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Research Note

Prediction and validation of double 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 synthesise 16 double crosses was estimated and validated on the basis of performance of their constituent single crosses. Out of 16 hybrids, DCH 15 recorded lower tasseling and silking days and hence it can be used further in breeding programme. While, DCH 13 recorded narrow mean for ASI are suggested for use in deriving superior inbred lines with a combination of narrow ASI and higher ear circumference and kernel rows ear^{-1}.The expected yield performance of DCH 5 (125.88), DCH 8 (124.23), DCH 10 (123.96), DCH 15 (123.73), DCH 6 (122.77) and DCH 12 (120.76) out yielded best check, Hema (119.00) for grain yield plant^{-1}respectively. DCH 12 predicted better for most of the characters *viz*., ASI, ear length, ear circumference, kernel rows^{-1} and 100 grain weight. While, DCH 15 predicted better for characters *viz*., days to tasseling, days to silking, plant height (cm), ear height (cm), kernels row^{-1} and shelling percentage. Therefore, these two crosses may be used as double cross hybrids for breeding programme. In both prediction methods, nearly 14 out of 16 double cross hybrids manifested significant differences between realised and predicted performance suggesting involvement of epistasis in genetic control of grain yield plant^{-1}.

Key words

ASI, DCH, Epistasis

The discovery of heterosis phenomenon, the development of hybrid breeding technology and successful commercial exploitation of heterosis in maize is considered as significant landmark achievement in the history of agriculture during the present century. Shull (1908 and 1911) proposed to exploit heterosis in maize by developing single cross hybrids between pure inbred lines derived from 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, double cross hybrids resulting from the cross between two single crosses were proposed by Jones (1918) as they were more productive than homozygous inbred lines. The first double cross maize hybrids were grown by farmers during the 1930´s (Crabb, 1992).

Synthesis and identification of heterotic double-cross hybrids (DCH) 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 double-cross hybrids. The performance evaluation of such a large number of double cross hybrids is a highly resource demanding uphill task. To save the precious resources and time, Jenkins (1934) suggested models to predict the double cross hybrid performance based on the performance of single crosses. Anderson (1938) found close correspondence between predicted and realized yield of double cross hybrids in maize. Subsequently, models were also proposed to predict performance of three way cross hybrids (Jenkins, 1934). Hence, the present study was carried out to predict and validate the performance of double cross hybrids in maize.

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 selected six F_1's were crossed in full diallel mating design to synthesise 16 double cross hybrids during *kharif* 2012 at K-block of the Department of Genetics and Plant Breeding, UAS, GKVK, Bangalore. The experiment consisting of 16 double 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* 2012and *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 double 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 DCH [(A×B)×(C×D)] was predicted by following two methods as proposed by Jenkins (1934).

1. Average of all possible single cross hybrids involved in DCH and
2. Average of non-parental single cross hybrids involved in DCH

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

Calculated $\chi^2 = (O-E)^2 \times$ 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 double cross hybrids. Further, non-agreement also suggested possible involvement of epistasis in controlling the inheritance of 12 traits investigated in the present study.

The *per se* performance of 16 double cross hybrids was estimated on the basis of performance of their constituent single crosses. The predicted performance of yield and its component traits of 16 double crosses over two seasons were presented in table 2. The mean performance for days to tasseling varied from 58.81 (DCH 15) to 65.71 (DCH 10)and for silking it varied from 61.22 (DCH 15) to 68.29 (DCH 14). Out of 16 hybrids, DCH 15 recorded lower days to tasseling and silking and hence it can be used further in breeding programme. Anthesis silking interval (ASI), among hydrids varied from 0.66 (DCH 13) to 2.67 (DCH 1). The double cross hybrids, DCH 13 with narrow mean for ASI is suggested for use in deriving superior inbred lines with a combination of narrow ASI and higher ear circumference and kernel rows ear^{-1}. 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 15.34 (DCH 2) to 17.3(DCH 12), 15.85 (DCH 3) to 16.49 (DCH 16), 31.46 (DCH 1) to 35.12 (DCH 5), 14.39 (DCH 3) to 16.39 (DCH 9), 23.73 (DCH 3) to 30.51 (DCH 8) and 79.90 (DCH 3) to 86.65 (DCH 15), respectively. The expected yield performance of double crosses varied from 100.61 (DCH 3) to 125.88 (DCH 5).

Out of 16 double cross hybrids, DCH 5 (125.88), DCH 8 (124.23), DCH 10 (123.96), DCH 15 (123.73), DCH 6 (122.77) and DCH 12 (120.76) out yielded best check, Hema (119.00) while, DCH 5 was on par with check, Nithyashree (126.00). Out of these top ranking double crosses, DCH 12 predicted better for most of the characters *viz.*, ASI, ear length, ear circumference, kernel rows^{-1} and 100 grain weight. While, DCH 15 predicted better for characters *viz.*, days to tasseling, days to silking, plant height (cm), ear height (cm), kernels row^{-1} and shelling percentage.

Good agreement between realised and predicted performances of double cross hybrid indicated 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 double cross hybrids {(A × B) × (C × D)} includes only those genotypes which are produced in the AC, AD, BC and BD single crosses. Thus, the magnitude of additive and dominance effects expressed in double cross hybrids would be the same as that of non-parental single cross hybrids. These two populations *i.e.,* ‘double crosses’ and 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 both prediction methods, nearly 14 out of 16 double cross hybrids 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 double cross hybrids for all characters except for 100 grain weight, grain yield plant^{-1}and shelling percentage.

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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 16 double cross hybrids for 12 quantitative traits in maize over two seasons

Code	Double cross hybrids	Days to tasseling	Days to silking	ASI	Plant height (cm)	Ear height (cm)	Ear length (cm)	Ear Circum -ference (cm)	Kernels row^{-1}	Kernel rows ear^{-1}	100 grain weight (g)	Grain yield plant^{-1} (g)	Shelling percenta-ge
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	61.11	63.78	2.67	204.50	96.94	15.83	14.68	31.46	15.57	26.85	104.00	83.27
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	64.62	67.06	2.07	211.07	112.67	15.34	14.85	32.21	15.04	25.23	100.63	80.39
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	62.44	64.05	1.60	220.60	115.51	15.85	14.03	34.67	14.39	23.73	100.61	79.90
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	61.89	63.63	1.69	200.06	99.73	16.16	14.69	34.09	15.17	25.00	119.38	86.17
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	61.07	62.35	1.28	190.81	90.69	16.31	14.90	35.12	14.64	27.50	125.88	84.35
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	61.92	64.23	2.31	210.06	107.27	16.32	15.26	32.45	14.90	29.77	122.77	82.85
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	61.57	63.92	2.35	209.96	102.63	16.64	15.07	33.25	14.97	28.65	117.64	83.32
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	63.60	64.63	1.02	222.10	117.71	16.84	14.89	32.60	14.56	30.51	124.23	83.69
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	65.30	67.94	1.90	231.27	125.32	15.91	15.00	33.74	16.76	23.80	118.62	82.26
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	65.71	67.49	1.26	206.96	105.33	15.75	14.85	33.04	15.78	27.15	123.96	85.76
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	62.51	64.57	1.05	215.07	108.79	16.39	14.14	34.11	14.94	26.02	111.40	85.57
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	62.97	65.74	1.00	219.66	115.22	17.30	15.24	32.18	15.56	29.00	120.76	82.21
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	63.91	65.54	0.66	205.93	100.21	15.99	14.17	32.47	14.54	25.29	103.82	84.00
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	65.19	68.29	0.83	207.86	109.07	16.02	15.13	32.02	15.17	27.74	116.53	81.23
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	58.81	61.22	1.22	201.88	99.99	16.21	14.79	34.44	15.11	26.51	123.73	86.65
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	59.75	62.16	1.15	207.23	109.33	16.49	15.31	32.51	14.87	28.38	115.23	81.14
Check 1	Nithyashree	64.60	66.10	1.50	221.48	121.58	16.15	15.10	29.90	15.40	27.67	126.00	81.44
Check 2	Hema	65.90	68.50	2.60	214.42	122.83	15.20	15.67	31.43	16.13	26.49	119.00	81.42
	S.Em ±	0.50	0.52	0.15	2.44	2.20	0.12	0.10	0.27	0.15	0.51	2.20	0.52

Table 3. Estimates of realized and predicted mean performances of 16 double cross hybrids for 12 quantitative traits in maize

Code	Double cross hybrids	Days to tasseling					Days to silking				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	61.11	62.42	85.25**	62.48	93.03**	63.78	63.76	0.02	63.92	0.76
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	64.62	61.67	35.67*	61.78	33.22	67.06	63.34	64.41**	63.65	54.24**
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	62.44	62.52	0.078	62.38	0.072	64.05	64.22	0.393	64.36	1.250
CH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	61.89	61.47	2.79	61.48	2.68	63.63	62.49	20.95	62.51	20.24
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	61.07	62.27	36.43*	62.13	28.32	62.35	63.58	45.45**	63.68	52.48**
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	61.92	61.84	0.16	62.08	0.73	64.23	63.69	5.66	63.89	2.21
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	61.57	60.61	29.83	60.91	14.20	63.92	62.05	70.75**	62.18	61.04**
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	63.60	61.17	32.46	61.20	31.72	64.63	62.73	27.05	62.73	27.05
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	65.30	61.87	48.36**	61.65	54.66**	67.94	63.50	80.81**	63.53	79.60**
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	65.71	61.56	50.42**	61.60	49.35**	67.49	63.10	52.24**	63.28	47.97**
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	62.51	63.15	3.46	63.33	5.63	64.57	64.63	0.041	64.98	1.66
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	62.97	61.57	2.36	61.68	2.03	65.74	63.09	7.10	63.00	7.62
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	63.91	62.07	5.75	62.38	3.99	65.54	63.28	10.59	63.69	7.07
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	65.19	60.74	32.57	61.10	27.50	68.29	62.21	61.66**	62.43	57.40**
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	58.81	63.02	224.63**	63.25	250.21**	61.22	63.67	51.61**	63.81	57.49**
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	59.75	62.22	56.53**	62.78	84.59**	62.16	63.69	25.77	64.17	44.33**

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

Table 3. Contd.,

Code	Double cross hybrids	ASI					Plant height (cm)				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	2.67	1.34	190.40**	1.44	162.07**	204.50	222.08	28.87	223.78	34.73*
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	2.07	1.67	10.89	1.88	2.61	211.07	211.65	0.05	213.53	0.89
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	1.60	1.71	0.8317	1.98	11.6313	220.60	226.11	3.84	228.46	7.82
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	1.69	1.02	45.05**	1.03	43.57**	200.06	215.45	44.57**	213.78	35.44*
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	1.28	1.32	0.18	1.55	8.80	190.81	220.57	52.13**	224.44	66.59**
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	2.31	1.85	22.54	1.82	25.90	210.06	216.43	2.53	221.39	8.01
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	2.35	1.44	65.90**	1.28	91.61**	209.96	207.94	0.29	209.98	0.00003
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	1.02	1.56	17.28	1.53	15.58	222.10	209.75	8.05	215.67	2.19
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	1.90	1.63	4.37	1.88	0.01	231.27	223.04	6.02	225.23	3.25
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	1.26	1.54	4.694	1.68	10.324	206.96	217.94	5.88	222.97	12.49
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	1.05	1.48	8.440	1.65	16.15	215.07	230.93	20.22	235.70	34.20*
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	1.00	1.52	15.57	1.33	6.03	219.66	219.36	0.01	225.80	2.67
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	0.66	1.21	10.89	1.32	15.45	205.93	212.54	4.57	209.41	1.27
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	0.83	1.47	23.04	1.32	13.42	207.86	203.51	2.06	203.33	2.24
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	1.22	0.66	32.95	0.56	45.39**	201.88	222.06	17.10	226.68	25.82
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	1.15	1.47	15.66	1.39	9.19	207.23	208.69	0.13	214.08	2.92

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

Table 3. Contd.,

Code	Double cross hybrids	Ear height (cm)					Ear length (cm)				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	96.94	115.98	66.02**	118.42	84.08**	15.83	15.90	0.15	15.90	0.14
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	112.67	108.35	7.61	109.38	4.41	15.34	15.83	18.49	16.27	65.69**
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	115.51	115.01	0.08	115.25	0.02	15.85	16.15	4.88	16.45	19.88
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	99.73	111.66	53.24**	111.18	49.07**	16.16	16.35	1.152	16.47	2.87
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	90.69	114.43	121.75**	115.85	136.74**	16.31	15.96	3.87	16.13	1.05
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	107.27	112.97	4.74	117.52	15.37	16.32	16.02	1.55	16.47	0.38
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	102.63	106.12	2.02	108.21	5.17	16.64	16.09	6.25	16.27	2.80
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	117.71	108.21	9.77	111.87	3.69	16.84	15.75	10.90	16.01	6.35
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	125.32	113.83	14.11	115.20	10.94	15.91	16.20	5.59	16.35	12.72
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	105.33	116.61	9.99	121.77	21.23	15.75	15.56	0.91	15.85	0.24
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	108.79	120.10	15.71	122.87	24.38	16.39	16.23	1.165	16.58	1.55
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	115.22	111.87	1.05	115.88	0.04	17.30	15.60	115.14**	15.83	85.68**
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	100.21	109.39	17.91	107.78	12.17	15.99	16.13	0.75	16.13	0.75
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	109.07	103.55	7.40	104.36	5.38	16.02	15.72	2.24	15.72	2.28
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	99.99	118.53	86.22**	122.00	121.49**	16.21	16.20	0.00	16.48	3.57
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	109.33	105.87	3.76	108.36	0.30	16.49	15.60	14.47	15.78	9.14

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

Table 3. Contd.,

Code	Double cross hybrids	Ear circumference (cm)					Kernels row^{-1}				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	14.68	14.31	31.28	14.48	8.80	31.46	36.18	65.88**	36.98	89.80**
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	14.85	14.68	5.49	14.73	2.907	32.21	34.36	13.10	35.07	23.09
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	14.03	14.06	0.04	14.13	0.46	34.67	36.77	11.49	37.13	15.86
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	14.69	14.37	18.322	14.57	2.71	34.09	37.76	53.03**	38.13	64.51**
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	14.90	14.36	51.47**	14.47	33.21	35.12	36.73	6.77	37.15	10.79
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	15.26	14.71	27.96	14.61	39.77*	32.45	34.41	8.87	34.28	7.68
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	15.07	15.23	2.31	15.35	7.45	33.25	34.18	2.89	33.45	0.13
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	14.89	15.13	2.87	15.12	2.59	32.60	34.55	6.39	34.56	6.45
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	15.00	14.44	39.19*	14.69	12.35	33.74	36.37	47.43**	37.25	84.74**
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	14.85	14.55	9.60	14.53	10.88	33.04	33.71	1.31	34.09	3.23
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	14.14	13.99	5.696	14.03	3.23	34.11	37.89	48.88**	38.83	75.88**
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	15.24	14.87	18.03	14.84	20.79	32.18	33.82	12.01	33.38	6.49
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	14.17	14.24	0.76	14.37	6.07	32.47	37.70	111.76**	38.05	127.23**
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	15.13	15.08	0.36	15.12	0.01	32.02	33.17	4.40	31.93	0.03
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	14.79	14.35	23.28	14.45	13.93	34.44	37.75	57.70**	38.68	94.88**
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	15.31	14.89	23.76	14.76	41.47*	32.51	33.36	4.68	32.77	0.44

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

Table 3. Contd.,

Code	Double cross hybrids	Kernel rows ear^{-1}					100 grain weight (g)				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	15.57	14.43	53.01**	14.53	44.09**	26.85	24.64	119.88**	24.61	124.16**
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	15.04	14.92	0.40	15.07	0.02	25.23	26.96	80.42**	27.33	120.17**
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	14.39	14.19	0.68	14.35	0.03	23.73	24.71	23.97	25.14	50.09**
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	15.17	14.50	30.67	14.75	11.98	25.00	24.78	1.16	24.84	0.60
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	14.64	14.06	12.45	14.42	1.81	27.50	26.10	50.90**	25.92	64.77**
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	14.90	15.06	0.720	15.00	0.292	29.77	25.19	528.38**	25.08	551.41**
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	14.97	15.81	26.93	16.07	45.66**	28.65	26.15	161.70**	26.12	167.66**
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	14.56	14.99	7.10	15.17	14.12	30.51	27.41	263.47**	27.10	314.51**
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	16.76	14.88	69.87**	15.20	48.03**	23.80	25.16	46.43**	25.37	62.94**
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	15.78	14.91	29.31	15.05	20.67	27.15	26.63	7.06	26.84	2.52
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	14.94	13.87	58.10**	13.87	58.10**	26.02	24.08	90.39**	24.19	80.68**
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	15.56	14.77	12.59	14.57	19.71	29.00	27.37	73.378**	28.35	12.22
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	14.54	14.29	2.46	14.44	0.40	25.29	24.28	24.88	24.09	34.83*
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	15.17	15.62	8.43	15.78	15.52	27.74	26.33	52.88**	26.39	48.65**
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	15.11	13.59	86.34**	13.72	72.45**	26.51	26.77	1.78	26.92	4.44
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	14.87	14.44	6.35	14.35	9.49	28.38	28.66	2.14	28.98	10.17

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

Table 3. Contd.,

Code	Double cross hybrids	Grain yield plant^{-1} (g)					Shelling percentage				
		Realized	Method 1		Method 2		Realized	Method 1		Method 2	
			Predicted	χ2 statistic	Predicted	χ2 statistic		Predicted	χ2 statistic	Predicted	χ2 statistic
DCH 1	(HKI-26-2-4-(1-2) × CML-41) × (CML-359 × CML-326)	104.00	113.11	9382.15**	116.75	18377.18**	83.27	84.69	170.99**	84.59	146.64**
DCH 2	(CML-359 × CML-326) × (CML 470-Bx15 × CML-41)	100.63	121.83	54767.21**	127.25	90163.56**	80.39	85.61	2333.27**	85.42	2162.32**
DCH 3	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-358)	100.61	115.89	27046.18**	120.17	45949.46**	79.90	84.52	1807.51**	84.01	1417.99**
DCH 4	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CM-500)	119.38	121.61	605.86**	125.42	4571.74**	86.17	84.84	149.17**	84.63	198.57**
DCH 5	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-411)	125.88	122.72	1222.01**	126.33	26.22	84.35	85.50	113.69**	85.42	97.10**
DCH 6	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-358)	122.77	124.56	398.84**	127.00	2276.57**	82.85	83.75	66.82**	83.29	15.93
DCH 7	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CM-500)	117.64	130.61	21804.10**	132.75	30304.93**	83.32	83.85	23.41	83.60	6.33
DCH 8	(CML 470-Bx15 × CML-41) × (HKI-26-2-4-(1-2) × CML-411)	124.23	130.28	4764.11**	131.50	6949.09**	83.69	84.18	20.02	83.88	2.89
DCH 9	(CML-359 × CML-326) × (HKI-26-2-4-(1-2) × CML-41)	118.62	121.67	1126.97**	129.58	15566.17**	82.26	85.09	683.00**	85.19	730.96**
DCH 10	(CML 470-Bx15 × CML-41) × (CML-359 × CML-326)	123.96	116.78	6021.11**	119.67	2204.07**	85.76	85.81	0.25	85.73	0.09
DCH 11	(HKI-26-2-4-(1-2) × CML-358) × (CML-359 × CML-326)	111.40	116.78	3372.27**	121.50	12384.44**	85.57	84.68	67.27**	84.25	148.29**
DCH 12	(HKI-26-2-4-(1-2) × CML-358) × (CML 470-Bx15 × CML-41)	120.76	120.83	0.58	121.42	51.74**	82.21	84.19	328.80**	83.95	254.70**
DCH 13	(HKI-26-2-4-(1-2) × CM-500) × (CML-359 × CML-326)	103.82	116.72	19432.11**	118.08	24025.06**	84.00	84.81	55.20**	84.59	29.05
DCH 14	(HKI-26-2-4-(1-2) × CM-500) × (CML 470-Bx15 × CML-41)	116.53	120.00	1446.76**	116.83	10.91	81.23	83.60	471.41**	83.22	332.35**
DCH 15	(HKI-26-2-4-(1-2) × CML-411) × (CML-359 × CML-326)	123.73	124.11	18.10	128.42	2821.58**	86.65	84.55	374.70**	83.98	598.68**
DCH 16	(HKI-26-2-4-(1-2) × CML-411) × (CML 470-Bx15 × CML-41)	115.23	122.61	6684.89**	120.00	2733.47**	81.14	83.95	666.43**	83.54	482.55**

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