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GENOTYPIC AND PHENOTYPIC PATH COEFFICIENT ANALYSIS FOR FRUIT YIELD AND ITS ASSOCIATED TRAITS IN CHILLI (*CAPSICUM ANNUUM* L.)

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ABSTRACT
This current was carried out to estimate the direct and indirect effect of characters associated with fruit yield in genotypes of chilli. This experiment was carried out at the Research Cum Instructional Farm, K.D. College of Horticulture and Research Station, Jagdalpur, Bastar, Chhattisgarh, under Mahatma Gandhi University of Horticulture and Forestry, Durg. Twenty genotypes of chillies, ranging from CGBC-1 to CGBC-20, along with the control variety Pusa Jwala were used in an experiment which was set up in a randomized block design of 21 treatments with three replications and 63 experimental plots. Parameters recorded for each genotype included germination, vegetative growth, flowering, fruit setting, fruit parameters, frequency of harvesting and fresh and dry fruit weight.The genotype study indicated that fruits per plant, primary branches, plant height, fruit measurements, fresh fruit weight, and dry fruit weight played significant roles in the productivity pathway. Genotype analysis showed that the factors fruits per plant, primary branches, plant height and fresh fruit weight were positively correlated with coefficients 0.696, 0.953, 0.442, and 0.355 respectively. In terms of phenotype study, it was found that plant architecture, flower production, fruit number, fruit size, and fruit weight were also responsible for the productivity, although the degree of contribution was not same for each of the pathways. The results suggest that yield improvement should involve several characters instead of a single character.

KEYWORDS: Chilli, path analysis, fruit yield, direct effects, and indirect effects.

INTRODUCTION

Chilli (*Capsicum annuum* L.) is one of the most commercially significant vegetable and spice crops, which belongs to the Solanaceae family. Chilli is grown in tropical and subtropical areas and is highly significant in the agricultural sector due to its wide application in various sectors, such as nutrition, medicine and industry. The chilli fruits are used in the form of fresh fruits, dried, powdered and processed and are significant because of the presence of pungency, colour, flavor and nutritional value. Pungency is present in the fruits mainly due to the presence of capsaicinoids, especially capsaicin. On the other hand, the red color present in the ripe fruits is because of carotenoid pigments. Along with being consumed domestically, chilli is an essential raw material in spice-processing, food, pharmaceutical and oleoresin industries.

The yield in chilli is an important quantitative character which depends on numerous morphological, physiological, reproductive and genetic characters, as well as environmental influences. Some important yield-related characters include plant height, number of primary and secondary branches, days taken for flowering, days to harvest fruits, number of fruits per plant, fruit length, fruit diameter, mean fruit weight and the fruiting period. There will be variation in the expression of such characters among different genotypes because of differences in their genetic makeup and reaction to the environmental influences. Thus, the development of good genotypes and appropriate yield-related characters is extremely important in developing chillies of high yield potential. A thorough knowledge of the interactions among yield and its related characters is very useful in breeding programmes (Sran & Jindal, 2019).

The technique of correlation analysis is very commonly applied in the development of crops in order to identify the nature and intensity of the relationship between fruit yield and its components. Genotypic correlation is a measure of the correlation resulting due to genetic differences in the characters, while phenotypic correlation is an indication of the relationship caused by genetic and environmental interaction. In a number of cases in crop breeding research, genotypic correlations have proved to be higher than phenotypic correlations, which implies that the effect of environment partly distorts the genetic relationships. Nevertheless, the presence of a positive relationship between the particular trait and fruit yield cannot be a sure sign of the contribution of that trait to the increase in fruit productivity. The association can be either due to the direct impact on yield or indirect due to the relationship with the other components.

The method of path coefficient analysis, first introduced by Wright (1921), offers an appropriate tool for statistical analysis which helps in segregating the direct and indirect effects of each trait on the dependent variable. In breeding of crops, the fruit yield per plant is regarded as the dependent variable, and the morphological, phenological, reproductive and fruit traits are taken as the explanatory variables. The path

coefficient analysis technique enables to understand which traits have significant direct effects on fruit yield and which have indirect effects on fruit yield through other traits.

Empirical studies have also shown that this approach is applicable in chilli. In the study conducted by Usman et al. (2017), which involved the evaluation of 26 genotypes of chilli pepper grown in a tropical environment, fruit weight and the number of fruits per plant were found to have direct positive influence on yield. Likewise, in the study conducted by Sran and Jindal (2019), a significant positive relationship was observed between fruit yield and traits like number of fruits per plant, fruit weight, plant spread and plant height. From their results, it can be deduced that certain fruit and quality traits could also be used in selection for improved yield.

The pooled analysis of genotypic and phenotypic path coefficients proves to be more relevant in cases where observations are recorded across several environments or seasons. Pooled genotypic path analysis helps in the evaluation of the direct and indirect correlation amongst the traits at the genetic level whereas, pooled phenotypic path analysis is indicative of their relationship under the influence of genetics as well as environment. The analysis of both the levels of correlations would help in the determination of consistency of character association and would prove useful in differentiating between genetically significant characters and others whose significance depends upon the environmental influence. This would improve the chances of selection criteria development for chilli improvement.

Considering the intricacies associated with the inter-relationships amongst the yield contributing characters, the current research titled "Pooled Genotypic and Phenotypic Path Coefficient Analysis for Fruit Yield and its Associated Traits in Chilli (*Capsicum annuum* L.)" has been undertaken to find out the effect of various quantitative and qualitative characters on fruit yield. The goal of the study is to find out the characters that play a vital role in the determination of the fruit yield at both the genotypic and phenotypic level through pooling of data.

MATERIALS AND METHODS

The present research was carried out at the Research Cum Instructional Farm, K.D. College of Horticulture and Research Station, Jagdalpur, Bastar, Chhattisgarh – 494001 under Mahatma Gandhi University of Horticulture and Forestry, Durg, Chhattisgarh. Twenty chilli genotypes (CGBC-1 to CGBC-20) and one check variety (Pusa Jwala) from the different locations of Bastar plateau constituted the experimental material used for the study. The experiments were done using the Randomized Block Design (RBD) having 21 treatments with three replications each, thus making up 63 experimental plots. Each plot was of size 3 × 2 meters and seedlings were transplanted at an inter-row and intra-row spacing of 60 × 45 cm, respectively.The data was collected on the basis of twenty quantitative characters which include days to first emergence, days to 50% emergence, percentage of germination, plant height (in cm), stem girth (in cm), number of primary branches per plant, number of secondary branches per plant, days to first flowering, number of flowers per plant, days to first fruit formation, days to first fruit setting, number of fruits per plant, fruit length (in cm), fruit girth (in cm), fruit stalk length (in cm), number of seeds per fruit, number of pickings, fresh fruit weight (in grams) and dry fruit weight (in grams). The data was taken into consideration in order to study the genetic variation and association between them and fruit yield. The treatments included are as follows: T1: CGBC-1, T2: CGBC-2, T3: CGBC-3, T4: CGBC-4, T5: CGBC-5, T6: CGBC-6, T7: CGBC-7, T8: CGBC-8, T9: CGBC-9, T10: CGBC-10, T11: CGBC-11, T12: CGBC-12, T13: CGBC-13, T14: CGBC-14, T15: CGBC-15, T16: CGBC-16, T17: CGBC-17, T18: CGBC-18, T19: CGBC-19, T20: CGBC-20 and T21: Pusa Jwala (Check variety).

Path coefficient analysis for both genotypes and phenotypes was carried out to quantify the direct and indirect effects of the observed characters on yield per plant. The procedure employed was that which was proposed by Wright (1921) and later used in crops by Dewey and Lu (1959). Yield per plant was considered as the dependent character whereas the other observed characters were considered as independent characters. Different analyses were done separately based on genotypic and phenotypic correlation coefficients to differentiate the genetic relationships from those affected by environmental influences. The residual effect was also quantified to find the proportion of variance in yield per plant not accounted by the other traits considered in the analysis.

RESULTS AND DISCUSSION

Pooled Genotypic path coefficient analysis for fruit yield and associated traits in chilli genotypes

The pooled genotypic path coefficient analysis presented in Table-1a revealed a complex network of positive and negative pathways among the characters associated with fruit weight per plant in chilli. The pooled genotypic analysis indicated that the expression of fruit productivity was influenced by interactions among germination, vegetative growth, flowering, fruit initiation, fruit number, fruit dimensions, harvesting frequency and fruit biomass. Considerable variation in the magnitude of the coefficients was observed among the different characters.

Days to first germination showed positive pathways through germination percentage (10.740), plant height (3.757), primary branches per plant (4.198), days to first fruit initiation (16.550), days to first fruit set (2.565), fruits per plant (14.626), fruit length (10.940), number of pickings (0.440), fresh fruit weight (10.682) and dry fruit weight (15.752). Negative pathways were observed through stem girth (−0.885), secondary branches (−7.381), days to first flowering (−19.254), flowers per plant (−0.454), fruit girth (−17.139), fruit stalk length

(−7.459) and fruit weight per plant (−6.896). Thus, DFG showed strong contrasting pathways, particularly through reproductive and fruit-related characters, (sharmeen et al., 2024).

Days to 50% germination exhibited positive pathways through germination percentage (2.760), stem girth (2.507), primary branches (5.253), days to first fruit initiation (3.773), fruits per plant (4.346), fruit length (5.253), number of pickings (0.691), fresh fruit weight (5.133) and dry fruit weight (3.927). Negative pathways were recorded through plant height (−2.940), secondary branches (−2.351), days to first flowering (−3.716), days to first fruit set (−0.107), fruit girth (−6.453), fruit stalk length (−1.829) and fruit weight per plant (−3.268). These results indicated that germination timing had both favourable and unfavourable indirect pathways towards productivity, (Krishnamurthy et al., 2013).

Germination percentage showed positive pathways through DFG (2.185), plant height (0.451), secondary branches (1.004), days to first flowering (0.793), flowers per plant (1.568), days to first fruit set (3.841), fruit length (3.834), fruit stalk length (0.936), number of pickings (0.615) and fruit weight per plant (0.188). Negative pathways occurred through D50G (−2.064), primary branches (−1.960), days to first fruit initiation (−5.112), fruits per plant (−1.616), fruit girth (−2.429), fresh fruit weight (−0.735) and dry fruit weight (−2.016). The positive pathways through fruit length and flowering-related characters indicated the indirect role of germination performance in subsequent reproductive development.

Plant height showed positive pathways through DFG (0.084), D50G (0.240), germination percentage (0.049), stem girth (0.739), primary branches (0.092), flowers per plant (0.650), days to first fruit initiation (0.576), days to first fruit set (0.012), fruit length (1.642), number of pickings (0.203) and fruit weight per plant (0.442). Negative pathways were observed through secondary branches (−0.097), days to first flowering (−1.058), fruits per plant (−1.316), fruit girth (−0.121), fruit stalk length (−0.215), fresh fruit weight (−1.347) and dry fruit weight (−1.068). The positive pathway through fruit length was comparatively prominent and indicated an indirect relationship between plant stature and fruit development, (Vikram et al., 2014).

Stem girth exhibited positive pathways through plant height (0.867), secondary branches (0.296), days to first flowering (0.429), days to first fruit initiation (0.069), days to first fruit set (0.006), fruits per plant (1.042), fruit girth (0.383), fruit stalk length (0.290), fresh fruit weight (0.654) and dry fruit weight (0.885). Negative pathways occurred through DFG (−0.023), D50G (−0.240), germination percentage (−0.006), primary branches (−0.541), flowers per plant (−0.353), fruit length (−1.607), number of pickings (−0.306) and fruit weight per plant (−0.138). The positive pathways through fruits per plant, fresh fruit weight and dry fruit weight suggested the importance of plant vigour in fruit productivity, (Likeng-le-Ngue et al., 2025).

Primary branches per plant showed positive pathways through D50G (0.555), germination percentage (0.277), stem girth (0.597), flowers per plant (0.816), days to first fruit initiation (1.742), fruit length (3.789), number of pickings (0.282) and fruit weight per plant (0.953). Negative pathways were observed through DFG (−0.121), plant height (−0.119), secondary branches (−0.320), days to first flowering (−2.080), days to first fruit set (−0.124), fruits per plant (−2.060), fruit girth (−1.723), fruit stalk length (−0.479), fresh fruit weight (−3.299) and dry fruit weight (−0.563). The relatively high positive pathway through fruit length and the positive coefficient associated with fruit weight per plant indicated an important contribution of primary branching to productivity through fruit development, (Negi and Sharma, 2019).

Secondary branches per plant exhibited positive pathways through D50G (0.748), germination percentage (0.427), stem girth (0.982), primary branches (0.965), days to first fruit initiation (1.118), fruits per plant (0.603), fruit length (1.092), fruit girth (0.201) and fresh fruit weight (0.138). Negative pathways were observed through DFG (−0.639), plant height (−0.378), days to first flowering (−0.130), flowers per plant (−0.760), days to first fruit set (−1.126), fruit stalk length (−0.256), number of pickings (−0.172) and dry fruit weight (−1.031). The positive pathways through stem girth, primary branches, fruits per plant and fruit length indicated the contribution of branching to reproductive productivity.

Days to first flowering showed positive pathways through DFG (0.755), plant height (1.864), secondary branches (0.059), flowers per plant (0.865), days to first fruit set (1.077), fruit length (2.551), number of pickings (0.355) and fruit weight per plant (1.104). Negative pathways were recorded through D50G (−0.535), germination percentage (−0.153), stem girth (−0.644), primary branches (−2.834), days to first fruit initiation (−0.267), fruits per plant (−1.726), fruit girth (−1.261), fruit stalk length (−0.173), fresh fruit weight (−3.101) and dry fruit weight (−0.567). The positive pathway through fruit length contrasted with the negative pathways through fruits per plant and fresh fruit weight.

Flowers per plant exhibited positive pathways through DFG (0.050), stem girth (1.501), primary branches (3.145), secondary branches (0.973), days to first flowering (2.446), days to first fruit set (1.648), fruits per plant (2.678), fruit girth (4.517), fruit stalk length (1.099) and fresh fruit weight (6.095). Negative pathways occurred through D50G (−0.194), germination percentage (−0.854), plant height (−3.242), days to first fruit initiation (−4.291), fruit length (−5.685), number of pickings (−0.379), dry fruit weight (−1.986) and fruit weight per plant (−1.783). The strong positive pathways through fresh fruit weight, fruit girth, primary branches and fruits per plant indicated that reproductive potential was closely connected with fruit productivity, (Kumar et al., 2014).

Days to first fruit initiation showed positive pathways through DFG (0.197), plant height (0.308), stem girth (0.031), secondary branches (0.153), days to first flowering (0.081), flowers per plant (0.460), days to first fruit set (0.792), fruit length (0.166), fruit girth (0.358), fruit stalk length (0.126), number of pickings (0.127) and fruit weight per plant (0.213). Negative pathways occurred through D50G (−0.165), germination percentage

(−0.299), primary branches (−0.720), fruits per plant (−0.654), fresh fruit weight (−0.419) and dry fruit weight (−0.738). The comparatively moderate coefficients indicated a mixed contribution of fruit initiation timing to productivity, (Belay and Tsehaye, 2020).

Days to first fruit set showed positive pathways through DFG (0.071), D50G (0.011), germination percentage (0.524), plant height (0.015), stem girth (0.007), primary branches (0.120), days to first fruit initiation (1.847), fruits per plant (0.126), fruit length (1.633), number of pickings (0.062), dry fruit weight (1.043) and fruit weight per plant (0.177). Negative pathways were observed through secondary branches (−0.361), days to first flowering (−0.762), flowers per plant (−0.412), fruit girth (−1.722), fruit stalk length (−0.431) and fresh fruit weight (−1.019). The positive pathways through fruit initiation, fruit length and dry fruit weight indicated their importance in the fruit-set pathway, (Deepo et al., 2020).

Fruits per plant showed positive pathways through D50G (0.207), germination percentage (0.103), plant height (0.768), secondary branches (0.090), days to first fruit initiation (0.713), fruit length (0.337), fruit girth (0.343) and fruit weight per plant (0.696). Negative pathways were observed through DFG (−0.190), stem girth (−0.518), primary branches (−0.929), days to first flowering (−0.571), days to first fruit set (−0.059), fruit stalk length (−0.129), number of pickings (−0.038), fresh fruit weight (−1.716) and dry fruit weight (−0.302). The coefficient of 0.696 for fruit weight per plant represents one of the more prominent positive pathways in the supplied pooled genotypic matrix and highlights the importance of fruit number in overall productivity, (Tilahum et al., 2022).

Fruit length showed positive pathways through D50G (0.554), stem girth (1.769), primary branches (3.782), days to first flowering (1.869), fruits per plant (0.747), fruit stalk length (0.553), number of pickings (0.205), fresh fruit weight (3.170) and dry fruit weight (0.244). Negative pathways occurred through DFG (−0.314), germination percentage (−0.541), plant height (−2.120), secondary branches (−0.362), flowers per plant (−1.473), days to first fruit initiation (−0.402), days to first fruit set (−1.690), fruit girth (−0.073) and fruit weight per plant (−1.249). The positive pathways through primary branches and fresh fruit weight indicated a close association between fruit length, plant architecture and fruit biomass, (Vikram et al., 2014).

Fruit girth exhibited highly contrasting pathways. Positive contributions were recorded through D50G (3.894), stem girth (2.410), primary branches (9.833), secondary branches (0.381), days to first flowering (5.281), days to first fruit initiation (4.947), fruit length (0.418), fruit stalk length (2.168) and dry fruit weight (1.979). Negative pathways were observed through DFG (−2.814), germination percentage (−1.960), plant height (−0.891), flowers per plant (−6.692), days to first fruit set (−10.191), fruits per plant (−4.348), number of pickings (−0.831), fresh fruit weight (−0.070) and fruit weight per plant (−0.743). The particularly high positive pathway through primary branches and negative pathway through days to first fruit set demonstrate the strong indirect interactions affecting fruit girth, Similar as result reported by (Srinivas et al., 2020).

Fruit stalk length showed positive pathways through D50G (1.664), germination percentage (1.139), stem girth (2.756), primary branches (4.128), days to first flowering (1.096), days to first fruit initiation (2.631), fruits per plant (2.466), fruit girth (3.270), fresh fruit weight (4.564) and dry fruit weight (0.899). Negative pathways were recorded through DFG (−1.847), plant height (−2.397), secondary branches (−0.733), flowers per plant (−2.455), days to first fruit set (−3.848), fruit length (−4.775), number of pickings (−0.667) and fruit weight per plant (−1.602). Thus, fruit stalk length was influenced by several strong positive and negative pathways, (Sreelathkumary and Rajamony, 2004).

Seeds per fruit showed a comparatively moderate and balanced pathway pattern. Positive pathways were observed through DFG (0.085), germination percentage (0.214), plant height (0.073), stem girth (0.186), secondary branches (0.247), days to first flowering (0.094), flowers per plant (0.158), days to first fruit set (0.082), fruits per plant (0.291), fruit length (0.436), fruit girth (0.521), fruit stalk length (0.193), number of pickings (0.117), fresh fruit weight (0.348), dry fruit weight (0.407) and fruit weight per plant (0.295). Negative pathways were recorded through D50G (−0.142), primary branches (−0.121) and days to first fruit initiation (−0.176). The positive pathways through fruit girth, fruit length and dry fruit weight suggested that seed number was associated with fruit development and biomass.

Number of pickings showed positive pathways through D50G (0.450), stem girth (2.079), primary branches (1.736), secondary branches (0.351), days to first flowering (1.607), fruit length (1.268), fruit girth (0.896), fruit stalk length (0.477), seeds per fruit (3.746) and fresh fruit weight (0.437). Negative pathways occurred through DFG (−0.078), germination percentage (−0.536), plant height (−1.618), days to first fruit initiation (−1.891), days to first fruit set (−0.394), fruits per plant (−0.515), dry fruit weight (−2.539) and fruit weight per plant (−0.269). The positive pathway through seeds per fruit was particularly pronounced, (Singh et al., 2018).

Fresh fruit weight showed positive pathways through D50G (0.086), germination percentage (0.017), plant height (0.277), days to first fruit initiation (0.161), days to first fruit set (0.168), flowers per plant (0.251), fruit length (0.505), fruit girth (0.002), number of pickings (0.011) and fruit weight per plant (0.355). Negative pathways occurred through DFG (−0.049), stem girth (−0.115), primary branches (−0.524), secondary branches (−0.007), days to first flowering (−0.362), fruits per plant (−0.605), fruit stalk length (−0.084) and dry fruit weight (−0.231). The positive pathways through fruit length and fruit weight per plant indicated the importance of fruit size and fresh biomass, (Singh and Singh, 2004).

Dry fruit weight exhibited positive pathways through DFG (0.595), stem girth (1.281), primary branches (0.739), days to first flowering (0.546), flowers per plant (0.677), days to first fruit set (1.420), fruits per plant

(0.881), fruit girth (0.455), fruit stalk length (0.137), number of pickings (0.541) and fresh fruit weight (1.904). Negative pathways were observed through D50G (−0.545), germination percentage (−0.374), plant height (−1.814), secondary branches (−0.449), days to first fruit initiation (−2.342), fruit length (−0.321) and fruit weight per plant (−0.678). The positive pathway through fresh fruit weight (1.904), along with those through fruits per plant and flowers per plant, indicated the close association of dry fruit biomass with reproductive and fruit-weight traits, (Singh et al., 2026).

Overall, the pooled genotypic path analysis indicated that fruits per plant, primary branches, plant height, fruit length, fruit girth, fruit stalk length, fresh fruit weight and dry fruit weight were involved in important pathways associated with fruit weight per plant. Among the supplied coefficients, fruits per plant showed a positive pathway of 0.696, primary branches showed 0.953, plant height showed 0.442, fresh fruit weight showed 0.355, and seeds per fruit showed 0.295 with fruit weight per plant. These results suggest that yield improvement in chilli may be more effective when selection considers a combination of fruit number, fruit size, fruit biomass and plant architecture.The findings are in broad agreement with previous studies on chilli in which fruits per plant, fruit weight, fruit dimensions and plant growth traits were identified as important components of yield. Rana et al. (2015) reported positive relationships of yield with plant height, branches, fruits per plant, fruit length, fruit breadth and average fruit weight. Sran and Jindal (2019) also reported significant associations of fruit yield with number of fruits per plant and fruit weight, while Srinivas et al. (2020), Vidya et al. (2018) and Singh et al. (2023) emphasized the importance of fruit number, fruit dimensions and fruit weight in determining yield performance.

Pooled Phenotypic path coefficient analysis for fruit yield and associated traits in chilli genotypes.

The pooled phenotypic path coefficient analysis presented in Table-2b revealed that fruit weight per plant was influenced through a complex combination of positive and negative pathways involving germination, plant growth, flowering, fruit initiation, fruit number, fruit dimensions, harvesting frequency and fruit biomass. The pooled phenotypic analysis provides an overall picture of the interrelationship among the component characters across the experimental years.

Days to first germination showed positive pathways through D50G (0.548), plant height (4.737), stem girth (0.468), days to first flowering (1.463), days to first fruit set (1.044), fruits per plant (1.817), fruit length (1.232), fruit stalk length (0.018), seeds per fruit (0.040), fresh fruit weight (2.962) and dry fruit weight (0.821). Negative pathways were observed through germination percentage (−0.140), primary branches (−0.168), secondary branches (−1.507), flowers per plant (−1.758), days to first fruit initiation (−2.397), fruit girth (−1.747), number of pickings (−0.109) and fruit weight per plant (−1.644). The same coefficient of −1.644 was reported for fruit weight per plot and fruit yield per hectare in the supplied matrix. The results indicated that germination timing had several contrasting indirect pathways, particularly through plant height, fruit number and fruit biomass, (Vidya et al., 2018).

Days to 50% germination exhibited positive pathways through germination percentage (0.209), plant height (10.778), stem girth (0.141), days to first flowering (4.113), days to first fruit set (2.735), fruits per plant (6.076), fruit length (1.620), seeds per fruit (0.002), number of pickings (−0.130 as negative), fresh fruit weight (8.002) and dry fruit weight (2.912). Negative pathways were observed through DFG (−1.561), primary branches (−0.749), secondary branches (−3.357), flowers per plant (−3.679), days to first fruit initiation (−5.476), fruit girth (−3.865), fruit stalk length (−0.111) and fruit weight per plant (−4.343). The large positive pathways through plant height, fruits per plant and fresh fruit weight indicated strong indirect relationships with productivity, (Shweta et al., 2018).

Germination percentage showed positive contributions through DFG (0.199), D50G (0.104), plant height (1.426), stem girth (0.512), days to first flowering (1.010), flowers per plant (0.080), days to first fruit set (0.628), fruits per plant (0.339), fruit length (1.670), fruit girth (0.752), fruit stalk length (0.798), number of pickings (0.832) and fruit weight per plant (0.490). Negative pathways occurred through primary branches (−1.688), secondary branches (−2.145), days to first fruit initiation (−1.621), seeds per fruit (−0.739), fresh fruit weight (−0.796) and dry fruit weight (−2.533). Thus, germination percentage showed favourable pathways through plant height and fruit-related characters but unfavourable pathways through branching and fruit biomass, (Srinivas et al., 2020).

Plant height exhibited positive pathways through D50G (3.904), germination percentage (1.036), stem girth (0.635), primary branches (8.032), secondary branches (6.499), days to first fruit initiation (0.158), days to first fruit set (1.681), seeds per fruit (2.530) and fresh fruit weight (5.049). Negative pathways were observed through DFG (−4.886), days to first flowering (−2.608), flowers per plant (−1.022), fruits per plant (−3.367), fruit length (−2.997), fruit girth (−5.151), fruit stalk length (−1.551), number of pickings (−2.807), dry fruit weight (9.484 as positive in the supplied matrix) and fruit weight per plant (−3.638). The strong positive pathways through primary and secondary branches indicated that plant height was closely associated with plant architecture, (Srilakshmi, 2006).

Stem girth showed positive pathways through DFG (−0.109 as negative), D50G (0.012), germination percentage (0.084), plant height (0.144), primary branches (0.111), secondary branches (0.742), days to first fruit initiation (0.368), days to first fruit set (0.174), flowers per plant (0.219), fruit stalk length (0.010), seeds per fruit (0.076) and dry fruit weight (1.124). Negative pathways occurred through days to first flowering (−0.369), fruits per plant (−0.384), fruit length (−0.511), fruit girth (−0.432), number of pickings (−0.197) and fresh fruit weight

(−0.325). The coefficient for fruit weight per plant was 0.108. Thus, stem girth had relatively moderate pathways compared with some of the other characters, (Vishvkarma et al., 2025).

Primary branches per plant showed positive pathways through plant height (1.154), stem girth (0.070), days to first flowering (0.537), days to first fruit set (0.153), fruits per plant (0.199), fruit length (0.512), fruit girth (0.198), fruit stalk length (0.099), seeds per fruit (−0.101 as negative), number of pickings (0.149), fresh fruit weight (−0.365 as negative), dry fruit weight (−0.800 as negative) and fruit weight per plant (0.188). Negative pathways were observed through DFG (−0.039), D50G (−0.039), germination percentage (−0.176), secondary branches (−0.689), flowers per plant (−0.191) and days to first fruit initiation (−0.614). The positive pathway through plant height and fruit length indicated the contribution of primary branching through plant architecture and fruit development, (Murmu et al., 2017).

Secondary branches per plant showed positive pathways through DFG (0.147), plant height (0.613), stem girth (0.309), days to first flowering (0.640), fruits per plant (0.451), fruit length (0.630), fruit girth (0.341), fruit stalk length (0.094), number of pickings (0.202) and fruit weight per plant (0.131). Negative pathways were observed through D50G (−0.115), germination percentage (−0.147), primary branches (−0.452), flowers per plant (−0.304), days to first fruit initiation (−0.382), days to first fruit set (−0.230), seeds per fruit (−0.005), fresh fruit weight (−0.174) and dry fruit weight (−1.223). The positive pathways through plant height, fruit number and fruit length indicated that secondary branching could influence productivity through plant structure and fruit development, (Kadwey et al., 2015).

Days to first flowering exhibited positive pathways through D50G (0.338), germination percentage (0.166), primary branches (0.847), secondary branches (1.537), flowers per plant (0.294), days to first fruit initiation (0.520), days to first fruit set (0.307), seeds per fruit (0.401), number of pickings (−0.398 as negative), fresh fruit weight (−0.171 as negative), dry fruit weight (1.485) and fruit weight per plant (−0.086). Negative pathways were observed through DFG (−0.342), plant height (−0.591), stem girth (−0.370), fruits per plant (−1.242), fruit length (−0.597), fruit girth (−0.677) and fruit stalk length (−0.239). The results showed a contrasting influence of flowering time on subsequent fruit productivity, (Sharmeen et al., 2024).

Flowers per plant showed positive pathways through DFG (1.220), germination percentage (0.039), stem girth (0.650), days to first flowering (0.873), days to first fruit initiation (0.975), fruits per plant (2.676), fruit length (0.448), fruit girth (1.299), fruit stalk length (0.305), number of pickings (0.700), fresh fruit weight (0.089) and fruit weight per plant (0.331). Negative pathways were observed through D50G (−0.897), plant height (−0.688), primary branches (−0.892), secondary branches (−2.167), days to first fruit set (−1.609), seeds per fruit (−0.735) and dry fruit weight (−2.066). The positive pathway through fruits per plant was particularly important, indicating that greater flower production could contribute to yield through increased fruit formation.

Days to first fruit initiation exhibited positive pathways through DFG (0.508), plant height (0.033), stem girth (0.335), days to first flowering (0.472), flowers per plant (0.298), days to first fruit set (0.468), fruits per plant (0.319), fruit length (0.585), fruit girth (0.707), fruit stalk length (0.229), number of pickings (0.387) and fruit weight per plant (0.252). Negative pathways occurred through D50G (−0.408), germination percentage (−0.242), primary branches (−0.879), secondary branches (−0.833), fresh fruit weight (−0.236) and dry fruit weight (−1.532). Thus, fruit initiation showed favourable pathways through fruit dimensions but negative pathways through branching and dry fruit biomass, (Kumar et al., 2014).

Days to first fruit set showed positive pathways through D50G (0.297), germination percentage (0.137), plant height (0.504), stem girth (0.231), primary branches (0.319), days to first flowering (0.406), flowers per plant (−0.718 as negative), days to first fruit initiation (0.682), fruits per plant (1.057), fruit length (0.009), fresh fruit weight (0.778), dry fruit weight (0.152) and fruit weight per plant (−0.349). Negative pathways occurred through DFG (−0.323), secondary branches (−0.731), fruit girth (−0.076), fruit stalk length (−0.059), seeds per fruit (−0.043) and number of pickings (−0.046). The positive pathway through fruits per plant suggested an important relationship between fruit setting and final fruit number, (Tilahun et al., 2022).

Fruits per plant showed positive pathways through D50G (0.269), germination percentage (0.030), primary branches (0.169), secondary branches (0.584), flowers per plant (0.486), days to first fruit initiation (0.189), days to first fruit set (0.431), fruit length (−0.140 as negative), fruit stalk length (0.018), dry fruit weight (0.419) and fruit weight per plant (0.196). Negative pathways were observed through DFG (−0.229), plant height (−0.411), stem girth (−0.207), days to first flowering (−0.669), fruit girth (−0.007), seeds per fruit (−0.101), number of pickings (−0.064) and fresh fruit weight (−0.512). The positive pathway through secondary branches and flowers per plant indicated the importance of plant reproductive architecture in determining fruit number, (Shumbulo et al., 2017).

Fruit length showed positive pathways through D50G (0.063), germination percentage (0.130), primary branches (0.383), secondary branches (0.717), flowers per plant (0.072), days to first fruit initiation (0.306), days to first fruit set (0.003), fruit stalk length (−0.139 as negative), seeds per fruit (0.058), fresh fruit weight (0.408), dry fruit weight (1.158) and negative pathways through DFG (−0.136), plant height (−0.322), stem girth (−0.242), days to first flowering (−0.283), fruits per plant (−0.124), fruit girth (−0.077), number of pickings (−0.167) and fruit weight per plant (−0.192). The positive pathways through secondary branches, fresh fruit weight and dry fruit weight suggested an association between fruit length and fruit biomass, (Saisupriya, et al., 2020).

Fruit girth showed positive pathways through DFG (0.385), germination percentage (0.117), primary branches (0.294), secondary branches (0.770), flowers per plant (0.412), days to first fruit initiation (0.734), fruit length (−0.153 as negative), fruit stalk length (0.035), number of pickings (0.080), fresh fruit weight (0.139) and dry fruit weight (1.426). Negative pathways occurred through D50G (−0.299), plant height (−1.099), stem girth (−0.407), days to first flowering (−0.638), days to first fruit set (−0.054), fruits per plant (−0.012), seeds per fruit (−0.194) and fruit weight per plant (−0.050). Dry fruit weight represented the strongest positive pathway in this row, (Misra et al., 2010).

Fruit stalk length showed positive pathways through germination percentage (0.893), plant height (−2.388 as negative), primary branches (1.059), secondary branches (1.526), flowers per plant (0.698), days to first fruit initiation (1.712), fruits per plant (0.226), fruit girth (0.251), fresh fruit weight (1.096) and dry fruit weight (2.192). Negative pathways were observed through DFG (−0.028), D50G (−0.062), days to first flowering (−1.626), days to first fruit set (−0.303), fruit length (−1.989), seeds per fruit (−0.046), number of pickings (−0.288) and fruit weight per plant (−0.455). The positive pathways through dry fruit weight, days to first fruit initiation and secondary branches indicated its association with fruit development and biomass, (Pujar et al., 2017).

Seeds per fruit showed relatively moderate pathways. Positive contributions were observed through DFG (0.169), germination percentage (2.185), primary branches (2.846), secondary branches (0.194), flowers per plant (4.447), days to first fruit initiation (6.798), days to first fruit set (0.584), fruits per plant (3.371), fruit girth (3.695), fruit stalk length (0.121), fresh fruit weight (1.410) and fruit weight per plant (0.138). Negative pathways occurred through D50G (−0.002), plant height (−10.294), stem girth (−1.360), days to first flowering (−7.195), fruit length (−2.179), number of pickings (−0.096) and dry fruit weight (−1.186). The large positive pathways through days to first fruit initiation and flowers per plant indicate strong indirect interactions involving seed production, (Negi and Sharma, 2019).

Number of pickings showed positive pathways through DFG (0.122), germination percentage (0.656), primary branches (1.122), secondary branches (2.321), flowers per plant (1.129), days to first fruit initiation (2.039), fruits per plant (−0.568 as negative), fruit length (−1.688 as negative), fruit girth (0.404), seeds per fruit (0.026), fresh fruit weight (−0.488 as negative), dry fruit weight (1.708) and fruit weight per plant (0.248). Negative pathways were observed through D50G (−0.051), plant height (−3.047), stem girth (−0.942), days to first flowering (−1.906), days to first fruit set (−0.167), fruit stalk length (−0.203) and other negative routes indicated in the matrix. The positive pathways through secondary branches, days to first fruit initiation and dry fruit weight suggested that repeated picking was associated with cumulative fruit biomass, (Krishnamurthy, et al., 2013).

Fresh fruit weight showed positive pathways through D50G (0.412), plant height (0.718), flowers per plant (0.019), days to first fruit set (0.369), fruit length (0.540), fruit girth (0.092), fruit stalk length (0.101), dry fruit weight (−0.370 as negative according to the supplied matrix) and fruit weight per plant (0.348). Negative pathways were observed through DFG (−0.434), germination percentage (−0.082), stem girth (−0.204), primary branches (−0.361), secondary branches (−0.263), days to first flowering (−0.107), days to first fruit initiation (−0.163), fruits per plant (−0.596), seeds per fruit (−0.049) and number of pickings (−0.064). The positive coefficient of 0.348 for fruit weight per plant indicated a favourable pathway of fresh fruit biomass towards total plant productivity, (Vikram et al., 2014).

Dry fruit weight showed positive pathways through D50G (0.050), plant height (0.452), stem girth (0.236), primary branches (−0.265 as negative), days to first flowering (0.312), days to first fruit set (0.024), fruits per plant (0.163), fruit length (0.514), fruit girth (0.318), fruit stalk length (0.068), seeds per fruit (0.014), number of pickings (0.075) and fresh fruit weight (−0.124 as negative). Negative pathways were observed through DFG (−0.040), germination percentage (−0.088), secondary branches (−0.617), days to first fruit initiation (−0.355) and fruit weight per plant (0.082). The positive pathways through fruit length and fruit girth indicated the contribution of fruit dimensions to dry fruit biomass, (Srinivas, et al., 2020).

Overall, the pooled phenotypic path analysis indicated that plant height, primary and secondary branches, flowers per plant, fruits per plant, fruit dimensions and fresh/dry fruit weight were important components within the pathway structure associated with fruit productivity. Fruits per plant showed a positive coefficient of 0.196, plant height −3.638, primary branches 0.188, fruit stalk length −0.455, fresh fruit weight 0.348 and dry fruit weight 0.082 for fruit weight per plant in the supplied matrix. Among the fruit-related characters, fruit number, fruit length, fruit girth and fruit biomass repeatedly appeared in important positive pathways, supporting their importance as yield-associated characters, (Usman et al., 2017).

The pooled phenotypic results are broadly consistent with previous chilli studies reporting the importance of fruit number, fruit weight, fruit dimensions and plant architecture in determining yield. Rana et al. (2015) reported positive relationships of yield with plant height, branches, fruits per plant, fruit length, fruit breadth and average fruit weight. Sran and Jindal (2019), Srinivas et al. (2020), Vidya et al. (2018) and Singh et al. (2023) similarly emphasized fruit number, fruit size and fruit weight as important components of yield in chilli.

A comparison with the pooled genotypic path analysis in Table-1a suggests that the direction and magnitude of several pathways differed between genotypic and phenotypic levels. This is expected because phenotypic relationships include environmental as well as genetic sources of variation. Nevertheless, fruit number, fruit

dimensions, branching and fruit biomass repeatedly appeared as important components at both levels. Therefore, these characters may be considered collectively while identifying superior genotypes for fruit productivity.

It is important to note that several coefficients in Table-2b are unusually large, particularly those associated with D50G, plant height, seeds per fruit and some fruit-related pathways. Such large coefficients can indicate strong multicollinearity or instability in the underlying path estimation. In addition, the supplied matrix includes fruit weight per plant, fruit weight per plot and fruit yield per hectare as closely related dependent/productivity variables, which can create substantial mathematical dependence if they are simultaneously included in the path model.

Table 1a. Path Matrix Based on Pooled Genotypic Correlations

Dependent \ Predictor	DFG	D50G	GP	PH	SG	PB	SB	DFF	FPP	DFFI	DFFS	FP	FL	FG	FSL	NP	FFW	DFW	Direct Correlated with Fruit weight/plant (g)
Days to first germination	-	-0.006	10.740	3.757	- 0.885	4.198	-7.381	-19.254	-0.454	16.550	2.565	14.626	10.940	-17.139	-7.459	0.440	10.682	15.752	-6.896
Days to 50% germination	0.002	-	2.760	-2.940	2.507	5.253	-2.351	-3.716	-0.477	3.773	-0.107	4.346	5.253	-6.453	-1.829	0.691	5.133	3.927	-3.268
Germination percentage	2.185	-2.064	-	0.451	- 0.051	-1.960	1.004	0.793	1.568	-5.112	3.841	-1.616	3.834	-2.429	0.936	0.615	-0.735	-2.016	0.188*
Plant height (cm)	0.084	0.240	0.049	-	0.739	0.092	-0.097	-1.058	0.650	0.576	0.012	-1.316	1.642	-0.121	-0.215	0.203	-1.347	-1.068	0.442*
Stem girth (cm)	-0.023	-0.240	-0.006	0.867	-	-0.541	0.296	0.429	-0.353	0.069	0.006	1.042	-1.607	0.383	0.290	-0.306	0.654	0.885	-0.138*
Primary branches/plant	-0.121	0.555	0.277	-0.119	0.597	-	-0.320	-2.080	0.816	1.742	-0.124	-2.060	3.789	-1.723	-0.479	0.282	-3.299	-0.563	0.953*
Secondary branches/plant	-0.639	0.748	0.427	-0.378	0.982	0.965	-	-0.130	-0.760	1.118	-1.126	0.603	1.092	0.201	-0.256	-0.172	0.138	-1.031	-0.127*
Days to first flowering	0.755	-0.535	-0.153	1.864	-0.644	-2.834	0.059	-	0.865	-0.267	1.077	-1.726	2.551	-1.261	-0.173	0.355	-3.101	-0.567	1.104**
Flowers/plant	0.050	-0.194	-0.854	-3.242	1.501	3.145	0.973	2.446	-	-4.291	1.648	2.678	-5.685	4.517	1.099	-0.379	6.095	-1.986	-1.783*
Days to first fruit initiation	0.197	-0.165	-0.299	0.308	0.031	-0.720	0.153	0.081	0.460	-	0.792	-0.654	0.166	0.358	0.126	0.127	-0.419	-0.738	0.213**
Days to first fruit set	0.071	0.011	0.524	0.015	0.007	0.120	-0.361	-0.762	-0.412	1.847	-	0.126	1.633	-1.722	-0.431	0.062	-1.019	1.043	0.177*
Fruits/plant	-0.190	0.207	0.103	0.768	- 0.518	-0.929	-0.090	-0.571	0.313	0.713	-0.059	-	0.337	0.343	-0.129	-0.038	-1.716	-0.302	0.696*
Fruit length (cm)	-0.314	0.554	-0.541	-2.120	1.769	3.782	-0.362	1.869	-1.473	-0.402	-1.690	0.747	-	-0.073	0.553	0.205	3.170	0.244	-1.249*
Fruit girth (cm)	-2.814	3.894	-1.960	-0.891	2.410	9.833	0.381	5.281	-6.692	4.947	-10.19	-4.348	0.418	-	2.168	-0.83	-0.07	1.979	-0.743

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Fruit stalk length (cm)	-1.847	1.664	1.139	-2.397	2.756	4.128	-0.733	1.096	-2.455	2.631	-3.848	2.466	-4.775	3.270	-	-0.667	4.564	0.899	-1.602*
Seeds/fruit	0.085	-0.142	0.214	0.073	0.186	-0.121	0.247	0.094	0.158	-0.176	0.082	0.291	0.436	0.521	0.193	0.117	0.348	0.407	0.295*
Number of pickings	-0.078	0.450	-0.536	-1.618	2.079	1.736	0.351	1.607	-0.606	-1.891	-0.394	-0.515	1.268	0.896	0.477	-	0.437	-2.539	-0.269*
Fresh fruit weight (g)	-0.049	0.086	0.017	0.277	-0.115	-0.524	-0.007	-0.362	0.251	0.161	0.168	-0.605	0.505	0.002	-0.084	0.011	-	-0.231	0.355**
Dry fruit weight (g)	0.595	-0.545	-0.374	-1.814	1.281	0.739	-0.449	0.546	0.677	-2.342	1.420	0.881	-0.321	0.455	0.137	0.541	1.904	-	-0.678**

Residual effect (R) = 0.0105

Table-42b. Path Matrix Based on Pooled Phenotypic Correlations

Dependent \ Predictor	DFG	D50G	GP	PH	SG	PB	SB	DFF	FPP	DFFI	DFFS	FP	FL	FG	FSL	SF	NP	FFW	DFW	Direct Correlated with Fruit weight/plant (g)
Days to first germination	-	0.548	-0.140	4.737	0.468	-0.168	-1.507	1.463	-1.758	-2.397	1.044	1.817	1.232	-1.747	0.018	0.040	-0.109	2.962	0.821	-1.644*
Days to 50% germination	-1.561	-	0.209	10.778	0.141	-0.749	-3.357	4.113	-3.679	-5.476	2.735	6.076	1.620	-3.865	-0.111	0.002	-0.130	8.002	2.912	-4.343
Germination percentage	0.199	0.104	-	1.426	0.512	-1.688	-2.145	1.010	0.080	-1.621	0.628	0.339	1.670	0.752	0.798	-0.739	0.832	-0.796	-2.533	0.490**
Plant height (cm)	-4.886	3.904	1.036	-	0.635	8.032	6.499	-2.608	-1.022	0.158	1.681	-3.367	-2.997	-5.151	-1.551	2.530	-2.807	5.049	9.484	-3.638
Stem girth (cm)	-0.109	0.012	0.084	0.144	-	0.111	0.742	-0.369	0.219	0.368	0.174	-0.384	-0.511	-0.432	0.010	0.076	-0.197	-0.325	1.124	0.108*
Primary branches/plant	0.025	-0.039	-0.176	1.154	0.070	-	-0.689	0.537	-0.191	-0.614	0.153	0.199	0.512	0.198	0.099	-0.101	0.149	-0.365	-0.800	0.188**
Secondary branches/plant	0.147	-0.115	-0.147	0.613	0.309	-0.452	-	0.640	-0.304	-0.382	-0.230	0.451	0.630	0.341	0.094	-0.005	0.202	-0.174	-1.223	0.131**
Days to first flowering	-0.342	0.338	0.166	-0.591	-0.370	0.847	1.537	-	0.294	0.520	0.307	-1.242	-0.597	-0.677	-0.239	0.401	-0.398	-0.171	1.485	-0.086*
Flowers/plant	1.220	-0.897	0.039	-0.688	0.650	-0.892	-2.167	0.873	-	0.975	-1.609	2.676	0.448	1.299	0.305	-0.735	0.700	0.089	-2.066	0.331*
Days to first fruit initiation	0.508	-0.408	-0.242	0.033	0.335	-0.879	-0.833	0.472	0.298	-	0.468	0.319	0.585	0.707	0.229	-0.344	0.387	-0.236	-1.532	0.252**
Days to first fruit set	-0.323	0.297	0.137	0.504	0.231	0.319	-0.731	0.406	-0.718	0.682	-	1.057	0.009	-0.076	-0.059	-0.043	-0.046	0.778	0.152	-0.349*
Fruits/plant	-0.229	0.269	0.030	-0.411	-0.207	0.169	0.584	-0.669	0.486	0.189	0.431	-	-0.140	-0.007	0.018	-0.101	-0.064	-0.512	0.419	0.196*

Fruit length (cm)	-0.136	0.063	0.130	-0.322	-0.242	0.383	0.717	-0.283	0.072	0.306	0.003	-0.124	-	-0.077	-0.139	0.058	-0.167	0.408	1.158	-0.192*
Fruit girth (cm)	0.385	-0.299	0.117	-1.099	-0.407	0.294	0.770	-0.638	0.412	0.734	-0.054	-0.012	-0.153	-	0.035	-0.194	0.080	0.139	1.426	-0.050*
Fruit stalk length (cm)	-0.028	-0.062	0.893	-2.388	0.070	1.059	1.526	-1.626	0.698	1.712	-0.303	0.226	-1.989	0.251	-	-0.046	-0.288	1.096	2.192	-0.455*
Seeds/fruit	0.169	-0.002	2.185	-10.294	-1.360	2.846	0.194	-7.195	4.447	6.798	0.584	3.371	-2.179	3.695	0.121	-	-0.096	1.410	-1.186	0.138**
Number of pickings	0.122	-0.051	0.656	-3.047	-0.942	1.122	2.321	-1.906	1.129	2.039	-0.167	-0.568	-1.688	0.404	-0.203	0.026	-	-0.488	1.708	0.248*
Fresh fruit weight (g)	-0.434	0.412	-0.082	0.718	-0.204	-0.361	-0.263	-0.107	0.019	-0.163	0.369	-0.596	0.540	0.092	0.101	-0.049	-0.064	-	-0.370	0.348*
Dry fruit weight (g)	-0.040	0.050	-0.088	0.452	0.236	-0.265	-0.617	0.312	-0.146	-0.355	0.024	0.163	0.514	0.318	0.068	0.014	0.075	-0.124	-	0.082*

Residual effect (R) = 0.1335

Conclusion

The analysis of the pooled genotypic and phenotypic path coefficient provided insights into the intricate relationships between germination, vegetative growth, flowering, fruit development, and fruit yield in chilli. It was found out that fruit yield was linked to multiple yield-related characters, namely the number of fruits per plant, primary and secondary branches, plant height, fruit length, fruit girth, fruit stalk length, fresh fruit weight and dry fruit weight. In terms of genotypic analysis, the number of primary branches per plant and fruits per plant exhibited positive coefficients of 0.953 and 0.696 respectively relative to fruit weight per plant, and plant height and fresh fruit weight were found to have coefficients of 0.442 and 0.355 respectively.

Phenotypic analysis has shown differences in the direction and strength of pathways, suggesting that the relationships observed among the traits might be affected not only by genetic diversity but also by environmental variations. Nonetheless, fruit number, fruit size, fruit branching and fruit biomass appear to play an essential role in the structure of the pathway. Hence, the consideration of multiple yield-linked traits at once could prove more comprehensive approach to selecting genotypes than selection based only on a single character. These results could help in the development of selection programs for improving the yield potential of chilli in the agroclimatic conditions of Bastar plateau. But, the coefficients need to be carefully interpreted as some of them were quite large in magnitude indicating possible problems like multicollinearity or path coefficients being unstable in the path model. The original correlation matrix, path coefficients and residuals need to be cross checked before reaching any conclusions.

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