CONCLUSIONS

In conclusions, it may be worthwhile to bring together the various results obtained and evaluate their implications on the breeding methodology to be adopted in the improvement of bengal gram. The major objective in such a programme would, of course, be the improvement of the grain yield. Equally important, however, would be maintaining, if not increasing the protein content. The quality of the protein will also be an important consideration. One approach would be to aim to increase the content of the sulphur containing amino acids, methionine and tryptophane in which gram and pulse protein in general, are deficient. Another approach would be to breed for increased lysine content while maintaining the protein level. This becomes relevant when we consider that the Indian diet almost universally comprises a mixture of cereals and pulse and that the cereal proteins are highly deficient in lysine but have fair quantities of methionine and tryptophane.

An important consideration in a breeding programme would be the stability of genotypes over a range of environments. The environments sampled in this study undoubtedly constitute a wide range and understandably the component due to environment has overshadowed that due to genotypes except in the case of 100-grain weight and protein content. The component due to genotype x environment interaction is also appreciable though smaller than that due to genotypes. Earlier studies (Ramanujan, Rohewal and Singh, 1964) have also indicated the existence of appreciable genotype and environment interaction. One
approach would be to stratify the grass growing areas into ecologically
more homogeneous sub-regions. This, however, would not help to over-
come the unpredictable variations met with over the years at the same
location or locations within such sub-regions. In a crop like gram,
which is grown under barren conditions, especially such unpredictable
fluctuations are likely to be of appreciable magnitude. The breeding
objective should, therefore, be varieties which can adapt themselves
to such fluctuations and maintain the yield of the end product. In a
crop like gram, what would be needed, would be genotypes which can
give as good yield as other types under adverse circumstances but
would make maximum use of favourable seasons and give much higher yields
than the average in that environment. This may, of course, mean
fluctuations in total production and surpluses in some years. The
demand for pulses is, however, likely to increase considerably in the
future and such surplus should be no disadvantage. Also, the develop-
ment of adequate storage facilities would take care of surplus, if any,
in favourable years for marketing in less favourable seasons. The
objective would, therefore, be to select genotypes which would have a
high mean over environments but be of average stability as shown by
unit regression of performance over environmental indexes and low
deviations due to unexplainable causes. It is encouraging, therefore,
to note that a number of genotypes were identified which satisfied
these criteria. It would be interesting and important to study next
the inheritance of such phenotypic stability and see whether crosses
involving phenotypically stable parents would give stable progenies.
This would help in the programme for incorporating stability in
breeding material.
However, building buffering into genotypes will add to the already large number of objectives to be achieved by the breeder and might complicate the breeding process to a high degree. Another approach would be to exploit population buffering. Allard and Bradshaw (1964) have shown that heterozygous material has individual as well as population buffering and is more consistent in performance in different environments. Simmonds (1962) reported that mixed populations are nearly always more stable in yield than their components. Heterozygous and/or heterogeneous populations show, in general, small genotype x environment interaction (Rowe and Anderson, 1962; Eberhart and Russel, 1966). One approach would, therefore, be to grow mixtures of genotypes so chosen as to stabilise the yield at a high level in a majority of the environments. While attractive from the theoretical point of view, the several problems which may beset this approach in practice should be recognised. Even if varieties which complement each other in the desired direction so far as seed yield is concerned, do become available, the problems of phenotypic uniformity at least in respect of the grain, of possible competition between the genotypes, and of reaction to diseases and pests would need to be overcome. The possibilities are, however, intriguing and deserve to be studied further.

One method of building up a highly heterozygous population would, of course, be the exploitation of hybrid vigour. This approach may appear to be at first sight quite unsuitable for a highly self-pollinated crop like bengal gram. Recent developments, in the exploitation of hybrid vigour in Sorghum as well as the possibilities
inherent in hybrid wheat, should, however, serve to temper this view and suggest that the possibility of exploitation of heterosis should be carefully considered in all crop plants irrespective of their breeding systems. No doubt, it should be possible, at least theoretically, to isolate in self-pollinated species pure lines which should be as high yielding as the best hybrid combination. However, the reported greater advantage of heterozygotes under stress conditions (Griffing and Langridge, 1963, and Allard and Wiman, 1963) would be useful, particularly in a crop grown under harsh conditions as bengal gram is. It should, therefore, be interesting to inquire into the potentialities of heterosis breeding in this crop. Various considerations such as whether the floral biology is such as to permit the economic exploitation of heterosis, whether appreciable heterosis occurs in some hybrid combinations as compared to the best available homozygous genotype, have to be kept in mind in this connection. But the most important consideration will be whether the type of gene action involved is one which calls for or justifies a hybrid programme. As Cookman (1961) points out the existence of non-fixable gene effects would be the chief reason for adopting a hybrid programme. Though the results obtained in this study regarding the nature of genetic control of yield and its components as also of protein content are based on diallel crosses involving only seven selected parents, these should, at least give some indication. When the combining ability analysis and the gene effects analysis are considered together, it appears that while additive effects play an important role, non-additive effects may also be appreciable in the case of yield components.
and perhaps yield itself. In so far as protein content is concerned, there appears to be an appreciable element of overdominance. There would, therefore, appear to be scope for the exploitation of heterosis. It must also be noted that the existence of additive gene effects in the control of the components does not necessarily mean that the maximum expression of all the components can be easily combined in a pure genotype. This is because of the existence of unfavourable correlated responses and the resultant genetic slippage, when selection pressure is applied for two or more of the components. Such genetic slippage should be much less important in heterozygous material and would form sufficient justification for a hybrid programme.

The other aspects mentioned above may also be briefly considered. Bengal gram is known to be highly self-pollinated even though its flower is beautifully adapted for insect pollination. Such high self-pollination is, perhaps, to be traced to the dehiscence of the anthers before the flowers open so that the subsequent insect visits are without effect. If, therefore, cytoplasmic male sterility is discovered, the subsequent production of crossed seeds may not be difficult since insects would bring about ample pollination of the male-sterile lines. Economic hybrid seed production may, therefore, be practical. The other question concerns the existence of a useful quantum of superiority of hybrids over the best that can be had from homozygous types. The data in Table 25 on page 81 are relevant here. To recapitulate, only one cross out of 21, Fb. 7 x 6.49, showed higher grain yield over the better parent while none reached the level of the best parent, 6.29.
In respect of protein content, significant superiority over the better parent was observed in crosses of K.5 and C.49 with Fb.7 and F.0. and of C.49 with G.24, though none excelled the better parent, Utah Bold. The picture is, therefore, none too encouraging. It should, however, be remembered that only as few as seven parents have been utilised. It is quite possible that if other hybrid combinations are evaluated, some may turn out to be superior to the best available homozygous genotype, especially when protein yield per unit area is considered.