79** | -25.79** | -20.43** | -10.95** | -7.58** | -5.43** | -12.86** |
| 2 | CGWS.89X CGWS.91 | 77.11** | 56.95** | 207.65 | 33.37** | -32.98** | -30.65** | -25.64** | -20.28** | -49.09 | -36.36** | -34.89** | -40** |
| 3 | CGWS.89X CGWS.92 | 44.72** | 37.07** | 168.69 | 16.48** | -9.68** | -6.54** | 0.22** | 7.44** | -38.18** | -48.49** | -47.29** | -51.43 |
| 4 | CGWS.89X CGWS.93 | 177.23 | 87.07** | 266.69 | 58.96** | -22.45** | -19.75** | -13.95 | -7.75** | -22.12** | -33.33** | -31.78** | -37.14** |
| 5 | CGWS.90X CGWS.92 | 64.83** | 73.54** | 240.16 | 47.46** | -8.08** | 2.04** | 7.23** | 14.96** | -43.07** | -40.9** | -39.53** | -44.29** |
| 6 | CGWS.90X CGWS.93 | 58.34** | 66.7** | 226.77 | 41.66** | -48.78 | -44.28 | -40.25 | -35.94** | -59.12 | -57.58 | -56.59 | -60 |
| 7 | CGWS.91X CGWS.89 | 30.05** | 15.24** | 125.89 | -2.07** | -0.06** | 3.4** | 10.88** | 18.87** | -26.06** | -7.58** | -5.43** | -12.86** |
| 8 | CGWS.91X CGWS.90 | 19.77** | 26.09** | 147.17 | 7.15** | -18.34** | -11.17** | -4.75** | 2.11** | -45.45** | -31.82** | -30.23** | -35.71** |
| 9 | CGWS.91X CGWS.92 | 103.95 | 93.17 | 278.65 | 64.15** | 43.94 | 10.89** | 18.92** | 27.49** | -51.52 | -39.39** | -37.98** | -42.86** |
| 10 | CGWS.92X CGWS.89 | 1.46** | -3.9** | 88.37** | -18.34** | -3.49** | -0.14** | 7.09** | 14.8** | -30.09** | -45.45** | -44.19** | -48.57** |
| 11 | CGWS.92X CGWS.90 | 89.49** | 99.51 | 291.07 | 69.53** | 15.34** | 25.48** | 34.55** | 44.24 | -34.3** | -31.82** | -30.23** | -35.71** |
| 12 | CGWS.92X CGWS.91 | 63.78** | 55.12** | 204.06 | 31.81** | 48.01 | 14.03** | 22.28** | 31.09** | -36.97** | -21.21** | -19.38** | -25.71** |
| 13 | CGWS.92X CGWS.93 | -16.95** | -21.34** | 54.18** | -33.16** | -10.6** | -31.06** | -26.08** | -20.75** | -41.59** | -50 | -48.84** | -52.86 |
| 14 | CGWS.93X CGWS.89 | 116.5 | 46.09** | 186.37 | 24.14** | -12.44** | -9.4** | -2.85** | 4.15** | -23.64** | -36.36** | -34.88** | -40** |
| 15 | CGWS.93X CGWS.91 | 209.36 | 174.14 | 437.37 | 132.95 | 23.67** | -4.63** | 2.26** | 9.63** | -45.45** | -31.82** | -30.23** | -35.71** |
| 16 | CGWS.93X CGWS.92 | 345.75 | 322.19 | 727.57 | 258.76 | 49.47 | 15.26** | 23.59** | 32.49** | 0.88** | -13.64** | -11.63** | -18.57** |
| 17 | CGWS.94X CGWS.90 | 151.69 | 165 | 419.44 | 125.18 | -22.1** | -15.26** | -9.13** | -2.58** | -8.03** | -4.55** | -2.33** | -9.99** |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 18 | CGWS.94X CGWS.91 | 68.44** | 49.27** | 192.59 | 26.84** | -52.49 | -62.39 | -59.68 | -56.78 | -81.83 | -77.27 | -76.74 | -78.57 |
| 19 | CGWS.95X CGWS.91 | 18.46** | 12.44** | 120.39 | -4.46** | -42.07 | -56.95 | -53.83 | -50.5 | -75.76 | -69.69 | -68.99 | -71.43 |
| 20 | CGWS.95X CGWS.92 | 74.86** | 65.98** | 225.34 | 41.04** | 39.69** | 7.63** | 15.41** | 23.73** | -43.09** | -46.97** | -45.74** | -50 |

| S. No. | Crosses | 10. Root Branches/plant | | | | 11. Fresh root weight/plant (g) | | | | 12. Dry Root weight/plant (g) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | -44** | -34.89** | -12.5** | -44** | -21.84** | 42.99** | 8.33** | -7.83** | 6.59** | 77.97** | 121.05 | 37.25** |
| 2 | CGWS.89X CGWS.91 | -28.89** | -25.58** | -9.4** | -36** | 3.85** | 101.87 | 52.92** | 30.12** | 0** | 93.22** | 140 | 49.02** |
| 3 | CGWS.89X CGWS.92 | 2.22** | 6.98 | 43.75** | -8** | 13.92** | 47.19** | 11.5** | -5.12** | 21.83** | 103.39 | 152.63 | 56.86** |
| 4 | CGWS.89X CGWS.93 | 73.33 | 81.39 | 143.75 | 56** | 49.69** | 73.83** | 31.68** | 12.05** | 6.59** | 77.97** | 121.05 | 37.25** |
| 5 | CGWS.90X CGWS.92 | 31.99** | 53.49** | 106.25 | 32** | 18.39** | 116.59 | 64.07** | 39.61** | 58.82** | 128.81 | 184.21 | 76.47** |
| 6 | CGWS.90X CGWS.93 | -12** | 2.33** | 37.49** | -12** | -3.83** | 75.93** | 33.27** | 13.4** | 48.24** | 113.56 | 165.26 | 64.7** |
| 7 | CGWS.91X CGWS.89 | 2.22** | 6.98** | 43.75** | -8** | 3.273** | 100.75 | 52.07** | 29.39** | 18.42** | 128.81 | 184.21 | 76.47** |
| 8 | CGWS.91X CGWS.90 | -2.4** | 16.28** | 56.25** | -6** | -25** | 45.79** | 10.44** | -6.02** | 13.16** | 118.64 | 171.58 | 68.63** |
| 9 | CGWS.91X CGWS.92 | 51.11** | 58.14** | 112.49 | 35.99** | 17.69** | 128.79 | 73.31** | 47.47** | 36.84** | 164.41 | 228.42 | 103.92 |
| 10 | CGWS.92X CGWS.89 | 28.89** | 34.89** | 81.25 | 16** | 70.02** | 119.67 | 66.41** | 41.59** | 37.06** | 128.81 | 184.21 | 76.47** |
| 11 | CGWS.92X CGWS.90 | 11.99** | 30.23** | 74.99 | 11.99 | -4.83** | 74.11** | 31.89** | 12.23** | 23.53** | 77.97** | 121.05 | 37.25** |
| 12 | CGWS.92X CGWS.91 | 140 | 151.16 | 237.5 | 116 | -22.84** | 50** | 13.63** | -3.31** | -7.89** | 77.97** | 121.05 | 37.25** |
| 13 | CGWS.92X CGWS.93 | 170.27 | 132.56 | 212.5 | 100 | 15.23** | 48.88** | 12.78** | -4.04** | 77.78** | 62.71** | 102.1 | 25.49** |
| 14 | CGWS.93X CGWS.89 | 37.78** | 44.19** | 93.75 | 23.99** | 23.14** | 42.99** | 8.32** | -7.83** | -8.63** | 52.54** | 89.47** | 17.65** |
| 15 | CGWS.93X CGWS.91 | 166.67 | 179.07 | 275 | 140 | -29.47** | 37.1** | 3.86** | -11.6** | -47.37** | 1.69** | 26.32** | -21.57** |
| 16 | CGWS.93X CGWS.92 | 116.22 | 86.05 | 149.99 | 59.99** | 9.58** | 41.589** | 7.26** | -8.73** | 38.89** | 27.12** | 57.89** | -1.96** |
| 17 | CGWS.94X CGWS.90 | 79.99 | 109.3 | 181.25 | 80 | 28.12** | 134.39 | 77.56** | 51.08** | 129.41 | 230.51 | 310.53 | 154.9 |
| 18 | CGWS.94X CGWS.91 | -42.22** | -39.53** | -18.7** | -48** | -9.86** | 75.23** | 32.74** | 12.95** | -7.89** | 77.97** | 121.05 | 37.25** |
| 19 | CGWS.95X CGWS.91 | -33.33** | -30.23** | -6.25** | -40** | -27.88** | 40.19** | 6.19** | -9.64** | 10.53** | 113.56 | 165.26 | 64.71** |
| 20 | CGWS.95X CGWS.92 | 64.71** | 30.23** | 74.99 | 11.99** | 13.92** | 47.19** | 11.5** | -5.12** | 160.38 | 133.89 | 190.53 | 80.39** |

** represent significant levels at 1%.

**Continued…**

| S. No. | Crosses | 13. Fibre content in root (%) | | | | 14. Carbohydrate content in root (%) | | | | 15. Protein content in root (%) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | 7.15** | 7.17** | -21.89** | -0.86** | 5.53** | 8.87** | 48.49 | 8.5** | 6.24** | 33.97 | 15.37** | 69.37 |
| 2 | CGWS.89X CGWS.91 | 5.97** | 7.49** | -21.65** | -0.56** | -9.74** | 1.95** | 39.04 | 1.6** | 9.71** | 21.49** | 4.62** | 53.6 |
| 3 | CGWS.89X CGWS.92 | 26.23 | -0.92** | -27.79 | -8.35** | -24.83** | 0.96** | 37.69 | 0.62** | 12.52** | 24.61** | 7.3** | 57.53 |
| 4 | CGWS.89X CGWS.93 | -39.29 | 2.99** | -24.93 | -4.72** | -11.91** | -9.11** | 23.96 | -9.42** | 12.88** | 31.08** | 12.88** | 65.71 |
| 5 | CGWS.90X CGWS.92 | -18.17** | -18.15** | -40.35 | -24.29 | -15.76** | 13.15** | 54.32 | 12.76** | -7.89** | 16.16** | 0.03** | 46.86 |
| 6 | CGWS.90X CGWS.93 | -27.98 | 22.18** | -10.95** | 13.03** | 4.51** | 2.17** | 39.35 | 1.83** | -0.79** | 25.11** | 7.74** | 58.17 |
| 7 | CGWS.91X CGWS.89 | 1.08** | 2.54** | -25.27 | -5.15** | -9.18** | 2.58** | 39.9 | 2.23** | 14.3** | 26.58** | 8.99** | 60.02 |
| 8 | CGWS.91X CGWS.90 | -18.8** | -17.63** | -39.97 | -23.8 | -13.44** | -2.23** | 33.34 | -2.57** | -0.79** | 25.11** | 7.74** | 58.17 |
| 9 | CGWS.91X CGWS.92 | 1.15** | 2.6** | -25.2 | -5.08** | -34.1 | -11.49** | 20.7** | -11.79** | 32.93 | 26.19** | 8.67** | 59.54 |
| 10 | CGWS.92X CGWS.89 | 2.95** | -19.19** | -41.1 | -25.25 | -28.28** | -3.67** | 31.38 | -3.99** | 17.71** | 30.36** | 12.25** | 64.8 |
| 11 | CGWS.92X CGWS.90 | 3.04** | 3.06** | -24.89 | -4.66** | -34.07 | -11.45** | 20.77** | -11.75** | 0.37** | 26.58** | 8.99** | 60.02 |
| 12 | CGWS.92X CGWS.91 | 5.58** | 7.1** | -21.94** | -0.92** | -37.69 | -16.31** | 14.14** | -16.59** | 35.4 | 28.55** | 10.69** | 62.51 |
| 13 | CGWS.92X CGWS.93 | -37.63 | 5.79** | -22.89** | -2.13** | -27.17** | -2.19** | 33.4 | -2.52** | 9.29** | 26.92** | 9.29** | 60.46 |
| 14 | CGWS.93X CGWS.89 | -41.37 | -0.53** | -27.5 | -7.98** | -2.92** | 0.15** | 36.59 | -0.19** | 6.99** | 24.25** | 6.99** | 57.07 |
| 15 | CGWS.93X CGWS.91 | -36.71 | 7.37** | -21.75** | -0.68** | -13.84** | -2.68** | 32.72** | -3.01** | -7.49** | 7.43** | -7.49** | 35.82 |
| 16 | CGWS.93X CGWS.92 | -35.33 | 9.72** | -20.03** | 1.49** | -23.89** | 2.22** | 39.41 | 1.87** | -11.1** | 3.24** | -11.1** | 30.51** |
| 17 | CGWS.94X CGWS.90 | -31.84 | -16.98** | -39.49 | -23.19** | -14.08** | -15.99** | 14.57** | -16.28** | 0.66** | 26.94** | 9.31** | 60.48 |
| 18 | CGWS.94X CGWS.91 | -21.72** | -4.64** | -30.49 | -11.77** | -33.03 | -24.36** | 3.16** | -24.62** | 41.12 | 33.97 | 15.37** | 69.37 |
| 19 | CGWS.95X CGWS.91 | -32.49 | -15.28** | -38.25 | -21.63** | -21.84** | -11.72** | 20.39** | -12.02** | 20.96** | 25.11** | 7.74** | 58.17 |
| 20 | CGWS.95X CGWS.92 | -34.04 | -17.24** | -39.68 | -23.44 | -31.76 | -8.35** | 24.99** | -8.67** | 22.72** | 26.94** | 9.31** | 60.48 |

| S. No. | Crosses | 16. Harvest index (%) | | | | 17. Dry matter content (%) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | BP | SH 1 | SH 2 | SH 3 | BP | SH 1 | SH 2 | SH 3 |
| 1 | CGWS.89X CGWS.90 | -69.49** | 74.92** | 5.43** | -17.88** | 20.97 | 135.88 | 78.87** | 85.05** |
| 2 | CGWS.89X CGWS.91 | 5.566** | 213.16 | 38.34** | 85.96** | 0 | 195.06 | 101.42 | 139.89 |
| 3 | CGWS.89X CGWS.92 | 14.98** | 71.05** | 6.84** | -9.83** | 23.49 | 155.66 | 90.82** | 109.19 |
| 4 | CGWS.89X CGWS.93 | 20.67** | 84.07** | 15.64** | 16.82** | 2.74** | 88.78** | 59.77** | 52.01** |
| 5 | CGWS.90X CGWS.92 | 19.29** | 87.04** | 23.15** | 34.82** | 61.67** | 96.16 | 66.55** | 67.21** |
| 6 | CGWS.90X CGWS.93 | -3.7** | 52.89** | 11.38** | 10.94** | 46.66** | 79.11** | 56.54** | 52.8** |
| 7 | CGWS.91X CGWS.89 | 2.12** | 82.24** | 20.15** | 28.45** | 11.91** | 105.14 | 71.29** | 74.01** |
| 8 | CGWS.91X CGWS.90 | -15.11** | 21.02** | 2.53** | -3.16** | 7.95** | 54.45** | 41.64** | 36.03** |
| 9 | CGWS.91X CGWS.92 | 6.56** | 57.74** | 17.4** | 24.32** | 13.66** | 73.71** | 54.33** | 53.24** |
| 10 | CGWS.92X CGWS.89 | -200.23 | -272.54 | -687.47 | -85.31** | -105.98 | -293.35 | -1906.9 | -156.86 |
| 11 | CGWS.92X CGWS.90 | -2.16** | 25.79** | 6.09** | 4.81** | 10.52** | 27.12** | 23.09** | 14.66** |
| 12 | CGWS.92X CGWS.91 | -11.07** | 29.85** | 4.12** | -2.29** | -3.83** | 46.54** | 36.58** | 25.79** |
| 13 | CGWS.92X CGWS.93 | -22.43** | -67.59** | -23.06** | 5.41** | -114.53 | -86.7** | -184.23 | -34.1** |
| 14 | CGWS.93X CGWS.89 | 17.04** | 142.97 | 7.59** | -41.54** | -6.36** | 174.73 | 81.7** | 93.63 |
| 15 | CGWS.93X CGWS.91 | -4.39** | 6.47** | 0.39** | -2.26** | -7.06** | 0.29** | 2.67** | -4.19** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 16 | CGWS.93X CGWS.92 | 1.25** | 6.431** | 0.66** | -1.49** | 5.07** | 4.19** | 5.25** | -0.34** |
| 17 | CGWS.94X CGWS.90 | 6.08** | 23.44** | 7.88** | 9.91** | 27.99** | 40.19** | 31.54** | 30.06** |
| 18 | CGWS.94X CGWS.91 | -10.95** | 113.89 | 19.55** | 25.03** | -8.76** | 118.05 | 72.29** | 72.01** |
| 19 | CGWS.95X CGWS.91 | 50.35** | -74.6** | -24.08** | 16.66** | -19.0** | -210.8 | -643.04 | -111.86 |
| 20 | CGWS.95X CGWS.92 | -129.61 | 608.9 | 23.67** | 32.61** | -1493.3 | -1727.6 | 392.12 | -512.04 |

** represent significant levels at 1%.
BP = Better parent, SH1 = Standard check 1 (JA-20), SH2 = Standard check 2 (JA-134), SH3 = Standard check 3 (RVA-100)

## Conclusion

Heterosis was significant and positive for most of the characters, which revealed that its utilization in the ashwagandha breeding programme could be useful. The cross CGWS.92xCGWS.90, CGWS.92xCGWS.93, CGWS.93xCGWS.89 and CGWS.93xCGWS.92 were recorded negative heterosis better parent for days to 50% flowering, which indicates the scope for its utilization in evolving early flowering plant types. The low fibre content in the root (%) of ashwagandha is preferred, significant and negative heterosis reported in the cross *viz.*, CGWS.90xCGWS.92, CGWS.91xCGWS.90, CGWS.94xCGWS.91 over better parent and standard checks (JA-20) for fibre content in root (%). Significant and positive heterosis was found in the cross *viz.*, CGWS.89xCGWS.90, CGWS.89xCGWS.92, CGWS.93xCGWS.89, CGWS.94xCGWS.91 over better parent, and standard checks JA-20 and JA-134 for plant height. For no. of main branches/plant the significant positive heterosis was recorded in cross CGWS.89xCGWS.90, CGWS.90xCGWS.92, CGWS.90xCGWS.93, CGWS.91xCGWS.90 over better parent, standard checks JA-20, JA-134 and RVA-100. Similarly, for no. of secondary branches/plant was recorded in cross CGWS.91xCGWS.89, CGWS.94xCGWS.91, CGWS.95xCGWS.91 over better parent, standard checks JA-20, JA-134 and RVA-100. The cross CGWS.90xCGWS.93, CGWS.91xCGWS.90, CGWS.93xCGWS.92 was found significant and positive heterosis for no. of plant/plot over better parent, standard checks JA-20 and RVA-100. For root length significant and positive heterosis over better parent, standard checks JA-134 was recorded in cross CGWS.92xCGWS.90, CGWS.93xCGWS.91. Significant and positive heterosis recorded in cross CGWS.89xCGWS.91, CGWS.89xCGWS.92, CGWS.89xCGWS.93, CGWS.90xCGWS.92, CGWS.91xCGWS.89, CGWS.91xCGWS.92, CGWS.92xCGWS.89, CGWS.92xCGWS.93, CGWS.93xCGWS.89, CGWS.93xCGWS.92, CGWS.94xCGWS.90, CGWS.95xCGWS.92 over better parent, standard checks RVA-100 for fresh root weight/plant. For dry root weight/plant the significant and positive heterosis were recorded in cross CGWS.89xCGWS.90, CGWS.89xCGWS.91, CGWS.92xCGWS.90, CGWS.92xCGWS.93 over better parent, standard checks JA-20 and RVA-100. The best cross out of 20 crosses, two heterotic $F_1$ with high fresh root weight per plant, high carbohydrate content (%), high protein content (%) and low fiber content in root (%), were found in cross CGWS.90 x CGWS.92 and CGWS.94 X CGWS.91 over standard check. These high root weight, carbohydrate content, protein content and low fiber content in $F_1$ hybrid may be recommended for commercial exploitation.

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