Article Title (3 to 12 words)	**Higher order crossing plans for stable line production**
Article Summary (In short - What is your article about – Just 2 or 3 lines)	Hybridization techniques are being used for a long time in the field of plant and animal production. Breeders are always interested in crosses that are stable and resistant. Hybrid production generally involves lower order cross like two-way crosses and higher order crosses like three-way and four-way crosses. In comparison to lower order crosses the higher order crosses can be used to gain more information regarding the combining abilities of the parental lines involved in the crosses. In this article the model of three-way and four-way crosses has been given along with the importance of partial higher order cross plans. Partial three-way and four-way cross plans are described with examples and also the degree of fractionation has been calculated.
Category:	Agriculture (Agricultural Statistics)

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Introduction

Hybridization technique is one of the most important component in the area of commercial plant and animal production. The most important goal of any hybridization technique is to improve the genetic potential of parental lines and produce better offspring's. Similarly, in any breeding programme the main aim is to improve the genetic potential of individual lines. In any hybrid breeders are always interested in stability other than higher yield potential. These characters are directly influenced by the techniques used in the hybridization programme. The most commonly used techniques for the purpose of hybrid production are two-way cross, three-way cross and four-way cross. Among these techniques, two-way crosses are the lower order crosses and are most often used due to their simplicity in use by the breeders. Other two techniques are higher order crosses and are less often used by the breeders due to their complexity, but they are better in many ways as compared two two-way crosses. As compared to lower order cross hybrids, higher order cross hybrids are genetically more stable due to broad genetic base. Higher order cross hybrids shows better individual as well as population buffering mechanisms as compared to lower cross hybrids. There are a lot of examples in the area of plant and animal sciences where it has been established that higher order cross hybrids gives better results. According to the research work of Shunmugathai and Srinivasan (2012), three-way crosses are the commonly used economic technique of maize production. If we consider the area of poultry production then also according to Khwaja *et al.* (2013), three-way crossed chickens are found to have lower mortality rate, higher egg production and better egg size as compared to two-way cross bred chickens. The piggery production also amounts for better feed efficiency and faster carcass development when bred using higher order crosses. The methods are also used for silkworm production.

Complete Three-way cross plans

For n number of lines the total number of possible crosses of the type $(i\times j)\times k$ constitutes a complete three-way cross (CTC) plan. The total number of crosses N_1 in a CTC plan obtained for n lines can be calculated by the given formulae:

$$N_1 = \frac{n(n-1)(n-2)}{2}$$

Here is an example of CTC plan for number of lines $n = 5$ and total number of crosses $N_1 = 30$:

)1×2) × 3	)1×3) ×2	)2×3) ×1
)1×2) ×4	)1×4) ×2	)2×4) ×1
)1×2) × 5	)1×5) ×2	)2×5) ×1
)1×3) ×4	)1×4) ×3	)3×4) ×1
)1×3) × 5	)1×5) ×3	)3×5) ×1
)1×4) ×5	)1×5) ×4	)4×5) ×1
)2×3) × 4	)2×4) ×3	)3×4) ×2
)2×3) ×5	)2×5) ×3	)3×5) ×2
)2×4) × 5	)2×5) ×4	)4×5) ×2
)3×4) ×5	)3×5) ×4	)4×5) ×3

The model (Hinkelmann, 1965) for three-way cross is as follows:

$$y_{(ij)k} = \mu + h_i + h_j + g_k + d_{(ij)} + s_{(i)k} + s_{(j)k} + t_{(ij)k} + e_{(ij)k}$$

where $y_{(ij)k}$, is the response of three-way cross $(i \times j) \times k$, μ is the mean effect of crosses, h_i is the gca effect of i_{th} half parent involved in the three-way cross, h_j is the gca effect of j_{th} half parent involved in the three-way cross, g_k is the gca effect of k_{th} full parent involved in the three-way cross, $d_{(ij)}$ is two-line specific combining ability effects involving two half-parents $s_{(i)k}$, $s_{(j)k}$ are two-line specific combining ability effects involving a half-parent and a full-parent, $t_{(ij)k}$ is three-line specific combining ability effect and $e_{(ij)k}$ is i.i.d N(0,σ^2).

Complete four-way cross plans

Four-way cross hybrids are the first line progeny of two unrelated F_1 hybrids. They are generally depicted as)*A*×*B*(×) *C*×*D*(, where *A*, *B*, *C* and *D* four parental lines and) *A*×*B*(&) *C*×*D* (are the two F_1 . Thus a complete four-way cross (CFC) plan is the group of all possible four-way crosses of the type)*A*×*B*(×) *C*×*D*(. The total number of crosses N_2 in a CFC plan obtained for n lines can be calculated by the given formulae:

$$N_2 = \frac{n(n-1)(n-2)(n-3)}{8}$$

Here is an example of CFC plan for number of lines $n = 5$ and total number of crosses $N_2 = 15$:

(1×2) × (3×4)	(1×3) × (4×5)	(1×4) × (2×5)
(1×2) × (3×5)	(1×3) × (2×5)	(1×4) × (3×5)
(1×2) × (4×5)	(1×3) × (2×4)	(1×4) × (2×3)
(1×5) × (3×4)	(1×5) × (2×3)	(4×5) × (2×3)
(2×5) × (3×4)	(1×5) × (2×4)	(2×4) × (3×5)

The model (Rawlings and Cockerham, 1962) for four-way cross is as follows:

$$y_{(ij)(kl)} = \mu + G_{(ij)(kl)} + e_{(ij)(kl)}$$

where $y_{(ij)(kl)}$ is the response of four-way cross, μ is the mean effect of crosses, $G_{(ij)(kl)}$ is the component comprising of various general combining ability effects and specific combining ability effects, $e_{(ij)k}$ is i.i.d $N(0,\sigma^2)$ and *i,j,k,l* (*i≠j≠k≠l*)= 1, 2, …n.

Partial higher order (three-way and four-way) cross plans

If we consider the formulae of calculating the total number of crosses (N_1 and N_2) then we got to know that the total number of crosses increases many times with the increase in number of lines. This is a problematic situation for the breeders as it increases the cost of experimentation. To tackle this problem we can take and use a sample of higher order crosses, generally known as partial higher order crosses (partial three-way cross, PTC and partial four-way cross, PFC). Here the technique involves reducing the number of crosses rather than reducing the number of lines to obtain information on combining abilities effects related to the parental lines. Hinkelmann introduced the concept of PTC and defined it in 1965. In order to compare two higher order with same efficiency we can use degree of fractionation (*f*).

Degree of fractionation (*f*)

If there are N_p number of crosses in a partial higher order cross plan (PTC/PFC) obtained for n number of lines and the total number of crosses in the complete higher order cross plan (CTC/CFC) is N_p , then degree of fractionation (*f*) can be obtained by the following formulae:

$$f = \frac{N_p}{N_c}$$

Example 1: Here is an example of PTC plan (Harun *et al.,* 2016) for number of lines, $n = 7$ along with the degree of fractionation.

(1×2)×3	(1×3)×2	(2×3)×1	(1×3)×5	(1×5)×3	(3×5)×1	(1×4)×7	(1×7)×4	(4×7)×1
(2×3)×4	(2×4)×3	(3×4)×2	(2×4)×6	(2×6)×4	(4×6)×2	(2×5)×1	(2×1)×5	(5×1)×2
(3×4)×5	(3×5)×4	(4×5)×3	(3×5)×7	(3×7)×5	(5×7)×3	(3×6)×2	(3×2)×6	(6×2)×3
(4×5)×6	(4×6)×5	(5×6)×4	(4×6)×1	(4×1)×6	(6×1)×4	(4×7)×3	(4×3)×7	(7×3)×4
(5×6)×7	(5×7)×6	(6×7)×5	(5×7)×2	(5×2)×7	(7×2)×5	(5×1)×4	(5×4)×1	(1×4)×5
(6×7)×1	(6×1)×7	(7×1)×6	(6×1)×3	(6×3)×1	(1×3)×6	(6×2)×5	(6×5)×2	(2×5)×6
(7×1)×2	(7×2)×1	(1×2)×7	(7×2)×4	(7×4)×2	(2×4)×7	(7×3)×6	(7×6)×3	(3×6)×7

The total number of crosses, $N_p = 63$ for the above mentioned partial three-way cross plan and for a complete three-way cross plan involving the same number of lines, the total number of crosses, $N_c =$ 105. Thus, the degree of fractionation, $f = 63/105 =$)3/5(.

Example 2: Here is an example of PFC plan (Parsad *et al.,* 2005), constructed using balanced incomplete block design (8, 14, 7, 4, 3), for number of lines, $n = 8$ along with the degree of fractionation.

(2×4) × (6×8)   (1×3) × (5×7)

(3×5) × (7×8)   (2×4) × (6×1)

(4×5) × (1×8)   (3×5) × (7×2)

(5×7) × (2×8)	(4×6) × (1×3)
(6×1) × (3×8)	(5×7) × (2×4)
(7×2) × (4×8)	(6×1) × (3×5)
(1×3) × (5×8)	(7×2) × (4×6)

The total number of crosses, $N_p = 14$ for the above mentioned partial four-way cross plan and for a complete four-way cross plan involving the same number of lines, the total number of crosses, $N_c = 210$. Thus, the degree of fractionation, $f = 14/210=$) 1/15(.

There a lot of methods of construction and analysis procedure available in literature for partial three-way crosses involving prime or prime power number of lines (Harun *et al.*, 2016; Das and Gupta, 1997) and partial four-way crosses (Rawlings and Cockerham, 1962; Parsad *et al.*, 2005).

Conclusions

Here, the importance of higher order cross plan for hybrid production has been described. The breeders can obtain comparatively more resistant and stable lines using higher order crosses for hybrid production. Higher order crosses like three-way and four-way crosses are found to be suitable in this situation. The already developed methods of constructing higher order crossing plans can be used by the breeders to fulfill their goals. Breeders can get information regarding the combining abilities of more lines in lesser number of crosses by selecting a higher order cross plan with a lower degree of fractionation.

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