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MITOCHONDRIAL EFFICIENCY IN BREEDING HYBRID AND PURE-LINE WHEAT

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SUMMARY

The percentage additional mitochondrial efficiency, as measured by ADP:O ratios, of 1:1 mixtures of mitochrondria over their more efficient component lines was found to be significantly correlated with the percentage higher-parent yield heterosis of corresponding F_1 hybrids only when these were fully restored, relatively disease free and grown at low seed rate. This result indicates that measurements of mitochondrial complementation may have some value as a first screening test of potential parental lines when selecting for high combining ability. Some possible long-term consequences of this for breeding both hybrid and pure-line wheat are discussed.

Since the results of the work of three biochemists in the U.S.A. (McDANIEL and SARKISSIAN, 1966; SARKISSIAN and SRIVASTAVA, 1967, 1969; and McDANIEL, 1970) have appeared to show:

(a) that heterotic hybrids of maize, wheat and barley have more efficient mitochondria, as measured by ADP:O ratios, than their parental lines. This has been called mitochrondrial heterosis.

(b) that 1:1 mixtures of mitochondria extracted from the parental lines exhibit complementation and have ADP:O ratios approaching that of the F_1 hybrid. This has been called mitochondrial complementation.

(c) that heterosis for seedling characters in F_1 hybrids can be correlated with the expression of mitochondrial complementation.

Consequently it was suggested that mitochondrial complementation might be a means of estimating potential combining ability for yield without the necessity, in the first instance, for producing the actual F_1 hybrid combination. This possibility was investigated in a collaborative project with G. E. Hobson of the Glasshouse Crops Research Institute, Littlehampton, England.

MATERIALS AND METHODS

Nine F_1 hybrid wheats were produced in 1970 at Cambridge by wind-pollinating three cytoplasmically male-sterile lines with three restorer lines. The six parental lines used were the only locally adapted male-sterile and restorer lines available at the time, and it was not known whether the F_1 hybrids would exhibit heterosis for yield in the field. The nine hybrids, together with the male parents and the self-fertile maintainer lines of the male-sterile parents, were grown with five replications in a winter-sown trial at Cambridge at two seed rates, the higher of which produced about 197 plants/m^2 and the lower about 97 plants/m^2. The higher seed rate was designed to make economical use of seed but nevertheless produce ear densities at harvest comparable to those found in a normal commercial crop. The lower seed rate was very much lower than that normally used in British agriculture. The harvested area from each plot was 1.4 m^2.

During the winter, Hobson measured the ADP:O ratios of mitochondria extracted from the six parental lines and of the appropriate 1:1 mixtures of their mitochondria using four replications and methods which have been published (SAGE and HOBSON, 1973). Thus complementation data were available before the field performance of the hybrids was known.

RESULTS

Although some hybrids and mitochondrial mixtures gave yields and ADP:O ratios, respectively, that were higher than the appropriate parental lines, no differences were statistically significant and, when all nine hybrids were considered, the percentage additional mitochondrial efficiency of the 1:1 mixtures of mitochondria over their more efficient component did not correlate with the percentage increase in yield of the corresponding F_1 hybrid over its higher-yielding parent at either seed rate. Thus it appeared that we could draw no conclusion about complementation and heterosis for yield.

However, one hybrid was significantly lower yielding than the others due to severe attacks of eyespot (*Cercosporella*) and yellow rust (*Puccinia striiformis*), and another was partially sterile due to incomplete functioning of the restorer genes. Thus for both these hybrids there were clear-cut reasons to suppose that their expression of heterosis for yield was being restricted. When the data from these two hybrids were excluded, the above correlation for the remaining seven hybrids was very highly significant at the low seed rate but not at the higher, more agricultural, seed rate. The percentage heterosis for yield at each seed rate, the percentage mitochondrial complementation and the correlation coefficients are given in Table 1.

DISCUSSION

The efficiency with which mitochondria release energy for cellular work can be regarded as just one component of yield. If this efficiency in an F_1 hybrid were the major limiting factor of the expression of heterosis for yield, it might be expected that estimates of it, derived from complementation data, would correlate with the extent of yield heterosis and hence have some predictive value. However, in growing conditions where other yield components, such as disease susceptibility, levels of restoration or high interplant competition were likely to be more important limiting factors of heterosis, mitochondrial complementation might be expected to have little or no predictive value. The results presented here were considered to support these propositions, since complementation was predictive only with fully restored, relatively disease-free hybrids grown at a very low seed rate. If these conclusions are valid, they indicate that a wheat-breeding programme might usefully employ mitochondrial complementation only as a first screening test to select combinations of parental lines with a potentially high mitochondrial efficiency. Such combinations would then need to be produced and carried on to tests of actual heterotic performance under agricultural conditions.

The potential use of mitochondrial complementation has aroused considerable interest among workers concerned with hybrid cereals and of course could be of equal interest in other crops (DONEY *et al.*, 1972), including the pure-line breeding of wheat. However, the techniques of measuring ADP:O ratios are difficult and time-consuming, and not all workers have been able to repeat the original observations (ELLIS *et al.*, 1973; ZOBL *et al.*, 1972). But if the accurate measurement of mitochondrial efficiency is difficult, so is the accurate measurement of heterosis in the field. Adequate conclusions as to the potential use of mitochondrial complementation must await further experiments, preferably carried out over a number of seasons and using more highly heterotic hybrids than were used in this trial.

Table 1. Comparison and correlation between percentage higher-parent heterosis for F_1 yield at two seed rates and percentage advantage of mixture ADP:O ratios over their more efficient component

Hybrid	Seed rate and heterosis for F_1 yield (%)		% complementation
	Low	High	
M.R. x 74/34/3	109.7	106.0	107.0
306/45 x P	106.6	107.1	100.9
M.R. x M.B.	106.1	88.5	103.3
K x 74/34/3	104.3	95.5	98.6
306/45 x 74/34/3	99.8	104.3	94.3
K x M.B.	98.4	84.3	97.4
M.R. x P	98.3	99.3	94.4
306/45 x M.B.	97.0	85.5	98.5
K x P	81.2	81.7	99.3

Correlation coefficients	Low rate	High rate
All nine hybrids	0.447	0.118
t val., 7 d.f. (P = 0.05)	1.478 NS	0.317 NS
All hybrids except 306 x M.B. & K x P	0.921	0.113
t val., 5 d.f. (P = 0.05)	13.549***	0.256 NS

NS = not significant; *** P < 0.001

Hybrid wheat is unlikely in the short term future in Europe, especially if cytoplasmic male-sterility and restoring genes have to be used, not so much because of the biological problems as because of the economic problems. The major biological hurdles - restoration, cross-pollination and heterosis - may well be surmounted with extensive and careful breeding. In Europe it is the economic problems that are more formidable, e.g., the ratio of seed costs to return, the difficulties of lowering seed rates without incurring extra costs for precision drills, pelleting of seed etc., the difficulty of finding sufficient isolated, ergot-free land for seed crops, and always the constant competition from extensive pure-line programmes aimed at improving yield.

Hybrid wheat is worth pursuing, however, especially if a simple, cheap and reliable gametocide becomes available which will greatly alleviate some of the economic problems. If nothing else, hybrid wheats will provide high-yielding models at which to aim pure-line breeding, and will refine the use of male-sterility as a breeding tool.

If hybrid wheat becomes commercially feasible, then the question arises, which will produce yield advances faster, breeding for hybrid wheats or breeding pure lines? If some measure of mitochondrial efficiency must be regarded as just another component of yield, then its measurement, or its estimation by measurements of complementation, will assist in breeding both hybrid and pure-line varieties, certainly in the choice-of-parents phase of the breeding programme, if not also in the selection phase. The significance of the attempts to measure mitochondrial efficiency lies in the fact that selection could then be applied for a yield component important at a very early stage in the life cycle. As the biochemistry and physiology of wheat becomes better understood, breeders will increasingly want to select for a range of more fundamental yield components than they do at present. The sophisticated selection techniques required for such components may well be impossible or very time-consuming to apply to single plants. If at this stage the technical problems of hybrid variety production have been overcome, then it may be easier to make advances by applying exact selection techniques to a range of hybrid varieties or their potential parental lines, each of which is repeatedly available in reasonable quantities, rather than by selecting single plants from segregating populations. It is for these reasons that it is important to persist in attempts to relate measurements of fundamental biochemical efficiency to the overall performance of the crop.

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