The effect of feeding magnesium-enriched diets on the quality of the albumen of stored eggs

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(*Received* 22 *September* 1975 – *Accepted* 3 *November* 1975)

1. Pullets were given from 1-d-old diets containing 1·6, 4·1, 8·1 and 12·0 g Mg/kg. Only small effects of these diets on live weight, food consumption, egg number, egg weights or egg-shell thickness were observed except at the highest level (12·0 g Mg/kg) which caused diarrhoea and an appreciable lowering of the live weight of growing pullets. A further group was given from point-of-lay a diet containing 9·3 g Mg/kg.

2. Eggs laid on 3 consecutive days from each of eighteen hens were collected at intervals of 3 weeks until the birds were 68·5 weeks old. Eggs laid on the 3rd day were used to determine the initial proportion of thick egg-white present and also the concentration of Mg, Ca, Na and K in the thick egg-white. Eggs laid on the 1st and 2nd days were stored at 20° for 20 d to establish the proportion of thick egg-white remaining after storage.

3. With the unsupplemented diet the proportion of residual thick egg-white after storage of eggs for 20 d at 20° was 306, 161 and 305 mg/g total egg-white when the hens were 26·5, 53·5 and 68·5 weeks of age respectively. When the diet containing 9·3 g Mg/kg was given, the proportion of thick egg-white after storage remained approximately 400 mg/g throughout the period of the trial.

4. The mean Mg concentration in the thick egg-white of eggs laid by hens given unsupplemented diets was 5·77 mM. The addition of extra Mg to the diet increased the content of Mg in the thick egg-white, for example when the diet contained 9·3 g Mg/kg the mean concentration rose to 7·69 mM.

The natural liquefaction of the thick egg-white fraction of the domestic hen's egg during the collection and marketing of eggs is one of the causes of poor internal egg quality (Monsey & Robinson, 1974), such eggs being down graded causing financial loss to the producer. Moreover, the use of eggs with low quality egg-white impairs the commercial baking properties of egg-white (Sills, 1974) and makes culinary operations, e.g. frying, physically difficult. We have shown, first, that Mg^{2+} can reduce ovomucin-lysozyme (*EC* 3.2.1.17) interactions which may be responsible for the egg-white gel-to-sol transition (Robinson, 1972) and secondly that addition of Mg to isolated thick egg-white retards the natural thinning of the egg-white gel (Robinson & Monsey, 1972). From these results and those of Sauveur (1971, 1973), it is apparent that Mg^{2+} has an important role in the stabilization of the thick egg-white gel, and hence the maintenance of a good internal quality in domestic eggs. This paper reports the results of experiments carried out to determine whether the feeding of Mg-enriched diets can enhance the stability of the egg-white gel. A preliminary communication describing some of the results has been published (Robinson, Monsey, Miller & Clarke, 1975.

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Table 1. *Composition of basal diet (g/kg) given to laying hens*

Maize	180
Wheat	190
Barley	370
White fish	40
Extracted soya-bean meal	70
Meat and bone meal	50
Grass meal	45
Vitamins	1·8
Methionine	0·66
Minerals	57·8

MATERIALS AND METHODS

Hens and diets

A flock of 200 1-d-old pullets of a white egg strain, Babcock B300 (supplied by Babcock Farms Ltd, Chelmsford), was divided into four groups of fifty chicks. One group was given a normal basal diet (Table 1) which contained 1·5–1·8 g Mg/kg. The other groups were given the basal diet supplemented with Mg to give final concentrations of 4·1, 8·1 and 12·0 g Mg/kg respectively. The Mg was administered as an equimolar mixture of the chloride (hydrated) and the carbonate (hydrated, basic, light) salts (Fisons Ltd, Loughborough). At 21 weeks of age, eighteen hens were randomly selected from each of the groups receiving diets containing 1·6, 4·1 and 8·1 g Mg/kg, put into wire-floored cages and each given a layer's diet with the same Mg content as they had received previously. A fourth group of eighteen birds which had received the unsupplemented diet up to 21 weeks of age was given a layer's diet containing 9·3 g Mg/kg. The hens were fed *ad lib.* and given tap water to drink.

Egg numbers, egg weight, food consumption and mortality rate were recorded throughout the laying period.

Measurement of egg quality

When the hens were 23·5 weeks old, all the eggs laid by each group on 3 consecutive days (days 1, 2 and 3) were collected. Day 1 and 2 eggs were stored at 20° for 20 d. Day 3 eggs were broken within 5 h of collection and the proportion of thick egg-white of individual eggs measured by the method of Monsey & Robinson (1974). The thick and total thin egg-white were separated by a standard mesh gauze and their weights recorded. This is a simplification of the method of Brooks & Hale (1959), who determined the proportion of both the outer and the inner thin egg-white. The width of the square holes in the gauze and the diameter of the wire were 1·36 and 0·46 mm respectively. Day 1 and 2 eggs were broken after 20 d storage at 20° and the proportion of residual thick egg-white in each egg measured. The above procedure was repeated at intervals of 3 weeks until the hens were 68·5 weeks old.

An experiment was carried out to compare two methods of egg-white quality assessment. When the hens were 72·5 weeks old, eggs were collected from each group on 4 consecutive days (days 1, 2, 3 and 4) and stored for different periods of time (Table 5) at 20°. Within 5 h of collection from the laying cages day 4 eggs were broken and Haugh units (Haugh, 1937) were calculated from albumen height and egg weight

Table 2. *Effect of supplementation of diets with magnesium on daily live weight gain (g) and daily food intake (g) of pullets*

	Mg content of diet (g/kg)							
	1·6		4·1		8·1		12·0	
Age (d)	Weight gain	Food intake	Weight gain	Food intake	Weight gain	Food intake	Weight gain	Food intake
1–21	6·1	19·7	6·0	22·4	5·4	22·3	4·9	21·0
22–42	11·6	36·7	10·3	36·1	9·3	36·7	7·1	41·4
43–84	12·8	41·4	12·8	34·4	11·8	35·1	10·1	29·8
Mean	10·2	32·6	9·7	31·0	8·8	31·4	7·3	30·7

For significances see text.

Table 3. *Effect of supplementation of diets with magnesium on egg production and food consumption of laying hens between 21 and 70 weeks*

	Mg content of diet (g/kg)				
	1·6	4·1	8·1	9·3	L.S.D.*
Total no. of eggs laid by each group of 18 hens	4710	4905	3989	4117	
Total no. of hen days	6174	6174	5558	5999	
Total no. of eggs weighed	1317	1371	962	1165	
Average weight of eggs (g)	59·0	58·3	58·5	57·6	0·5
Average egg mass/hen per d (g)	44·1	45·3	41·1	40·1	2·0
No. of deaths	0	0	5	1	
Average hen weight (kg)†	1·51	1·54	1·50	1·50	0·03
Food consumption/hen per d (g)	108·9	111·4	109·8	103·0	2·0

* Least significant difference.
† Average for 6 hens weighed at 10 1-monthly intervals.

measurements using an Egg-quality slide rule (distributed by the Kaw Co., 223E Hanover Street, Trenton, N.J., USA). The proportion of thick egg-white was also determined on the same eggs. Day 1, 2 and 3 eggs stored at 20° for 10, 20 and 30 d respectively were similarly examined. These observations were also made after storage of eggs at 5°.

Measurements of shell thickness (membranes removed) were carried out on eggs laid by each group of hens on four different occasions. The mean value of three separate measurements made around the equator of the eggs was calculated.

Na, K, Ca and Mg analysis

Two duplicate 4 g samples of the isolated, combined and homogenized (MSE Ato-mix, slow speed) thick egg-white of the day 3 eggs from each group on ten occasions throughout the period of the trial were rapidly weighed, stored at −20° and analysed for Na, K, Ca and Mg by atomic adsorption spectrophotometry (Pye Unicam SP90; Pye Unicam Ltd, Cambridge).

Table 4. *Effect of supplementation of diets with magnesium on quality of egg-white of fresh eggs*

	Thick egg-white (mg/g total egg-white)							
	A		B		C		D	
Age of hen (weeks)	Mean	SD	Mean	SD	Mean	SD	Mean	SD
23·5	656	80	641	66	599	43	576	78
26·5	571	85	590	57	556	69	574	76
29·5	579	59	589	49	558	55	582	65
35·5	570	77	565	50	542	52	560	38
38·5	545	55	551	63	526	76	581	43
41·5	510	71	530	54	519	63	547	37
44·5	527	52	523	61	508	45	551	58
47·5	515	52	520	54	513	68	527	55
50·5	501	69	511	67	471	51	509	29
53·5	493	70	511	54	508	59	558	66
56·5	483	59	499	68	422	174	519	48
59·5	515	59	517	62	539	64	524	45
62·5	540	72	568	71	550	43	521	34
65·5	584	73	584	72	582	91	595	37
68·5	554	79	565	53	516	32	545	32
Mean	543		550		527		552	

A, diet containing 1·6 g Mg/kg given from 1 d old; B, diet containing 4·1 g Mg/kg given from 1 d old; C, diet containing 8·1 g Mg/kg given from 1 d old; D, diet containing 9·3 g Mg/kg given from 21 weeks of age.

RESULTS

Statistical treatment

Except where otherwise stated the data tabulated and analysed were the means of the measurements obtained on the eggs laid on a single day by the group of hens on each diet. Values were taken at various ages of hen. Analyses of variance were carried out with diet and age as factors using Duncan's multiple range test to investigate the differences between the diet means (taken over all ages) for significance at the 5% level.

Effect of dietary Mg on live-weight gain, food consumption and egg production

The pullets given a diet containing 12·0 Mg/kg scoured noticeably, consequently it was decided to discontinue with this particular group. Analysis of variance on the data given in Table 2 showed that the effect of dietary Mg on average food intake of pullets was not significant. Average gain in live weight was, however, related to diet, the mean for the diet containing 12·0 g Mg/kg being significantly lower than for the other diets but these were not significantly different from each other.

Over-all production figures for hens on the four diets is shown in Table 3. Chi-square analysis was used to investigate whether the proportion of total eggs laid to hen days was independent of diet. The proportion with the control diet was not significantly different from that with the 4·1 g Mg/kg diet but was significantly higher than those with the 8·1 and 9·3 g Mg/kg diets. For the other data in Table 3 the means obtained

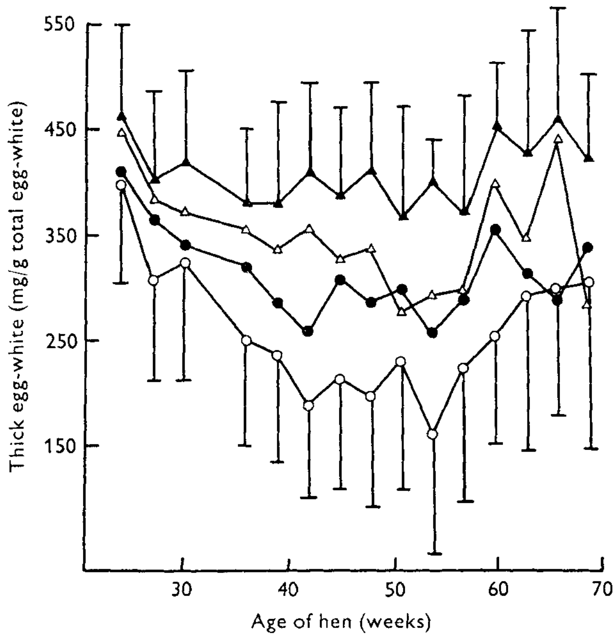

Fig. 1. The effect of dietary magnesium and age of hen on the proportion of thick egg-white of eggs stored at 20° for 20 d. (○) diet containing 1·6 g Mg/kg given from 1 d old; (●) diet containing 4·1 g Mg/kg given from 1 d old; (△) diet containing 8·1 g Mg/kg given from 1 d old; (▲) diet containing 9·3 g Mg/kg given from 21 weeks of age. Each point represents the mean thick egg-white content after storage of all eggs laid by eighteen hens from each group on two consecutive days. For the sake of clarity, standard deviations (as vertical bars) are shown for only two of the diets.

for each diet at different ages of hen were used to calculate least significant differences for the diet means. In all these analyses of variance age was a significant effect.

Effect of dietary Mg on the proportion of thick egg-white before and after storage at 20°

Analysis of variance of the data on average thick egg-white for unstored eggs (Table 4) and stored eggs (Fig. 1) showed, in both cases, a significant dependence on diet and age of hen. For stored eggs, all diet means were significantly different; for unstored eggs, the mean for the 8·1 g Mg/kg diet was the only one which showed a significant difference from the means of the other three diets. (The reason for this last result is not understood.) For stored eggs, regression analysis was used to predict the proportion of thick egg-white, TW (mg/g) from dietary Mg concentration (g Mg/kg);

$$TW = 17{\cdot}8\,Mg + 235 \; (t = 6{\cdot}8,\ P < 0{\cdot}001).$$

Age of hen was not a significant factor when included as a linear term in the regression equation but, when linear and quadratic components were included, both were highly significant ($P < 0{\cdot}001$), and the regression coefficient with Mg was unchanged. Having corrected for the linear and quadratic effects of age, the partial correlation coefficient between TW and Mg was 0·83.

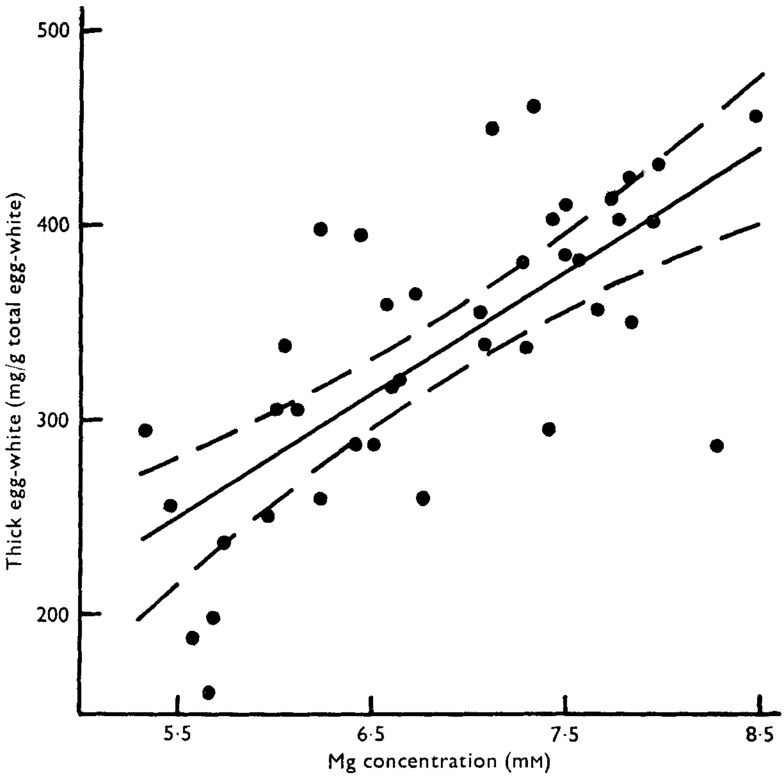

Fig. 2. Regression line for predicting the proportion of thick egg-white in hen's eggs after storage of eggs for 20 d at 20° from the magnesium content of the thick egg-white. Each point represents the mean thick egg-white content after storage of all eggs laid by eighteen hens from each group on 2 consecutive days and also the mean Mg content of two duplicate samples of the pooled, unstored thick white from the same eighteen laid in 1 d. The samples were taken on ten occasions between 23·5 and 68·5 weeks of age. The broken lines show the 95 % confidence limits of the regression equation (see below).

Effect of dietary Mg on the Mg, Na, K and Ca contents of thick egg-white

The Mg content of thick egg-white was not significantly affected by the age of the hen. The mean Mg contents for the 1·6, 4·1, 8·1 and 9·3 g Mg/kg diets (10 estimations for each diet) were 5·77, 6·50, 7·52 and 7·69 mM respectively. Except for the difference between the 8·1 and 9·3 g Mg/kg diets, all the means were significantly different.

The mean Na, K and Ca contents of the same samples of thick egg-white were found to be 78·5, 40·4 and 2·2 mM respectively. The concentrations of these metals were not related to the dietary Mg level.

Regression analysis was used to predict the proportion of thick egg-white, TW (mg/g), from the Mg content, C (mM) of the thick egg-white. Fig. 2 shows the calculated relationship.

$$TW = 63{\cdot}5C - 98{\cdot}7 \ (t = 6{\cdot}3,\ P < 0{\cdot}001).$$

When included in the equation, age of hen was a significant factor (the correction to the predicted TW being a reduction of 5·0 mg/g between minimum and maximum age

Table 5. *Effect of supplementation of hens' diets with magnesium on quality of egg-white after various storage conditions. A comparison between two methods of quality assessment*

(The two methods of quality assessment were used on the same eggs and each value represents the mean value for all eggs laid by one group of birds on one day. The hens were 72·5 weeks old (20° storage) and 71·5 weeks old (5° storage))

Storage time (d)	Thick white (mg/g total egg-white)								Haugh units*							
	A		B		C		D		A		B		C		D	
20°	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	546	81	553	100	522	94	563	72	77·2	4·6	80·4	6·4	83·4	6·3	84·9	7·2
10	343	141	451	120	396	96	468	77	52·3	7·3	63·7	13·1	60·0	10·5	63·3	8·1
20	183	130	318	195	320	200	402	153	46·3	12·8	58·1	7·7	59·8	13·6	53·3	10·3
30	76	90	187	181	247	176	339	170	35·8	13·4	53·5	9·7	47·0	11·9	50·1	13·9
5°																
0	541	90	567	96	545	48	573	52	79·0	5·3	80·7	7·6	83·5	5·0	85·0	6·0
15	500	50	539	40	497	81	485	51	73·3	5·5	69·9	10·1	75·2	7·3	71·8	3·5
30	469	90	495	67	451	47	489	92	63·8	5·6	71·4	4·8	69·3	6·5	70·7	3·1
45	457	69	473	46	449	16	476	38	60·6	9·9	69·1	4·6	69·6	2·1	68·6	4·1

* Haugh (1937).

A, diet containing 1·6 g Mg/kg given from 1 d old; B, diet containing 4·1 g Mg/kg given from 1 d old; C, diet containing 8·1 g Mg/kg given from 1 d old; D, diet containing 9·3 g Mg/kg given from 21 weeks of age.

https://doi.org/10.1079/BJN19770005 Published online by Cambridge University Press

Table 6. *Effect of supplementation of diets with magnesium on egg-shell thickness (mm)*

(Values given are mean values for all eggs laid by one group of hens on 1 d (day 3))

Age of hen (weeks)	Diet A Mean	A SD	Diet B Mean	B SD	Diet C Mean	C SD	Diet D Mean	D SD	Mean
41·5	0·33	0·04	0·32	0·04	0·31	0·02	0·32	0·03	0·320
50·5	0·32	0·03	0·32	0·03	0·32	0·04	0·31	0·03	0·318
59·5	0·31	0·05	0·30	0·04	0·31	0·04	0·29	0·03	0·303
72·5	0·30	0·05	0·29	0·05	0·28	0·03	0·27	0·02	0·285
Mean	0·315		0·308		0·305		0·298		

A, diet containing 1·6 g Mg/kg given from 1 d old; B, diet containing 4·1 g Mg/kg given from 1 d old; C, diet containing 8·1 g Mg/kg given from 1 d old; D diet containing 9·3 g Mg/kg given from 21 weeks of age. For significances see text.

of hen) but the over-all significance of the multiple regression was less than that of the simple regression.

Comparison of methods for assessing egg-white quality

Eggs laid by the four groups of hens when they were 72·5 and 71·5 weeks of age were stored for varying times at 20° and 5° respectively. Results of the measurement of the proportion of thick egg-white are shown in Table 5. The corresponding values for Haugh units determined on the same eggs are also given. The effect of increased Mg levels in the diet could be detected in the thick egg-white after 10 d storage at 20° but became more evident after longer periods of storage. For example, after 30 d the mean proportion of thick egg-white was 76 mg/g using unsupplemented diets and 339 mg/g when the diet containing 9·3 g Mg/kg was given. The corresponding mean values for Haugh units were 35·8 and 50·1 respectively. Smaller effects on the proportion of thick egg-white and on Haugh units were observed when eggs were stored at 5°. The relationship between thick egg-white and Haugh units was investigated for 246 eggs using individual results taken from various hens, diets and ages. The correlation coefficient was low ($r = 0·6$).

Effect of dietary Mg on egg-shell thickness

The mean egg-shell thicknesses in Table 6 were analysed and it was found that the only difference in diet means was between the 1·6 and 9·3 g Mg/kg diets. Age of hen was also significant. The over-all mean egg-shell thickness was 0·306 mm.

Mg content of tap water

The Mg concentration in the tap water was found to be 0·122 ± 0·004 mmol/l. It was calculated that the amount of Mg received by the laying hens from this source was negligible compared to the amount received from the diets.

DISCUSSION

The results indicate that it is unnecessary to give supplementary Mg, in order to achieve improved egg-white quality after storage, until the birds are near point-of-lay.

Egg production and egg weight were marginally lower when the supplemented diets were given although Staller & Sunde (1964) reported that egg production and egg weight were not depressed over a period of 8 months as a result of giving diets containing up to 13 g Mg/kg given as dolomite (the double carbonate of Mg and Ca).

Loose droppings were observed in pullets up to 12 weeks old when given the diet containing 12 g Mg/kg. Other workers have reported higher water contents in the faeces of hens when the Mg concentration in the diet was higher than 9 g/kg (Mehring & Johnson, 1965) or 13g/kg (Staller & Sunde, 1964).

McWard (1967) states that hens receiving 12 g Mg/kg produced eggs with thinner shells than those receiving 4·8 g Mg/kg. We also found egg-shells were thinner when the Mg level of the diet was raised.

The results show that feeding Mg-enriched diets to laying hens improved the quality of the albumen after storage. Roberson & Francis (1966) claimed that Haugh units of newly laid eggs were unaffected by additional Mg (given as the sulphate). We found, however, that Haugh units of unstored eggs increase slightly with increasing Mg in the diet; this may be due to the different salts of Mg used.

The low correlation between Haugh unit and the proportion of thick egg-white values is probably because the two methods are monitoring different, although related physical changes during the thinning of thick egg-white. The Haugh unit is an observation essentially based on albumen height whilst the proportion of thick egg-white is a measure of the volume of that part of egg-white which is more viscous than the thin egg-white. Brant, Otte & Norris (1951) claimed that the determination of the amount of thick egg-white is more useful than using Haugh units for determination of egg-white quality in storage experiments and Brooks & Hale (1959, 1961) have made extensive use of the method.

We have also shown that the Mg content of the thick egg-white fraction can be increased by feeding Mg. In absolute terms the effect on concentration is small and may be within the natural variation between individual eggs. A substantial increase in the Mg content of the diet is required to improve egg-white quality although the total Mg content of the diets is still less than 10 g/kg.

The mechanism by which Mg improves the storage quality of egg-white is unknown. Previous work (Robinson, 1972) has shown that Mg depresses the interaction between reduced ovomucin and lysozyme in vitro. Hawthorne (1950) postulated that ovomucin complexes with lysozyme in such a way as to change the physical state of the ovomucin molecules and destroy the gel structure, and it can be argued that Mg is acting in this way. Alternatively, Mg^{2+} could be an inhibitor of enzymes responsible for the degradation of ovomucin (Robinson, 1972).

We thank Mrs V. Newby for her valuable assistance and R. Stansfield for computer statistical analysis.

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Printed in Great Britain