Indian Journal of Animal Sciences **94** (4): 342–349, April 2024/Article
https://doi.org/10.56093/ijans.v94i4.146229

Development of novel egg type chicken variety with improved productivity for rural backyards of India

K S RAJARAVINDRA[1], ANEET KOUR[1], L L L PRINCE[1], S HAUNSHI[1], M NIRANJAN[1], S JAYAKUMAR[1], B L N REDDY[1] and U RAJKUMAR[1]✉

ICAR-Directorate of Poultry Research, Hyderabad, Telangana 500 030 India

Received: 11 December 2023; Accepted: 13 February 2024

ABSTRACT

Rural poultry farming with improved high producing chicken varieties is transforming the rural livelihoods. The present study was aimed at developing a high egg producing variety suitable for backyard poultry farming. A total of 602 female birds representing five crossbreds, i.e. *Kadaknath* × IWH (KH), PD-3 × IWH (DH), PD-2 × IWH (VH), PD-1 × IWH (CH) and PD-3 × KH (DKH) were evaluated for their performance up to 72 weeks under farm conditions. The traits evaluated were body weights at 8, 16, 20, 40, 52, 64 and 72 weeks age at sexual maturity (ASM), egg production and egg weight at 40, 52, 64 and 72 weeks and egg quality traits. Analysis of variance was used to assess the effect of genotypes on different traits and heterosis was estimated to check the superiority of the crosses over the parent lines. Genotype had significant influence on all the traits. Morphologically, only DKH crossbred had multi-coloured plumage, while all other crosses had white plumage with brown patches. DKH cross produced about 239.2±2.96 eggs annually and also witnessed the highest heterotic gains for all the body weight traits. Also, heterosis for ASM was very low for DKH cross and hence, in desired direction. Based on present findings, the three-way DKH cross owing to its multi-coloured plumage and good performance can be further studied for its potential as a high-producing layer variety in rural backyards.

Keywords: Egg quality, Heterosis, Layer cross, Rural poultry, Three-way cross

The quickest transformative change in supplementing nutritional needs and boosting rural incomes can be brought about by adopting poultry farming (Singh *et al.* 2022), particularly, in the rural backyards (Rajkumar *et al.* 2021a). Improved chicken varieties with faster growth and higher egg production amid limited feed access are highly desirable for rearing in the rural or tribal areas of the country (Haunshi *et al.* 2012; Rajkumar *et al.* 2020a). In this context, *Vanaraja* and *Gramapriya* varieties developed by ICAR-Directorate of Poultry Research, Hyderabad are household names in the hilly, rural and tribal backyards of India (Haunshi *et al.* 2009, Rajkumar *et al*. 2010, Haunshi *et al.* 2010, Rajkumar and Rama Rao 2015). These varieties are produced using specialized lines which are generally developed through several generations of selective breeding for a particular trait of interest. However, repeated use of same lines across generations results in reduced genetic variability in individuals, thus stagnating gains (Felsenstein 1965). Therefore, parent lines are continually selected and crossed in different combinations to evolve new crosses suited to farmers' demands and preferences (Falconer and Mackay 1989).

Present address: [1]ICAR-Directorate of Poultry Research, Hyderabad, Telangana. ✉Corresponding author email: ullengala @yahoo.com

Presently, most of the existing rural chicken varieties are dual purpose with few exceptions like *Gramapriya*, which can produce 160-180 eggs under backyard conditions. However, the rapidly expanding market of country eggs offers a huge opportunity for the development of rural poultry sector. The current egg production in rural backyards is unable to meet this rising demand. Therefore, there is a need to develop a layer variety which can produce more than 200 eggs under backyard conditions with minimum input requirements.

Since *Vanaraja* and *Gramapriya* varieties have already been established to be suitable for rural and tribal areas throughout the country, their parent lines can be crossed with white leghorn layer lines to develop a high-producing two-way or three-way cross for rural conditions. This study attempts to identify and develop a layer variety with a production potential of more than 200 eggs and desired rural features like multi-coloured plumage for propagation in rural backyards of the country.

MATERIALS AND METHODS

Experimental population: In this study, different pure lines, viz. *Gramapriya* female line (PD-3), *Vanaraja* male line (PD-1), *Vanaraja* female line (PD-2) and *Kadaknath*, an indigenous chicken breed were all crossed with White Leghorn line H (IWH) to produce four different crosses and

PD-3 line was further crossed to KH females to produce a three-way cross. All the five crosses, *Kadaknath* × IWH (KH), PD-3 × IWH (DH), PD-2 × IWH (VH), PD-1 × IWH (CH) and PD-3 × KH (DKH) were maintained under standard management conditions from day old to up to 72 weeks of age at ICAR - Directorate of Poultry Research, Hyderabaad. The birds were reared in deep litter system as straight run chicks up to eight weeks of age followed by sexing by phenotypic identification. Only female chicks were further reared up to 72 weeks of age. PD-3 line was evolved from Dahlem Red, an exotic chicken breed of Germany over the last twenty years and has been the female line of *Gramapriya*. PD-2 was the synthetic meat purpose line evolved over the years for egg production as female line of *Vanaraja*. PD-1 was evolved from mediocre Red Cornish population and used as the male line of *Vanaraja* variety. *Kadaknath* is one of the important indigenous chicken breeds known for its black coloured meat. IWH was evolved from White Leghorn and improved for higher egg production over the years. A total of 602 female birds survived up to 72 weeks of age and were evaluated for growth and production traits in the present study. The birds had brown and black patches on white feathers predominantly in two-way cross with single comb, while three-way cross birds were multi-coloured mostly. All the birds laid brown coloured eggs.

Rearing and management practices: The chicks were wing banded on day one and reared in a deep litter system, with a decreasing temperature schedule from 33^{0}C during first week to 23^{0}C at the end of fifth week in an open-sided house under standard management practices. The chicks were fed *ad lib.* with layer starter (2800 Kcal: ME and 18%: CP) diet based on maize-soybean meal up to 6 weeks of age. The birds were maintained on a layer grower ration (2700 Kcal: ME and 18%: CP) up to 16 weeks of age and on layer breeder ration (2650 Kcal: ME, 16.50%:CP and Calcium: 3.5%) up to the end of the 72 weeks of age. The birds were vaccinated against Marek's disease (1st day), Newcastle disease (ND), Lasota (7th and 30th day), infectious bursal disease (14th and 26th day), fowl pox (6th week), ND R_2B (9th week), infectious bronchitis (IB) and ND inactivated (18th week).

*Traits measured: B*ody weights at 8 (BW8), 16 (BW16), 20 (BW20), 40 (BW40), 52 (BW52), 64 (BW64) and 72 (BW72) weeks of age, age at sexual maturity (ASM), egg production at 40 (EP40), 52(EP52),64(EP64) and 72(EP72) weeks, egg weight at 28 (EW28), 40 (EW40), 52(EW52),64(EW64) and 72 (EW72) weeks of age were measured.

Measurement of egg quality traits: The eggs were weighed using an electronic balance to an accuracy of 0.01 g. The length and width of the eggs were measured using digital vernier calipers (least count, 0.01 mm). The eggs were subsequently broken and internal traits, viz. yolk weight, yolk height and albumen weights were recorded using the standard procedures. Haugh unit (HU) score, albumen height and yolk colour were measured using the egg quality tester machine (EMT 5200, Robotmation Co. Ltd. Japan). The shell weight is weighed on an electronic balance. The shell thickeness is measured using dial thickness gauge (Mitutoyo, Japan).

Statistical analysis: The data collected on various traits were analyzed using standard statistical methods (Snedecor and Cochran 1994). Single factor ANOVA model (SPSS 12.0) was used to assess the effect of genetic group on different traits. Two factor ANOVA with interaction was used to analyze the effect of genotype and age on egg quality traits. The heterosis between the lines was calculated using the following formula.

$$\text{Heterosis}= F_1-[(P_1+P_2)/2)] / (P_1+P_2)/2 \times 100$$

Where, F_1 is the crossbred mean, P_1 and P_2 are means of parental lines used to produce the crossbred.

RESULTS AND DISCUSSION

Plumage: Plumage and feather patterns play a major role in backyard poultry as it is the most important factor in determining the farmer acceptability. In the present study, all the two-way crosses had white plumage with brown or black patches depending on the parental plumage. Since, white allele is dominant in White Leghorn, all birds in cross-combination get white plumage invariably, which

Table 1. Body weight (g) at different ages in layer crosses developed for backyard poultry farming

Trait	Genotype				
	KH	DH	VH	CH	DHK
n	106	92	98	101	205
Body weight, g					
BW8	335.7±6.98^d	432.3±9.41^c	613.5±11.88^b	742.4±11.11^a	438.8±6.89^c
BW16	1036±13.83^d	1259±17.13^c	1430±12.39^b	1570±13.65^a	1056±9.25^d
BW20	1115±12.42^e	1430±20.07^c	1742±13.58^b	1804±15.63^a	1360±10.80^d
BW40	1631±23.11^d	1783±22.5^c	2008±24.66^b	2128±38.61^a	1685±14.15^d
BW52	1636±23.96^d	1833±26.99^c	2101±22.54^b	2284±30.30^a	1689±14.81^d
BW64	1685±25.93^d	1963±29.68^c	2226±24.76^b	2355±32.52^a	1733±14.82^d
BW72	1774±28.25^d	1960±45.82^c	2301±28.78^b	2546±37.18^a	1875±17.49^c

KH, *Kadaknath* × IWH; DH, *Gramapriya* female line × IWH; VH, *Vanaraja* female line × IWH; CH, Vanaraja male line × IWH; DKH, *Gramapriya* female line × *Kadakanth* IWH cross; BW, Body weight at 8, 16, 20, 40, 52, 64 and 72 weeks of age. The means with different superscripts between the columns with in a row differs significantly (P≤0.01).

was true in our study also. The three-way cross (DKH) had multi-coloured plumage with predominant dark to light brown feather colour as it is F_2 cross.

Body weight: Body weight is one of the critical factors regulating production and reproduction of a layer flock and consequently, the economics of a poultry farm (Lacin *et al.* 2008, Muir *et al.* 2022). Genotype had significant (P≤ 0.05) effect on body weight at all ages. The least-squares means for the body weight at 8, 16, 20, 40, 52, 64 and 72 weeks for different genotypes is presented in Table 1. In our study, CH cross recorded significantly (P≤0.05) higher body weights for all the traits at different ages (Table 1). This was on expected lines given the fact that PD-1 line is a male parent line of *Vanaraja*, a dual purpose variety evolved by rigorous selection for higher shank length at six weeks of age which, in turn, was positively correlated with body weight, resulting in higher body weights (Yahaya *et al.* 2012, Rajkumar *et al.* 2016, 2023). The body weights of CH cross observed in the present study was lesser compared to the pure PD-1 line (Padhi *et al.* 2015, Sankhyan and Thakur 2016, Rajkumar *et al.* 2021b) and higher from the IWH pure line (Chandan *et al.* 2019).VH crossbred with the inheritance of *Vanaraja* female line and white leghorn line was the second best performer for all the body weight traits. Previous studies have already highlighted the genetic gains achieved in body weight traits (BW20, BW40, BW52) while selecting for the primary trait (i.e. egg mass at 52 weeks of age) in PD-2 line (Rajkumar *et al.* 2021c). The additive genetic component for these traits was also high in PD-2 line which might have complemented the non-additive part to translate into better estimates in the crosses (Rajkumar *et al.* 2020b). DH cross recorded significantly (P≤0.05) higher body weights than KH (except for BW20) and DKH (except for BW8) for all the body weight traits. Interestingly, the LSMs for the crosses for BW20 (1430±20.07) and BW40 (1783±22.5) traits were higher than the estimates for PD-3 pure line (1322±0.15 and 1730±0.21, respectively) reported by Rajkumar *et al.* (2020a), which is indicative of heterosis operating in the layer cross in a favourable direction for body weights.

Production traits: The least-squares means for different production traits revealed that genotype had significantly (P≤0.05) influenced the traits (Table 2). Age at sexual maturity (ASM) was inversely related with egg production in layers and hence, dictates the production performance of a bird (Akbas and Takma, 2005, Chandan *et al.* 2019). In our study, CH, VH and DH crosses attained sexual maturity at an early age without any significant variation, while KH and DKH differed significantly within and also with other three crosses (Table 2). The presence of layer inheritance might be the possible reason for reduced ASM in crosses compared to the published data in pure lines utilized in the study (Rajkumar *et al.* 2020a, 2020b, Rajkumar *et al.* 2021b, c, d). KH cross matured at a later age than all other crosses which might be attributed to the inherent characteristic of indigenous chicken breeds including *Kadaknath* to attain sexual maturity at a later age (Rajkumar *et al.* 2017, Haunshi and Rajkumar 2020).

Egg production, being the primary trait of selection in layers was studied in detail at 40, 52, 64 and 72 weeks of age and the results are presented in Table 2. The genotype had significant (P≤0.05) effect on the egg production at different ages. DH cross was the highest egg producer among all the crosses with an annual production of 254±6.3 eggs. The CH cross recorded significantly (P≤0.05) lower egg production compared to all other crosses, which might be due to the low producing broiler Cornish inheritance. The average EP40 of DH cross (104.3±2.24) was significantly high as compared to the other crosses and one of the parent lines, PD-3 (75.60±0.01) reported by Rajkumar *et al.* (2020a).The higher egg production was expected in the DH cross as both parents were layers with good egg production potential (Chandan *et al.* 2019, Rajkumar *et al.* 2021d). KH

Table 2. Production performance in layer crosses developed for backyard poultry farming

Trait	Genotype				
	KH	DH	VH	CH	DHK
n	106	92	98	101	205
Age at sexual maturity, d	158.6±0.92^{a}	145.5±0.46^{bc}	142.7±0.95^{c}	142.7±0.95^{c}	147.9±1.04^{b}
Egg production, no.					
EP40	94.49±1.55^{b}	104.3±2.24^{a}	96.54±2.32^{b}	75.82±2.05^{c}	98.48±1.58^{b}
EP52	158.3±2.61^{a}	163.9±3.68^{a}	155.3±3.14^{ab}	117.1±3.23^{c}	149.6±2.11^{b}
EP64	217.8±3.62^{a}	223.0±5.35^{a}	213.5±3.92^{ab}	163.9±4.13^{c}	205.9±2.64^{b}
EP72	246.8±4.27^{ab}	253.7±6.30^{a}	249.4±4.53^{ab}	190.2±4.85^{c}	239.2±2.96^{b}
Egg weight, g					
EW28	45.08±0.26^{c}	53.39±0.33^{a}	51.52±035^{b}	51.61±0.34^{b}	51.03±0.24^{b}
EW40	48.43±0.32^{c}	54.24±0.44^{a}	53.40±0.43^{a}	53.35±0.94^{a}	51.71±0.29^{b}
EW52	49.89±0.33^{d}	58.15±0.37^{a}	56.70±0.45^{bc}	57.87±0.44^{ab}	56.43±0.37^{c}
EW64	52.04±0.32^{c}	60.16±0.45^{a}	57.27±0.35^{b}	59.24±0.42^{a}	56.55±0.31^{b}
EW72	53.88±0.36^{c}	61.13±0.59^{a}	58.44±0.46^{b}	59.92±0.90^{ab}	58.69±0.37^{b}

KH, *Kadaknath* × IWH; DH, *Gramapriya* female line × IWH; VH, *Vanaraja* female line × IWH; CH, *Vanaraja* male line × IWH; DKH, *Gramapriya* female line × *Kadakanth* IWH cross; EP, egg production at 40,52,64 and 72 weeks of age; EW, egg weight at 28, 40,52,64 and 72 weeks of age. The means with different superscripts between the columns with in a row differs significantly (P≤0.01).

and VH crosses also performed remarkably well similar to the DH cross as they did not differ significantly in any of the egg production traits barring EP40. The higher production in VH cross was on expected lines as both are female parent lines, however, the higher production in KH might be due to the heterosis and better nickability of the lines in a cross combination (Rajkumar *et al.* 2011, Khalil *et al*. 2023). In order to bring further clarity into the production profile of the crosses, the corresponding egg weights were evaluated at different ages. The egg weight traits at different ages significantly ($P \leq 0.05$) differed between the genotypes. DH cross recorded significantly($P \leq 0.05$) higher egg weight at 28 weeks of age compared to all crosses, which might be due to the fact that PD-3 line is known for egg weight (Rajkumar *et al.* 2021d). DH and CH cross had similar egg weights from 40 weeks onwards, while VH cross had similar EW40 with DH and CH (Table 2). KH cross recorded significantly ($P \leq 0.05$) lower egg weight at all ages, which was again due to the breed characteristic of indigenous *Kadaknath* chicken breed. DKH cross recorded reasonably fair egg weights though significantly lower from DH cross. The variations in egg weights were attributable to the breed characteristics to a large extent (Niranjan *et al.* 2008, Rajkumar *et al.* 2014, 2017, Padhi *et al.* 2022).

Heterosis: Heterosis percentages were estimated to obtain a clear picture of the gains made in crosses over the parental lines and is presented in Table 3 for various body weight and production traits. DKH and DH crossbreds involving PD-3 line as male parent witnessed the highest heterotic gains for all the body weight traits (Table 3). This indicates that the difference in the frequencies of genes controlling body weight between the selected lines, viz. PD-3 and IWH combined with directional dominance operating favourably in the cross (Falconer and Mackay 1989), thus resulting in higher heterosis for body weight. The body weight gains made in the PD-3 crosses become more pertinent in the light of the fact that former is a layer line and hence, higher body weight gains make it more attractive for the backyard poultry system (Rajkumar *et al.* 2020a).

The heterosis for ASM was either negative (VH and CH) or very low (DKH, DH and KH) which was in desired direction as birds mature at early age or almost similar age of the parents in the cross combinations. These findings are quite obvious given the fact that the parental lines IWH, PD-3 and PD-2 were female lines which are known for early maturity and higher egg production (Chandan *et al.* 2019, Rajkumar *et al.* 2020a, b). However, PD-1 selected for shank length and body weight, on crossing with IWH is expected to surpass the parental average owing to differential selection in the two lines (Falconer and Mackay 1989) which was not true in the study. The mid parent value was higher than the ASM in crossbred resulting in negative heterosis in desired direction which was due to the lesser ASM in IWH, an established layer parent line. Heterosis percentage for the trait EP40 was positive only in VH (7.59%) cross and also the highest for EP52 and positive for EP72 trait (Table 3). KH cross also recorded positive heterosis (7-12%) from EP52 onwards except for EP40. The positive heterosis, in VH and KH crosses revealed that the parental lines had better nickability in a cross combination exploiting the maximum heterosis in the crossbred (Vispute *et al*. 2022). *Kadaknath*, mostly selected as a meat breed with low egg laying potential (120-140 eggs annually) unleashed the full potential of heterosis for egg production traits in its cross with the White Leghorn line (Haunshi and Prince 2021, Dalal *et al.* 2022). DH, CH and DKH crosses had negative

Table 3. Heterosis estimates for different traits in various cross combinations

Trait	Genotype				
	KH	DH	VH	CH	DHK
Age at sexual maturity, d	1.46	0.75	-7.46	-9.43	0.31
Body weight, g					
BW20	-8.18	1.46	4.46	4.50	14.79
BW40	6.97	9.65	1.88	-1.70	7.06
BW52		6.81	0.62	2.40	6.84
BW64		10.29			6.03
BW72		5.63			10.86
Egg production, no.					
EP40	-1.20	-8.83	7.59	-9.09	-8.88
EP52	7.12	-7.65	20.74	-9.48	-12.85
EP64	10.80	-4.57			-10.94
EP72	12.41	-1.75	5.15	-8.60	-8.07
Egg weight, g					
EW28	2.22	5.28	4.45	4.53	9.54
EW40	2.00	2.46	1.84	1.93	4.86
EW52		2.39	1.78	0.36	7.69
EW64		5.33			6.14
EW72		4.76			7.17

heterosis with reduced performance of the crossbred compared to the mid parent estimate. In CH cross, the production was lesser as PD-1 is a broiler with mediocre production potential. The results were in expected lines, as the performance of the crossbred was inferior to the parent lines as both the parental lines (PD-3 and IWH) are high egg producing lines, resulting in higher mid parent value and subsequently negative heterosis estimates. Egg weight traits demonstrated the highest heterotic gains for DKH cross followed by DH across. The heterosis was positive for all egg weight traits among all the crossbreds. The fact that PD-3, PD-1 and IWH are reasonably good egg weight lines resulted in better egg weights in crosses, thus, leading to positive heterosis in crosses. All the parent lines nicked well in cross combination with respect to egg weight traits as positive heterotic gains were recorded in the crossbreds

Egg quality traits: The least squares mean for egg weight and other egg quality traits are presented in Table 4. Interaction effect was significant (P≤0.01) for only two traits: yolk colour and shell thickness. Egg quality traits are crucial for determining the efficiency and economics of a poultry rearing system (Dunn 2011).There was a highly significant (P≤0.01) influence of genotype on all the traits except shape index, yolk index and albumin index which showed non-significant effect. Significant effect of genotype on different egg quality traits were reported earlier by many authors (Niranjan *et al.* 2008, Padhi *et al.* 2022). Shape index is the unit of uniformity of egg size and shape. The shape indices of the eggs observed in the present study were optimum (about 74-75) indicating the optimum uniformity in the eggs of crosses. Similar shape index values were reported in different chicken populations 74.65 for naked neck birds from Nigeria (Yakubu *et al.* 2008); 75.46 for *Aseel* eggs collected from field (Singh *et al.* 2000), while higher shape index values were reported in rural crosses (Padhi *et al.* 2022) and in *Aseel* (Haunshi *et al.* 2010, Rajkumar *et al.* 2014). Egg weight was highest in DH (62.03±0.73) and lowest in KH (53.13±0.71) cross. The observed egg weights were similar with non-significant difference between CH, DKH and VH crosses. The egg weight in present study were considerably higher than reports from the earlier studies in *Gramapriya* and *Vanaraja* (Niranjan *et al.* 2008); in *Kadaknath* (Haunshi *et al.* 2013); in White Leghorn (Sreenivas *et al.* 2013); in *Aseel* (Rajkumar *et al.* 2014). Yolk colour estimate and yolk weight were significantly (P≤0.01) higher in VH cross. Almost similar results for yolk colour have been reported by Niranjan *et al*. (2008) in *Vanaraja* line with slightly lower estimates for yolk weight (17.4 g). Further, Sreenivas *et al.* (2013) reported contrasting results for yolk weight in different white leghorn strains, which might be due to the breed variations. Haugh unit (HU) which is an indicator of egg albumin quality was highest in DKH cross (84.36±1.45) while all other crosses had non-significant differences amongst them. Debnath and Ghosh (2015) observed further higher HU values (88.24±0.64) for *Gramapriya* layers while lower values were reported

Table 4. Effect of genotype and age on egg quality traits in crosses at different ages

	Egg weight, g	Shape index	Yolk colour	Yolk index	Yolk weight, g	Haugh unit	Albumin index	Albumin weight, g	Shell weight, g	Shell thickness, mm
Genotype	**	NS	**	NS	**	**	NS	**	**	**
KH	53.13±0.71^{c}	74.13±0.52	7.5±0.14^{b}	0.44±0.31	16.81±0.22^{c}	78.03±1.41^{b}	0.09±0.05	21.57±0.50^{b}	5.03±0.07^{c}	0.39±0.003^{ab}
DH	62.03±0.73^{a}	74.89±0.52	7.6±0.14^{b}	0.45±0.32	17.60±0.22^{b}	77.7±1.44^{b}	0.08±0.05	25.37±0.50^{a}	5.52±0.07^{ab}	0.40±0.003^{b}
VH	57.71±0.73^{b}	74.71±0.53	8.16±0.15^{a}	1.21±0.32	18.58±0.23^{a}	79.41±1.45^{b}	0.09±0.05	24.99±0.52^{a}	5.70±0.07^{a}	0.41±0.003^{ab}
CH	58.61±0.75^{b}	74.37±0.54	7.4±0.15^{b}	0.44±0.33	17.85±0.23^{b}	75.71±1.49^{b}	0.21±0.05	24.80±0.53^{a}	5.46±0.07^{bc}	0.41±0.003^{a}
DKH	58.26±0.73^{b}	74.88±0.53	7.2±0.15^{b}	0.44±0.32	17.23±0.23^{bc}	84.36±1.45^{a}	0.10±0.05	26.27±0.52^{a}	5.29±0.07^{b}	0.38±0.003^{c}
Age	**	NS	**	NS	**	NS	NS	NS	*	**
52 weeks	57.31±0.56^{b}	74.91±0.40	6.69±0.11^{b}	0.43±0.24	17.17±0.17^{b}	87.20±1.11	0.11±0.04	25.09±0.40	5.26±0.05^{b}	0.39±0.014^{b}
64 weeks	56.80±0.57^{b}	74.39±0.41	7.96±0.11^{a}	0.91±0.25	17.48±0.18^{b}	84.68±1.13	0.17±0.04	24.07±0.40	5.49±0.05^{a}	0.43±0.015^{a}
72 weeks	59.73±0.56^{a}	74.49±0.41	8.13±0.11^{a}	0.45±0.25	18.19±0.17^{a}	65.30±1.12	0.06±0.042	24.64±0.40	5.45±0.05^{a}	0.38±0.014^{c}
Genotype ×age			**							**

** Significant at P≤0.01; *Significant at P≤0.05; NS, Non-significant. The means with different superscripts between the rows with in a column differs significantly (P≤0.01).

for *Kadaknath* (79.82±1.09) and IWH cross (72.99±1.03) by Kumar *et al.* (2022). Non-significant variations were observed for albumen weight between different crosses except KH cross which recorded significantly (P≤0.01) lower estimates. As far as albumin weight was concerned, similar findings were observed by Parmar *et al*. (2006) in *Kadaknath* chicken. The maximum shell weight was recorded in VH cross followed by DH, CH, DKH and least in KH cross. These estimates were higher than the reports in IWH (Sreenivas *et al.* 2013); in naked neck ecotypes (Rajkumar *et al.* 2009); in *Vanaraja* (Niranjan *et al.* 2008); in backyard crosses (Padhi *et al.* 2022). Almost similar shell thickness estimates to the present results were documented in *Gramapriya* layers (Debnath and Ghosh, 2015). Shell thickness was significantly higher in CH and VH (0.41±0.003 mm) crosses and it was considerably higher than the estimates in brown egg dwarf layers and White Leghorn lines (Zhang *et al.* 2005, Sreenivas *et al.* 2013). Padhi *et al.* (2022) also reported lower shell thickness values in crosses developed for backyard poultry farming compared to the present findings.

Age of the laying hens had significant (P≤0.05) effect on egg weight, yolk colour, yolk weight, shell weight and shell thickness, while other traits, i.e. shape index, yolk index, haugh unit, albumin index and albumin weight had non-significant variations. In line with the expectations, the egg weight was highest at 72 weeks of age due to the reason that old and heavier birds lay heavier eggs as egg weight and body weight are positively correlated traits. Similar observations were reported by many authors in different chicken populations in the literature (Rajkumar *et al.* 2009, Padhi *et al.* 2013, Padhi *et al.* 2022). Yolk weight also showed increasing trend with age of the birds, which might be due to possible increase of dietary fatty acids leading to increased proportion of yolk (Whitehead *et al.* 1991, Dinesh *et al.* 2022) in addition to the increased egg weight (Rajkumar *et al.* 2014, Padhi *et al.* 2022). Yolk colour increased significantly with age with the highest estimated values in 72 weeks (8.13±0.11) followed by 64 weeks (7.96±0.11) and 52 weeks (6.69±0.11). These findings are in agreement with Nagarajan *et al*. (1991) who also reported similar phenomenon in Japanese quail. However, Padhi *et al*. (2013) found that yolk colour values increased from 28 weeks (6.71±0.16) to 64 weeks (8.29±0.34) of age and thereafter, witnessed a steep fall at 72 weeks (6.77±0.14). Since yolk weight and egg weight increases with the advancing age of the bird, shell thickness and shell weight suffer a fall due to lack of calcium deposition (Roland *et al.* 1975). Therefore, shell weight and shell thickness increased till 64 weeks of age and then reduced at 72 weeks in our study.

The DH, VH and KH crosses were superior with respect to egg production, egg weight and egg quality traits, however the plumage pattern was predominantly white with brown or black patches. The DKH cross produced 239.2±2.96 eggs annually with 58.69±0.37 g egg weight and had positive heterosis for important traits and optimum egg quality parameters. The DKH cross was characterized by multi coloured plumage with brown coloured eggs. Based on the results it was concluded that the DKH cross offers a bright scope as potential layer variety which needs to be further studied under field conditions for its performance.

REFERENCES

Akbas Y and Takma C H. 2005. Canonical correlation analysis for studying the relationship between egg production traits and body weight, egg weight and age at sexual maturity in layers. *Czech Journal of Animal Science* **50**:163–68.

Chandan P, Prince L L L, Bhattacharya T K, Rajkumar U and Chatterjee R N. 2019. Estimation of heritability and genetic correlation of egg production traits using animal model in commercial layer. *Indian Journal of Animal Sciences* **89**: 1269–273.

Dalal D S, Ratwan P and Yadav A S. 2022. Genetic evaluation of growth, production and reproduction traits in *Aseel* and *Kadaknath* chickens in agroclimatic conditions of northern India. *Biological Rhythm Research* **53**: 40–49.

Debnath B C and Ghosh T K. 2015. Phenotypic correlations between some external and internal egg quality traits in *Gramapriya* layers. *Exploratory Animal and Medical Research* **5**: 78–85.

Dinesh K, Sankhyan V, Thakur D, Verma N and Bhardwaj N. 2022. Effect of age on egg quality traits of Dahlem Red chicken under intensive system of management in Himachal Pradesh. *Indian Journal of Animal Sciences* **92**: 347–52.

Dunn I. 2011. Poultry breeding for egg quality: Traditional and modern genetic approaches. Improving the Safety and Quality of Eggs and Egg Products: Egg chemistry, production and consumption 245–260.

Falconer D S and Mackay T F C. 1989. Introduction to Quantitative Genetics. Longman Scientific and Technical, Longman Group UK Limited.

Felsenstein J. 1965. The effect of linkage on directional selection. *Genetics* **52**: 349–63.

Haunshi S and Prince L L L. 2021. Kadaknath: A popular native chicken breed of India with unique black colour characteristics. *World's Poultry Science Journal* **77**: 427–40.

Haunshi S and Rajkumar U. 2020. Native chicken production in India: present status and challenges. *Livestock Research for Rural Development* **32**.

Haunshi S, Doley S and Kadirvel G. 2010. Comparative studies on egg, meat, and semen qualities of native and improved chicken varieties developed for backyard poultry production. *Tropical Animal Health and Production* **42**: 1013–019.

Haunshi S, Doley S and Shakuntala I. 2009. Production performance of indigenous chicken of northeastern region and improved varieties developed for backyard farming. *Indian Journal of Animal Sciences* **79**: 901–05.

Haunshi S, Padhi M K, Niranjan M, Rajkumar U, Shanmugam M and Chatterjee R N. 2013. Comparative evaluation of native breeds of chicken for persistency of egg production, egg quality and biochemical traits. *Indian Journal of Animal Sciences* **83**: 59–62.

Haunshi S, Shanmugam M, Padhi M K, Niranjan M, Rajkumar U, Reddy M R and Panda A K. 2012. Evaluation of two Indian native chicken breeds for reproduction traits and heritability of juvenile growth traits. *Tropical Animal Health and Production* **44**: 969–73.

Khalil M, Hassan H A, El-Gendi G and EL Nagar A G 2023. Heterotic components for age at first egg, egg production, some partial egg records, clutch sizes and pause duration in crossing four Egyptian strains of chickens. *Egyptian Poultry Science Journal* 4**3**(1):109–25.

Kumar M, Dahiya S P, Ratwan P, Sheoran N, Kumar S and Kumar N. 2022. Assessment of egg quality and biochemical parameters of *Aseel* and *Kadaknath* indigenous chicken breeds of India under backyard poultry farming. *Poultry Science* **101**: 101589.

Lacin E, Yildiz A, Esenbuga N and Macit M. 2008. Effects of differences in the initial body weight of groups on laying performance and egg quality parameters of Lohmann laying hens. *Czech Journal of Animal Science* **53**: 466–71.

Muir W I, Akter Y, Bruerton K and Groves P J. 2022. The influence of hen size and diet nutrient density in early lay on hen performance, egg quality, and hen health in late lay. *Poultry Science* **101**.

Nagarajan S, Narahari D, Jayaprasad I A and Thyagarajan D. 1991. Influence of stocking density and layer age on production traits and egg quality in Japanese quail. *British Poultry Science* **32**: 243–48.

Niranjan M, Sharma R P, Rajkumar U, Chatterjee R N, Reddy B L N and Bhattacharya T K. 2008. Egg quality traits in chicken varieties developed for backyard poultry farming in India. *Livestock Research for Rural Development* **20**.

Padhi M K, Chatterjee R N, Rajkumar U, Bhattacharya T K and Bhanja S K. 2015. Genetic and phenotypic parameters estimates for body weight, conformation, production and reproduction traits of PD1 (*Vanaraja* male line) during different periods. *Indian Journal of Animal Sciences* **85**: 883–88.

Padhi M K, Chatterjee R N and Rajkumar U. 2022. Effect of age on egg quality in chicken. *Indian Journal of Poultry Science* **57**: 133–38.

Padhi M K, Chatterjee R N, Haunshi S and Rajkumar U. 2013. Effect of age on egg quality in chicken. *Indian Journal of Poultry Science* **48**: 122–25.

Parmar S N, Thakur M S, Tomar S S and Pillai P V A. 2006. Evaluation of egg quality traits in indigenous *Kadaknath* breed of poultry. *Livestock Research for Rural Development* **18**.

Rajkumar U, Prince L L L, Haunshi S, Jayakumar S, Rajaravindra K S, Niranjan M, Reddy B L N and Chatterjee R N. 2023. Does selection index application for highly heritable traits need revisiting – A comprehensive study with bodyweight and shank length in Vanaraja male line chicken. *Indian Journal of Animal Sciences* **93**(10): 1021–025.

Rajkumar U, Prince L L L, Paswan C, Haunshi S and Chatterjee R N. 2021b. Variance component analysis of growth and production traits in *Vanaraja* male line chickens using animal model. *Animal Bioscience* **34**: 471–75.

Rajkumar U, Prince L L L, Rajaravindra K S, Haunshi S, Niranjan M and Chatterjee R N. 2021d. Analysis of (co) variance components and estimation of breeding value of growth and production traits in Dahlem Red chicken using pedigree relationship in an animal model. *PLoS One* **16**: e0247779.

Rajkumar U and Rama Rao S V. 2015. *Gramapriya*, a prolific brown egg layer for rural backyards. *Indian Farming* **65**: 32–34.

Rajkumar U, Haunshi S, Paswan C, Raju M V L N, Rao S R and Chatterjee R N. 2017. Characterization of indigenous *Aseel* chicken breed for morphological, growth, production, and meat composition traits from India. *Poultry Science* **96**: 2120–126.

Rajkumar U, Niranjan M, Prince L L L, Haunshi S, Paswan C and Reddy B L N. 2021c. Short term selection response for higher 52 week egg mass based on Osborn index in *Vanaraja* female parent line chicken. *Indian Journal of Animal Sciences* **91**: 41–45.

Rajkumar U, Niranjan M, Prince L L L, Paswan C, Haunshi S and Reddy B L N. 2020a. Genetic evaluation of growth and production performance and short term selection response for egg mass in *Gramapriya* female line chicken. *Indian Journal of Animal Sciences* **90**: 401–06.

Rajkumar U, Padhi M K, Haunshi S and Chatterjee R N. 2016. Genetic and phenotypic response in Vanaraja male line chicken under short term selection experiment. *Indian Journal of Animal Sciences* **86**: 1287–290.

Rajkumar U, Prince L L L, Haunshi S, Paswan C and Reddy B L N. 2020b. Evaluation of Vanaraja female line chicken for growth, production, carcass and egg quality traits. *Indian Journal of Animal Sciences* **90**: 603–09.

Rajkumar U, Raju M V L N, Niranjan M, Haunshi S, Padhi M K and Rao S R. 2014. Evaluation of egg quality traits in native *Aseel* chicken. *Indian Journal of Poultry Sciences* **49**: 324–27.

Rajkumar U, Rama Rao S V and Sharma R P. 2010. Backyard poultry farming: Changing the face of rural India. *Indian Farming* **59**: 20–23.

Rajkumar U, Rama Rao S V, Raju M V L N and Chatterjee R N. 2021a. Backyard poultry farming for sustained production and enhanced nutritional and livelihood security with special reference to India: A review. *Tropical Animal Health and Production* **53**.

Rajkumar U, Sharma R P, Padhi M K, Rajaravindra K S, Reddy B L N, Niranjan M and Chatterjee R N. 2011. Genetic analysis of juvenile growth and carcass traits in a full diallel mating in selected colored broiler lines. *Tropical Animal Health and Production* **43**: 1129–136.

Rajkumar U, Sharma R P, Rajaravindra K S, Niranjan M, Reddy B L N, Bhattacharya T K and Chatterjee R N. 2009. Effect of genotype and age on egg quality traits in naked neck chicken under tropical climate from India. *International Journal of Poultry Science* **8**: 1151–155.

Roland D A, Sloan D R and Harms R H. 1975. The ability of hens to maintain calcium deposition in the egg shell and egg yolk as the hen ages. *Poultry Science* **54**: 1720–723.

Sankhyan V and Thakur Y P. 2016. Comparative performance of Vanaraja and indigenous chicken under intensive system in subtemperate climatic condition of North Western Himalayan state of Himachal Pradesh. *International Journal of Science, Environment and Technology* **5**: 449–53.

Singh M, Mollier R T, Paton R N, Pongener N, Yadav R, Singh V, Katiyar R, Kumar R, Sonia C, Bhatt M, Babu S, Rajkhowa D J and Mishra V K. 2022. Backyard poultry farming with improved germplasm: Sustainable food production and nutritional security in fragile ecosystem. *Frontiers in Sustainable Food Systems* **6**: 393.

Singh M, Singh U and Gurung B S. 2000. Evaluation of egg weight and its various measurements attributes in indigenous *Aseel* breed of chicken. *Indian Journal of Poultry Science* **35**: 312–14.

Snedecor G W and Cochran W G. 1994. Statistical methods, 8th Edition, Iowa State University Press, Ames.

Sreenivas D, Prakash M G, Mahender M and Chatterjee R N. 2013. Genetic analysis of egg quality traits in White leghorn chicken. *Veterinary World* **6**: 263–66.

Vispute M M, Saxena V K, Narayan R, Tomar S, Rokade J J. and

Verma M R. 2022. Evaluation of crossbreeding parameters for immunocompetence and serum enzyme profile in a partial diallel cross involving three genetic groups of chicken. *Indian Journal of Animal Research* **56**(9): 1063–70.

Whitehead C C, Bowman A S and Griffin H D. 2007. The effects of dietary fat and bird age on the weights of eggs and egg components in the laying hen. *British Poultry Science* **32**: 565–74.

Yahaya H K, Ibrahim H and Abdulsalam S. 2012. Correlation between body weight and body conformation of two broiler strains under the same dietary treatment. *International Journal of Animal and Veterinary Advances* **4**: 181–83.

Yakubu A, Ogah D M and Barde R E. 2008. Productivity and egg quality characteristics of free range naked neck and normal feathered Nigerian indigenous chickens. *International Journal of Poultry Science* **7**: 579–85.

Zhang L C, Ning Z H, Xu G Y, Hou Z C and Yang N. 2005. Heritabilities and genetic and phenotypic correlations of egg quality traits in brown-egg dwarf layers. *Poultry Science* **84**: 1209–213.