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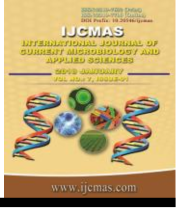

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Prediction and Validation of Three Cross Hybrids in Maize (*Zea mays* L.)

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ABSTRACT

The experiment comprised of six F_1's, which were selected based on the combinations of low yield × high yield and low ASI × high ASI. The selected six F_1's were crossed in full diallel mating design to synthesis 18 three way crosses was estimated and validated on the basis of performance of their constituent single crosses. Out of 18 hybrids, TWC 3 recorded lower days to tasseling and silking and hence it can be used further in breeding programme. While, TWC 4 (0.32), TWC 11 (0.5), TWC 9 (0.76), TWC 10 (0.79), TWC 14 (0.81) and TWC 5 (0.89) recorded least ASI. Hence, it is suggested to be used in deriving superior inbreds of narrow ASI or hybrids suitable for water deficit conditions. The expected yield performance of TWC 1 (128.13) and TWC 2 (126.24) out yielded best check, Nithyashree (126.00) while, TWC 15 (125.49), TWC 17 (123.19), TWC 16 (121.92), TWC 4 (119.51) out yielded best check, Hema (119.00). All 18 three way crosses manifested significant differences between realised and predicted performance suggesting involvement of epistasis in genetic control of grain yield plant^{-1}. By and large, there was a good agreement between realized and predicted performance of three way cross hybrids for all characters except for grain yield plant^{-1} and shelling percentage.

Keywords

ASI, Epistasis, Predicted, Realised, TWC

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Introduction

The breakthrough of heterosis phenomenon in the development of hybrids which successfully exploited commercial heterosis in maize is considered as significant milestone in the agriculture history during the present century. During 1908 and 1911, Shull exploited heterosis in maize by developing single cross hybrids by a hybridizing two pure homozygous inbred lines derived from an open-pollinated varieties. However, parental homozygous inbred lines derived from the open-pollinated cultivars were so weak that it was not feasible to use them in commercial hybrid seed production. Consequently, instead of single crosses, three way cross hybrids resulting from the cross between single crosses hybrid and homozygous line were proposed by Jones (1918) as they were more productive than homozygous inbred lines. Subsequently, three-way cross hybrids were also developed as a supplement to double cross hybrids and were grown by farmers during the 1930´s (Crabb, 1992).

Synthesis and identification of heterotic three way cross (TWC) depends on a number of single-cross hybrids (SCH) involved in the crosses which become unfeasible with an increase in the number of single-cross hybrids. For instance, with just ten inbred lines the breeders need to develop 630 three way cross hybrids. The performance evaluation of such a large number of three way cross hybrids is a highly resource demanding uphill task. To save the precious resources and time, Jenkins (1934) suggested models to predict the three way cross hybrid performance based on the performance of single crosses. Anderson (1938) found close correspondence between predicted and realized yield of three way cross hybrids in maize. Hence, the present study was carried out to predict and validate the performance of three way cross hybrids in maize.

Materials and Methods

The experiment comprised of six newly developed F_1's during summer 2012, which were selected based on the combinations of low yield × high yield and low ASI × high ASI as detailed below (Table 1). The same six F_1's were crossed to three inbred lines viz., CML-439, DMRN-21 and CML-139 which were used as males to synthesise 18 TWC hybrids during *kharif* 2012 at K-block of the Department of Genetics and Plant Breeding, UAS, GKVK, Bangalore. The experiment consisting of 18 three way cross hybrids along with two checks *viz*., Nithyashree and Hema (public bred hybrids) were evaluated in farmer's field at Sabbenahalli, Chickballapur district (Zone5), Karnataka during *rabi* 2012 and *summer* 2013. The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Each entry was planted in three rows of 3m length with row-to-row and plant-to-plant distance of 60cm and 30cm, respectively. All the recommended package of practices was followed to raise a good and healthy crop under protected condition. Data on 12 different quantitative characters were recorded on 24 randomly selected plants to calculate weights.

Trait means and variances of 13 quantitative traits for each three way cross hybrid were computed as detailed below. These means and variances were estimated as follows

$$\text{Mean}=\frac{\sum xi}{n}$$

$$\text{Variance}=\frac{\sum x_i^2-\frac{\sum xi}{n}}{n-1}$$

Variance of sample mean = Variance/n

$$\text{Standard error (SE)}=\sqrt{\frac{\text{Variance of TWC/DC hybrids population}}{n}}$$

Where,

x_i = trait value of i^{th} plant in TWC/DC hybrids

n = Number of plants on which data were recorded

Predicting the performances of double cross hybrid

Quantitative trait mean of a TWC [(A×B) × C] hybrid was predicted by the average performance of non-parental single crosses hybrids involved in TWC hybrids as parents proposed by Jenkins (1934).

$$\overline{(A\times B)\times C}=\frac{(A\times C)+(B\times C)}{2}$$

The agreement of predicted quantitative trait mean of each of three way cross hybrids with those of observed means was tested using χ^2 test. As three way cross hybrid means are not estimated with equal precision, weights defined as the reciprocal of trait variances of each of three way cross hybrids were used for calculating χ^2 test statistic.

Calculated χ^2 = (O-E)^2×Weight

$$\text{Where, Weight} = \frac{n}{\sigma^2_{TWC/DC}}$$

Significance of chi square statistic suggested the non-agreement of predicted and realized trait means of three way cross hybrids. Further, non-agreement also suggested possible involvement of epistasis in controlling the inheritance of 12 traits investigated in the present study.

Results and Discussion

The *per se* performance of 18 three way cross hybrids was estimated on the basis of performance of their constituent single crosses. The predicted performance of yield and its component traits of 18 three way crosses over two seasons were presented in Table 2. The mean performance for days to tasseling varied from 57.21 days (TWC 3) to 70.13 days (TWC 4) and for silking it varied from 59.59 days (TWC 3) and 72.04 days (TWC 4). Out of 18 hybrids, TWC 3 recorded lower days to tasseling and silking and hence it can be used further in breeding programme. ASI is concerned, the TWC 4 (0.32) and TWC 1 (1.58) recorded smallest and the highest ASI. The three way cross hybrids, TWC 4 (0.32), TWC 11 (0.5), TWC 9 (0.76), TWC 10 (0.79), TWC 14 (0.81) and TWC 5 (0.89) recorded least ASI. Hence, it is suggested to be used in deriving superior inbreds of narrow ASI or hybrids suitable for water deficit conditions.

The mean performance for yield attributing characters *viz.*, ear length, ear circumference, kernels row^{-1}, kernel rows ear^{-1}, 100 grain weight (g) and shelling percentage varied from 15.29 cm (TWC 9) to 17.26 cm (TWC 1), 13.81 cm (TWC 14) to 15.02 cm (TWC 1), 29.06 (TWC 9) to 35.43 (TWC 1), 15.76 (TWC 1) to 14.31 (TWC 18), 24.34 g (TWC 14) to 29.11 g (TWC 18) and 82.90% (TWC 10) to 89.70% (TWC 7), respectively.

The expected yield performance of three way cross hybrid varied from 102.79 g (TWC 3) to 128.13 g (TWC 1). Out of 18 three way crosses, TWC 1 (128.13) and TWC 2 (126.24) out yielded best check, Nithyashree (126.00) while, TWC 15 (125.49), TWC 17 (123.19), TWC 16 (121.92), TWC 4 (119.51) out yielded best check, Hema (119.00)

Table.1 Details of six F$_1$'s selected for synthesis of double cross hybrids

Sl. No	F1's	Salient characteristics	
1.	HKI 26-2-4(1-2) × CML 41	Low yielding (0.074 kg/plant)	High yielding (0.22 kg/ plant)
2.	CML 470 –Bx15 × CML 41	Low yielding (0.13 kg/plant)	High yielding (0.22 kg/ plant)
3.	HKI 26-2-4(1-2) × CM 500	Low yielding (0.074 kg/plant)	High yielding (0.14 kg/plant)
4.	CML359 × CML 326	Low ASI (2.5 days)	High ASI (7.7 days)
5.	HKI 26-2-4(1-2) × CML 358	High ASI (7.7 days)	Low ASI (2.0 days)
6.	CML 326 × DMRN-21	High ASI (7.7 days)	Low ASI (1.95days)

Table.2 Average performance of 18 three way cross hybrids for 12 quantitative traits in maize over two seasons

Code	Three way cross hybrids	Days to tasseling	Days to silking	ASI	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear circumference (cm)
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	57.37	59.92	1.58	223.72	120.60	17.26	15.02
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	57.85	60.40	1.33	224.62	129.30	16.11	14.51
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	57.21	59.59	1.35	206.81	116.03	15.90	14.14
TWC 4	(CML-359 × CML-326) × CML-139	70.13	72.04	0.32	208.75	106.14	16.56	14.11
TWC 5	(CML-359 × CML-326) × DMRN-21	61.16	63.07	0.89	201.65	109.89	16.05	14.10
TWC 6	(CML-359 × CML-326) × CML-139	58.85	61.00	1.06	202.29	105.38	15.84	14.47
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	59.74	63.31	1.57	212.98	110.41	16.39	14.50
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	60.39	62.91	1.06	209.46	122.98	16.40	14.58
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	61.64	63.72	0.76	198.31	109.15	15.29	14.67
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	61.33	63.52	0.79	210.06	112.19	16.56	14.64
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	61.51	62.75	0.50	212.50	112.85	16.86	14.02
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	58.56	60.28	1.16	217.85	119.71	16.20	14.07
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	59.61	61.29	1.06	202.08	102.94	16.23	14.59
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	59.79	61.33	0.81	203.40	109.13	16.59	13.81
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	58.02	60.21	1.38	209.23	114.56	15.80	14.86
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	58.05	60.58	1.36	211.92	113.33	16.21	14.93
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	58.71	60.96	1.24	203.35	115.13	16.19	14.39
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	58.42	60.38	1.10	176.25	92.00	16.86	14.58
Check 1	Nithyashree	64.60	66.10	1.50	221.48	121.58	16.15	15.10
Check 2	Hema	65.90	68.50	2.60	214.42	122.83	15.20	15.67
	S.Em ±	0.79	0.67	0.81	2.52	1.96	0.12	0.08

Contd…

Code	Three way cross hybrids	Kernels row^{-1}	Kernel rows ear^{-1}	100 grain weight (g)	Grain yield plant^{-1} (g)	Shelling percentage
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	35.43	15.76	26.24	128.13	83.41
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	33.98	15.39	26.67	126.24	85.64
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	31.54	15.76	25.23	102.79	85.52
TWC 4	(CML-359 × CML-326) × CML-139	34.17	15.11	26.37	119.51	85.83
TWC 5	(CML-359 × CML-326) × DMRN-21	33.90	14.69	25.03	114.87	85.39
TWC 6	(CML-359 × CML-326) × CML-139	33.22	14.67	26.47	117.46	85.62
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	30.49	15.36	27.14	107.08	89.70
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	32.10	14.42	28.57	111.77	83.43
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	29.06	15.01	28.65	110.75	83.72
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	34.73	15.36	24.43	113.41	82.90
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	34.03	14.99	25.34	114.65	85.20
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	31.37	15.33	25.06	105.25	84.25
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	34.07	14.54	25.16	106.12	83.17
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	33.32	14.53	24.34	105.17	84.63
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	32.05	15.00	27.75	125.49	84.25
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	35.40	15.00	25.73	121.92	83.08
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	33.44	14.60	27.55	123.19	86.31
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	33.26	14.31	29.11	119.00	83.97
Check 1	Nithyashree	29.90	15.40	27.67	126.00	81.44
Check 2	Hema	31.43	16.13	26.49	119.00	81.42
	S.Em ±	0.40	0.10	0.35	1.88	0.38

Table.3 Estimates of realized and predicted mean performances of 18 three way cross hybrids for 12 quantitative traits in maize

Code	Three way cross hybrids	Days to tasseling			Days to silking		
		Realized	Predicted	χ2 statistic	Realized	Predicted	χ2 statistic
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	57.37	62.95	789.80**	59.92	64.45	471.25**
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	57.85	62.60	337.38**	60.40	63.50	136.03**
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	57.21	61.90	991.56**	59.59	62.78	424.58**
TWC 4	(CML-359 × CML-326) × CML-139	70.13	64.80	297.43**	72.04	67.18	71.21**
TWC 5	(CML-359 × CML-326) × DMRN-21	61.16	61.60	0.61	63.07	62.58	0.78
TWC 6	(CML-359 × CML-326) × CML-139	58.85	63.85	80.67**	61.00	64.97	58.82**
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	59.74	62.75	63.23**	63.31	64.52	7.37
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	60.39	62.60	36.18*	62.91	63.82	3.18
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	61.64	60.60	6.28	63.72	60.93	45.36**
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	61.33	63.30	36.37*	63.52	64.55	8.81
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	61.51	61.75	0.11	62.75	63.25	0.56
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	58.56	62.65	260.68**	60.28	63.80	196.93**
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	59.61	62.35	77.05**	61.29	64.00	82.47**
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	59.79	61.70	25.27	61.33	62.85	21.53
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	58.02	61.75	669.75**	60.21	63.10	176.30**
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	58.05	62.05	197.35**	60.58	63.50	132.74**
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	58.71	61.55	83.31**	60.96	62.07	9.91
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	58.42	62.20	200.43**	60.38	63.05	67.38**

*Significant at $P \leq 0.05$, ** Significant at $P \leq 0.01$, *** Significant at $P \leq 0.001$

Contd…

Code	**Three way cross hybrids**	**Ear height (cm)**			**Ear length (cm)**		
		Realized	**Predicted**	**χ2 statistic**	**Realized**	**Predicted**	**χ2 statistic**
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	120.60	107.32	50.45**	17.26	16.44	33.77
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	129.30	112.11	132.07**	16.11	15.96	0.88
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	116.03	113.89	0.55	15.90	15.57	3.87
TWC 4	(CML-359 × CML-326) × CML-139	106.14	113.99	16.28	16.56	14.72	151.06**
TWC 5	(CML-359 × CML-326) × DMRN-21	109.89	117.10	8.27	16.05	17.04	29.79
TWC 6	(CML-359 × CML-326) × CML-139	105.38	112.38	18.86	15.84	14.73	58.55**
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	110.41	107.28	3.28	16.39	15.78	8.94
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	122.98	117.72	6.37	16.40	15.55	19.44
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	109.15	114.67	2.98	15.29	14.34	27.72
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	112.19	108.61	1.47	16.56	16.50	0.16
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	112.85	112.20	0.04	16.86	16.90	0.05
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	119.71	112.98	3.78	16.20	16.51	2.29
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	102.94	102.98	0.0002	16.23	16.75	4.72
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	109.13	104.45	2.18	16.59	16.97	3.86
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	114.56	105.79	9.29	15.80	16.72	32.21
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	113.33	111.71	0.26	16.21	16.19	0.02
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	115.13	112.96	0.65	16.19	16.71	8.87
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	92.00	115.66	109.58**	16.86	16.23	12.89

* Significant at P ≤0.05, ** Significant at P ≤0.01, *** Significant at P ≤0.001

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Code	Three way cross hybrids	Ear circumference (cm)			Kernels row^{-1}		
		Realized	**Predicted**	**χ2 statistic**	**Realized**	**Predicted**	**χ2 statistic**
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	15.02	14.88	2.82	35.43	34.70	2.27
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	14.51	14.30	8.27	33.98	35.90	25.56
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	14.14	14.57	32.59	31.54	33.13	11.46
TWC 4	(CML-359 × CML-326) × CML-139	14.11	13.42	121.10**	34.17	31.45	34.84*
TWC 5	(CML-359 × CML-326) × DMRN-21	14.10	14.21	4.74	33.90	39.45	141.10**
TWC 6	(CML-359 × CML-326) × CML-139	14.47	13.83	72.34**	33.22	31.52	14.62
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	14.50	15.18	132.56**	30.49	33.25	21.45
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	14.58	14.61	0.13	32.10	33.60	7.69
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	14.67	14.44	6.34	29.06	29.80	4.06
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	14.64	13.72	217.30**	34.73	34.53	0.15
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	14.02	14.43	27.51	34.03	38.45	63.01**
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	14.07	14.32	21.41	31.37	35.85	82.00**
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	14.59	14.39	10.93	34.07	36.75	15.90
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	13.81	14.13	19.86	33.32	36.95	63.09**
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	14.86	14.67	3.47	32.05	35.70	74.40**
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	14.93	14.46	44.94**	35.40	35.72	0.39
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	14.39	14.42	0.21	33.44	37.10	32.06
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	14.58	14.46	1.39	33.26	34.02	5.00

* Significant at P ≤0.05, ** Significant at P ≤0.01, *** Significant at P ≤0.001

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Code	Three way cross hybrids	Kernel rows ear^{-1}			100 grain weight (g)		
		Realized	**Predicted**	**χ2 statistic**	**Realized**	**Predicted**	**χ2 statistic**
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	15.76	15.23	14.42	26.24	25.11	32.21
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	15.39	15.17	1.62	26.67	24.46	119.46**
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	15.76	14.38	95.68**	25.23	27.32	119.83**
TWC 4	(CML-359 × CML-326) × CML-139	15.11	14.73	4.45	26.37	22.03	415.12**
TWC 5	(CML-359 × CML-326) × DMRN-21	14.69	14.87	2.46	25.03	25.01	0.01
TWC 6	(CML-359 × CML-326) × CML-139	14.67	14.23	7.29	26.47	25.97	6.69
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	15.36	15.33	0.03	27.14	26.78	3.47
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	14.42	15.50	32.30	28.57	26.76	87.28**
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	15.01	14.20	62.14**	28.65	29.53	23.00
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	15.36	14.67	35.32*	24.43	23.14	38.46*
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	14.99	14.97	0.02	25.34	24.73	9.08
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	15.33	14.32	34.70*	25.06	26.61	64.08**
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	14.54	14.13	13.89	25.16	24.24	20.66
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	14.53	14.50	0.04	24.34	24.01	2.59
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	15.00	13.98	43.52**	27.75	27.45	2.46
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	15.00	14.13	26.28	25.73	26.02	2.21
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	14.60	13.78	28.38	27.55	28.24	13.31
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	14.31	13.82	7.25	29.11	29.56	5.83

* Significant at P ≤0.05, ** Significant at P ≤0.01, *** Significant at P ≤0.001

Contd…

Code	Three way cross hybrids	Grain yield plant^{-1}			Shelling percentage		
		Realized	Predicted	χ2 statistic	Realized	Predicted	χ2 statistic
TWC 1	(HKI-26-2-4-(1-2) × CML-41) × CML-439	128.13	115.17	19338.60**	83.41	82.33	96.27**
TWC 2	(HKI-26-2-4-(1-2) × CML-41) × DMRN-21	126.24	123.67	819.99**	85.64	86.89	136.05**
TWC 3	(HKI-26-2-4-(1-2) × CML-41) × CML-139	102.79	116.83	23032.53**	85.52	83.38	381.96**
TWC 4	(CML-359 × CML-326) × CML-139	119.51	93.50	63273.55**	85.83	84.35	184.05**
TWC 5	(CML-359 × CML-326) × DMRN-21	114.87	126.00	15603.46**	85.39	86.27	66.60**
TWC 6	(CML-359 × CML-326) × CML-139	117.46	106.67	12427.97**	85.62	85.83	3.56
TWC 7	(CML 470-Bx15 × CML-41) × CML-139	107.08	119.00	16898.83**	89.70	82.45	4334.51**
TWC 8	(CML 470-Bx15 × CML-41) × DMRN-21	111.77	130.50	45763.95**	83.43	87.33	1329.29**
TWC 9	(CML 470-Bx15 × CML-41) × CML-139	110.75	112.33	281.61**	83.72	84.24	23.09
TWC 10	(HKI-26-2-4-(1-2) × CML-358) × CML-139	113.41	104.67	8004.70**	82.90	83.17	6.31
TWC 11	(HKI-26-2-4-(1-2) × CML-358) × DMRN-21	114.65	132.83	43935.50**	85.20	85.89	40.94*
TWC 12	(HKI-26-2-4-(1-2) × CML-358) × CML-139	105.25	119.83	25501.14**	84.25	82.41	278.75**
TWC 13	(HKI-26-2-4-(1-2) × CM-500) × CML-139	106.12	112.67	4823.25**	83.17	82.33	57.63**
TWC 14	(HKI-26-2-4-(1-2) × CM-500) × DMRN-21	105.17	123.17	39911.47**	84.63	86.09	182.36**
TWC 15	(HKI-26-2-4-(1-2) × CM-500) × CML-139	125.49	122.67	975.11**	84.25	82.85	163.18**
TWC 16	(HKI-26-2-4-(1-2) × CML-411) × CML-139	121.92	119.67	608.81**	83.08	83.28	3.54
TWC 17	(HKI-26-2-4-(1-2) × CML-411) × DMRN-21	123.19	134.33	16688.00**	86.31	85.93	12.63
TWC 18	(HKI-26-2-4-(1-2) × CML-411) × CML-139	119.00	128.83	12469.92**	83.97	84.19	3.98

* Significant at P ≤0.05, ** Significant at P ≤0.01, *** Significant at P ≤0.001

Good agreement between realised and predicted performances of three way crosses indicating the adequacy of additive-dominance model in the inheritance of all characters except grain yield plant^{-1} and shelling percentage (Table 3). The rationale of high predictive power of the prediction method is that for any individual locus, the three way cross hybrids {(A × B) × C} includes only those genotypes which are produced in the AC and BC single crosses. Thus, the magnitude of additive and dominance effects expressed in three way cross hybrids would be the same as that of non-parental single cross hybrids. These two populations *i.e.*, 'three way crosses' and a group of non-parental single crosses however, may differ with respect to a few specific combinations of genes at different loci which is of course inconsequential so long as genes at different loci are independent in action, *i.e.*, epistasis is absent (Hallauer and Miranda, 1988). In prediction method, all 18 three way crosses manifested significant differences between realised and predicted performance suggesting involvement of epistasis in genetic control of grain yield plant^{-1} (Bauman 1959, Chahal and Gosal, 2002) (Table 3). By and large, there was a good agreement between realized and predicted performance of three way cross hybrids for all characters except for grain yield plant^{-1}and shelling percentage.

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