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Variability and Association of Capsaicin and Oleoresin on Seed Quality in Hot Pepper (*Capsicum* spp)

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Seventeen hot pepper characters studied manifested higher level of GCV except for seed germination (16.47 %) and seedling dry weight (13.12 %) manifested moderate level of GCV. Phenotypic Co-efficient of Variation (PCV) for germination (16.79%) and seedling dry weight (13.12%) manifested moderate level of PCV. Significant positive correlation was recorded with germination while electrical conductivity (-0.8125), fresh ungerminated seeds (-0.8890), capsaicin (-0.7482) showed significant negative correlation with seed germination. Path coefficient analysis revealed that, at phenotypic level, seedling length (0.7297) recorded the highest positive direct effect on vigour index I, followed by germination per cent (0.3452) which were of considerable magnitude. Number of seed fruit^{-1} (-0.1266), electrical conductivity (-0.0627), total dehydrogenase activity (-0.0312), vigour index II (-0.0339) and ASTA color value (-0.0872) recorded the negative direct effect on fruit rot disease incidence on ripe fruits.

Introduction

Hot pepper (*Capsicum annuum* L.) is highly valued as a vegetable and spice, as well as commercial crop and becoming increasingly important in terms of production and consumption. The Crop can be raised all round the year with the benefits of faster, cleaner production and a premium quality end product. At the same time, chilies are rich source of vitamin ‘A’ and ‘C’. Many chilli pepper constituents have importance for nutritional value, flavour, aroma, texture, and colour. Besides, Fruits of chilli comprises numerous chemicals components including steam-volatile oil, fatty oils, capsaicinoids, carotenoids, vitamins, protein, fiber, and mineral elements (Bosland and Votava, 2000).

Two important quality attributes of hot pepper is pungency imparted by the presence of capsaicinoids and the color due to carotenoids. Capsaicin is a unique alkaloid of the plant kingdom restricted to the genus *Capsicum*. Capsaicin is the pungency factor, a bioactive molecule of food and of medicinal importance. Capsaicin is used as a counterirritant, anti-arthritic, analgesic, antioxidant, and anticancer agent. The rich supplies of chilli peppers carotenoids contribute to food nutritional value and color (Anon. 2003).

Pungency or "heat" found in *Capsicum* fruit results from the biosynthesis and accumulation of alkaloid compounds known as capsaicinoids in the dissepiments, placental tissue adjacent to the seeds. Pepper cultivars vary with respect to their level of pungency because of quantitative and qualitative variation in capsaicinoid content. A total of six different main effect QTL affecting capsaicinoid content were identified that are mapped to chromosomes 3, 4 and 7 (Arnon, 2006).

The hot flavor of chilies is due to presence of a group of seven closely related compounds called capsaicinoids, but capsaicin (8-methyl-*N*-vanillyl-6-nonenamide) and dihydrocapsaicin are responsible for approximately 90(%) of the pungency1–3. Chilli hotness is measured in Scoville Heat Units (SHU) which is originally a subjective measure but today, chilli hotness is more frequently determined by HPLC (high performance liquid chromatography), whose results can be correlated to traditional Scoville ratings: the conversion generally accepted is that 15 Scoville units is equal to 1 ppm capsaicin plus capsaicinoids (Ritesh *et al.*, 2000).

Tewksbury and Nabhan (2001) investigated directed deterrence by capsaicin in chilies (*Capsicum*) and revealed that capsaicin, the chemical responsible for the fruit's peppery heat, selectively discourages vertebrate predators without deterring more effective seed dispersers. And opined that, worldwide popularity of chilies has prompted numerous investigations of the biological properties of capsaicin yet its evolutionary significance in the plants that produce it has not been examined completely.

Tewksbury *et al.*, (2008) showed that chemical defense of chilli ripe fruit reflects variation in the risk of microbial attack in *Capsicum chacoense*. In population producing varied contents of capsaicinoids in naturally polymorphic proportion, showed that variation is directly linked to variation in the damage caused by *Fusarium* fungal pathogen on chilli seeds and experimentally demonstrated that capsaicinoids protect chilli seeds from *Fusarium*. They also opined that pungency in chillies may be an adaptive response to selection by a microbial pathogen.

Materials and Methods

Forty seven (47) hot pepper genotypes belonging to three *Capsicum* species *viz.*, *Capsicum annuum var. longum*, *Capsicum frutescens* and *Capsicum chinense* were grown during March, 2008 using Completely Randomized Design following recommended package of practices (Anon. 2006). These genotypes showing consistent morphological characters confirming the true to type were subjected to self-pollination and the resulted seeds were used in the present studies.

The following observations were record. *viz.*, No. of seed fruit^{-1}, 1000 seed weight (g), Electrical conductivity (µS cm^{-1} g$^{-1)}$, Total dehydrogenase activity (TDH), Germination (%), Fresh ungerminated seeds (%), Seedling length (cm), Seedling vigour index-I, Seedling dry weight (mg). Seedling vigour index II, Seed infection (%), Fruit rot disease incidence on ripe fruits, Capsaicin (mg/g) (Sadasivam and Manickam, 1996 by calorimetric method), α-amylase activity (µg /ml/min.) as outlined by Sadasivam and Manickam, 1996, Total soluble seed protein content as per Lowry *et al.,* 1951, Oleoresin (%) as envisaged by Ranganna, 1996 with necessary modifications and ASTA color value.

Analysis of variance (ANOVA) was carried out as per the method suggested by Cochran and Cox (1959). The phenotypic and genotypic coefficient of variation was computed as per Burton and Dewane (1953) for low moisture stress. Heritability estimate was calculated using the formula (Hanson *et al.,* 1956) as per cent mean. Heritability percentage was categorized as given by Robinson *et al.,* 1949. Genetic advance was calculated by using formula given by Johnson *et al.*, (1955) and was expressed as per cent of mean. To estimate the degree of association between the traits studied, phenotypic correlation was computed by using the formula given by Sundararaj *et al.*, (1972). Path coefficient analysis was carried out as suggested by Wright (1921) and illustrated by Dewey and Lu (1959) in F_2 generations. Standard path coefficients, which are standardized partial regression coefficients, were obtained by solving the following sets of 'P' simultaneous equation by "DOOLITTLE TECHNIQUE" as described by Goulden, 1959. The data obtained from the experiment were statistically analyzed by using appropriate ANOVA by WINDOWSTAT version 9.1 from INDOSTAT services, Hyderabad licensed to Agriculture Knowledge Management Unit, GKVK, UAS, Bangalore.

Results and Discussion

Genetic variability and seed quality parameters

Phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV)

Number of seed fruit^{-1},1000 seed weight, electrical conductivity, total dehydrogenase activity, fresh ungerminated seeds, Seedling lengh, seedling vigour index I, seedling vigour index II, seed infection, fruit rot disease incidence on ripe fruits, α-amylase activity, total soluble seed protein content, capsaicin, oleoresin, ASTA colour value manifested higher level of PCV and GCV while germination *per cent* and seedling dry weight manifested moderate level of PCV and GCV with close correspondence between them indicated lesser influence of environment on these traits thus selection for these traits to study seed quality attributes at in hot peppers cultivars will be effective (Table 1).

Present results are in accordance with the earlier reports of high PCV and GCV for no. of seed fruit^{-1} (Mini *et al.,* 2004; Yudhvir and Madhu Sharma, 2008), oleoresin (Pitchumuthu and Pappiah,1995), fresh unfermented seeds (Claudinei *et al.,* 2006), fruit rot disease incidence on ripe fruits (Jayashree *et al.,* 2007 and Gadal *et al.,* 2003),total soluble seed protein content (Yudhvir *et al.,* 2009), capsaicin (Hedau *et al.,* 2008), oleoresin and ASTA colour value (Mini *et al.,* 2004; Naresh *et al.,* 2013; Shiva *et al.,* 2014).

Heritability and genetic advance

Electrical conductivity, total dehydrogenase activity, seedling dry weight, seed infection, fruit rot disease incidence on ripe fruits, total soluble seed protein content, capsaicin, ASTA color value, number of seed/fruit, 1000 seed weight, germination *per cent,* fresh ungerminated seeds, seedling length, seedling vigour index I, seedling vigour index II, α-amylase activity and oleoresin manifested higher heritability and GAM indicated the role of additive gene effects and hence selection would be rewarding for improvement of such traits (Table 1).

Whereas, the present study reported presence of moderate PCV and GCV for germination, seedlings dry weight, α-amylase activity, seed infection, seedling length, seedling vigour index I and II in the studied hot pepper genotypes.

Similarly, many researchers observed such presence of high GCV, PCV and high heritability coupled with genetic advance in (%) grand mean *viz.*, Sarkar *et al.*, (2009) for number of seeds fruit^{-1}; Manju and Srilathakumari (2002) for seed yield per fruit; Mini and Khader (2004) for 100 seed weight; Verma *et al.*, (2004) for days to 50 (%) germination; Yudhvir Singh and Madhu Sharma (2008) for oleoresin and capsaicin content in hot peppers.

Table.1 Genetic variability parameters in hot pepper

Sl. No.	Characters	Range		Grand Mean	GCV (%)	PCV (%)	h^2 (%) (Broad Sense)	GAM
		Highest	Lowest					
1	No. of seed fruit^{-1}	242.33	17.67	91.41	48.99	50.32	95	98.26
2	1000 seed weight (g)	9.74	0.3	5.49	27.65	28.49	94	55.28
3	Electrical conductivity (µS cm^{-1} g$^{-1)}$	13.48	0.33	2.15	144.13	144.14	100	296.91
4	Total dehydrogenase activity (TDH)	3.18	0.88	2.17	28.44	28.44	100	58.57
5	Germination (%)	96.33	38.67	77.2	16.47	16.79	96	33.27
6	Fresh ungerminated seeds (%)	9.73	0.71	1.83	136.81	137.23	99	280.98
7	Seedling length (cm)	17.88	5.87	12.81	21.44	22.4	92	42.28
8	Seedling vigour index-I	1488.67	283.33	1015.63	30.49	31.31	95	61.18
9	Seedling dry weight (mg)	14.69	8.11	11.48	13.12	13.12	100	27.03
10	Seedling vigour index II	1235.67	344.67	901.43	24.41	25.17	94	48.78
11	Seed infection (%)	82	0	31.57	68.06	68.18	100	139.97
12	Fruit rot disease incidence on ripe fruits	94.53	0	41.3	70.84	70.97	100	145.66
13	α-amylase activity (mg^{-1} ml^{-1}- min^{-1}.)	37.03	12	26.68	24.42	24.63	98	49.85
14	Total soluble seed protein content	18.05	6.38	11.65	29.24	29.24	100	60.24
15	Capsaicin (µg g^{-1})	417	27	178.95	54.43	54.55	100	111.85
16	Oleoresin (%)	22.58	3.2	11.65	35.82	35.99	99	73.43
17	ASTA color value	165.1	2.43	68.96	69.77	69.77	100	143.7

Where,

X_1 : Number of seed fruit^{-1}
X_2 : Test weight (g)
X_3 : Electrical conductivity (mS cm^{-1} g^{-1})
X_4 : Total dehydrogenase activity (A^0 480nm)
X_5 : Germination (%)
X_6 : Fresh ungerminated seeds (%)
X_7 : Seedling length (cm)
X_8 : Seedling vigour index-I
X_9 : Seedling dry weight (mg)
X_{10} : Seedling vigour index-II
X_{11} : Seed infection (%)
X_{12} : Fruit rot disease incidence on ripe fruits (%)
X_{13} : α-amylase activity (µg ml^{-1} min^{-1}.)
X_{14} Total soluble seed protein content (µg g^{-1})
X_{15} : Capsaicin (µg g^{-1})
X_{16} : Oleoresin (%)
X_{17} : ASTA color value

Table.2 Estimation of phenotypic correlation coefficients between seed quality attributes and germination

	X_1	X_2	X_3	X_4	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_5
X_1	**1**	0.6053**	-0.3062**	0.5047**	-0.3291**	0.6084**	0.532**	0.5887**	0.4577**	0.5743**	0.4477**	0.4876**	0.4061**	-0.5051**	0.1868**	0.5139**	0.2816**
X_2		**1**	-0.3445**	0.3995**	-0.2952**	0.4838**	0.4475**	0.5547**	0.4772**	0.3692**	0.3435**	0.3764**	0.2829**	-0.3989**	0.1383	0.2495**	0.2997**
X_3			**1**	-0.5398**	0.8228**	-0.6637**	-0.7374**	-0.5517**	-0.7284**	-0.537**	-0.4623**	-0.5984**	-0.4037**	0.678**	-0.0686	-0.336**	-0.8125**
X_4				**1**	-0.627**	0.6094**	0.6764**	0.6517**	0.7158**	0.6073**	0.5414**	0.9876**	0.7862**	-0.7846**	0.2855**	0.762**	0.6566**
X_6					**1**	-0.7278**	-0.81**	-0.5762**	-0.7905**	-0.5763**	-0.4733**	-0.6519**	-0.4447**	0.7141**	-0.2492**	-0.4027**	-0.889**
X_7						**1**	0.9682**	0.8302**	0.8227**	0.6161**	0.4852**	0.6241**	0.6225**	-0.7477**	0.245**	0.5025**	0.7296**
X_8							**1**	0.8212**	0.9106**	0.6211**	0.4953**	0.6966**	0.684**	-0.7993**	0.2824**	0.5484**	0.8694**
X_9								**1**	0.8757**	0.552**	0.455**	0.665**	0.6581**	-0.6961**	0.1717**	0.4966**	0.6276**
X_{10}									**1**	0.5901**	0.4927**	0.7373**	0.7078**	-0.7832**	0.2715**	0.5541**	0.8991**
X_{11}										**1**	0.8712**	0.6106**	0.4627**	-0.7655**	0.2012**	0.5425**	0.5309**
X_{12}											**1**	0.5462**	0.423**	-0.6076**	0.2813**	0.4788**	0.4458**
X_{13}												**1**	0.7786**	-0.7982**	0.2585**	0.7454**	0.6895**
X_{14}													**1**	-0.6283**	0.3724	0.6853**	0.6082**
X_{15}														**1**	-0.1467**	-0.6213**	-0.7482**
X_{16}															**1**	0.5346**	0.2786**
X_{17}																**1**	0.4885**

R^2= 0.9859 Residual effect = 0.1186

Where,

X_1 : No. of seed fruit^{-1}
X_2 : Test weight (g)
X_3 : Electrical conductivity (mS cm^{-1} g^{-1})
X_4 : Total dehydrogenase activity (A^0 480nm)
X_5 : Germination (%)
X_6 : Fresh ungerminated seeds (%)
X_7 : Seedling length (cm)
X_8 : Seedling vigour index-I
X_9 : Seedling dry weight (mg)
X_{10} : Seedling vigour index-II
X_{11} : Seed infection (%)
X_{12} : Fruit rot disease incidence on ripe fruits (%)
X_{13} : α-amylase activity (µg ml^1 min^1)
X_{14} : Total soluble seed protein content (µg g^{-1})
X_{15} : Capsaicin (µg g^{-1})
X_{16} : Oleoresin (%)
X_{17} : ASTA color value

Table.3 Estimation of phenotypic path coefficients between seed quality attributes and germination

	X_1	X_2	X_3	X_4	X_6	X_7	X_8	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_5
X_1	**0.0038**	0.0023	-0.0012	0.0019	-0.0012	0.0023	0.002	0.0022	0.0017	0.0022	0.0017	0.0018	0.0015	-0.0019	0.0007	0.0019	0.2816
X_2	0.0034	**0.0056**	-0.0019	0.0022	-0.0016	0.0027	0.0025	0.0031	0.0027	0.0021	0.0019	0.0021	0.0016	-0.0022	0.0008	0.0014	0.2997
X_3	0.0237	0.0266	**-0.0773**	0.0417	-0.0636	0.0513	0.057	0.0427	0.0563	0.0415	0.0357	0.0463	0.0312	-0.0524	0.0053	0.026	-0.8125
X_4	-0.0579	-0.0458	0.0619	**-0.1147**	0.0719	-0.0699	-0.0776	-0.0748	-0.0821	-0.0697	-0.0621	-0.1133	-0.0902	0.09	-0.0328	-0.0874	0.6566
X_5	0.0747	0.067	-0.1866	0.1422	**-0.2268**	0.1651	0.1837	0.1307	0.1793	0.1307	0.1074	0.1479	0.1009	-0.162	0.0565	0.0913	-0.889
X_6	-0.7929	-0.6306	0.865	-0.7943	0.9487	**-1.3034**	-1.2619	-1.0822	-1.0723	-0.8031	-0.6325	-0.8135	-0.8114	0.9745	-0.3193	-0.655	0.7296
X_7	0.9793	0.8237	-1.3574	1.2451	-1.491	1.7822	**1.8408**	1.5117	1.6762	1.1432	0.9118	1.2822	1.2592	-1.4714	0.5198	1.0095	0.8694
X_8	-0.0696	-0.0656	0.0652	-0.077	0.0681	-0.0981	-0.097	**-0.1182**	-0.1035	-0.0652	-0.0538	-0.0786	-0.0778	0.0823	-0.0203	-0.0587	0.6276
X_9	0.0838	0.0874	-0.1334	0.1311	-0.1447	0.1506	0.1667	0.1604	**0.1831**	0.1081	0.0902	0.135	0.1296	-0.1434	0.0497	0.1015	0.8991
X_{10}	-0.032	-0.0206	0.0299	-0.0338	0.0321	-0.0343	-0.0346	-0.0307	-0.0329	**-0.0557**	-0.0485	-0.034	-0.0258	0.0426	-0.0112	-0.0302	0.53
X_{11}	0.0192	0.0147	-0.0198	0.0232	-0.0203	0.0208	0.0212	0.0195	0.0211	0.0374	**0.0429**	0.0234	0.0181	-0.0261	0.0121	0.0205	0.4458
X_{13}	0.0354	0.0273	-0.0434	0.0716	-0.0473	0.0453	0.0505	0.0482	0.0535	0.0443	0.0396	**0.0725**	0.0565	-0.0579	0.0187	0.054	0.6895
X_{14}	0.0019	0.0013	-0.0019	0.0036	-0.002	0.0029	0.0031	0.003	0.0033	0.0021	0.0019	0.0036	**0.0046**	-0.0029	0.0017	0.0031	0.6082
X_{15}	0.0079	0.0062	-0.0106	0.0122	-0.0111	0.0116	0.0125	0.0108	0.0122	0.0119	0.0095	0.0124	0.0098	**-0.0156**	0.0023	0.0097	-0.7482
X_{16}	-0.0015	-0.0011	0.0006	-0.0024	0.0021	-0.002	-0.0023	-0.0014	-0.0022	-0.0017	-0.0023	-0.0021	-0.0031	0.0012	**-0.0083**	-0.0044	0.2786
X_{17}	0.0026	0.0013	-0.0017	0.0039	-0.0021	0.0026	0.0028	0.0025	0.0028	0.0028	0.0024	0.0038	0.0035	-0.0032	0.0027	**0.0051**	0.4885

R^2= 0.9859 Residual effect = 0.1186

Where,

X_1	: No. of seed fruit^{-1}	X_{11}	: Seed infection (%)
X_2	: Test weight (g)	X_{12}	: Fruit rot disease incidence on ripe fruits (%)
X_3	: Electrical conductivity (mS cm^{-1} g^{-1})	X_{13}	: α-amylase activity (µg ml^{-1} min^{-1})
X_4	: Total dehydrogenase activity (A^0 480nm)	X_{14}	: Total soluble seed protein content (µg g^{-1})
X_5	: Germination (%)	X_{15}	: Capsaicin (µg g^{-1})
X_6	: Fresh ungerminated seeds (%)	X_{16}	: Oleoresin (%)
X_7	: Seedling length (cm)	X_{17}	: ASTA color value
X_8	: Seedling vigour index-I		
X_9	: Seedling dry weight (mg)		
X_{10}	: Seedling vigour index-II		

Table.4 Estimation of phenotypic correlation coefficients between seed quality attributes and seed infection

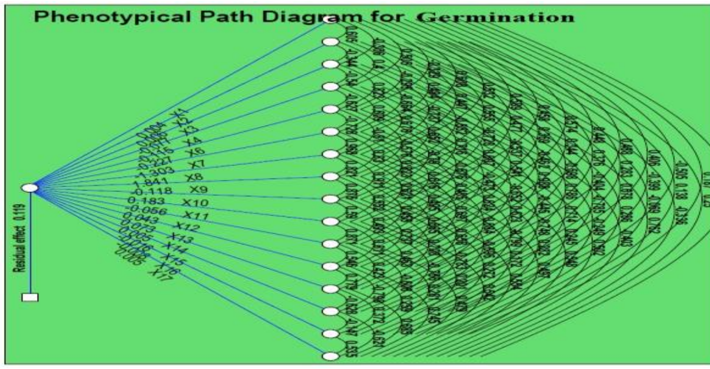
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9	X_{10}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}	X_{17}	X_{11}
X_1	**1**	0.6053**	-0.3062**	0.5047**	0.2816**	-0.3291**	0.6084**	0.532**	0.5887**	0.4577**	0.4477**	0.4876**	0.4061**	-0.5051**	0.1868**	0.5139**	0.5743**
X_2		**1**	-0.3445**	0.3995**	0.2997**	-0.2952**	0.4838**	0.4475**	0.5547**	0.4772**	0.3435**	0.3764**	0.2829**	-0.3989**	0.1383	0.2495**	0.3692**
X_3			**1**	-0.5398**	-0.8125**	0.8228**	-0.6637**	-0.7374**	-0.5517**	-0.7284**	-0.4623**	-0.5984**	-0.4037**	0.678**	-0.0686	-0.336**	-0.537**
X_4				**1**	0.6566**	-0.627**	0.6094**	0.6764**	0.6517**	0.7158**	0.5414**	0.9876**	0.7862**	-0.7846**	0.2855**	0.762**	0.6073**
X_5					**1**	-0.889**	0.7296**	0.8694**	0.6276**	0.8991**	0.4458**	0.6895**	0.6082**	-0.7482**	0.2786**	0.4885**	0.5309**
X_6						**1**	-0.7278**	-0.81**	-0.5762**	-0.7905**	-0.4733**	-0.6519**	-0.4447**	0.7141**	-0.2492**	-0.4027**	-0.5763**
X_7							**1**	0.9682**	0.8302**	0.8227**	0.4852**	0.6241**	0.6225**	-0.7477**	0.245**	0.5025**	0.6161**
X_8								**1**	0.8212**	0.9106**	0.4953**	0.6966**	0.684**	-0.7993**	0.2824**	0.5484**	0.6211**
X_9									**1**	0.8757**	0.455**	0.665**	0.6581**	-0.6961**	0.1717**	0.4966**	0.552**
X_{10}										**1**	0.4927**	0.7373**	0.7078**	-0.7832**	0.2715**	0.5541**	0.5901**
X_{12}											**1**	0.5462**	0.423**	-0.6076**	0.2813**	0.4788**	0.8712**
X_{13}												**1**	0.7786**	-0.7982**	0.2585**	0.7454**	0.6106**
X_{14}													**1**	-0.6283**	0.3724**	0.6853**	0.4627**
X_{15}														**1**	-0.1467	-0.6213**	-0.7655**
X_{16}															**1**	0.5346**	0.2012**
X_{17}																**1**	0.5425**

R^2= 0.8807 Residual effect = 0.3453

Where,

X_1 : No. of seed fruit^{-1}
X_2 : Test weight (g)
X_3 : Electrical conductivity (mS cm^{-1} g^{-1})
X_4 : Total dehydrogenase activity (A^0 480nm)
X_5 : Germination (%)
X_6 : Fresh ungerminated seeds (%)
X_7 : Seedling length (cm)
X_8 : Seedling vigour index-I
X_9 : Seedling dry weight (mg)
X_{10} : Seedling vigour index-II
X_{11} : Seed infection (%)
X_{12} : Fruit rot disease incidence on ripe fruits (%)
X_{13} : α-amylase activity (μg ml^{-1} min^{-1})
X_{14} : Total soluble seed protein content (μg g^{-1})
X_{15} : Capsaicin (μg g^{-1})
X_{16} : Oleoresin (%)
X_{17} : ASTA color value

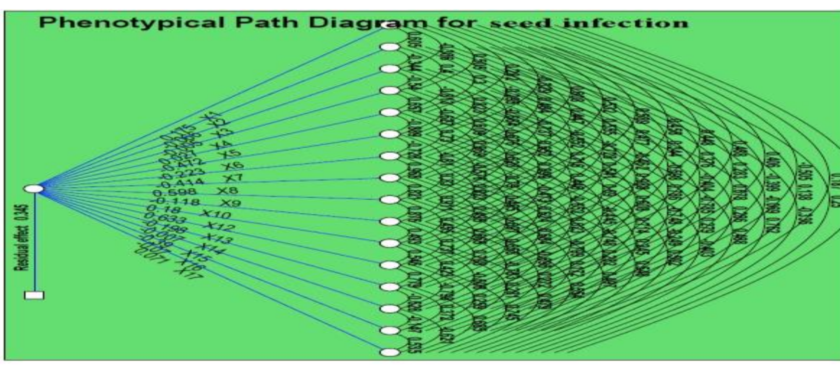
Fig.1 Estimation of phenotypic path coefficients between seed quality attributes and germination



Where:

X_1 : No. of seed fruit^{-1}
X_2 : Test weight (g)
X_3 : Electrical conductivity (mS cm^{-1} g^{-1})
X_4 : Total dehydrogenase activity (A^0 480nm)
X_5 : Germination (%)
X_6 : Fresh ungerminated seeds (%)
X_7 : Seedling length (cm)
X_8 : Seedling vigour index-I
X_9 : Seedling dry weight (mg)
X_{10} : Seedling vigour index-II
X_{11} : Seed infection (%)
X_{12} : Fruit rot disease incidence on ripe fruits (%)
X_{13} : α-amylase activity (μg ml^{-1} min^{-1})
X_{14} :Total soluble seed protein content (μg g^{-1})
X_{15} : Capsaicin (μg g^{-1})
X_{16} : Oleoresin (%)
X_{17} : ASTA color value

Fig.2 Estimation of phenotypic path coefficients between seed quality attributes and seed infection



Where:

X_1 : No. of seed fruit^{-1}
X_2 : Test weight (g)
X_3 : Electrical conductivity (mS cm^{-1} g^{-1})
X_4 : Total dehydrogenase activity (A^0 480nm)
X_5 : Germination (%)
X_6 : Fresh ungerminated seeds (%)
X_7 : Seedling length (cm)
X_8 : Seedling vigour index-I
X_9 : Seedling dry weight (mg)
X_{10} : Seedling vigour index-II
X_{11} : Seed infection (%)
X_{12} : Fruit rot disease incidence on ripe fruits (%)
X_{13} : α-amylase activity (μg ml^{-1} min^{-1})
X_{14} : Total soluble seed protein content (μg g^{-1})
X_{15} : Capsaicin (μg g^{-1})
X_{16} : Oleoresin (%)
X_{17} : ASTA color value

Association of characters

Germination (%)

The characters such as number of seed fruit^{-1} (0.2816), 1000 seed weight (0.2997), total dehydrogenase activity (0.6566), seedling length (0.7296), vigour index I (0.8694), vigour index II (0.8991) seed infection (0.5309), fruit rot disease incidence on ripe fruits (0.4458), α-amylase activity (0.6895), total soluble seed protein content (0.6082), oleoresin (0.2786), ASTA color value (0.4885) and seedling dry weight (0.6276) showed significant positive correlation with germination per cent while electrical conductivity (-0.8125), fresh ungerminated seeds (-0.8890), capsaicin (-0.7482) showed significant negative correlation with germination per cent (Table 2.).

Number of seed fruit^{-1}, 1000 seed weight, total dehydrogenase activity, seedling length, seedling vigour index-I, seedling vigour index-I, seed infection, fruit rot disease incidence on ripe fruits, α-amylase activity, total soluble seed protein content, oleoresin, ASTA colour value and seedling dry weight manifested significant positive correlation with germination per cent suggested the effectiveness of selection based on these characters in improving the germination per cent while electrical conductivity, fresh ungerminated seeds and capsaicin showed significant negative correlation with germination per cent indicated limited success of selection for these traits in improving germination per cent.

Seed infection (%)

The characters such as number of seed fruit^{-1} (0.5743), 1000 seed weight (0.3692), total dehydrogenase activity (0.6073), germination (0.5309), seedling length (0.6161), vigour index I (0.6211), seedling dry weight (0.5520), vigour index II (0.5901), fruit rot disease incidence on ripe fruits (0.8712), α-amylase activity (0.6106), Total soluble seed protein content (0.4627), oleoresin (0.2012), ASTA color value (0.5425) showed significant positive correlation with seed infection while Electrical conductivity (-0.5370), fresh ungerminated seeds (-0.5763), capsaicin (-0.7655) showed significant negative correlation with seed infection (Table 3) .

The characters such as number of seed fruit^{-1}, 1000 seed weight, total dehydrogenase activity, germination, seedling length, seedling vigour index-I, seedling dry weight, seedling vigour index-II, fruit rot disease incidence on ripe fruits, α-amylase activity, total soluble seed protein content, oleoresin and ASTA colour value showed significant positive correlation with seed infection suggested the effectiveness of selection based on these characters in improving the seed infection. While, electrical conductivity, fresh ungerminated seeds and capsaicin showed significant negative correlation with seed infection indicated limited success of selection for these traits in improving seed infection.

Direct effect of different characters on seed germination per cent at phenotypic level

At the phenotypic level, seedling vigour index-I recorded the highest positive direct effect on germination per cent, followed by seedling vigour index-II which was of considerable magnitude. number of seed fruit^{-1}, 1000 seed weight, fruit rot disease incidence on ripe fruits, α-amylase activity, total soluble seed protein content and ASTA colour value recorded positive direct effects on germination per cent but their magnitude were low. However, seedling length recorded the highest negative direct effect on germination per cent followed by fresh ungerminated seeds, seedling dry weight, and total dehydrogenase activity. Electrical conductivity, seed infection, capsaicin and oleoresin recorded negative direct effect on germination per cent but their magnitude were low (*Fig*. 1).

Direct effect of different characters on seed infection at phenotypic level

At the phenotypic level, fruit rot disease incidence on ripe fruits recorded the highest positive direct effect on seed infection, followed by vigour index I which was of considerable magnitude. Number of seed fruit^{-1}, total dehydrogenase activity, vigour index ii and ASTA colour value recorded positive direct effects on seed infection but their magnitude were low. Whereas, germination per cent recorded the highest positive direct effect on seed infection followed by seedling length, capsaicin which was of considerable magnitude. 1000 seed weight, electrical conductivity, fresh ungerminated seeds, seedling dry weight, α-amylase activity, total soluble seed protein content and oleoresin recorded the negative direct effect on seed infection but their magnitude were low (*Fig*. 2). Such findings were also reported by Dewey and Lu, 1957 in wheat grass, Jayashree *et al.,* 2007 and Sarkar *et al.*, 2009 for path analysis of morphological characters in hot pepper.

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