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## Similar increase in reproductive performance in different continents of female line, male line and parent stock broiler breeders genetically selected in the UK or South America

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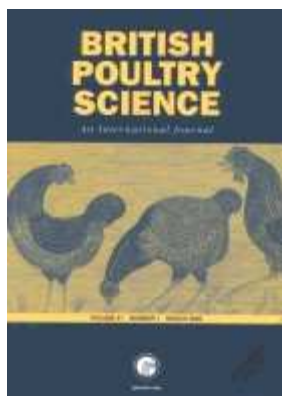
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**Similar increase in reproductive performance in different continents of female line, male line and parent stock broiler breeders genetically selected in the UK or South America**

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8 3 **Similar improvements in reproductive performance of male line, female line and parent**  
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10 4 **stock broiler breeders genetically selected in the UK or in South America**  
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15 6 P. M. HOCKING AND C. C. MCCORQUODALE  
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18  
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21 *Scotland*  
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29 12 **RUNNING TITLE: REPRODUCTIVE PERFORMANCE OF BROILER BREEDERS**  
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2  
3 24 **Abstract.** 1. Field data on the reproductive performance of parent stock and grandparent  
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5 25 female line and male line broiler breeders were extracted from a commercial database  
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8 26 covering the years of hatch from 1989 to 2002. The data were from the UK, Western Europe,  
9  
10 27 Central and South America and Japan. Quadratic regression curves were fitted to the data to  
11  
12 28 estimate the long term phenotypic trends in total egg production, hatching egg production,  
13  
14 29 chick numbers, hatchability and female mortality.  
15  
16  
17 30 2. Changes in performance over time were similar in the UK, Western Europe and Central  
18  
19 31 and South America and are consistent with the suggestion that genetic selection in separate  
20  
21 32 breeding programmes in the UK (supplying the UK and Western Europe) and Brazil (serving  
22  
23 33 Central and South America) was associated with similar improvements in the performance of  
24  
25 34 commercial parent stock and grandparent flocks. Changes in performance in Japan (supplied  
26  
27 35 from the UK) were different but recent performance was similar to those in the other regions.  
28  
29 36 3. The mean annual improvement over 10 years to 2002 for male line, female line and parent  
30  
31 37 stock respectively were 0.4, 1.7 and 1.7 for total egg number; 0.5, 1.8 and 1.6 for hatching  
32  
33 38 egg number; 0.6, 1.8 and 1.3 for total chick production; 0.25, 0.47 and 0.09 % for  
34  
35 39 hatchability; and -0.69, -0.05 and -0.41 % for female mortality.  
36  
37 40 4. The results are consistent with claims that significant genetic change in pedigree selection  
38  
39 41 (nucleus) flocks by the primary breeding company are reflected in substantial improvements  
40  
41 42 in reproductive performance in commercial flocks. The presence of similar rates of  
42  
43 43 improvement in different geographical regions as a result of genetic selection in two  
44  
45 44 continents representing tropical and temperate regions suggests that genotype-environment  
46  
47 45 interactions for reproduction traits are not important.  
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## 47 INTRODUCTION

48 Genetic selection of broiler chickens for increased broiler traits results in a decline in  
49 reproductive output in selection experiments because of the negative genetic correlation  
50 between growth rate and egg production (Chambers, 1990). Commercial breeders therefore  
51 expend some selection effort in maintaining or improving reproduction in female lines,  
52 whereas there is much less emphasis on egg production in the male lines with which they are  
53 mated to generate commercial broilers.

54 It has sometimes been stated by those organisations that are critical of modern animal  
55 breeding programmes that genetic selection for increased broiler productivity has led to lower  
56 fitness as shown by decreased reproductive performance and higher mortality. Breeding  
57 companies, on the other hand, maintain that they select for increased reproduction and better  
58 health in their lines and that reproductive performance has increased, particularly in recent  
59 years. Estimates of the genetic progress from selection decisions in purebred nucleus flocks  
60 can be obtained routinely using modern statistical methods for calculating breeding values.  
61 However the environments in which commercial hybrids are kept are very different from  
62 those in the pedigree flocks and selection progress in selection environment may not be  
63 translated into comparable improvements in commercial performance. Part of the objective of  
64 this study was to quantify the changes that have occurred over a recent 15 year period in a  
65 large number of flocks of commercial parent stock, and the main female and male lines  
66 (grandparents of commercial broilers) of a major broiler breeding company.

67 The Aviagen breeding company operates a voluntary system of flock recording for  
68 customers producing grandparent crosses for commercial flocks of broiler parent stock  
69 (broiler breeders). The performance of parent stock flocks can also be entered into the system.  
70 The data are used to provide comparative information on the relative performance of different  
71 flocks for technical advice and as an aid in identifying management problems that may be

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3 72 inhibiting optimum reproductive performance. The great-grandparents of commercial broilers  
4  
5 73 (the parents of the female and male lines) are supplied by Aviagen from separate pedigree  
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8 74 breeding populations in the UK, Brazil and USA using similar breeding structures and  
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10 75 technologies. A second objective was therefore to determine whether there had been similar  
11  
12 76 changes in reproductive performance of flocks of broiler breeders supplied from separate  
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14  
15 77 breeding programmes in two climates, one temperate (UK) and one tropical (Brazil). The UK  
16  
17 78 selection programmes supplies customers in the UK, Western Europe and Japan, and Brazil  
18  
19 79 provides chicks for customers in Central and South America (C&S America). Selection  
20  
21  
22 80 objectives and procedures were identical in the two locations. Primary selection objectives in  
23  
24 81 male lines were feed efficiency and muscle yields, whereas in female lines selection  
25  
26 82 emphasised improved reproduction in addition to other traits. Our third objective was  
27  
28 83 therefore to compare the changes in different continents to assess the importance of putative  
29  
30 84 genotype x environment interactions, *i.e.* whether similar changes had occurred in very  
31  
32 85 different commercial conditions in three continents (Europe, C&S America and Asia).  
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## 36 86 MATERIALS AND METHODS

### 37 87 **Data source and data edits**

38  
39 88 Flock data were entered by flock managers and Aviagen technical staff from farm records  
40  
41 89 dating from 1984. Data analysed were hen housed egg production (total egg  
42  
43 90 production/number of hens at housing), hen housed hatching egg numbers (total hatching egg  
44  
45 91 production/number of hens at housing), hen housed chicks (total chick production/number of  
46  
47 92 hens at housing), hatchability of eggs set (total number of eggs hatching/total number of eggs  
48  
49 93 set, %) and female laying house mortality (total number of hen deaths/number of hens at  
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51 94 housing). All 5 traits were adjusted to 60 weeks of age by unspecified commercial correction  
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53 95 factors.  
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3 96 Data from the Ross 308 in the UK, Western Europe, C&S America and Japan were  
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5 97 selected for statistical analysis. Commercial broilers are produced by mating an (A ♂ x B ♀)  
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7  
8 98 male with a (C ♂ x D ♀) female. Information on female reproductive performance of the  
9  
10 99 grandparent male line B (ML), female line D (FL) and commercial parent stock (PS) that  
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12  
13 100 contribute to the Ross 308 commercial broiler were selected for analysis.

### 15 101 **Statistical analysis**

16  
17  
18 102 Quadratic regression curves were fitted using restricted maximum likelihood (REML)  
19  
20 103 methods (Patterson and Thompson, 1971) to represent long term time trends in the  
21  
22 104 observations. This shape of curve was chosen because it allowed for a long term trend to be  
23  
24  
25 105 increasing, decreasing or both. Higher order polynomials or other curves with multiple  
26  
27 106 turning points were thought to be implausible representations of long term trends. REML was  
28  
29  
30 107 required to estimate variance components between and within hatch week and other sources  
31  
32 108 of random variation associated with the different customers supplying the data.

33  
34 109 The manner and extent to which individual data points had been aggregated over  
35  
36 110 birds, houses and farms was unknown. All observations were therefore given the same weight  
37  
38  
39 111 in the fitting process. Standard errors were calculated using deviations about the fitted curve  
40  
41 112 as random variation, assuming the part of the variation due to farms, houses and birds to be  
42  
43  
44 113 small compared with that due to deviation about fitted curves. Estimates of regression  
45  
46 114 coefficients of the trend using equal weights will be unbiased providing there is no association  
47  
48  
49 115 between the size of an observation and the number of birds, houses or farms over which it has  
50  
51 116 been aggregated. Variation between customers in the shape of the curves was taken to be  
52  
53 117 random and the standard errors include this variation. Variation between customers in the  
54  
55  
56 118 level of the curves was taken to be a fixed effect so that any gross differences between them  
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58 119 (due to management or climate, for example) would not contribute to the trend. Customers  
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60 120 with data spanning less than 3 years were omitted in the estimation of long term trends as

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3 121 short term trends could be qualitatively different from those in the long term (seasonal cycling  
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5 122 within a year, for example). Fitted curves and predicted means in multi-customer regions  
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7  
8 123 were arrived at by averaging equally over all customers.  
9

## 10 124 RESULTS

11  
12 125 Data were extracted from the database in mid-2004 when it was assumed that all flocks  
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14 126 hatched in 2002 would have completed records. This was the case for all regions except  
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16  
17 127 Japan. Data for the period from 1984 to 1990 were not extensive and results of the analyses of  
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19 128 data from birds hatched over a 10-year period from 1991 to 2001 or 2002 are presented. The  
20  
21 129 numbers of records analysed and the number of customers contributing to each data set are  
22  
23  
24 130 presented in Table 1. Mean flock performance in 2002 for each trait and all 4 regions are  
25  
26  
27 131 presented in Table 2. Tables 1,2,3 near here

28  
29 132 Response curves for individual PS flock means from birds hatched from 1991 to 2002  
30  
31 133 in the UK are plotted in Figure 1 and regional curves for PS, FL and ML respectively are  
32  
33 134 plotted in Figures 2, 3 and 4. The data and curves for hen housed hatching egg numbers were  
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35  
36 135 similar to those for total hen housed egg production for all three lines and are not presented. It  
37  
38 136 should be noted that the range but not the scale for total and hatching egg numbers in Figures  
39  
40  
41 137 1 to 4 are not the same and care should be exercised in comparisons between them.  
42  
43 138 Appropriate numerical contrasts between the three lines may be made by reference to Tables  
44  
45  
46 139 2 and 3.

47  
48 140 Response curves and individual data points for PS in the UK (Figure 1) illustrate the  
49  
50 141 wide spread of flock means about the fitted curve that was also observed for FL and ML in  
51  
52 142 the UK and PS, FL and ML in the other regions (data not shown).

53  
54 143 The response curves for PS in the UK, W. Europe, C&S America and Japan are  
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56 144 presented in Figure 2. There was an early decline followed by an improving response for total  
57  
58 145 and hatching egg production. Hatchability showed a small decline in the early 1990s followed  
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3 146 by a subsequent increase in three of the four regions and there was a trivial decline from a  
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5 147 relatively high mean hatchability in Western Europe. Mortality also improved in recent years  
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8 148 in three regions and showed a small increase in the UK from a relatively low starting point  
9

10 149 There was a steady increase in egg production, chick numbers and hatchability in the  
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12 150 FL (Figure 3) over the study period and a recent decline in female mortality in all regions  
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15 151 except the UK and Western Europe where there was a small increase. Japan showed a  
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17 152 substantial decrease in hatchability and chick numbers from a high in the early years and a  
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19  
20 153 recent increase to similar levels as the other regions.  
21

22 154 Responses for ML flocks (Figure 4) were similar for the UK, W. Europe and C&S  
23  
24 155 America and show a recent improvement in egg and chick production, decreased female  
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26 156 mortality and little change in hatchability. The responses for Japan were very different and  
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28  
29 157 were comparable with those for PS and FL.  
30

31 158 Estimates of the change in response for each trait over the 10 years to 2002 by  
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33 159 geographical region are presented in Table 3. The mean annual changes for ML, FL and PS  
34  
35 160 respectively were 0.4, 1.7 and 1.7 for total egg number; 0.5, 1.8 and 1.6 for hatching egg  
36  
37 161 number; 0.6, 1.8 and 1.3 for total chick production; 0.25, 0.47 and 0.09 % for hatchability;  
38  
39 162 and -0.69, -0.05 and -0.41 % for female laying house mortality. Part of the differences in the  
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42 163 responses over time for ML in Japan (Table 3) is associated with a change in management of  
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44  
45 164 the birds introduced by the customer. Figures 1,2,3,4 near here  
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47

## 48 165 DISCUSSION

49  
50 166 There is little comparable information in the public domain on changes in reproductive  
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52 167 performance in broiler breeders with which to compare these results. Schall and Cherian  
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54 168 (2007) reported that there was no detectable change in average hatchability of about 80 %  
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56 169 from 1985 to 2005 in the USA. In a smaller data set from 38 rearing farms in Norway from  
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59 170 1996 to 1998 average hatchability was also about 80 % (Heier and Jarp, 2001). Hatchability  
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3 171 for PS at the end of our study period was higher than these values with regional means  
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5 172 ranging from 80 to 85 %; corresponding means were 70 to 80 % for FL and 65 to 75 % for  
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8 173 ML. In contrast to PS, the range of hatchabilities for FL and ML are large and suggest that  
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10 174 there is considerable scope for management changes to hatchery procedures to improve the  
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12 175 hatchability of these lines in some regions.

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15 176 Genetic stocks in the UK, W. Europe and Japan are sourced from the same pedigree  
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17 177 (nucleus) selection flocks whereas those for C&S America are supplied from Brazil. The  
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19 178 similarity of changes in reproduction traits of commercial flocks of parents and grandparents  
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21 179 in the UK, W. Europe and C&S America does not contradict the suggestion that genetic  
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23 180 selection in the UK and Brazil has resulted in similar changes in commercial performance in  
24  
25 181 different geographical regions. We cannot distinguish between genetic changes and  
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27 182 improvements in flock management but there has been little technical innovation, such as the  
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29 183 introduction of separate sex feeding in the late 1980s, which could have led to improved  
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31 184 reproductive performance in the study period. Conversely, changes that have occurred, *e.g.*  
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33 185 the move from manual to automatic egg collection may have had a negative impact on egg  
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35 186 production. It is assumed that in principle all customers followed the management targets for  
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37 187 body weight control and general management procedures recommended by the breeding  
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39 188 company but it is impossible to verify the extent to which these were adhered to in individual  
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41 189 flocks. Nevertheless by analysing data from a large number of flocks the influence of  
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43 190 temporary differences in flock management practices are minimized: the results are virtually  
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45 191 population parameters for FL and ML and encompass a substantial proportion of PS flocks in  
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47 192 the regions analysed.

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50 193 Reporting bias is unquantifiable in the data set but biased reporting serves no useful  
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52 194 purpose to the instigator. If there is any form of selective reporting it is likely to be negative  
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54 195 because producers with poor flocks are more likely to record flock performance as a means of

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3 196 solving management problems, or as part of the process of obtaining financial recompense  
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6 197 from the breeding company and chick supplier.  
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8 198 The extent of the recent phenotypic improvement in egg production (Table 3) is  
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10 199 comparable to that attained in commercial table-egg laying hens and if genetic selection is  
11  
12 200 responsible, suggests that this primary breeder is placing heavy emphasis on improving egg  
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14 201 and chick production. Taken together the results are consistent with the conclusion that  
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16 202 genetic selection in pedigree flocks has been successful and has resulted in substantial  
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18 203 improvements in reproductive traits in commercial flocks of broiler breeders in very different  
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20 204 geographical regions and climates.  
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24 205 Recent improvements in female mortality are impressive in all regions except for the  
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26 206 UK where there has been a slight increase in FL and PS (Table 3). Part of this change may be  
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28 207 due to improved husbandry or vaccination and some to selection on fitness traits. We chose to  
29  
30 208 examine female mortality only because many flocks did not report male mortality.  
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32 209 Furthermore the male data were considered to be unreliable because regular culling of males  
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34 210 is conducted during the laying period on an *ad hoc* basis to maintain overall male fitness and  
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36 211 to adjust the male:female mating ratio to avoid over-mating and consequential damage to  
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38 212 females.  
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43 213 Whereas the reproductive traits analysed in this paper have been treated as female  
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45 214 traits, it should be noted that the male has an influence not only on traits such as hatchability  
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47 215 and chick numbers, but potentially on egg production and female mortality *via* social and  
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49 216 sexual cues (Leonard *et al.*, 1993; Widowski *et al.*, 1998) and the effects of social and mating  
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51 217 stress (Millman and Duncan, 2000a and b).  
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55 218 Reproductive efficiency, productivity and health are important considerations in  
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57 219 assessing the welfare of any group of animals and the evidence of this analysis is that genetic  
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59 220 selection has led to substantial improvements in these criteria over a recent 10 year period. A  
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3 221 corollary is that feed restriction during the rearing period has not had a negative effect on  
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5 222 reproductive fitness during a decade of substantial genetic improvement in broiler growth rate  
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8 223 and feed efficiency.  
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10 224 In conclusion, there has been substantial improvement over a recent 10 year period in  
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12 225 the reproductive traits of PS and FL, which contribute half the PS genetic material, and  
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15 226 mortality has shown an improvement in parent and grandparent flocks of broiler breeders in  
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17 227 three of the four regions analysed. The change in total eggs, hatching eggs and chick numbers  
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19 228 over the same period in ML have also increased but at about half the rate in PS and FL. The  
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21 229 rate of change has been similar in different geographical regions and in areas supplied by  
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23  
24 230 primary breeding flocks in the UK and Brazil, and are consistent with claims of significant  
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26 231 genetic improvement of reproduction traits in primary breeding populations. The similarity of  
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28 232 the phenotypic changes in different continents suggests that significant genotype x  
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30 233 environment interactions for reproductive performance has not occurred. There is little or no  
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32  
33 234 evidence that reproductive traits have decreased during the study period.  
34

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42 238 the BBSRC.  
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3 259 **Figure Legends**  
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7  
8 261 **Figure 1.** *Individual flock means and fitted regression curves for parent stock broiler*

9  
10 262 *breeders hatched in the UK from 1991 to 2002 for (a) total hen housed egg production, (b)*

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12 263 *hatchability of eggs set, (c) number of chicks per hen housed and (d) female mortality.*

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17 265 **Figure 2.** *Response curves of flock means of parent stock broiler breeders hatched in the UK,*

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19 266 *Western Europe, Central and South America and Japan from 1991 to 2002 for (a) total hen*

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21 267 *housed egg production, (b) hatchability of eggs set, (c) number of chicks per hen housed and*

22  
23 268 *(d) female mortality.*

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29 270 **Figure 3.** *Response curves of flock means of female line grandparent broiler breeder females*

30  
31 271 *hatched in the UK, Western Europe, Central and South America and Japan from 1991 to*

32  
33 272 *2002 for (a) total hen housed egg production, (b) hatchability of eggs set, (c) number of*

34  
35 273 *chicks per hen housed and (d) female mortality.*

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41 275 **Figure 4.** *Response curves of flock means of male line grandparent broiler breeder females*

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43 276 *hatched in the UK, Western Europe, Central and South America and Japan from 1991 to*

44  
45 277 *2002 for (a) total hen housed egg production, (b) hatchability of eggs set, (c) number of*

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47 278 *chicks per hen housed (d) and female mortality.*

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**Table 1.** Total number of flocks and customers for hen housed egg production, hatchability of eggs set, hen housed chick numbers and female mortality to 60 weeks of age for broiler grandparent male and female lines and broiler parent stock in the UK, Western Europe, Central and South America and Japan

Genotype	Location	Total eggs, n/hh <sup>1</sup>		Hatching eggs, n/hh		Chicks, n/hh		Hatchability, %		Female mortality, %	
		Flocks	Customers	Flocks	Customers	Flocks	Customers	Flocks	Customers	Flocks	Customers
Male line	UK	302	1	304	1	279	1	280	1	285	1
	W. Europe	362	7	350	8	206	5	210	5	348	7
	C&S America	352	8	334	8	294	7	294	7	296	8
	Japan <sup>2</sup>	106	1	106	1	90	1	90	1	96	1
Female line	UK	650	1	650	1	570	1	570	1	610	1
	W. Europe	425	8	398	8	235	5	236	5	394	7
	C&S America	498	12	482	12	404	10	404	10	436	12
	Japan <sup>2</sup>	110	1	107	1	92	1	92	1	105	1
Parent stock	UK	1469	17	1570	17	1555	17	1555	17	765	14
	W. Europe	495	13	514	15	439	11	442	11	506	15
	C&S America	1038	16	1065	17	1036	15	1037	15	851	13
	Japan <sup>2</sup>	759	19	757	19	283	12	284	12	725	19

<sup>1</sup> hh = hen housed.

<sup>2</sup> Means for birds hatched to 2001.

**Table 2.** Means and standard deviation for hen housed egg production, hatchability of eggs set, hen housed chick numbers and female mortality to 60 weeks of age for broiler grandparent male and female lines and broiler parent stock hatched in 2002 in the UK, Western Europe, Central and South

*America and Japan*

Genotype	Location	Total eggs, n/hh <sup>1</sup>		Hatching eggs, n/hh		Chicks, n/hh		Hatchability, %		Mortality, %	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Male line	UK	103	12	92	10	63	8	67.6	1.0	13.2	4.1
	W. Europe	101	7	94	8	67	8	72.6	2.7	13.1	5.8
	C&S America	123	4	108	6	85	3	78.7	3.8	7.2	1.0
	Japan <sup>2</sup>	99	9	90	9	68	8	75.8	3.0	9.8	1.0
Female line	UK	159	10	142	9	103	12	72.6	5.0	11.3	3.0
	W. Europe	155	7	146	7	112	9	77.6	2.6	10.8	3.1
	C&S America	156	11	143	12	105	16	73.4	6.3	11.8	3.2
	Japan <sup>2</sup>	164	3	151	4	122	7	80.4	4.4	7.4	1.9
Parent stock	UK	168	7	160	7	132	8	82.7	2.4	9.5	3.1
	W. Europe	161	8	153	8	122	8	79.6	2.8	9.5	4.3
	C&S America	176	12	168	12	149	6	84.5	2.2	6.9	3.5
	Japan <sup>2</sup>	166	8	153	9	130	9	85.0	3.1	7.5	4.3

<sup>1</sup> hh = hen housed.

<sup>2</sup> Means and SD for birds hatched in 2001.



**Table 3.** Total 10 year change to 2002 of hen housed egg production, hatchability of eggs set, hen housed chick numbers and female mortality to 60 weeks of age estimated by fitting a quadratic regression model to flock means for broiler grandparent female and male lines and broiler parent stock in the UK, Western Europe, Central and South America and Japan

Genotype	Location	Total eggs, n/hh <sup>1</sup>		Hatching eggs, n/hh		Chicks, n/hh		Hatchability, %		Mortality, %	
		Change	SE	Change	SE	Change	SE	Change	SE	Change	SE
Male line	UK	12.4	2.25	11.9	2.23	8.9	1.92	4.1	0.97	-6.7	1.01
	W. Europe	7.3	2.76	7.6	3.10	12.7	2.75	2.4	1.50	-11.3	1.36
	C&S America	10.2	3.18	12.7	3.21	9.8	2.80	1.1	1.41	-2.7	1.99
	Japan <sup>2</sup>	-15.3	3.01	-10.7	3.18	-6.5	2.83	2.4	1.56	-6.7	2.32
	<i>Mean</i>	3.7		5.4		6.2		2.5		-6.9	
Female line	UK	16.7	1.64	13.3	1.73	10.8	1.86	-0.3	0.85	1.8	0.60
	W. Europe	21.6	2.07	25.1	2.65	20.8	2.32	6.0	1.19	-3.5	0.90
	C&S America	20.1	2.61	21.1	2.66	21.8	2.94	5.5	1.08	0.4	1.18
	Japan <sup>2</sup>	8.3	2.74	13.7	2.73	17.2	2.98	4.7	1.43	-0.6	1.56
	<i>Mean</i>	16.7		18.3		17.7		4.0		-0.5	
Parent stock	UK	17.8	1.1	16.2	1.35	14.7	1.25	0.9	0.38	1.4	1.06
	W. Europe	14.6	4.05	14.6	3.83	10.2	5.52	1.3	1.92	-5.5	1.89
	C&S America <sup>2</sup>	18.0	3.84	17.8	3.40	13.3	4.23	-0.6	0.99	-8.1	2.89
	Japan <sup>2,3</sup>	15.4	1.43	11.0	1.55	14.1	1.89	2.6	0.61	-2.8	0.61
	<i>Mean</i> <sup>4</sup>	16.8		16.2		12.7		0.9		-4.1	

<sup>1</sup> hh = hen housed.

<sup>2</sup> Changes to 2001 only.

<sup>3</sup> Data for the last 5 years only were available.

<sup>4</sup> Mean excluding Japan.

Figure 1

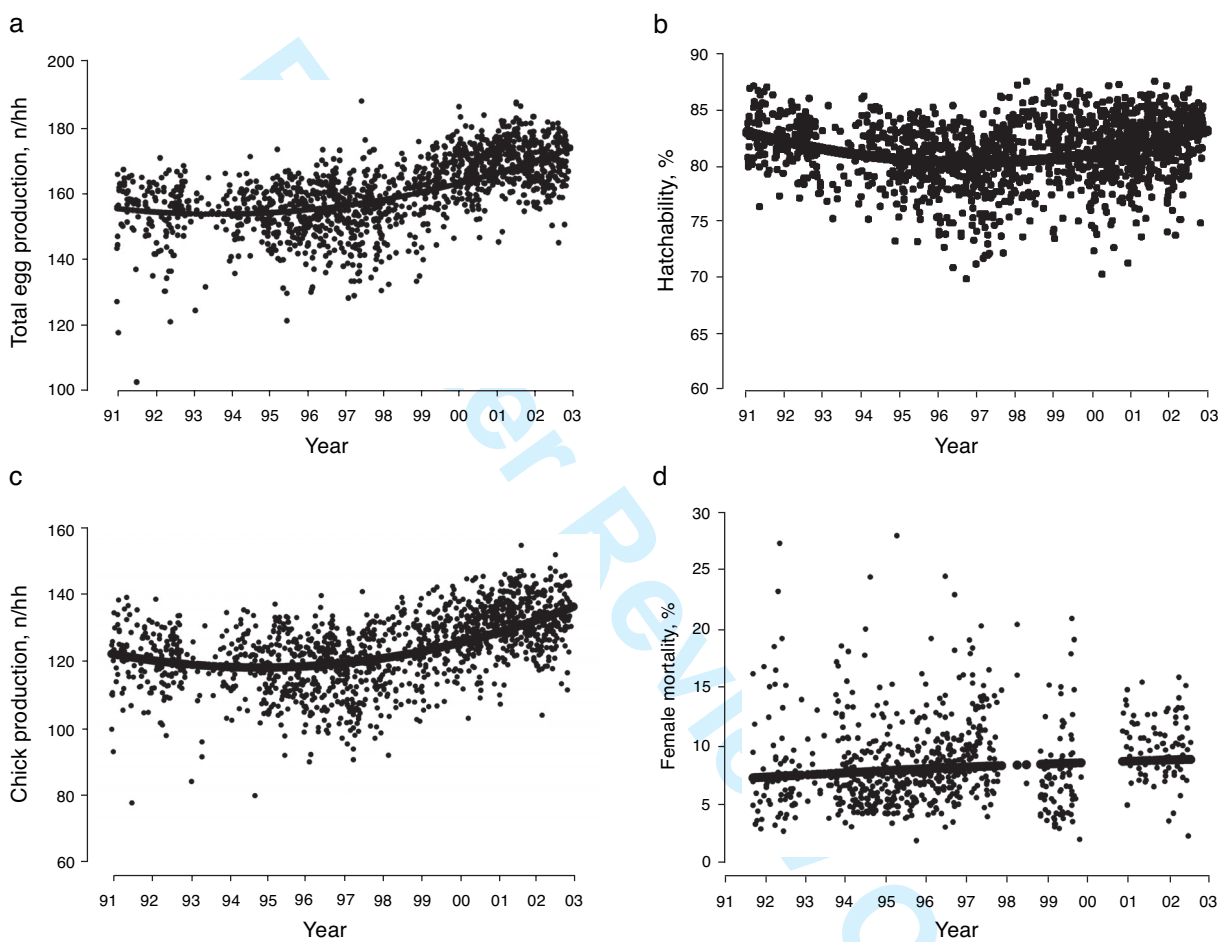


Figure 2

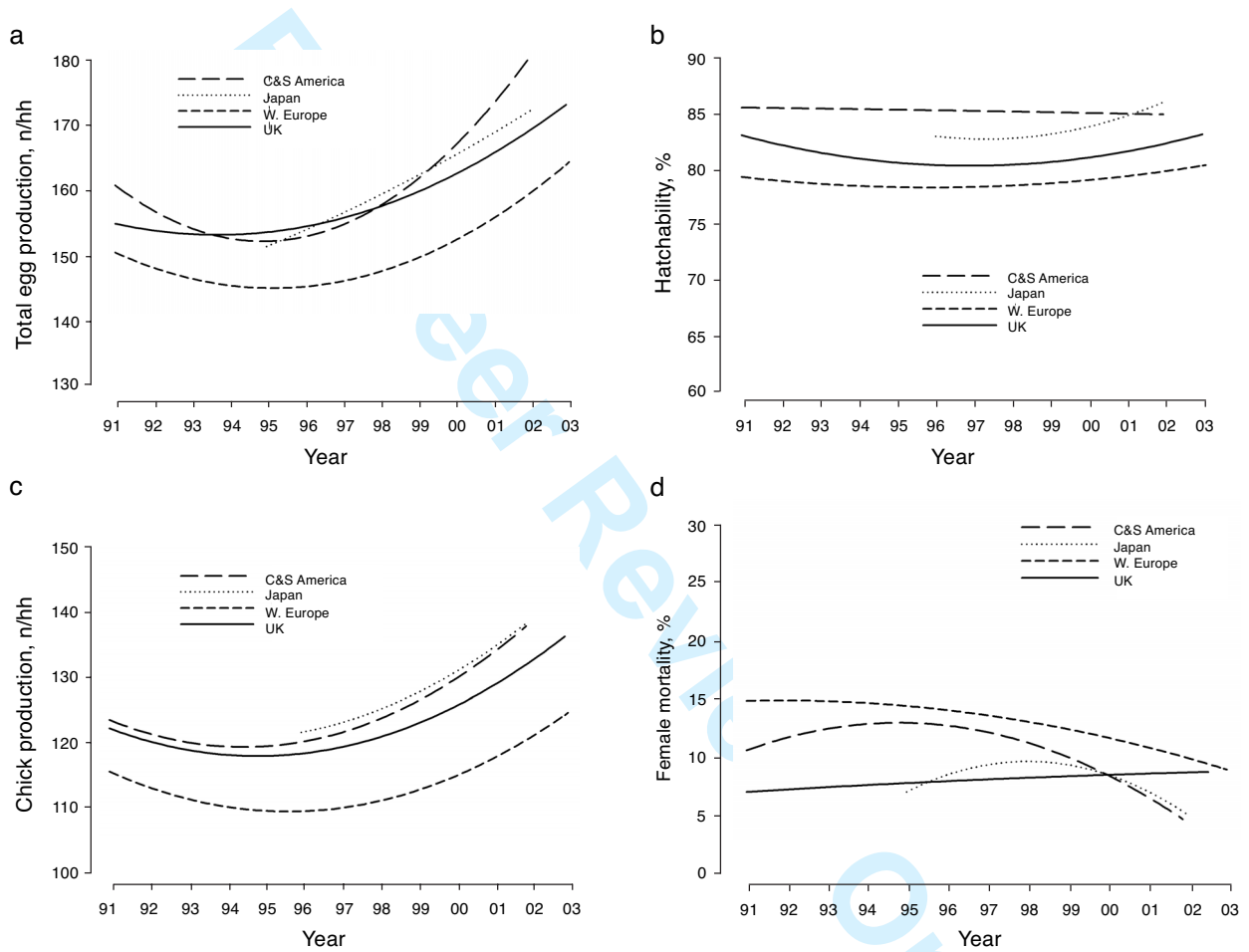


Figure 3

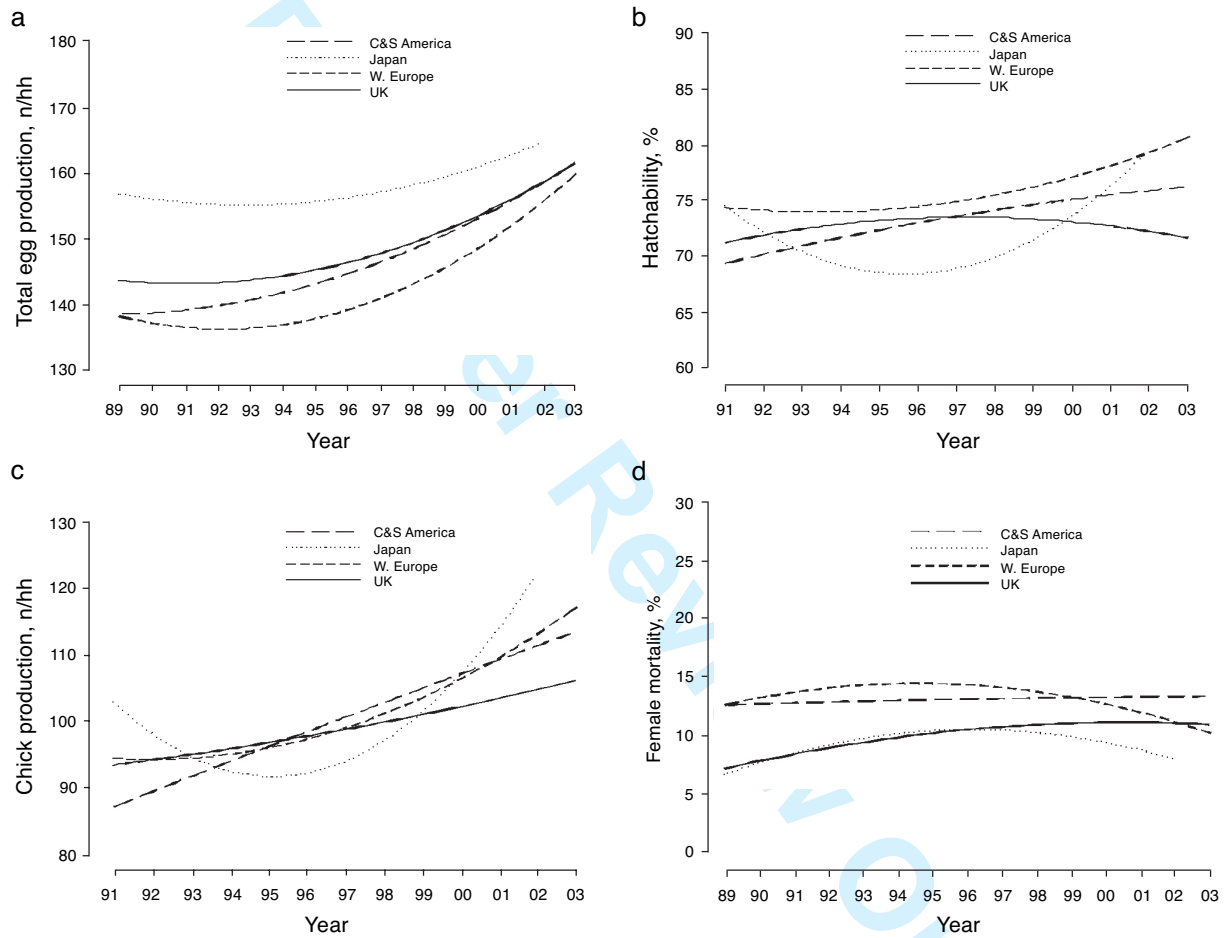


Figure 4

