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Heterosis and Combining Ability in Partial Diallel Crosses of Sweet Pepper (*Capsicum annuum* L.)

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The present study was aimed at evaluating various crosses under a partial diallel mating design for quantitative and qualitative parameters to develop suitable F_1S. Heterosis and combining ability studies of 25 hybrids along with their 10 parents were carried out. Analysis of variance for combining ability revealed that variances due to GCA (general combining ability) and SCA (specific combining ability) were highly significant for all the characters studied indicating the importance of additive and non-additive gene effects. Significant relative heterosis was revealed in order of magnitude by total chlorophyll (283.10%) followed by fruit yield/plant (198.11%), ascorbic acid (148.22%) fruit weight (93.13%), number of fruits/plant (60.08%), pericarp thickness (40.74%), fruit circumference (34.23%) and fruit length (12.50%). In view of the best performance in yield, the F_1 hybrid (09/ Cvar1 x DARL 74) may be recommended for commercial utilization followed by (09/ Cvar 5 x DARL 82).

Key Words: ***Capsicum annuum*****, Combining ability, Heterosis, Partial Diallel Cross**

Introduction

Sweet pepper or capsicum is normally considered as a luxury vegetable, consumption being greater in and around the cities (Singh *et al.*, 1993). Being a cool season crop, it is popularly grown in the hills of Uttarakhand, Himanchal Pradesh and Uttar Pradesh. Exploitation of hybrid vigour based on the information of combining ability is an important and efficient breeding approach in crop improvement. Thus, breeding value of an individual genotype becomes one of the significant criteria for selection as parental line to be used in hybrid breeding program. Due to environmental variance, selection of parents on the basis of *per se* performance may not necessarily lead to desirable results (Allard, 1960). The partial diallel mating system is suitable for estimation of combining abilities among crosses. The theory of partial diallel cross for a random set of genotypes was introduced (Kempthorne and Curnow, 1961). The number of crosses is reduced relative to the complete diallel, thus, allowing the evaluation of a greater number of parents or genotypes, which enhances the efficiency of the design for the estimation of variances and of combining abilities of the parents. F_1 hybrids in capsicum are gaining increasing popularity among farmers throughout the world. Hybrids play an important role in enhancing the yield potential (Mamedow and Pyshnaja, 2001).The present investigation therefore was undertaken to identify potential parental combinations in order to have superior hybrids of excellent quality coupled with high yields.

Materials and Methods

Ten diverse genotypes *viz.*, 09/Cvar 1, 09/Cvar 2, 09/ Cvar 3, 09/Cvar 4, 09/Cvar 5, 09/Cvar 6, DARL 73, DARL 74, DARL 7 and DARL 82 were crossed in a partial diallel mating design. A total of 25 hybrids were found successfully with S= 5 and K=3 (symmetrical circulant matrix A). This means that in each array, five crosses were made (S=5) and sampling was to begin after 3rd array i.e. from the fourth array. The experimental material consisting of 25 F_1S with their 10 parents was sown in February, 2012 and transplanted in the field in the month of April, 2012 in a randomized block design with three replications at Defence Institute of Bio Energy Research, Pithoragarh. Net plot size was 3 m x 2 m = 6 m^2. The inter-row and inter-plant distance was 50 cm x 50 cm. Observations were recorded on five randomly selected plants in each replication for fruit length (cm), fruit circumference (cm), fruit weight (g), fruits/plant (no.), fruit yield/plant (kg), pericarp thickness (mm), plant height (cm), ascorbic acid (mg/100g) and total chlorophyll (mg/100g), anti-oxidant activity (µg/100g). The pericarp thickness was measured with the help of Vernier Caliper and the mean values were calculated. Sweet pepper fruits with thicker pericarp not only withstand long distance transportation, but also have invariably longer shelf life (Choudhary *et al.*, 2011).

The chemical analyses of fresh fruits included determination of ascorbic acid by 2, 6 dichlorophenol indophenols titration method (AOAC, 1970) and total

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chlorophyll (Witham *et al.*, 1971). The dried fruits of parents and F_1 hybrids were analyzed for antioxidant activity using DPPH method (Hatano, 1988). Data were analyzed and found significant. The mean values of different genotypes for various characters were statistically analyzed using SPAR-1 programme of Doshi and Gupta (1981). SPAR I (developed by Indian Agricultural Statistical Research Institute, New Delhi, India) software was used for statistical analysis. Heterosis was expressed as percent deviation of the F_1 from mid parent (relative heterosis) and calculated by the formula given by Alllard (1960). Mid Parent Heterosis = F_1 Value – Mid Parent Value/ Mid Parent Value x 100.

Results and Discussion

Analysis of variance (ANOVA) for combining ability revealed that variances due to GCA (general combining ability) and SCA (specific combining ability) were highly significant for all the characters studied indicating the importance of additive and non - additive gene effects (Table 1). For almost all characters both additive and non-additive gene action influenced the performance of the hybrids. The non-additive effects played a more important role than additive effects. The magnitudes of GCA and SCA effects are indicative of the relative importance of additive and non-additive gene actions in the inheritance of a trait, respectively. Patil *et al.* (2010) studied combining ability analysis in chilli (*Capsicum annuum* L.) and found the same results. The magnitude of σ^2 GCA (variance of general combining ability) was lower than σ^2 SCA (variance of specific combining ability) for all the characters. The large GCA: SCA variance ratio suggests the importance of additive gene effects, while a low ratio signifies presence of dominant and/or epistatic gene effects. The lower σ2g/σ2s ratio indicates that the predominance of non-additive (dominance or epistasis) gene action is important for all the traits (Table 1). The involvement of non-additive gene effects suggests the improvement of these characters through hybrid breeding. Similar studies were carried out in Yelllow Sarson by Singh and Mishra (2001) and by Torres and Geradi (2007) in rice, Hasanuzzaman *et al.* (2012) in chilli, Chaudhary *et al.* (2013) in chilli and Nascimento *et al.* (2014) in pepper.

In the present investigation, potentiality of the parents was assessed by general combining ability effects (Table 2). Considering the GCA effects, the general combiners were DARL 82 (0.755) for fruit length, DARL 77(2.219) for fruit circumference, 09/Cvar 4 (18.859) for fruit weight, 09/Cvar3 (3.111) for fruit number, 09/Cvar 3 (0.318) for fruit yield per plant, DARL 82 (-6.496) for plant height, 09/Cvar 5 (45.731) for ascorbic acid, 09/ Cvar5 (2.358) for total chlorophyll, DARL 77 (-0.815) for antioxidant activity, 09/Cvar 4 (0.421) for pericarp thickness. High GCA effects are mostly due to additive gene effects or additive x additive gene effects. The negative estimates of GCA effects are desirable for reduce plant height and anti oxidant activity. Good general combiners for number of fruits/plant and yield of chilli were reported by a number of workers (Zewdie and Bosland, 2001; Prasath and Ponnuswami, 2008 and Payakhapaab *et al.*, 2012).

Among 10 parents used in the study, the parent 09/ Cvar 4 for fruit length, DARL 82 for fruit circumference and fruit yield per plant, 09/Cvar 5 for fruit weight and fruit number, 09/Cvar6 for ascorbic acid, pericarp thickness and plant height (dwarfness), 09/Cvar 3 for total chlorophyll and 09/Cvar 2 for antioxidant activity were found best as *per se* performance (Table 3). In order of merit DARL 82, DARL 73 and 09/Cvar 5 were found to be the best performing lines for yield/plant.

Significant relative heterosis was revealed (Table 4) in order of magnitude by total chlorophyll (283.10%) followed by fruit yield per plant (198.11%), ascorbic acid (148.22%), fruit weight (93.13%), number of fruits per plant (60.08%), pericarp thickness (40.74%), fruit width (34.23%) and fruit length (12.50%). The heterosis response observed in most of the hybrids further supported the predominant role of non-additive component in the inheritance of the character studied. Sood and Kaul (2006) also studied a diallel set of six pure lines in capsicum. For fruit length heterosis percentage ranged from -28.91 to 38.55 and the cross 09/ Cvar 2 x DARL 74 exhibited the maximum heterotic percentage (38.55%) followed by 09/ Cvar 3 x DARL 82 (30.20%). For the character fruit circumference, cross 09/ Cvar 2 x DARL 73 showed highest heterosis percentage (34.23) followed by 09/ Cvar 2 x DARL 77 (30.02). For fruit yield 09/ Cvar 1 x DARL 74 exhibited the highest heterosis percentage (198.11) followed by 09/ Cvar5 x DARL 82 (160.51). Cross 09/ Cvar1 x DARL 74 was found superior heterotic cross having relative heterosis 60.08 percent followed by 09/ Cvar 4 x DARL 73 (56.38%) for number of fruits per plant. For plant height 09/ Cvar 3 x DARL 74 exhibited the maximum negative heterosis (-37.40%) followed by 09/ Cvar4 x DARL 77 (-32.745) which is

Table 1. ANOVA for combining ability for quantitative and qualitative characters

Source	df	Fruit length (cm)	Fruit circumference (cm)	Fruit weight (g)	Fruit number (no)	Fruit yield (kg)	Plant height (cm)	Ascorbic acid (mg/100g)	Total chlorophyll (mg/100g)	Anti Oxidant activity (µg/100g)	Pericarp thickness (mm)
GCA	9	1.381**	20.40**	1465.88**	42.02**	0.558**	281.9**	7527.96**	30.4**	1.215**	0.6326**
SCA	24	1.458**	10.54**	729.93**	54.27**	0.095**	406.8**	11207.91**	27.71**	1.688**	1.477**
Error	48	0.645	1.224	56.99	1.208	0.0192	20.262	50.69	.0134	.00209	0.0432
Variance of GCA	σ^2 GCA	-0.057	0.739	55.19	-0.918	.0347	-9.369	275.99	0.2027	-0.354	-0.0633
Variance of SCA	σ^2 SCA	1.131	1.310	224.31	17.39	.0253	128.85	3719.07	1.923	1.229	0.4781
Average degree of variance	$\sqrt{\sigma^2 \text{GCA}/\sigma^2 \text{SCA}}$	-4.45	1.548	2.01	-4.352	0.853	-3.708	3.670	3.080	-1.863	-2.748

**, Significant at 1% level.

Table 2. Estimates of general combining ability (GCA) for different characters

Parents	Characters									
	Fruit length (cm)	Fruit circumference (cm)	Fruit weight (g)	Fruit number (no.)	Fruit yield (kg)	Plant height (cm)	Ascorbic acid (mg/100g)	Total chlorophyll (mg/100g)	Antioxidant activity (µg/100g)	Pericarp thickness (mm)
09/Cvar 1	-0.159	0.286	-0.934	-0.508	-0.328**	7.469**	-50.803**	0.462**	0.155**	-0.117
09/Cvar 2	0.364	1.055	2.590	-3.157**	0.075	-1.292	-7.751	-2.293**	0.576**	0.149
09/Cvar 3	-0.512	-1.010	0.953	3.111**	0.318**	-4.43**	-22.736**	-1.538**	0.313**	-0.203
09/Cvar 4	0.671	0.874	18.859**	1.665	0.278**	4.982**	30.849**	0.564**	-0.151**	0.421
09/Cvar 5	-1.155	-1.993*	-17.522**	-0.476	-0.145**	3.645**	45.731**	2.358**	0.358**	0.063
09/Cvar 6	-0.314	-2.230*	-7.071*	1.463	-0.192**	0.734	5.576	2.126**	-0.328**	-0.273
DARL 73	-0.097	0.355	-7.549*	0.338	-0.047	-0.845	-2.342	-1.468**	0.327**	-0.042
DARL 74	0.158	-0.328	5.108	0.470	0.102	-3.853**	4.800	0.860**	-0.125**	0.089
DARL 77	0.289	2.219*	-7.198*	-1.657	0.001	0.087	7.925	-0.807**	-0.815**	0.060
DARL 82	0.755	0.862	12.763**	-1.250	-0.062	-6.496**	-11.224	-0.267**	-0.311**	-0.145
(Gi-Gj)	0.851	1.957	135.41	10.06	0.017	75.47	2079.31	1.514	1.277	0.274

**, * Significant at 1% and 5% level respectively a desirable character. For antioxidant activity, 09/ Cvar 4 x DARL 74 (-70.15% heterosis) expressed highest antioxidant activity followed by 09/ Cvar 6 x DARL 77 (-67.81% heterosis). For ascorbic acid content, 09/ Cvar 3 x DARL 74 was found superior heterotic cross (148.22%) followed by 09/ Cvar 3 x DARL 74 (134.56%) and 09/ Cvar1 x DARL 74 (95.51%). For the character total chlorophyll, the cross combination 09/ Cvar 4 x DARL 82 was found superior having heterosis percentage (283.10) followed by 09/ Cvar1 x DARL 74 (172.63%). Heterosis for green fruit yield and its components in chilli was also studied by Patel *et al.* (2010). Heterosis studies for earliness, fruit yield and yield attributing traits in bell pepper was studied by (Sood and Kumar, 2010a; Sood and Kumar, 2010b; Shrestha *et al.*, 2011; Sharma *et al.*, 2013).

In the present study, three type of cross combinations were involved such as high x high, high x low and low x low, of which high x low combinations exhibited high heterosis, while high x high combinations showed less heterosis and low x low combinations showed considerable heterosis. The reason may be additive x additive and additive x dominance gene interactions. Negative significant heterosis may be due to inhibitory gene action and suppression of multiple allele by dominant gene.

From the present investigation, it is concluded that the general combiners for different characters can be used in future breeding programme for the development of varieties. To achieve higher yield through F_1 hybrid, the parental lines chosen should possess one or more of the important character like fruit yield/plant, fruit weight, number of fruits/plant along with bio-chemical parameters like ascorbic acid and antioxidant activity. The cross combinations had high heterosis for most of the yield contributing traits. These hybrids offer high scope for the exploitation of heterosis for improving horticultural traits. These cross-combinations could be utilized as hybrid breeding and can also be released as hybrids after further field testing. In view of the best performance in yield, the F_1 hybrid (09/Cvar1 x DARL 74) may be recommended for commercial utilization followed by (09/ Cvar 5 x DARL 82).

Table 3. ***Per se*** **performance of parental lines for different characters**

Parents	Characters (per se performance)									
	Fruit length (cm)	Fruit width (cm)	Fruit weight (g)	Fruit/plant (no)	Fruit yield/ plant (kg)	Plant height (cm)	Ascorbic acid (mg/100g)	Total chlorophyll (mg/100g)	Antioxidant activity (µg/100g)	Pericarp thickness (mm)
09/Cvar 1	8.70	23.00	95.00	15.33	0.780	60.00	133.00	5.30	2.42	3.52
09/Cvar 2	7.60	17.40	49.00	15.67	0.540	91.20	83.00	11.01	1.48	2.66
09/Cvar 3	7.67	17.00	77.33	21.33	0.380	93.87	72.00	14.17	2.04	2.32
09/Cvar 4	11.07	24.67	59.00	13.33	0.640	68.80	127.00	0.94	3.73	2.95
09/Cvar 5	10.13	20.53	108.67	22.00	1.050	56.87	154.00	7.90	5.07	3.33
09/Cvar 6	8.40	19.40	66.23	15.33	0.740	52.67	200.00	8.55	7.53	4.15
DARL 73	9.27	19.00	58.33	12.67	1.140	65.33	180.00	3.93	2.38	3.10
DARL 74	9.00	21.67	79.33	18.00	1.040	66.93	90.00	0.84	2.34	2.01
DARL 77	10.80	22.43	100.00	14.00	1.010	68.97	163.00	7.38	1.70	3.55
DARL 82	9.93	25.20	76.67	11.10	1.190	68.13	127.33	3.47	2.23	2.94
CD @ 1%	2.309	3.178	5.688	3.932	0.397	4.811	5.565	0.332	.0415	0.594
CD @ 5%	1.936	2.665	4.770	3.297	0.333	4.035	4.667	0.279	0.034	0.498
SEM	0.656	0.903	1.616	1.117	0.113	1.367	1.581	.0946	.0118	0.169

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Table 4. Per se performance of parental lines for different characters in hybrids and Heterosis percentage over mid parent value (Relative Heterosis %)

Hybrids	Characters									
	Fruit length (cm)		Fruit width (cm)		Fruit weight (g)		Fruit/plant (no)		Fruit yield/plant (kg)	
	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)
09/Cvar 1 x 09/Cvar4	9.20	-6.88	21.40	-10.19**	88.33	14.71**	22.00	53.63**	1.780	150.70**
09/Cvar 1 x 09/Cvar5	9.43	0.11	19.17	-11.90**	86.67	-14.18**	24.67	32.20**	1.830	100.00**
09/Cvar 1 x 09/Cvar6	7.50	-12.28**	17.33	-18.25**	57.67	-28.45**	13.33	-13.04**	1.190	56.57**
09/Cvar 1 x DARL 73	8.17	-9.02	21.73	3.47	60.00	-21.73**	15.00	7.14	1.430	57.14**
09/Cvar 1 x DARL 74	10.63	20.11**	20.60	-7.78	110.00	26.20**	26.67	60.08**	2.370	198.11**
09/Cvar 2 x 09/Cvar5	10.20	15.12**	21.07	11.07**	101.67	28.95**	18.00	-4.46	1.430	123.40**
09/Cvar 2 x 09/Cvar6	10.13	20.02**	21.20	15.21**	95.00	64.87**	23.90	54.19**	1.350	60.71**
09/Cvar 2 x DARL 73	10.47	24.50**	24.43	34.23**	96.67	80.15**	19.37	36.69**	1.260	59.49**
09/Cvar 2 x DARL 74	11.50	38.55**	22.47	15.05**	110.00	71.44**	15.87	-5.76	1.340	49.72**
09/Cvar 2 x DARL 77	8.13	-11.63**	20.57	30.02**	70.00	-6.04	16.50	11.26**	1.130	101.78**
09/Cvar 3 x 09/Cvar6	8.20	1.99	19.67	8.07	57.67	-19.05**	17.27	-5.78	0.850	11.84
09/Cvar 3 x DARL 73	10.00	18.06**	21.50	19.44**	83.67	23.35**	13.50	25.92**	0.830	5.06
09/Cvar 3 x DARL 74	10.43	25.21**	20.80	7.60	72.67	-7.22	18.33	39.81**	0.620	-10.79
09/Cvar 3 x DARL 77	9.30	51.21**	18.47	-6.29	78.00	-12.02**	16.27	0.24	0.740	-5.73
09/Cvar 3 x DARL 82	7.63	30.20**	21.77	3.17	71.67	-6.92	14.30	32.28**	0.730	-7.00
09/Cvar 4 x DARL 73	12.13	19.27**	25.10	14.92**	113.33	93.19**	20.33	56.38**	1.646	84.94**
09/Cvar 4 x DARL 74	9.46	5.77	22.00	-5.04	100.00	44.59**	17.66	12.77**	1.410	67.86**
09/Cvar 4 x DARL 77	8.66	18.79**	21.33	-2.33	60.00	-24.52**	20.00	46.11**	1.233	49.45**
09/Cvar 4 x DARL 82	7.80	-25.71**	23.66	-5.13	58.33	-14.01**	18.10	47.99**	1.348	47.32**
09/Cvar 5 x DARL 74	11.20	19.65**	22.16	5.02	103.33	9.92	22.60	13.00**	1.835	51.65**
09/Cvar 5 x DARL 77	10.40	-0.57	22.33	3.95	70.66	-32.28**	24.50	36.11**	1.353	20.80
09/Cvar 5 x DARL 82	7.13	-28.91**	23.33	2.05	100.00	7.90	23.33	40.12**	1.935	160.51**
09/Cvar 6 x DARL 74	12.50	30.20**	22.50	7.60	115.00	30.35**	20.00	36.42**	1.736	98.40**
09/Cvar 6 x DARL 77	7.43	-18.91**	18.33	-17.80**	76.66	7.29	16.00	21.02**	0.790	-18.13
09/Cvar 7 x DARL 82	8.56	-10.83**	19.76	-10.58**	60.00	-11.11**	12.33	3.78	0.536	-55.99**

** Significant at 1 % level

contd....

Table 4. contd....

Hybrids	Characters									
	Plant height (cm)		Ascorbic acid (mg/100g)		Total chlorophyll (mg/100g)		Antioxidant activity (μg/100g)		Pericarp thickness (mm)	
	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)	per se performance	Relative heterosis (%)
09/Cvar 1 x 09/Cvar4	62.87	-2.38	136.00	4.61	3.50	8.01	2.73	-11.36	2.29	-29.32**
09/Cvar 1 x 09/Cvar5	56.33	-3.61	180.33	25.78**	5.19	21.36**	4.29	14.70	4.13	-33.23**
09/Cvar 1 x 09/Cvar6	61.67	-8.65	100.67	-39.53**	4.99	-29.29**	2.33	-53.21**	2.42	7.55
09/Cvar 1 x DARL 73	58.33	-6.91	94.33	-39.91**	3.27	-29.22**	2.51	4.58	2.53	-26.88**
09/Cvar 1 x DARL 74	57.00	-10.17**	218.00	95.51**	8.37	172.63**	1.33	-44.11**	2.41	-7.24
09/Cvar 2 x 09/Cvar5	72.67	-1.85	163.00	37.55**	9.94	5.10	2.53	-22.86	2.64	-19.39
09/Cvar 2 x 09/Cvar6	65.67	-8.71	236.00	66.78**	8.05	-17.68	3.10	-31.11**	3.93	-22.58
09/Cvar 2 x DARL 73	86.67	10.73**	209.00	58.33**	7.18	-3.88	2.22	15.02	4.29	36.45**
09/Cvar 2 x DARL 74	65.00	-17.87**	100.00	15.60	3.70	-37.50**	2.10	9.94	2.68	15.02
09/Cvar 2 x DARL 77	66.67	-16.84**	104.00	-15.44	8.11	-11.75	2.32	45.91**	2.63	-13.82
09/Cvar 3 x 09/Cvar6	69.33	-5.38	209.00	53.67**	7.20	-26.38**	2.15	-47.94**	2.39	-18.83
09/Cvar 3 x DARL 73	63.00	-20.85**	314.00	148.22**	7.45	-17.67	1.67	-24.43	3.04	9.59
09/Cvar 3 x DARL 74	50.33	-37.40**	190.00	134.56**	8.60	14.66	1.45	-33.78**	2.83	40.74**
09/Cvar 3 x DARL 77	55.33	-32.04**	102.00	-13.19	8.53	-20.72	3.21	71.65**	2.95	-3.74
09/Cvar 3 x DARL 82	60.00	-25.92**	104.67	5.02	5.24	-40.58**	1.56	-56.66**	3.27	12.16
09/Cvar 4 x DARL 73	47.83	-28.77**	293.00	90.25**	4.95	102.86**	1.57	-48.85**	3.15	7.92
09/Cvar 4 x DARL 74	56.00	-17.48**	172.00	58.52**	7.45	0.078	1.68	-70.15**	2.23	27.01**
09/Cvar 4 x DARL 77	46.33	-32.74**	93.00	-35.86**	5.20	25.00**	1.66	-38.75**	2.01	-31.38**
09/Cvar 4 x DARL 82	48.00	-29.89**	95.00	-25.29**	8.43	283.10**	2.08	-2.11	3.08	-31.86**
09/Cvar 5 x DARL 74	63.73	4.30	136.00	11.47	8.44	93.14**	1.47	-60.24**	2.66	-80.34**
09/Cvar 5 x DARL 77	63.66	2.84	154.00	-2.83	7.10	-7.06	1.48	-56.50**	2.76	-22.67
09/Cvar 5 x DARL 82	62.40	-0.82	236.00	67.78**	4.40	-22.53	1.43	-60.87**	2.98	-12.10
09/Cvar 6 x DARL 74	66.30	9.01	100.00	-44.98**	8.15	2.38	1.49	-67.81**	3.64	-13.37
09/Cvar 6 x DARL 77	57.50	-4.80	105.00	-35.84**	4.28	-28.78**	2.01	-58.70**	3.38	7.30
09/Cvar 7 x DARL 82	56.66	-15.09**	94.00	-39.02**	4.09	10.59	2.31	0.52	3.11	2.98

** Significant at 1 % level

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