BREEDING AND GENETICS

Effects of the Sex-Linked Dwarfing Gene *(dw)* on Growth and Reproduction in White Leghorn Hens[1]

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ABSTRACT The influence of the dwarfing gene, *dw*, on growth and reproduction was determined by comparing 1) pure line and reciprocal cross dwarf and normal layers and 2) dwarf and normal full-sib sisters. In Experiment 1, two lines of chickens, the Oregon State University randombred dwarf Leghorn population (D) and Shaver Starcross "288" Leghorns (S), were mated within line and reciprocally to produce normal-sized (SS, SD) and dwarf (DS, DD) female progeny. All progeny were reared similarly until 18 weeks of age when birds were transferred to individual cages. At 18 weeks of age, half the pullets were fed a basal laying ration containing 15% protein while the remaining birds received the basal ration with .1% supplemental methionine. In Experiment 2, full-sib normal and dwarf sisters were obtained by mating hemizygous dwarf females to heterozygous males. Layers were reared in a similar manner to those in Experiment 1 with the exception that all layers received the basal ration with .1% methionine supplemented.

Methionine supplementation in Experiment 1 significantly increased egg weights at 35 and 62 weeks of age for all lines and crosses but had no effect on other growth and reproductive traits. Genotype X diet interactions were not observed for any of the measured traits. Normal-sized layers had significantly heavier body weights and longer shank lengths than dwarf layers in both experiments. Dwarf hens in both experiments showed reduced egg production capabilities, although ages at sexual maturity were similar among phenotypes. Dwarf layers laid smaller eggs than normal-sized layers. There were no consistent differences in feed efficiency measures between normals and dwarfs.

(Key words: dwarf gene, reciprocal cross, growth, reproduction, shell quality, albumen quality)

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INTRODUCTION

The influence of the sex-linked dwarfing gene *(dw)* on growth and reproduction in chickens has been well documented and shown to be somewhat dependent on the genetic background of the bird (Guillaume, 1976). In general, the *dw* gene in layer type stock depresses growth by approximately 30% (Hutt, 1959), delays age at sexual maturity by approximately 5 days (Bernier and Arscott, 1972), reduces egg size primarily due to the reduction in body size (Benoff and Renden, 1980), and decreases egg numbers (Bernier and Arscott, 1960; French and Nordskog, 1973). Many of the changes associated with the *dw* gene in layers can be alleviated through polygenic selection. Ngam (1980) found that 13 generations of selection for earlier maturity, greater egg number, and increased egg size dramatically decreased age at sexual maturity (from 32 to 22 weeks of age) and increased egg numbers (from 51 to 218 eggs). Egg size was not altered through genetic selection.

Bernier and Arscott (1972) reported that dwarf layers, in spite of their reproductive performance, were more efficient than normal layers, and they attributed this efficiency to reduced maintenance requirements of the dwarf. However, when French and Nordskog (1973) compared the reproductive efficiency of dwarf and normal layers produced from pure line and reciprocal crosses of small and large-bodied dwarf and normal laying hens, their data suggested that improved feed efficiency in dwarf birds was due to decreased body size and not the *dw* gene *per se*.

The objectives of this study were to investigate the effects of the *dw* gene on growth and reproduction by comparing 1) pure line

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and reciprocal cross female progeny and 2) full-sib sisters differing only in the allelomorph at the dwarf locus. The source of the *dw* gene was the Oregon State University (OSU) dwarf Leghorn population, a population whose background genome had been modified through 13 generations of selection for increased egg number, greater egg size, and reduced age of sexual maturity to the extent that the performance of these birds compared favorably to normal-sized layers (Ngam, 1980). Arscott and Bernier (1968) and Bernier and Arscott (1972) observed that dwarf Leghorns laid larger eggs in response to a diet supplemented with .1% methionine but that egg sizes from normal-sized layers were not altered by the addition of methionine. These data suggested a genotype-environment interaction for egg size. Consequently, in Experiment 1, involving the pure line and reciprocal crosses, the nature of the genotype × diet interaction was examined by providing all lines and crosses with two diets differing in methionine content.

MATERIALS AND METHODS

Experiment 1

Pure Line and Reciprocal Cross Comparisons. Female progeny utilized in this experiment were obtained from within-line matings and reciprocal crosses of Shaver Starcross "288" (S) and the OSU randombred dwarf Leghorn population (D). Population D was homozygous for the sex-linked *dw* gene and had undergone prior to this study 13 generations of genetic selection for increased egg number, increased egg size, and earlier sexual maturity (Bernier and Arscott, 1972). The generation immediately prior to this experiment, D, had undergone one generation of random mating. Although the lines were not pure stock, the term pure will be used in this experiment to represent within-line matings.

Phenotypically normal-sized layers having the genotype *(Dw*/-w) were obtained by mating Shaver males to Shaver females to yield line SS and Shaver males mated to OSU dwarf females to yield cross line SD progeny. Dwarf-sized layers having the genotype *(dw*/-w) were derived from matings of OSU dwarf males to Shaver females to provide DS offspring and mating OSU dwarf males to OSU dwarf females to obtain pure line DD progeny. Only data from hens surviving to 64 weeks of age (N = 471) were analyzed. Bird numbers by pure line and cross at the conclusion of this experiment were 129, 143, 93, and 106 for SS, SD, DS, and DD, respectively.

The chicks were wing-banded and sexed upon hatching, and females were brooded together until 8 weeks of age. To reduce the possible genotype × environment correlation in body weight due to competition between heavy and light individuals for common resources, birds were sorted into two weight classes (high and low body weight) at 8 weeks of age and reared within a weight class until housing at 18 weeks of age. All birds received the same developer I starter and developer II rations to 18 weeks of age. At 18 weeks of age, hens were housed in individual cages. For purposes of obtaining feed consumption data, 14 hens within a line or cross were housed adjacently forming a block. There were 8, 9, 10, and 11 blocks for DS, DD, SS, and SD birds, respectively. These blocks were randomly distributed throughout the cage house to minimize possible location effects. One-half of the blocks of birds within each line or cross were fed a standard layer ration (2900 metabolizable energy [ME] kcal/kg, 15% protein, .26% methionine) while the other half received the same standard ration supplemented with .1% methionine (2896 ME kcal/kg, 15% protein, .36% methionine). All birds received 14 hr of illumination daily, were fed *ad libitum*, and were provided with water for eight 15-min periods at 2-hr intervals during the light period.

Individual body weights were obtained at 1, 2, 4, 8, 16, 32, and 64 weeks of age. Shank length was measured at 8 weeks of age for each bird. Eggs were collected from each hen during a 3-day period at 35 and again when hens were 62 weeks of age, and their weights, specific gravities, and Haugh units were determined. The average egg weight, specific gravity, and Haugh unit for each hen at each age were the values used in the statistical analyses. For purposes of statistical analysis, egg production was divided into two production periods: the initial period being from sexual maturity to 40 weeks of age and the residual period from 41 to 64 weeks of age. Feed consumption was determined for each line × diet group during two 28-day periods (33 to 37 weeks and 60 to 64 weeks of age).

Body weights obtained after 18 weeks of age, age at sexual maturity, percent hen-day egg production for the initial, residual, and total

production periods, egg weights, specific gravities, and Haugh units were analyzed according to the following model to determine the significance of line and diet effects:

$$Y_{ijk} = \mu + D_i + L_j + (DL)_{ij} + E_{ijk}$$

where:

μ = overall mean,
D_i = the i^{th} diet effect, i = 1, 2,
L_j = the j^{th} line effect, j = 1, 2, 3, 4,
$(DL)_{ij}$ = the i^{th} diet by j^{th} line interaction, and
E_{ijk} = random error.

The significance of differences in body weights and shank length before 18 weeks of age among lines was determined using a simpler model where the effects of diets and the interaction between lines and diets were omitted, since pullets were fed uniformly prior to this age.

To determine the influence of line, heterosis, and *dw* gene (i.e., sex chromosome) effects on body weights, shank length, and reproductive measures, the following statistical model was used:

$$Y_{ijkl} = \mu + G_i + Z_j + H_k + E_{ijkl}$$

where:

μ = overall mean,
G_i = genetic effect of line i,
Z_j = effect of the sex chromosome of sire line j in the cross,
H_k = heterosis effect of cross *vs.* pure line,
E_{ijkl} = random error due to differences among individuals.

The matrix of coefficients for estimating line (G_i), heterotic (H_k), and sex chromosome (Z_j) effects were modified from French (1972). The four crosses were compared as follows:

$$\begin{aligned}
Y_{SS.} &= \mu + G_S + H_1 \\
Y_{SD.} &= \mu + \tfrac{1}{2}G_S + \tfrac{1}{2}G_D + Z_S + H_c \\
Y_{DS.} &= \mu + \tfrac{1}{2}G_S + \tfrac{1}{2}G_D + Z_D + H_c \\
Y_{DD.} &= \mu + G_D + H_1
\end{aligned}$$

Because autosomal gene effects and maternal effects are completely confounded in this study,

$\hat{G}$ = $[\hat{Y}_{SS.} - \hat{Y}_{DD.}]/2$ estimates $G_S - G_D$;
$\hat{Z}$ = $[\hat{Y}_{SD.} - \hat{Y}_{DS.}]/2$ estimates $Z_S - Z_D$,
where the sex chromosome and dwarf *dw* gene are confounded; and

$\hat{H}$ = $.5\ [(\hat{Y}_{SD.} + \hat{Y}_{DS.}) - (\hat{Y}_{SS.} + \hat{Y}_{DD.})]$ estimates $H_c - H_1$. The effects of the *dw* gene on the measured traits were estimated in percentage terms according to:

$\hat{dw}$ = $[(\hat{Y}_{SD.} - \hat{Y}_{DS.}) / \hat{Y}_{SD.}]$ (100%).

Experiment 2

Comparison of Full-Sib Sisters Differing in the Allelomorph at the Dwarf Locus. Forty hemizygous dwarf females (*dw*/-w) were artificially inseminated with semen individually collected from 8 males heterozygous (*Dw*/dw) at the dwarf locus to produce full-sib sisters with phenotypes in the ratio of 1 normal: 1 dwarf. The parent birds were derived from crosses between an OSU randombred dwarf male line (D) and Shaver Starcross "288" females (S). Chicks were obtained from three hatches, wing-banded and sexed upon hatching, beak trimmed at 12 days of age, and females brooded together within each hatch until 10 weeks of age. At 10 weeks of age, birds were segregated and reared in two phenotypic classes (small and large). Genotypic class was determined by measuring body weight and shank length at 10 weeks of age. All birds received the same OSU developer I starter and developer II rations to 18 weeks of age.

At 18 weeks of age, pullets were housed in a cage unit such that families of half-sib sisters were housed adjacently although in individual cages. All birds were fed a laying ration with 15% protein, 2896 kcal/kg ME, and .36% methionine *ad libitum*. Caged pullets received 14 hr of illumination daily and were provided water for eight 15-min periods at 2-hr intervals during the light period. Data from 389 hens that survived to 60 weeks of age were analyzed in this experiment.

Growth was determined by measuring individual body weights at 5, 10, 20, 40, and 60 weeks of age and shank length at 10 and 20 weeks of age. Daily egg production to 60 weeks of age was determined for each hen. Egg production to 60 weeks of age was divided into two production periods: from sexual maturity

to 40 weeks of age (initial period) and from 40 to 60 weeks of age (residual period). Individual egg weight, shell quality (specific gravity), and internal egg quality (Haugh unit) were determined for eggs collected during 3 days at 35 and 58 weeks of age. The average egg weight, specific gravity, and Haugh unit for each hen at each age were the values used in the statistical analyses. Feed consumption was measured for each genotype only on hens derived from hatch 1 during two 28-day periods, first at 33 to 37 weeks, and again at 56 to 60 weeks of age.

The significance of differences in growth and reproductive traits between dwarf and normal-sized layers was determined using the following statistical model:

$$Y_{ijk} = H_i + G_j + F_k + E_{ijk}$$

where:

- H_i is the effect of the i^{th} hatch considered to be a random effect,
- G_j is the effect of the j^{th} genotype taken to be a fixed effect,
- F_k is the effect of the k^{th} family considered to be a random effect, and
- E_{ijk} is the residual error containing interaction and experimental error MS

The significance of differences in percent livability between normal-sized and dwarf layers was determined by chi square (Snedecor and Cochran, 1973).

RESULTS AND DISCUSSION

Diet Effects (Experiment 1)

Egg weights at 35 and 62 weeks of age were the only measured variables influenced by the two rations fed (Table 1). These findings are in partial agreement with those of Arscott and Bernier (1968) and Bernier and Arscott (1972) who observed improvements in egg weight of dwarf hens with the addition of .1% methionine. Egg weight is known to be associated with body weight (Benoff and Renden, 1980), although in this experiment increases in egg weight at 35 and 62 weeks of age due to the supplemented methionine were not due to changes in body weight at these ages as there were no statistically significant differences in body weight for hens across diet. All lines and crosses responded similarly to the added methionine as indicated by the lack of a significant line × diet interaction for all traits measured.

TABLE 1. *Egg weights at 35 and 62 weeks of age by line, cross, and diet (Experiment 1)*

Line and reciprocal cross[1]	35 weeks		62 weeks	
	Basal	Basal + meth[2]	Basal	Basal + meth[2]
SS	58	61	63	65
SD	59	60	63	64
DS	52	55	57	59
DD	52	54	56	57
$\bar{X}$	55[b]	57[a]	60[b]	61[a]
% Dwarf effect	−.12	−.08	−.10	−.08

[a,b]Overall means ($\bar{X}$) within an age across diets with the same superscript are not significantly different at $P \leq .05$.

[1]OSU randombred dwarf Leghorn (D) and Shaver Starcross "288" Leghorns (S), were mated within line and reciprocally to produce normal-sized (SS, SD) and dwarf (DS, DD) progeny.

[2]Diet supplemented with .1% methionine.

[3](DS − SD/SD) × 100%.

Line Effects (Experiment 1)

Growth. Significant differences among the lines in body weight were observed at all ages (Table 2). Normal hens were heavier than dwarf individuals at all ages measured with the exception of SD birds, which were lighter than dwarf birds (DS) at 1 week of age. Many studies (Hutt, 1949; Rajaratnam *et al.*, 1969; Ricard, 1971) have shown a strong positive relationship between initial chick weight and egg weight. Such maternal effects diminish with age of the chick. Normal SD birds originated from eggs of dwarf dams. These eggs were not weighed but probably were smaller than eggs from normal-sized dams. Consequently, chicks hatching from these eggs would be expected to have lower initial body weights.

Within phenotypes (i.e., SS *vs.* SD and DS *vs.* DD), cross line birds grew more rapidly than their pureline counterparts (Table 2), indicating a certain amount of dominant or epistatic gene action for growth rate regardless of the presence or absence of the *dw* allele. The degree of heterosis is presented in Table 3.

TABLE 2. *Least squares means and percent dwarf gene effect on body weight and shank length for pure line and reciprocal cross females of Experiment 1 and full-sib normal and dwarf sisters of Experiment 2*

	Line[1] and reciprocal cross of Experiment 1 (N)					Progeny phenotype of Experiment 2 (N)		
Growth trait	SS (129)	SD (143)	DS (95)	DD (106)	% Dwarf effect[2]	Normal (213)	Dwarf (176)	% Dwarf effect[3]
Body weight, g								
1 week	50[a]	42[c]	45[b]	39[d]	7.1	...	...	...
2 weeks	80[a]	73[b]	73[b]	65[c]	.0	...	...	...
4 weeks, Exp. 1 5 weeks, Exp. 2	241[a]	233[b]	204[c]	185[a]	−12.4	314[a]	241[b]	−23.2
8 weeks, Exp. 1 10 weeks, Exp. 2	566[a]	577[a]	430[b]	406[c]	−25.5	711[a]	479[b]	−32.6
16 weeks, Exp. 1 20 weeks, Exp. 2	1120[b]	1172[a]	806[c]	767[d]	−31.2	1407[a]	963[b]	−31.6
32 weeks, Exp. 1[4] 40 weeks, Exp. 2	1728[b]	1797[a]	1241[c]	1210[c]	−30.9	1856[a]	1243[b]	−33.0
60 weeks, Exp. 1[4] 64 weeks, Exp. 2	1781[b]	1922[a]	1285[c]	1276[c]	−33.1	1968[a]	1339[b]	−32.0
Shank length, mm								
8 weeks, Exp. 1 10 weeks, Exp. 2	78[b]	80[a]	69[c]	68[d]	−13.8	82[a]	67[b]	−18.3
20 weeks, Exp. 2	...	...	...	...	...	97[a]	76[b]	−21.6

[a,b,c,d]Means within a row within an experiment with the same superscript are not significantly different at $P \leq .05$.

[1] OSU randombred dwarf Leghorn (D) and Shaver Starcross "288" Leghorns (S), were mated within line and reciprocally to produce normal-sized (SS, SD) and dwarf (DS, DD) progeny.

[2] (DS − SD/SD) × 100%.

[3] (Normal −Dwarf/Normal) × 100%.

[4] Values pooled across diets.

TABLE 3. *Estimates of line ($\hat{G}$), heterosis ($\hat{H}$), and dwarf ($\hat{Z}$) effects on body weight (BW, g) and shank length (SL, mm)*

Trait	$\hat{G}$	$\hat{H}$	$\hat{Z}$
BW (1 week)	10.9	4.8	1.3
BW (2 weeks)	15.3	8.7	−.2
BW (4 weeks)	56.2	33.6	−14.3
BW (8 weeks)	160.4	97.7	−73.2
BW (16 weeks)	352.8	221.6	−183.0
BW[1] (32 weeks)	516.8	307.5	−278.4
BW[1] (64 weeks)	502.0	323.1	−319.4
SL (8 weeks)	10.4	7.0	−5.4

[1] Pooled across two diets.

The major genetic difference between SD and DS birds was the Z chromosome and presumably the major difference in Z chromosomes was the allelomorph at the *dw* locus. Therefore, the effect of the *dw* gene ($\hat{Z}$) on growth rate was determined by comparing SD and DS individuals (Table 3). Initially (i.e., at 1 and 2 weeks of age), dwarf birds were heavier than nondwarf birds most likely because of maternal influence of egg size. By 8 weeks of age, the *dw* gene depressed body weight of the dwarf birds by about 26%.

Dwarf birds had smaller body frames than normal-sized birds as indicated by 8-week shank length. Shank lengths were 78, 80, 69, and 68 mm for SS, SD, DS, and DD line birds, respectively (Table 2). The reduction in shank length attributable to the *dw* allele was 13.8%.

Reproduction. Significant differences in age at sexual maturity and hen-day egg production among the lines were observed (Table 4). Hens carrying the *dw* gene (i.e., DS and DD) matured at an age intermediate to the age of maturity for nondwarf birds (SS and SD). Normal SD hens matured significantly earlier than homozygous normal SS hens. This could be explained by a heterotic effect (Table 4) in the SD cross. Age at sexual maturity for dwarf DS and DD progeny were nearly equal. If sexual maturity was influenced by additive gene action, DS hens would have an intermediate maturation age (i.e., 155) to SS and DD; however, indications are that some degree of dominance existed in the direction of earlier maturation. The effect of the dwarf gene *per se* was to delay sexual maturity (Table 4). The negative value of $\hat{H}$ for sexual maturity (Table 5) implies that the crosses were heterotic for earlier maturity while the positive value for $\hat{Z}$ indicated that *dw* gene delayed sexual maturity.

Hen-day egg production differed significantly among the lines (Table 4) with dwarf DS and DD hens laying significantly fewer eggs than the normal-sized layers. The *dw* gene depressed egg production by more than 10% for the entire production period (Table 4). A heterotic effect toward increased egg production was observed (Table 5). A negative effect of the *dw* gene on egg production in layers has been reported by several researchers, including Bernier and Arscott (1972) and French and Nordskog (1973). However, the percent hen-day egg production of dwarfs in this study is considerably higher than that reported for dwarf chickens of comparable size (French and Nordskog, 1973; Reddy and Siegel, 1977). The higher egg production observed in these dwarfs might be attributed to their prior history of long term selection for earlier maturity and increased egg number (Ngam, 1980). Within each phenotype, the cross line birds laid at a higher rate than the respective pure line. A similar heterotic effect for increased egg production of comparable size birds was reported by French and Nordskog (1973).

As there were no significant interactions observed in egg weight among lines and diets (Table 1), sex chromosome effects and heterotic effects were determined with data pooled across diets. Dwarf birds laid significantly smaller eggs than normal hens at 35 and 62 weeks of age (Table 4). Benoff and Renden (1980) observed that small-bodied chickens had reduced oviduct surface area, particularly in the magnum, which contributed to the formation of small eggs. The *dw* gene in this study reduced egg size by approximately 9% (Table 4) but reduced body size by 32%, indicating that dwarf hens lay larger eggs for their body size than normal-sized hens. A slight heterotic effect towards larger egg size was observed in this study (Table 5). This result agrees with that of French and Nordskog (1973) who reported a similar heterotic effect in their small Leghorn line crosses.

Little difference was observed among the lines in internal egg quality as evidenced by the magnitudes of the Haugh unit measurements (Table 4). The dwarf cross line (DS) exhibited a higher quality egg at 35 weeks of age than the other lines; however, no differences among lines

TABLE 4. *Least squares means and percent dwarf gene effect on various reproductive traits for pure line and reciprocal cross female progeny of Experiment 1, data pooled across diets, and by phenotype for full-sib sisters of Experiment 2*

Reproductive trait	Line[1] and reciprocal cross in Experiment 1 (N)					Phenotypes in Experiment 2 (N)		
	SS (129)	SD (143)	DS (93)	DD (106)	% Dwarf effect[5]	Normal (213)	Dwarf (176)	% Dwarf effect[6]
Age at sexual maturity (days)	158[a]	146[c]	153[b]	152[b]	4.8	153[a]	152[a]	−.7
% Hen/day egg production								
Initial[2]	86[a]	85[a]	77[b]	72[c]	−9.4	83[a]	73[b]	−12.0
Residual[3]	70[a]	74[a]	64[b]	57[c]	−13.5	71[a]	62[b]	−12.7
Total[4]	77[a]	79[a]	70[b]	64[c]	−11.4	77[a]	67[b]	−13.0
Egg weight								
35 weeks	59[a]	59[a]	54[b]	53[b]	−8.5	60[a]	54[b]	−10.0
62 weeks	64[a]	64[a]	58[b]	56[c]	−9.4	64[a]	59[b]	−7.8
Haugh unit								
35 weeks	71[b]	71[b]	74[a]	71[b]	4.2	72[a]	74[a]	2.8
62 weeks, Exp. 1 58 weeks, Exp. 2	71[a]	71[a]	72[a]	70[a]	1.4	74[a]	75[a]	1.4
Specific gravity								
35 weeks	1.083[b]	1.082[b]	1.084[a]	1.082[b]	.2	1.0797[b]	1.0826[a]	.3
62 weeks	1.076[b]	1.077[b]	1.079[a]	1.076[b]	.2	1.0745[a]	1.0746[a]	.0

[a,b,c]Means for each experiment within a row with the same superscript are not significantly different at $P \leq .05$.

[1] OSU randombred dwarf Leghorn (D) and Shaver Starcross "288" Leghorns (S), were mated within line and reciprocally to produce normal-sized (SS, SD) and dwarf (DS, DD) progeny.

[2] From sexual maturity to 280 days of age.

[3] From 281 to 449 days of age for Experiment 1 and from 281 to 420 days of age for Experiment 2.

[4] From sexual maturity to 449 days of age for Experiment 1 and from sexual maturity to 420 days of age for Experiment 2.

[5] (DS − SD/SD) × 100%.

[6] (Dwarf − Normal/Normal) × 100%.

TABLE 5. *Estimates of line ($\hat{G}$), heterosis ($\hat{H}$), and dwarf ($\hat{Z}$) effects on reproduction and egg characteristics*

Trait	$\hat{G}$	$\hat{H}$	$\hat{Z}$
Age at sexual maturity, days	5.7	−2.6	3.5
% Hen-day egg production			
Initial[1]	13.7	9.0	−3.8
Residual[2]	13.1	11.9	−5.1
Total[3]	12.5	10.1	−4.6
Egg weight, g			
35 weeks	6.2	3.4	−2.8
62 weeks	7.6	4.6	−2.8
Haugh unit			
35 weeks	−.1	1.3	1.6
62 weeks	.6	1.3	.8
Specific gravity			
35 weeks (× 10^5)	111.5	152.6	125.0
62 weeks (× 10^5)	−52.5	129.5	96.6

[1] From sexual maturity to 280 days of age.

[2] From 281 to 449 days of age.

[3] From sexual maturity to 449 days of age.

in Haugh units were observed at 62 weeks of age.

Cross-line dwarf hens (DS) laid eggs with significantly better shell quality than hens derived from other matings as determined by specific gravity (Table 4), although the *dw* gene *per se* had little influence on shell quality. The smaller egg size of dwarf hens (DS) compared to that of normal hens (SS and SD) may have partially accounted for better shell quality (Hamilton, 1978).

Feed Consumption. Feed consumption measures by line, diet, and age are presented in Table 6. Dwarf hens (DS and DD) consumed less feed than normal hens (SS and SD) when expressed in terms of feed consumed/bird/day. Cross-line dwarf hens (DS) were the most efficient based on feed consumed per unit of egg mass and per dozen eggs. The body weights of dwarf hens (DS and DD) at 32 and 64 weeks of age were not significantly different (Table 2), suggesting that body weight *per se* was not the main cause of the better feed efficiency of DS hens. The reduced feed efficiency of DD hens might be attributed to their decreased rate of production (French and Nordskog, 1973) compared to hens of the other lines. When comparison is made between normal hens (SD) and dwarf hens (DS), enhanced feed efficiency is obtained due to the *dw* gene. Results from this study indicate improved feed efficiency for dwarf layers compared to normal layers, which is in agreement with other reports (Selvarajah *et al.*, 1970; Bernier and Arscott, 1972; Polkinghorne and Lowe, 1973).

Line Effects (Experiment 2)

Growth. Significant differences in body weight between normal and dwarf sisters were observed from the first weighing at 5 through 60 weeks of age (Table 2). The dwarf gene depressed body weights from 23 to 33% depending on the age of the hens (Table 2). In contrast to the results reported in Experiment 1, the *dw* gene exerted its influence on growth at an early age. Dwarf and normal progeny obtained in this experiment arose from eggs of dwarf-sized dams whereas the dwarf-sized progeny obtained in Experiment 1 came from normal-sized dams, thereby confounding growth with genotype and maternal effects. Rath *et al.* (1980) reported sizable *dw* gene effects on body weight at an early age, which agrees with the results of Experiment 2.

Dwarf pullets had reduced shank lengths compared to normal pullets, but the percent effect of the dwarfing gene on shank length was less than for body weight (Table 2) as was also the case in Experiment 1. Guillaume (1976) observed that the *dw* gene exerted differential influence on the growth of various body parts.

Reproduction. Initial, residual, and total percent hen-day egg production of normal hens were significantly better than their dwarf sisters (Table 4). The *dw* gene reduced total percent egg production by 13%, which is similar to the results reported in Experiment 1 and with other reports in the literature (Selvarajah *et al.*, 1970; Horst and Petersen, 1977). Other studies have shown that the effect of the *dw* gene on egg production was caused by delayed sexual maturity, poor persistency of lay (Yoo *et al.*, 1980), and short clutch length (Merat, 1969), although the percent hen-day measurement of egg production is free of the age-at-sexual-maturity component. As in Experiment 1, normal hens produced significantly larger eggs compared to dwarf hens at both ages measured (Table 4). This can be explained, in part, by the reduced body weight of the dwarfs, because there is a high correlation between body weight and egg weight (Hogsett and Nordskog, 1958).

TABLE 6. *Feed efficiency measures by line, diet,*[1] *and age (Experiments 1 and 2)*

Feed consumed per	Diet	Line[2] and reciprocal cross in Experiment 1 (N)				Progeny phenotype in Experiment 2 (N)	
		SS (129)	SD (143)	DS (93)[4]	DD (106)[4]	Normal (213)	Dwarf (176)
				Early production period[3]			
Bird/day, g	Dwarf[1]	124	123	94	97	...	...
	Normal	123	125	90	87	125	91
Egg mass, g feed/g egg	Dwarf[1]	2.4	2.4	2.2	2.6	...	...
	Normal	2.4	2.4	2.2	2.3	2.5	2.4
Dozen eggs, kg feed/dozen eggs	Dwarf[1]	1.7	1.7	1.4	1.7	...	...
	Normal	1.6	1.7	1.4	1.5	1.8	1.6
				Late production period[4]			
Bird/day, g	Dwarf[1]	114	124	86	80	...	...
	Normal	116	118	85	84	96	73
Egg mass	Dwarf[1]	2.7	2.8	2.5	2.8	...	...
	Normal	2.3	2.9	2.5	3.2	2.2	2.3
Dozen eggs	Dwarf[1]	2.1	2.2	1.7	1.9	...	...
	Normal	1.7	2.2	1.7	2.1	1.7	1.7

[1] Basal diet supplemented with .1% methionine.

[2] OSU randombred dwarf Leghorn (D) and Shaver Starcross "288" Leghorns (S), were mated within line and reciprocally to produce normal-sized (SS, SD) and dwarf (DS, DD) progeny.

[3] 33 to 37 weeks of age in Experiments 1 and 2.

[4] 60 to 64 weeks of age in Experiment 1; 56 to 60 weeks of age in Experiment 2.

The ratio of dwarf egg weight to normal egg weight increased from .90 at 35 weeks of age to .92 at 58 weeks of age. Similar observations were reported by Guillaume (1976). The internal egg quality (Haugh unit) of eggs from dwarf hens was better than eggs from normal hens at 35 and 58 weeks of age (Table 4), although the difference was not statistically different. Merat (1972) also reported greater albumen height for eggs from dwarf hens. Eggs from dwarf hens had significantly better shell quality as indicated by specific gravity measurements than those of their normal-sized sisters at 35 weeks of age but not at 60 weeks, which may be related to reduced egg weight or size (Hamilton, 1978). These data are in agreement with the findings in Experiment 1 and with those of Polkinghorne and Lowe (1973).

Hen-house livability was 93.4% for the normal hens and 97.2% for the dwarf hens. The dwarf gene increased livability significantly by 4.1 percentage points. Similar results of dwarf gene effects were reported by Quisenberry (1972) and Polkinghorne and Lowe (1973). The dwarf gene appears to confer a positive influence on livability and resistance to such environmental stresses as hot weather (Bernier and Arscott, 1972; Polkinghorne and Lowe, 1973).

Dwarf birds at all ages consumed less feed per bird per day than their normal-sized sisters (Table 6). When birds were 33 to 37 weeks old, dwarfs tended to be more efficient utilizers of feedstuffs for egg mass and per dozen eggs, whereas normal-sized birds had a slight advantage at older ages. Many studies have demonstrated a better feed efficiency for dwarfs compared to normal layers (Selvarajah *et al.*, 1970; Bernier and Arscott, 1972); however, when rate of lay differences are large, such feed efficiency advantages of dwarfs may not be observed (McClung *et al.*, 1971; McClung and Jones, 1973; Doran and Quisenberry, 1974). This is further supported by French and Nordskog (1973), who indicated that variation in feed efficiency is mainly due to differences in body weight and rate of egg production.

Significant family effects were observed for

all variables measured with the exception of age at sexual maturity, indicating that phenotypic variation and probably genetic variation for these traits is still present in this population of birds. Genetic selection should improve performance further, although the *dw* gene *per se*, even when present in an improved background genome, would probably exert negative effects on certain performance characteristics. The better livability and smaller space requirements of dwarf hens are advantages that must be weighed economically against reduced performance.

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