METABOLIZABLE ENERGY OF CEREALS OF VARYING CHEMICAL COMPOSITION

by

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A thesis submitted to the
Faculty of Graduate Studies and Research in
partial fulfilment of the requirements for the degree of
Master of Science

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ABSTRACT

Twenty-two barley and 16 wheat samples were analyzed for metabolizable energy and chemical composition. The chemical components considered as potential prediction of ME included proximate analyses, neutral detergent fiber (NDF), acid detergent fiber (ADF), hemi-cellulose, cellulose, lignin, residual ash, total starch, amylopectin (barley only) and B-glucan (barley only). Wheat and barley results were treated separately for regression analysis. For barley, when covariance analysis was employed to remove between-experiment differences, ME was significantly correlated to crude fiber (-.63**), ash (-.73**), NDF (-.68**), ADF (-.66**), lignin (-.76**) and total starch (.75**). Every measure correlated to ME for barley was also significantly correlated with every other. For wheat ME was significantly correlated with NDF (-.58*) only. Inclusion of additional measures failed to improve the prediction attained by the first.

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INTRODUCTION

During recent years the Canadian government has encouraged Western farmers to diversify from traditional hard red spring wheat production in an effort to stabilize farm income patterns. One such area of diversification has been "feed" grains; barley and "utility" wheats which sacrifice high quality milling and malting characteristics for yield (Candlish 1973). Total feed yield is a function of yield per unit of land--dependent on genetic and environmental interactions and the feed value of the grain.

Overall efficiency of any animal industry depends on this total feed yield and how efficiently it can be transformed into animal products. Maximization of efficiency entails increasing this total feed yield and its utilization by the animal in question. The two areas are integrated through the estimation of feeding value--the availability of nutrients.

One of the weakest inputs in quantitively describing the nutritional worth of a feed, particularly an "energy" feed such as wheat or barley, is the availability of energy itself. It is also the most important single criterion of the nutritional worth of a feed grain (Christison and Bell 1975). Typically this is measured in poultry as metabolizable energy obtained through direct bioassay. This is a time-consuming, laborious, and costly procedure; impractical in most situations.

An accurate estimation of energy availability

according to chemical composition, or perhaps some physical trait, could provide an opportunity for plant geneticists to differentiate between yield and energy per unit yield in the selection of superior genetic lines of feed grains. Selection for a measure of feed value such as energy for poultry should render a feed grain more valuable for other classes of livestock and possibly as a direct human food resource.

Nutritionists must also estimate the energy content of grain samples when formulating diets. Since poultry adjust feed intake according to energy level (Scott et al. 1969) and other requirements tend to be absolute, it is of fundamental importance that nutritionists have as accurate an estimation as possible of the energy content of the feed ingredients and the final diet. In practice, they usually rely on mean values. If a grain sample is analyzed according to the usual proximate analysis, it is of limited value, as there is no commonly accepted procedure to express it in terms of energy. Carpenter and Clegg (1956) comment that generally the usual proximate analysis do not correlate well with ME. This discontinuity jeopardizes the entire ration formulation system.

The objectives of this study are to determine ME data for a number of varieties of barley and wheat biologically, and to relate chemical analyses to observed differences with the objective of developing prediction

equations from appropriate analyses. It is also intended as an evaluation of different analytical systems.

LITERATURE REVIEW

a) Energy Availability - General Concepts

The concept of energy in nutrition concerns energy released by oxidation measured as heat loss. The gross energy of a given feed is the total energy released in this manner. It represents the maximum potential a feed has as a feed energy source. Different systems of measuring energy availability reflect various losses that occur in the utilization of the gross energy of the feed.

Ideally, productive energy would be the most useful term for describing the energy contribution of a feedstuff--that is, the efficiency of energy transfer from the feed to the product itself, which would provide simple and obvious cost-yield relationships essential for efficient management. Unfortunately the determination of productive energy is influenced by environmental factors that render precision difficult (e.g. plane of nutrition, nutrient balance, etc.) (Bayley 1974). This forces nutritionists to rely on other indices of energy conversion, namely digestible energy (DE) and metabolizable energy (ME). Digestible energy is measured as the gross energy of the feed minus the gross energy of the feces, expressed per unit of feed intake. Metabolizable energy is measured as the gross energy of the feed minus the gross energy of the feces and urine, again expressed per unit of feed intake. Since the urine and feces are voided together (separation usually involves surgically altering the birds), ME remains the most practical method for

describing the available energy of a feedstuff for poultry.

Nitrogen-corrected metabolizable energy values (ME_n) are "classical" ME values (ME_c) corrected to compensate for nitrogen retention, presumably deposited as protein and reflected by varying growth rates. The nitrogen retained can be determined as the difference between the total nitrogen consumed and the total nitrogen excreted. The energy cost to excrete 1 g of nitrogen is 8.73 kcal/g (Titus 1959). The "nitrogen-corrected" ME would be "classical" ME - 8.73 (nitrogen retained). ME_n is an expression of ME_c where growth rate or nitrogen retention has been theoretically adjusted to zero.

Arguments against this procedure have been proposed by Kleiber (1961), who comments that efforts to decrease variability of results by nitrogen-correction has led to the loss of a clear concept. That correction for nitrogen implies protein quality is additive would lend support to Kleiber's argument. A more pragmatic approach is whether any improvement in precision justifies the additional labour in an already tedious and costly procedure. Generally ME_n is directly proportional to ME_c. (Bayley 1974, Baldini 1961, Sibbald and Slinger 1963).

The validity of nitrogen-correction is unresolved. Since ME values are conventionally published on a nitrogen-corrected basis, any desire for comparison with previously published results dictates nitrogen-

correction. Sibbald et al. (1975) has suggested using adult roosters for ME determination. Since roosters approximate a zero-nitrogen retention state, ME_c equals ME_n and nitrogen-correction is not necessary.

The validity of using ME_c or ME_n is based on several assumptions (Reynters 1972); the additivity of ME, a lack of effect of intake level, and a lack of effect of age. These are general assumptions for which there are many exceptions. Some examples include a lack of additivity in the case of alfalfa meal, which depresses ME when included at high levels (Childs 1972), an effect of intake level with birds fed below maintenance requirements (Guillaume and Summers 1970) and age effect, again for certain problem ingredients. An increase in ME_n was observed for rapeseed meal when the test period was extended from 14 to 21 days (Rao and Clandinin 1970).

While there are many examples of such exceptions, they reflect special circumstances and introduce additional problems for ME determination for many ingredients. In comparison with alternative methods of measuring energy availability, ME remains the simplest, most direct and most reliable method of describing the available energy for poultry.

Metabolizable energy determination can be based on a "practical" diet, where the test ingredient is substituted by simple dilution into a basal ration composed of common feedstuffs, or it can be based on a semi-

purified diet (Hill and Anderson 1958) where the test material is substituted for glucose. The glucose is assumed to have a constant ME value. (Rao and Clandinin 1970) studying rapeseed meal, suggested that the use of purified ingredients altered the rate of flow of digesta in the gut, resulting in a reduction of ME values. It is contended that a practical diet simulates the normal feeding situation more closely than feeding a purified ingredient such as glucose (Sibbald and Slinger 1963). However this demands that the basal ration be high in protein to meet requirements after substitution of the test material. (May and Bell 1971) suggest that the large urinary losses associated with deamination of digested protein in the case of high protein diets results in a depression of ME compared with normal feeding circumstances. The influence of a high protein basal diet in the test diet may be underestimated to some extent. May and Bell (1971) and Slinger (1962) reported that level of substitution (hence protein level) was too small to be of practical significance. Studies based on a practical diet have fewer disadvantages, presuming the protein effect, if any, would be fairly consistent.

ME calculations require quantification of consumption and fecal output. Consumption is simply the total weight of feed consumed. Fecal output can be estimated by total collection or by using a nutritionally inert indicator such as chromium sesquioxide. The indicator

method is preferred by Sibbald and co-workers, others (March et al. 1973) prefer total collection. Problems associated with chromium determinations have been largely overcome by the use of atomic absorption (Halloran 1972). When using total collection, the entire fecal collection must be dried to express output or a dry weight basis. Ideally it should be freeze-dried, as this minimizes nitrogen and energy losses. Shannon and Brown (1969) reported substantial losses when fecal samples were dried in a forced air oven and suggested this was due to fermentation. They suggest, when using heat, drying should be as rapid as possible.

Fecal nitrogen loss is a minor problem compared to other problems of ME methodology. Nitrogen-correction, the type of reference ration, and quantification of fecal output are all controversial areas. Opinion and evidence pertaining to these matters is often contradictory. For what purpose ME values are intended, as well as the facilities available must be important considerations in deciding which is the "best" or "proper" method of ME determination.

b) ME Calculation

Conventional formulae calculate ME_n for an ingredient from ME_n of a basal and test diet by assuming additivity. Extending this assumption, it can be shown these formulae calculate indirectly a gross energy and and nitrogen value for the ingredient alone, which can be

determined directly. All ME formulae introduce sources of error that are not directly apparent from ME observations.

"Classical" ME

The uncorrected or "classical" ME represents:

energy input - energy output (feces and urine)

energy input = gross energy ration

energy output = gross energy feces (and urine)

The fecal energy loss is expressed per gram of ration consumed by multiplying by a "recovery" factor which compensates for that portion of the feed digested and absorbed.

$$\text{"recovery"} = \frac{\text{total fecal weight}}{\text{consumption weight}}$$

$$\text{Classical ME } (ME_c) = \text{gross energy ration} - \left(\frac{\text{total fecal weight}}{\text{consumption weight}} \times \text{gross energy feces}\right) \quad 1.$$

All terms are corrected to a dry matter basis prior to calculation.

Nitrogen Correction

The nitrogen retained per gram of ration is multiplied by 8.73 (Titus 1959) and subtracted from the classical ME.

Calculation of nitrogen retention is analogous to calculating energy retention.

$$\text{N retained} = \text{ration N} - \left(\frac{\text{total fecal weight}}{\text{consumption weight}} \times \text{fecal N}\right) \quad 2.$$

$$ME_n = ME_c - 8.73\ (\text{N retained}) \quad 3.$$

Assuming additivity permits the calculation of the ME_n for an ingredient (ME_nING) from the ME_n of the basal (ME_n BASAL) and the test (ME_nTEST) rations (basal ration + test ingredient). X refers to the level of the test ingredient in the test ration. Yoshida (1972) calculated ME_nING:

$$ME_n\text{ING} = \frac{ME_n\text{TEST} - (1-X)\ ME_n\ \text{BASAL}}{X} \quad 4.$$

If X is replaced by 1/3, the level of the test ingredient in the test ration in the present study, the equation reduces to:

$$ME_n\text{ING} = 3\ ME_n\text{TEST} - 2\ ME_n\ \text{BASAL} \quad 5.$$

The calculation of ME_nING involves 3 steps: determining ME_n BASAL, ME_nTEST, and finally determination of ME_nING itself. This process results in calculation duplication which can be avoided by combining the formulae. A convenient approach is to isolate the "classical" ME determination and nitrogen correction for the ingredient. Substituting equation (3) for test ration and basal ration into equation (5) gives:

ME_n = 3 (ME_cTEST - N CORRECTION TEST)-2(ME_cBASAL - N CORRECTION BASAL)

= (3 ME_cTEST - 3N CORRECTION TEST - 2 ME_cBASAL + 2N CORRECTION BASAL)

= (3 ME_cTEST - 2 ME_cBASAL) - (3N CORRECTION TEST - 2N CORRECTION BASAL)

This breaks down into two parts:

(3 ME_cTEST - 2 ME_cBASAL) representing ME_cING 6.

(3N CORRECTION TEST - 2N CORRECTION BASAL) representing nitrogen-correction for the ingredient. 7.

Considering term (6); ME_cTEST and ME_cBASAL can be replaced with the equations from which they were derived (1). This gives an unwieldy equation that through re-arrangement and factoring becomes (appendix 1):

$$(3\ RE_{TEST} - 2\ RE_{BASAL}) - \left[3\ \left(\frac{FW_{TEST}}{CW_{TEST}} \times FE_{TEST}\right) - 2\ \left(\frac{FW_{BASAL}}{CW_{BASAL}} \times FE_{BASAL}\right)\right] \quad 8.$$

where RE_{TEST} = gross energy content of the test ration

RE_{BASAL} = gross energy content of the basal ration

FW_{TEST} = dry fecal weight test

FW_{BASAL} = dry fecal weight basal

CW_{TEST} = dry consumption test

CW_{BASAL} = dry consumption basal

FE_{TEST} = gross energy content of the test feces

FE_{BASAL} = gross energy content of the basal feces

This provides a different perspective of the relationship between ME of the rations and ME of an ingredient. The term ($3\ RE_{TEST} - 2\ RE_{BASAL}$) is analogous to the original expression used to calculate ME_{ING} given ME_{TEST} and ME_{BASAL} (i.e. (5)).

Extending the original assumption that the ME of dietary ingredients are additive it follows that the gross energies are also additive--a ration is a simple mixture, there is no appreciable energy released (as heat) during the mixing process. The original equations calculate in an indirect manner a gross energy value for the ingredient. This can be replaced by a gross energy value determined directly (GE_{ING}).

The expression for nitrogen retained (7) can be manipulated in a similar manner. By substituting equation (2) for N_{TEST} and N_{BASAL} respectively, equation (7) becomes (appendix 2):

$$(3\ N_{TEST} - 2\ N_{BASAL}) - \left[\left(3\ \frac{FW_{TEST}}{CW_{TEST}} \times FN_{TEST}\right) - \left(2\ \frac{FW_{BASAL}}{CW_{BASAL}} \times FN_{BASAL}\right)\right]$$

The term $3\ N_{TEST} - 2\ N_{BASAL}$ is equivalent to N_{ING} which again can be derived directly.

In summation, the ME_n of a test ingredient can be calculated:

$$GE_{ING} - \left[3\ \left(\frac{FW_{TEST}}{CW_{TEST}} \times FE_{TEST}\right) - 2\ \left(\frac{FW_{BASAL}}{CW_{BASAL}} \times FE_{BASAL}\right)\right]$$

$$- 8.73\left[N_{ING} - \left(3\left(\frac{FW_{TEST}}{CW_{TEST}} \times FN_{TEST}\right) - 2\ \left(\frac{FW_{BASAL}}{CW_{BASAL}} \times FN_{BASAL}\right)\right)\right]$$

Considering the second term $(3\ FE_{TEST} - 2\ FE_{BASAL})$, the logic of these calculations becomes more apparent. Again assuming additivity this term determines that portion of the fecal energy attributable to the test ingredient alone. The ME for the test ingredient is then the gross energy of the test ingredient minus that portion of the fecal energy attributable to it.

The nitrogen correction relationship is similar $(3\ FN_{TEST} - 2\ FN_{BASAL})$. By determining fecal nitrogen due to the test ingredient alone and subtracting it from test ingredient nitrogen gives nitrogen retained due to the test ingredients alone. This assumes protein quality is additive - which is wrong, but common to any method of calculation. This raises serious questions as to the validity of attempting to correct for nitrogen-retention with mixed rations.

Equation (9) can be rewritten as follows (appendix 3):

$$(GE_{ING} - 8.73\ N_{ING}) - \left[3\ \left(\frac{FW_{TEST}}{CW_{TEST}}\right)\ (FE_{TEST} - 8.73\ FN_{TEST})\right.$$

$$\left. - 2\ \left(\frac{FW_{BASAL}}{CW_{BASAL}}\right)\ (FE_{BASAL} - 8.73\ FN_{BASAL})\right]$$

This divides into 3 parts, each associated with a series of measurements; the analyses of the ingredient, the analyses of the test ration feces, and the analyses of the basal ration feces.

Error Determination

Variation for any set of ME_n values will include biological variation and analytical error. Biological variation, due to inherent differences among birds, will be influenced by group size, number of groups, level of ingredient in the test ration (Yoshida 1972) as well as days on test (Sibbald and Price 1975). Analytical error, due to the technology involved; the "machine" error of gross energy, dry matter, nitrogen determination and total feed and fecal estimation, will be influenced by the level of the ingredient in the test ration and the replication of the analyses (Potter 1972). Any estimate of error from individual observations will underestimate "true" error due to the use of mean values in ME calculation. These include dry matter (ingredient and ration), gross energy (ingredient or ration), nitrogen (ingredient or ration) as well as all measurements on the basal ration. Since ME of an ingredient is always determined relative to a basal

ration, an estimate of error of its determination will reflect the accuracy of the procedure.

Calculation of $ME_n ING$ can be divided into 3 terms:

a) $GE_{ING} - 8.73\ N_{ING}$ representing analytical measurements of the ingredient.

b) $3(\frac{FW_T}{CW_T})(FE_T - 8.73\ FN_T)$ representing analytical measurements of the test ration feces.

c) $2(\frac{FW_B}{CB_B})(FE_B - 8.73\ FN_B)$ representing analytical measurements of the basal ration feces.

The variation of $ME_n ING$ will be the sum of the variation of each term (Topping 1955).

$$A = B + C + D \quad (\text{or } A = B - C + D)$$
$$6^2_A = 6^2_B + 6^2_C + 6^2_D$$

The directly measurable error; where all values are uniquely determined for a single observation, is confined to the second (b) term. The constant 3, determined by the level of the test ingredient; in the test diet, will directly influence the magnitude of error for $ME_n ING$. For example, the standard deviation of an ingredient substituted at a level of 1/3 would be 3 times the standard deviation of an ingredient fed at 100%. The mean values

occur in terms (a) and (c), measurements of the test ingredient and the basal ration.

Accuracy, including error in measurements on the basal ration would be 3 times the standard deviation of the test ration plus 2 times the standard deviation of the basal ration (or 5x, assuming error of the diet is the same in each case). As the level of inclusion of the test ingredient in the test ration decreases, precision will decrease linearly and accuracy will decrease curvilinearly.

This still makes no allowances for error of term (a) the determinations of gross energy and nitrogen for the ingredient. This would be minor when ME_n calculation is based on ingredient analysis. Where calculations are based on test ration gross energy and nitrogen, this source of error could become large, again particularly when the level of ingredient is low. Calculating a gross energy for the ingredient indirectly introduces additional sources of error not apparent from observations not uniquely determined.

This difficulty in attaching a "true" error estimate to ME_n has several repercussions in attempting to interpret ME_n differences. It is difficult to determine levels of significance when all sources of error haven't been accounted for. In any regression analysis observed "significant" lack of fit may be due to a common source of error in observations assumed to be independent. Lack of fit may not be due to any short-comings of some or all chemical methods but rather an underestimation of the error