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Meeting the energy needs of poultry

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A detailed study of the energy needs of poultry is of scientific and economic importance, and is of topical interest, as can be judged from the publication of the proceedings of a symposium held last year on this subject (Morris & Freeman, 1974).

Measurement and partition of dietary energy

The partition of gross energy of the diet into its various components is shown in Fig. 1.

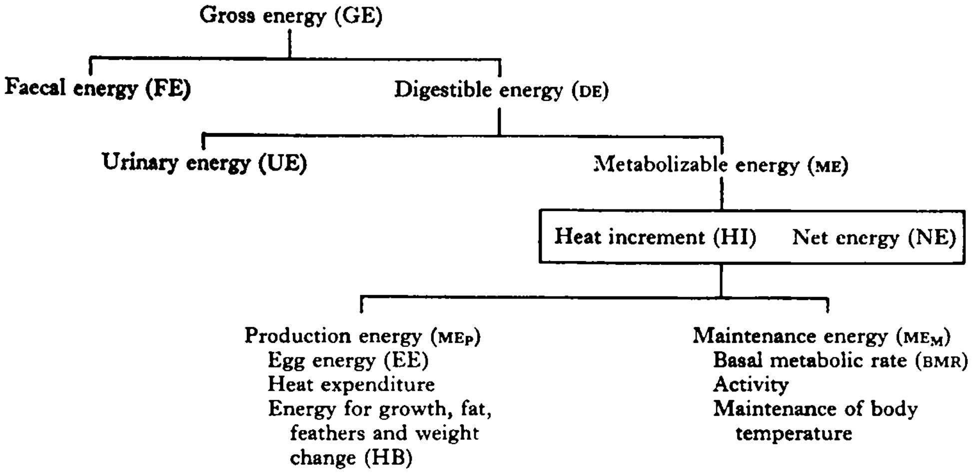

Fig. 1. Partition of dietary energy in poultry.

The most popular way is to evaluate the diet in terms of its metabolizable energy (ME) content measured in kcal (1 kcal=4·184 kJ). The problems associated with the determination of ME have been recently reviewed by Miller (1974). Unfortunately, the ME of a diet is not always equal to the sum of the ME values of its constituent parts (Vohra, 1972). It is reduced by the presence of toxicants, but is improved by certain fats, owing to the low energy cost of digestion, absorption, transport and deposition of dietary fats relative to the energy requirements for fat synthesis. The topic of carbohydrates and fats as dietary energy sources was reviewed by Annison (1974). The only practical way of predicting the ME of a diet would be from its chemical composition, but no single regression equation fulfills that role as yet. We need to develop regression equations to include the positive and the negative contributions of the chemical constituents.

$$\text{ME}=(\text{carbohydrate}\times\text{DC}\times\text{GE})+(\text{fat}\times\text{DC}\times\text{GE})+(\text{protein}\times\text{DC}\times\text{GE})-(\text{effects of toxicants on energy}),$$

where DC and GE are the digestibility coefficient and gross energy of the respective constituents. Actually, a part of dietary ME is lost as heat increment (HI) to give the balance as net energy (NE) for maintenance and production. De Groote (1974) suggests that NE is a preferable measure and has proposed factors for conversion of ME of the dietary ingredients to NE. The problems encountered in ME determination would be also applicable for NE. However, NE may have a place in least-cost diet formulations.

Maintenance energy (ME_M)

For practical purposes we may define that part of ME which is not utilized for production (ME_P) as ME_M. It includes basal metabolic rate (BMR), HI and activity-like components.

BMR of adult homeotherms both large and small can be correlated to their metabolic body size by the following expression: BMR (kcal/d)$=AW^k$ where A is some constant number of kcal, W is body-weight (kg), and k is some power to correlate body-weight to surface area. Kleiber (1969) assigned a value of 70 kcal (293 kJ) to A, and discussed the rationale of using $k=0\cdot75$ to give BMR (kcal/d)$=70\ W^{0\cdot75}$.

A major part of the requirement of ME_M is for BMR and is also expressed in terms of a function of metabolic body size. From the literature, ME_M (kcal/d) for laying hens is in the range 99–133 $W^{0\cdot75}$ and the average would be about 100 kcal/kg$^{0\cdot75}$ (Grimbergen, 1974). The efficiency of utilization of ME for ME_M is about 85% for adult and growing chicks (De Groote, 1974).

Energy for production

The ME_P portion of ME can be utilized for any of the production functions such as growth, deposition of fat, feathers or egg production. The GE of lean body mass may be taken as 1·4 kcal(5·9 kJ)/g, of fat as 9·5 kcal(39·7 kJ)/g, and of eggs with shell as 1·6 kcal(6·7 kJ)/g. The energy associated with a change in body-weight would be between 1·4 and 9·5 kcal(5·9–39·7 kJ)/g. For practical purposes it may be regarded as 4 kcal(16·7 kJ)/g change in body-weight.

With this information, it is possible to predict the ME requirement for production purposes by assigning an over-all efficiency value of 80% for ME_P. Grimbergen (1974) estimated the efficiency of utilization of ME for egg production and fat synthesis at 60% and 80%, respectively.

Zone of thermal neutrality

Adult chickens are homeothermic, and consequently the maintenance of normal body temperature takes precedence over any production of eggs or fat. A certain amount of energy is needed for this purpose, depending upon the ambient temperature, and this energy has to be provided by the dietary energy. Animals, in general, have a region between the lower and upper critical temperatures which is called the zone of thermal neutrality, in which the fasting metabolic rate (FMR), to differentiate from BMR (animals have some movement), is minimal. On the other hand, the metabolic rate of a fully fed animal at rest is called the resting metabolic rate and is higher than the FMR owing to the thermogenic effect of food. In the thermoneutral zone, the heat production of the animal is constant and heat loss variations maintain the body temperature. But if the ambient temperature falls above or below the thermoneutral range, the heat production increases.

Ideal environmental temperature

The ideal environmental temperature in a poultry house would be in the zone of thermoneutrality, so that the resting metabolic rate is at its lowest, the energy requirement for maintenance is low, and the maximum amount of ME is available for production purposes. Actually, the zone of thermoneutrality is not well-defined for avian species, partly because acclimatization may occur. Its existence has been questioned by several investigators (West & Hart, 1966; Waring & Brown, 1967; Shannon & Brown, 1969). A temperature range from 5° to 25° was most favourable for egg production by White Leghorn hens on the basis of nitrogen retention (Romijn, 1970). Shifts from insulative to metabolic heat regulation were observed with lower temperatures.

In poultry, a continuous decrease of heat production is usually observed with increasing environmental temperatures concomitant with a decrease in food intake and an alteration in behaviour. In the animals which have a well-defined zone of thermal neutrality, food intake and behaviour remain constant during all temperature treatments. An attempt to explain the zone of thermal neutrality on the basis of a combination of feeding, production and activity level of poultry was made by van Es, van Aggelen, Nijkamp, Vogt & Scheele (1973).

Measurement of FMR

The FMR can be measured in several ways: (1) by direct or indirect calorimetry; (2) by energy-balance techniques from body composition as detailed by Farrell (1974); or (3) from certain regression equations as reviewed by Balnave (1974), Grimbergen (1974) and Emmans (1974). Using the expression $\text{FMR}=AW^k$, estimated values of 1·08 (Tasaki & Sasa, 1970), 1·0 (Grimbergen, 1974), 0·653 (Byerly, 1941) as well as 0·75 (Kleiber, 1969) have been given to k; and estimates of 68·7–114·0 kcal (287–477 kJ) have been given for A (Balnave, 1974).

No attention has been paid to the biochemical variations among the members of a flock, or among flocks of the same or different strains, which do exist. These cause differences in metabolic rates, as does the process of egg formation. In general, the estimated values from Kleiber's formula agree reasonably with the values determined by indirect calorimetry from oxygen consumption and carbon dioxide output using the expression of J. R. King as quoted by Romijn (1970):

$$\text{FMR (kcal/d)}=3{\cdot}871\ O_2+1{\cdot}194\ CO_2-0{\cdot}048P,$$

where O_2 and CO_2 are measured in l and $P = 6 \cdot 25 \times$ urinary N. For practical purposes, P can be assigned a value of zero.

Factors affecting metabolic rates

The metabolic rates of chickens can be influenced by a number of factors such as age, sex, breed, diurnal rhythms, activity, seasonal variations, feathering, plane of nutrition, environmental temperature, diet and feeding regimen, acclimatization, and egg formation. Some of these factors have been discussed in some detail by Balnave (1974).

The literature values indicate that FMR of laying hens vary from about 61 to 117 kcal (255–490 kJ)/$kg^{0 \cdot 75}$ per d while the corresponding values for maintenance requirements were about 82–134 kcal (343–561 kJ)/$kg^{0 \cdot 75}$ per d. Since about 80% of the ME_M requirement is for FMR, any factors influencing FMR, naturally, would influence the maintenance requirements.

For example, FMR of poorly feathered cockerels is 2·5 times that of feathered ones at 22° (O'Neill, Balnave & Jackson, 1971), suggesting higher maintenance requirements of such birds.

Acclimatization of FMR to higher temperatures is more rapid than to low temperatures (Harrison & Biellier, 1969). The following regression equation has been suggested to fit FMR against temperature from $-5°$ to 40° (van Kampen, 1974):

$$\text{FMR } (\text{kcal/kg}^{0 \cdot 75} \text{ per d}) = 0 \cdot 0058\ T_a^2 - 4 \cdot 517\ T_a + 192,$$

where T_a is ambient temperature in °C.

As the ambient temperature increased from 21° to 29·5°, still within the accepted thermoneutral zone, FMR of White Leghorn hybrids decreased from 106 to 96 kcal/$kg^{0 \cdot 75}$ per d (Waring & Brown, 1967) implying a decrease in maintenance requirements. This would lead to a reduction in energy intake for the same status of production at 29·5° and 31°, but not at 16° and 28°. Distinct populations with different metabolic rates were observed in the same flock by Tasaki & Sakurai (1969).

The further interactions between the factors lead to the complexity of the problem of prediction of FMR.

Energy needs for egg production

On the basis of the above comments, the energy requirements of laying hens can be expressed in the following general terms:

ME requirement $= ME_M \pm$ energy associated with change in body-weight ($a\Delta W$) $+$ energy associated with daily egg mass produced (bE).

Byerly (1941) developed the following equation to estimate the food needs of hens of different body-weights and rates of egg production:

$F = 0 \cdot 523\ W^{0 \cdot 653} \pm 1 \cdot 126\ \Delta W + 1 \cdot 135\ E$, where food consumption (F), average body-weight (W), daily change in body-weight (ΔW) and egg mass per hen per d (E) were all in g. On the supposition that diets of that time contained 2900 kcal (12·13 MJ) ME/kg, Combs (1962) rewrote Byerly's expression as follows:

$$\text{ME } (\text{kcal/d}) = 1 \cdot 517\ W^{0 \cdot 653} \pm 3 \cdot 265\ \Delta W + 3 \cdot 292\ E.$$

Janssen (1970) used the following regression equation for caged layers:

$$\text{ME (kcal/d)} = 0{\cdot}676\ W^{0{\cdot}75} + 2{\cdot}866\ E + 19.$$

If W is expressed in kg, and the values of 1·6 kcal (6·7 kJ)/g and 4 kcal (16·7 kJ)/g are assigned to egg energy (EE) and body energy (BE), the regression equations of various investigators can be compared as in Table 1.

Table 1. *Estimates of the daily metabolizable energy* (ME) *intake* (*kcal*) *of laying hens calculated for a 2 kg hen producing an egg containing* 80 *kcal energy, neglecting any change in body-weight*

$\text{ME} = 138\ W^{0{\cdot}653} + 2{\cdot}06\ \text{EE} + 0{\cdot}816\ \text{BE}^*$	$= 382$	(Byerly, 1941)
$\text{ME} = 106\ W^{0{\cdot}75} + 1{\cdot}19\ \text{EE}$	$= 274$	(Waring & Brown, 1965)
$\text{ME} = 133\ W^{0{\cdot}75} + 1{\cdot}16\ \text{EE}$	$= 316$	(Waring & Brown, 1967)
$\text{ME} = 120\ W^{0{\cdot}75} + 1{\cdot}79\ \text{EE} + 19^*$	$= 345$	(Janssen, 1970)
$\text{ME} = 113\ W^{0{\cdot}75} + 1{\cdot}25\ \text{EE}$	$= 290$	(van Es, Vik-Mo, Janssen, Bosch, Spreeuwenberg, Vogt & Nijkamp, 1970)
$\text{ME} = 126\ W^{0{\cdot}75} + 1{\cdot}27\ \text{EE}$	$= 313$	(Burlacu & Baltac, 1971)
$\text{ME} = 99\ W^{0{\cdot}75} + 1{\cdot}68\ \text{EE} + 1{\cdot}20\ \text{BE}^*$	$= 301$	(Hoffmann & Schiemann, 1974)
$\text{ME} = 102\ W^{0{\cdot}75} + 1{\cdot}56\ \text{EE}$	$= 296$	(Grimbergen, 1974)

W, body-weight; EE, egg energy; BE, body energy.

*Neglected in this table.

Effect of temperature on ME *intake*

The food consumption was markedly influenced by both the ambient temperature and the dietary energy. Some results from one of our recent experiments are given in Table 2.

The estimated values from Byerly's equation or from calorimetric studies were in fair agreement for layers maintained between 5° and 24°, but were 5–15% low at temperatures below 5°, and exceeded the observed values by even 100% above 29·4° (Longhouse, Ota & Ashby, 1960). At temperatures ranging from −5° to 30°, a reduction of about 1·6% in food intake occurred per °C increase in ambient temperature, according to a review by Payne (1967). Above 30° the decrease is even greater (Wilson, 1949). A number of regression equations have been proposed to correlate energy intake with production at different temperatures, as shown in Table 3.

However, when daily ME intake of White Leghorn hybrids is corrected to constant metabolic body-weight, the relationship is curvilinear within the temperature range

Table 2. *The effect of giving diets with two levels of metabolizable energy* (ME) *to Leghorn-type laying hens on their performance over* 168 *d*

Environmental temperature . . .	15·5°		26·5°	
Diet energy (ME) (MJ/kg)	11·72	8·37	11·72	8·37
(kcal/kg)	(2800)	(2000)	(2800)	(2000)
Mean initial body-weight (kg)	1·522	1·498	1·430	1·406
Mean final body-weight (kg)	1·547	1·474	1·456	1·384
Egg production (%hens/d)	70·0	75·7	82·1	73·9
Egg weight (g)	43·3	44·0	41·6	42·4
Food consumption (g/d per hen)	97·5	115·9	83·3	98·2
ME intake (kJ/d)	1142·2	969·9	975·7	821·7
(kcal/d)	(273·0)	(231·8)	(233·2)	(196·4)

of 21°–38° (Smith, 1971). As the temperatures increased, the energy intake decreased at a faster rate than heat production and less energy was available for egg production, leading to a reduction in egg production or egg size or both. Little effect of temperature on egg production was observed in the range 15°–27°, but production was depressed at 30°. The food consumption does decrease by about 14% at 27° compared to 15°, but this may not be an economic advantage if the nutrients have to be concentrated in the diet (Marsden, Wethli, Kinread & Morris, 1973). The egg production of light hybrid layers was maintained at about 88% when the diets contained 2·64 or 3·35 kcal (11 or 14 kJ) ME/g at fluctuating temperatures of 18°–30°, but was 10% less for the lower-energy group at a constant temperature of 30° (Mowbray & Sykes, 1971).

Table 3. *Regression equations to correlate metabolizable energy* (ME) *intake* (*kcal/d*) *with ambient temperature in poultry*

$\mathrm{ME} = \mathrm{T}(1{\cdot}45\ \mathrm{W}^{0{\cdot}653}) \pm 3{\cdot}13\ \mathrm{W} + 3{\cdot}15\ \mathrm{E}$ (where $\mathrm{T} = 1{\cdot}78 - (0{\cdot}012 \times \text{ambient temperature in °F}))$	(Combs, 1968)
$\mathrm{ME} = (a + bt)\mathrm{W}^{0{\cdot}75} \pm c\mathrm{EE} + d\mathrm{BE}$ (t, °C below lower critical temperature; a, b, c and d, constants)	(van Es, van Aggelen, Nijkamp, Vogt & Scheele, 1973)
$\mathrm{ME} = \mathrm{W}(170 - 2{\cdot}2\ t) + 2\mathrm{E} + 5\Delta\mathrm{W}$ (for White strains)	(Emmans, 1974)
$\mathrm{ME} = \mathrm{W}(140 - 2{\cdot}0\ t) + 2\mathrm{E} + 5\Delta\mathrm{W}$ (for Brown strains) (t, °F)	(Emmans, 1974)
$\mathrm{ME}\ (\mathrm{kcal/kg}^{0{\cdot}75}) = 195{\cdot}2 + 0{\cdot}5(0{\cdot}2\mathrm{T} - 16) - 5{\cdot}6\ (0{\cdot}2\mathrm{T} - 16)^2$; (T, °F)	(Smith, 1971)

W, body-weight; E, egg mass (per hen per d); EE, egg energy; BE, body energy.

Energy requirements of broilers

The biological and economic responses of broilers to dietary energy concentration have been analysed by C. Fisher & B. J. Wilson (personal communication) and suggestions have been given to enable the producer and formulators to make their own rational decisions on the basis of local conditions rather than provide accurate estimates of optimum energy level for general use.

The results of Deaton & Reece (1970) indicate that broilers reared at the low temperature cycle (1·7°–18·3°) were 0·12 kg heavier than those raised at 18·3°–35°, but also consumed 0·68 kg more food, making them less efficient to grow. Relative humidity had no effect on this performance below 26·7°.

Restricted feeding of layers

Layers can adjust their energy intake over a range of dietary energy levels, but tend to overconsume diets more concentrated in ME when offered on a free-choice basis (Morris, 1968). This leads to an increase in body-weight and maintenance requirement. A number of reports do suggest that the net utilization of energy by layers can be improved by restricting the energy intake to levels below those on a free-choice basis. This topic was covered in some detail by Snetsinger & Zimmerman (1974). The amino acids, vitamins and minerals of restricted diets have to be increased to prevent any deficiencies occurring during dietary restriction. If the restriction is about 10%, the production can be maintained, but the egg size is depressed by about 1 g. The choice of restricting dietary intakes, and of methods of accomplishing this, must be judged on an economic basis, and this favours adjusting consumption to that of a peer group, but as yet no hard and fast rules can be established.

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