Nature of the extrametabolic effect of supplemental fat in diets for laying hens

Gonzalo Gonzalez Mateos

Iowa State University

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NATURE OF THE EXTRAMETABOLIC EFFECT OF SUPPLEMENTAL FAT IN DIETS FOR LAYING HENS

Iowa State University

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Nature of the extrametabolic effect of supplemental fat in diets for laying hens

by

Gonzalo Gonzalez Mateos

A Dissertation Submitted to the Graduate Faculty in Partial Fulfillment of the Requirements for the Degree of DOCTOR OF PHILOSOPHY

Department: Animal Science
Major: Animal Nutrition

Approved:

Signature was redacted for privacy.

In Charge of Major Work

Signature was redacted for privacy.

For the Major Department

Signature was redacted for privacy.

For the Graduate College

Iowa State University
Ames, Iowa

1980
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GENERAL INTRODUCTION

Fats have been used commercially in poultry rations since the 1950s to improve physical characteristics of feeds and to increase the caloric density of rations. Fats of animal origin have been instrumental in facilitating formulation of high energy diets for poultry. Vermeersch and Vanschoubroek (1968) reviewed the literature on fat supplementation for broiler chickens and found that the addition of fat to diets decreased feed consumption and improved efficiency of feed utilization proportionally to the amount of fat added.

There have been, however, discrepancies in regard to the utilization of fats in laying hen diets. Donaldson (1962) found that the addition of high levels of fat (up to 30.4%) to laying hen diets reduced egg production. Donaldson and Gordon (1960), Waring et al. (1968), and Jackson et al. (1969) reported that dietary fat decreased the efficiency of energy utilization by laying hens. In contrast, numerous reports indicate that fats can be used successfully in diets for laying hens, provided that adequate concentrations of nutrients are used (Lillie et al., 1952; Treat et al., 1960; March and Biely, 1963; Sell et al., 1976; Sell, 1977; Horani and Sell, 1977a; Sell et al., 1979). The magnitude of improvements in productivity has been considered to be a reflection of increased metabolizable energy (ME) concentration of the diet as a consequence of fat supplementation. Recently, however, data have been accumulated indicating that the generally recognized ME values for feed-grade fats underestimate fat's true energy contribution to practical rations for growing poultry (Touchburn and Naber, 1966; Jensen et al., 1970; Whitehead and Fisher,
1975) and laying hens (Horani and Sell, 1977b; Sell et al., 1979). These authors found that the addition of fat to poultry diets increased the ME concentration of the ration beyond the expected increase.

Touchburn and Naber (1966) and Jensen et al. (1970) used the term "extracaloric benefit" to describe the improvement in dietary energy utilization caused by fat supplementation. The favorable effect of fat observed by these researchers was related to an apparent improvement in the efficiency with which the ME was utilized by the bird as a consequence of a reduction in heat increment. Horani and Sell (1977b), however, observed a different type of effect of fat on energy utilization of diets and suggested that the term "extrametabolic effect" should be used. The term "extrametabolic effect" would indicate an improvement in energy utilization at the nutrient absorption level exclusive of changes in heat increment.

It has been observed (Young, 1961; Artman, 1964; Lewis and Payne, 1966) that the presence of unsaturated fatty acids in dietary constituents may improve the ability of chickens to absorb supplemental fat. Leeson and Summers (1976) and Sibbald (1978) suggested that the extrametabolic effect of supplemental fats in poultry diets could be due to a synergism between the saturated fatty acids of the supplemental fat and the unsaturated fatty acids of vegetable origin whereby micelle formation and overall fat absorption were improved. Data obtained by Sibbald and Kramer (1977) indicating that the true metabolizable energy of tallow was greater in a corn- than in a wheat-based diet support this hypothesis.
Synergism among dietary fatty acids, however, cannot explain satisfactorily the entire extrametabolic effect attributable to vegetable oils (Cullen et al., 1962; Carew and Hill, 1964) or the ME of fats that has been reported to be greater than their gross energy (Gomez and Polin, 1974; Horani and Sell, 1977b). It is thermodynamically impossible for the ME of a feed ingredient to exceed its gross energy. Thus, it is logical to suggest that supplemental fats improve the utilization of other dietary ingredients, thereby increasing dietary ME beyond expectations.

The research reported herein was conducted 1) to study the influence of fat supplementation on the amount of energy that is derived from laying hen diets and 2) to quantitate and more closely define the extrametabolic effect of supplemental yellow grease when used in diets for laying hens which contain selected carbohydrates as a main ingredient.

Explanation of Dissertation Format

The six experiments reported in this dissertation have been published in or submitted for publication to the Journal of Nutrition (1), Poultry Science (4), and Nutrition Reports International (1) under the authorship of Gonzalo G. Mateos and Jerry L. Sell.
SECTION I. TRUE AND APPARENT METABOLIZABLE ENERGY VALUE OF FAT FOR LAYING HENS: INFLUENCE OF LEVEL OF USE
TRUE AND APPARENT METABOLIZABLE ENERGY VALUE OF FAT
FOR LAYING HENS: INFLUENCE OF LEVEL OF USE

G. G. Mateos
J. L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
SUMMARY

White Leghorn hens in egg production were fed rations that contained 0, 3, 6, 9, 12, or 15% yellow grease. True metabolizable energy (TME) and nitrogen-corrected apparent metabolizable energy (AMEₙ) values of the rations were determined, and these data were used to estimate the TME and AMEₙ of yellow grease. An inverse relationship was observed between the level of yellow grease supplementation and the TME and AMEₙ values of this fat source. The TME and AMEₙ of yellow grease were 11,567 and 9,367 kcal/kg, respectively, when the supplemental level was 3%. Corresponding values when yellow grease constituted 15% of the ration were 8,907 and 8,653 kcal/kg, respectively. Variation in fatty acid composition of total dietary fat and associated changes in the TME and AMEₙ of yellow grease are discussed.
INTRODUCTION

Fats have been used in poultry rations for many years to improve physical characteristics of feeds and to increase the caloric density of rations. Feed-grade fats, primarily of animal origin, have been instrumental in facilitating high-energy poultry feeding programs. Dietary fats have been shown to consistently improve efficiency of feed utilization by growing poultry as well as by laying hens (Vermeersch and Vansehoubroek, 1968; Velu and Baker, 1974; Reid and Weber, 1975; Sell et al., 1976). The magnitude of improvements is considered to be a reflection of increased metabolizable energy (ME) concentration of the diet. Recently, data have been presented indicating that the generally recognized ME values for feed-grade fats underestimate fat's true energy contribution to practical rations (Touchburn and Naber, 1966; Jensen et al., 1970; Horani and Sell, 1977a). Indeed, Sell et al. (1976) and Horani and Sell (1977a,b) found that animal tallow had a ME value approaching or exceeding its gross energy content when used at low levels in laying hen rations.

The objective of the research reported herein was to determine the influence of different levels of inclusion of yellow grease in laying hen rations on the apparent metabolizable energy ($\text{AME}_n$) value of this energy source. Simultaneously, the true metabolizable energy (TME) of yellow grease as related to dietary level of the fat was measured.
EXPERIMENTAL PROCEDURE

Single Comb White Longhorn hens, 48 weeks of age, were used. The birds were kept in wire laying cages equipped with trays for collection of excreta. The cages were located in an environmentally controlled room maintained at 24°C.

Seven experimental groups were used and four individually caged hens were assigned randomly to each group. One group of hens was used to determine the energy excreted during a 24-hour period of fast. This energy excretion, which represented metabolic and endogenous energy, was used in the determination of ration TME by the method of Sibbald (1976) as described later. Each of the remaining groups was assigned to one of six experimental rations (Table 1). The control diet contained no added fat while increments of 3% of yellow grease were included in the formulas of the other five test rations. Appropriate adjustments were made in the corn, soybean meal, and methionine levels of the fat-supplemented rations so that relatively constant ME to protein and ME to methionine ratios were maintained. The AME_n value of yellow grease used for calculating the nitrogen-corrected AME_n content of the diet was 7900 kcal/kg and the AME_n's and TME's calculated in this way are termed "theoretical" AME_n or "theoretical" TME hereafter. Each 3% increment of fat up to 15% of the ration increased ration theoretical AME_n by about 112 kcal/kg. The data presented by Sibbald (1977) were used to calculate the TME levels of the rations.

The experiment consisted of two phases. In phase 1, six rations differing in fat content were fed to the respective hens for a 6-day
### Table 1. Composition of the experimental rations

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Control</th>
<th>3% fat</th>
<th>6% fat</th>
<th>9% fat</th>
<th>12% fat</th>
<th>15% fat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>69.50</td>
<td>64.39</td>
<td>59.19</td>
<td>53.98</td>
<td>48.87</td>
<td>43.66</td>
</tr>
<tr>
<td>Soybean meal (48.5% protein)</td>
<td>20.50</td>
<td>22.60</td>
<td>24.80</td>
<td>27.00</td>
<td>29.10</td>
<td>31.30</td>
</tr>
<tr>
<td>DL-methionine</td>
<td>.07</td>
<td>.08</td>
<td>.08</td>
<td>.09</td>
<td>.10</td>
<td>.11</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>7.78</td>
<td>7.78</td>
<td>7.78</td>
<td>7.78</td>
<td>7.78</td>
<td>7.78</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
<td>1.35</td>
</tr>
<tr>
<td>Salt-mineral mix&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Premix&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>Yellow grease&lt;sup&gt;c&lt;/sup&gt;</td>
<td>--</td>
<td>3.00</td>
<td>6.00</td>
<td>9.00</td>
<td>12.00</td>
<td>15.00</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

Calculated analysis:

- Metabolizable energy (kcal/kg)<sup>d</sup> 2894 3006 3118 3231 3344 3456
- True metabolizable energy (kcal/kg)<sup>e</sup> 3538 3638 3737 3835 3935 4033
- Crude protein, % 16.06 16.63 17.23 17.84 18.41 19.02
- Methionine, % .36 .37 .38 .39 .41 .42

<sup>a</sup>Supplied the following per kilogram of diet: Mn, 20 mg; iodized salt, 2.997 g.

<sup>b</sup>Supplied the following per kilogram of diet: vitamin A, 8000 IU; vitamin D<sub>3</sub>, 2400 IU; vitamin B<sub>12</sub>, 5 μg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline 440 mg; ethoxyquin, 11 mg.

<sup>c</sup>The yellow grease, with a gross energy content of 9,372 kcal/kg, had the following fatty acid composition: myristic, 18%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6% other fatty acids, 0.4%.

<sup>d</sup>As fed.

<sup>e</sup>Dry matter basis.
adaptation period. During a subsequent 5-day period, the hens continued
to consume the appropriate ration ad libitum, and excreta were collected
daily on a quantitative basis from each hen. The excreta samples were
freeze-dried, allowed to come to equilibrium with atmosphere moisture,
and were analyzed for dry matter, heat of combustion, and nitrogen con-
tent. These data were used to calculate nitrogen-corrected AMEₙ for all
rations. Immediately after the AMEₙ phase of the experiment, the TME's of
the rations were determined. The procedure described by Sibbald (1976)
was used. In the procedure, all hens were fasted for 24 hr and then were
force-fed 20 g of test ration per hen. The excreta produced during the
next 24 hr were collected quantitatively, dried, and analyzed for heat of
combustion.

The AMEₙ and TME values of the rations were used to estimate the AMEₙ
and TME of the supplemental fat (yellow grease). The regression of
changes in ration AMEₙ's or TME's against level of supplemental fat was
used for this purpose.
RESULTS AND DISCUSSION

The AME_n's and TME's of the rations, as measured experimentally, increased with each increment of supplemental yellow grease (Table 2). A comparison of the theoretical and determined AME_n's indicated that changes in ration AME_n's associated with supplemental fat were larger in the latter instance. Similar observations were made with TME's. To further assess this trend, the AME_n and TME of the diets were regressed against the levels of supplemental fat by using the model \( y = a + bx + cx^2 \). The regression curves obtained were defined by the equations \( TME (\text{kcal/kg}) = 3446.9 + 73.95x - 2.23x^2 \) and \( AME_n (\text{kcal/kg}) = 2919.8 + 53.8x - .62x^2 \), where \( x = \) percent supplemental yellow grease. Both equations conformed to a linear model (\( P \leq .01 \)) with a small quadratic component. The \( b \) factors of both equations exceeded those of the regression equations appropriate for the theoretical TME and AME_n values (TME, kcal/kg, = 3538 + 33x and AME_n, kcal/kg, = 2894 + 37.4x, respectively). The differences between the \( b \) values illustrate that the TME and AME_n of the rations, as determined experimentally, were changed more by supplemental fat than was predicted on the basis of reference ME value of the ration ingredients.

The regression equation based on determined AME_n's was used to obtain information needed to estimate AME_n of yellow grease. An assumption inherent in the calculations of AME_n of yellow grease was that all the changes in ration AME_n were due to added fat only. The method of calculation and the resulting AME_n of yellow grease observed at each level of fat supplementation are presented in Table 3. The highest AME_n of yellow grease (9367 kcal/kg) was found when the fat was used at 3% of the ration.
Table 2. Effect of supplemental yellow grease on the AME<sub>n</sub> and TME of the diets (kcal/kg)<sup>a</sup>

<table>
<thead>
<tr>
<th>Supplemental fat level, %</th>
<th>Theoretical AME&lt;sub&gt;n&lt;/sub&gt;</th>
<th>Determined AME&lt;sub&gt;n&lt;/sub&gt;</th>
<th>Theoretical TME&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Determined TME</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2894</td>
<td>2931±24</td>
<td>3538</td>
<td>3481±39</td>
</tr>
<tr>
<td>3</td>
<td>3006</td>
<td>3051±19</td>
<td>3638</td>
<td>3599±37</td>
</tr>
<tr>
<td>6</td>
<td>3118</td>
<td>3221±27</td>
<td>3737</td>
<td>3783±10</td>
</tr>
<tr>
<td>9</td>
<td>3231</td>
<td>3398±35</td>
<td>3835</td>
<td>3961±30</td>
</tr>
<tr>
<td>12</td>
<td>3344</td>
<td>3451±3</td>
<td>3935</td>
<td>4059±31</td>
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<tr>
<td>15</td>
<td>3456</td>
<td>3607±26</td>
<td>4030</td>
<td>4021±20</td>
</tr>
</tbody>
</table>

<sup>a</sup>Data are given on as-fed basis for AME<sub>n</sub> and on dry-matter basis for TME.

<sup>b</sup>TME determined by the procedure of Sibbald (1976).

<sup>c</sup>Mean ± standard error.

With each increment of yellow grease, AME<sub>n</sub> decreased until a value of about 8650 kcal/kg was observed at the 15% level of inclusion. TME values derived for yellow grease in an analogous manner showed the same trend (Table 4). When used at 3 to 12% of the ration, yellow grease seemed to have a TME in excess of its gross energy content. There was, however, a marked decline in the TME of yellow grease with each increment of inclusion. The highest value was 11,560 kcal/kg at 3% of the ration and the lowest was 8,910 kcal/kg at 15% of the ration. A summation of the estimated AME<sub>n</sub>'s and TME's of yellow grease, and those based on theoretical (literature) values, as influenced by level of supplementation is presented graphically in Figure 1.

As determined experimentally, the AME<sub>n</sub> data generally suggest that, when used at relatively low levels in a corn-based ration, the absorption
Table 3. Data used to estimate the AME\textsubscript{n} of yellow grease (kcal/kg)

<table>
<thead>
<tr>
<th>Supplemental fat level (%)</th>
<th>Theoretical AME\textsubscript{n}</th>
<th>AME\textsubscript{n} based on regression</th>
<th>Corrected theoretical AME\textsubscript{n}</th>
<th>Column C minus Column D</th>
<th>Theoretical AME\textsubscript{n} in diet from added fat</th>
<th>Total AME\textsubscript{n} of diet estimated as due to added fat</th>
<th>Estimated AME\textsubscript{n} of yellow grease (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>2894</td>
<td>2919</td>
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<td>3006</td>
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<td>3032</td>
<td>44</td>
<td>237</td>
<td>281</td>
<td>9367</td>
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<td>3222</td>
<td>3145</td>
<td>77</td>
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<td>3231</td>
<td>3358</td>
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<td>99</td>
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<td>810</td>
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<td>3344</td>
<td>3484</td>
<td>3373</td>
<td>111</td>
<td>948</td>
<td>1059</td>
<td>8825</td>
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<tr>
<td>15</td>
<td>3456</td>
<td>3599</td>
<td>3486</td>
<td>113</td>
<td>1185</td>
<td>1298</td>
<td>8653</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Predicted value from regression equation \( y = 2919.8 + 53.8x - .6x^2 \).

\textsuperscript{b}Since the determined AME\textsubscript{n} of the no-added-fat ration exceeded the theoretical AME, all theoretical AME\textsubscript{n}'s of the ration were adjusted according to the ratio (2919 kcal/kg)/(2894 kcal/kg) = 1.0086. Application of this factor compensated for apparent differences in the AME of the ingredients used in the basal diet as compared with literature values.

\textsuperscript{c}Assuming an AME\textsubscript{n} value for yellow grease of 7900 kcal/kg.

\textsuperscript{d}Sum of columns E and F.

\textsuperscript{e}[Column G divided by column A] x 100.
Table 4. Data used to estimate the TME of yellow grease (kcal/kg)

<table>
<thead>
<tr>
<th>Supplemental fat level (%)</th>
<th>A</th>
<th>B</th>
<th>C&lt;sup&gt;a&lt;/sup&gt;</th>
<th>D&lt;sup&gt;b&lt;/sup&gt;</th>
<th>E</th>
<th>F&lt;sup&gt;c&lt;/sup&gt;</th>
<th>G</th>
<th>H Estimated TME of yellow grease (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Theoretical TME based on regression</td>
<td>Corrected theoretical TME</td>
<td>Column C minus Column D</td>
<td>Theoretical TME in diet from added fat</td>
<td>Column E plus Column F</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>3538</td>
<td>3446</td>
<td>3446</td>
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<td>3</td>
<td>3638</td>
<td>3648</td>
<td>3543</td>
<td>105</td>
<td>242</td>
<td>347</td>
<td>11,567</td>
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<td>6</td>
<td>3737</td>
<td>3810</td>
<td>3640</td>
<td>170</td>
<td>484</td>
<td>654</td>
<td>10,900</td>
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<tr>
<td>9</td>
<td>9</td>
<td>3835</td>
<td>3931</td>
<td>3735</td>
<td>196</td>
<td>726</td>
<td>922</td>
<td>10,244</td>
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<tr>
<td>12</td>
<td>12</td>
<td>3935</td>
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<td>9,567</td>
</tr>
<tr>
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<td>15</td>
<td>4033</td>
<td>4054</td>
<td>3928</td>
<td>126</td>
<td>1210</td>
<td>1336</td>
<td>8,907</td>
</tr>
</tbody>
</table>

<sup>a</sup>Predicted from regression equation \( y = 3446.84 + 73.95 - 2.23x^2 \).

<sup>b</sup>Factor of correction = \( \frac{(3446 \text{ kcal/kg})}{(3538 \text{ kcal/kg})} = 0.974 \).

<sup>c</sup>Assumes a TME value for yellow grease of 8070 kcal/kg.
of fatty acids of yellow grease was relatively high. The magnitude of absorption declined as the level of yellow grease increased. This phenomenon may be related to the spectrum of fatty acids in the total dietary fat. The most pronounced change in fatty acid composition of dietary fat as related to level of supplemental yellow grease occurred with linoleic acid \((C_{18:2})\). On a calculated basis, the \(C_{18:2}\) content of fat contributed by corn and other ration ingredients of the no-added-fat ration was relatively high. With each increment of yellow grease, which contained a low level of linoleic acid, the proportion of \(C_{18:2}\) in the total dietary fat declined. As shown graphically in Figure 2, the decline in \(C_{18:2}\) content of the total dietary fat corresponded with a decrease in \(AME_n\) and TME of yellow grease.

Also, it is evident from the shape of the curves in Figure 2 that the relative changes in TME and \(AME_n\) became progressively larger with each decrement in linoleic acid level; the lower the proportion \(C_{18:2}\) in the total fat, the greater was the decrease in TME and \(AME_n\).

These data do not demonstrate conclusively a causal relationship between \(C_{18:2}\) level of fat and the useful energy therein, but do correspond to results of other researchers. Young et al. (1963) and Garrett and Young (1975) have shown that the inclusion of relatively unsaturated fatty acids in a mixture with saturated fatty acids improved the ability of chickens to absorb the latter. Data presented recently by Sibbald and Kramer (1977, 1978) and Sibbald (1978) provided additional evidence that the unsaturated fatty acids of a vegetable fat (especially linoleic acid) improved the efficiency with which ME was derived from a "saturated" fat.
Figure 1. $\text{AME}_n$ and TME of yellow grease in relation to level of fat supplementation in the ration.
Figure 2. $\text{AME}_n$ and TME of yellow grease in relation to linoleic acid level in total dietary fat.
Previously, Leeson and Summers (1976) hypothesized that the "extracaloric" effect of supplemental animal fats in poultry rations was due to a synergism between the unsaturated fatty acids of vegetable origin and the saturated fatty acids of supplemental feed grade fats.

This type of synergism may explain the relatively high AME\textsubscript{H} values of yellow grease observed in the research reported here, but will not explain adequately the unusually high TME values of this fat source. The TME data suggest that other interactions between supplemental fat and energy-contributing ration components occurred, whereby "extra" TME was derived from nonfat constituents of the ration. Additional research designed to detect the effects of interaction between supplemental fats and carbohydrates and/or protein components of laying hen rations is needed.
REFERENCES


SECTION II. INFLUENCE OF FAT AND CARBOHYDRATE SOURCE ON ENERGY UTILIZATION BY LAYING HENS
INFLUENCE OF FAT AND CARBOHYDRATE SOURCE ON
ENERGY UTILIZATION BY LAYING HENS

Gonzalo G. Mateos
Jerry L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
SUMMARY

An experiment was conducted to determine the influence of different levels of yellow grease (0, 4, 8 or 12%) and three dietary carbohydrates (sucrose, starch, rice hulls) on energy utilization of diets for laying hens. True metabolizable energy (TME) and nitrogen-corrected metabolizable energy (MEn) of the diets were determined, and these data were used to estimate TME and MEn of yellow grease. TME and MEn of the diets were changed more by supplemental fat than was predicted on the basis of reference MEn of dietary ingredients. The energetic contribution of yellow grease to diets was estimated to be 9343, 9429, and 8194 kcal TME/kg and 8897, 8247 and 8221 kcal MEn/kg for sucrose-, starch- and rice hull-containing diets, respectively, instead of 8070 kcal TME/kg and 7900 kcal MEn/kg as expected. The results suggest that supplemental fat may enhance the utilization of energy from nonlipid dietary constituents. The possible influence of fats on rate of food passage and its implications for energy utilization of diet by the hen are discussed.
INTRODUCTION

The beneficial effect of added fat upon metabolizable energy (ME) of poultry diets has been well documented. Several reports (Touchburn and Naber, 1966; Jensen et al., 1970; Horani and Sell, 1977; Mateos and Sell, 1980) indicate that the generally recognized ME values of feed grade fats underestimate the true energy contribution of fats to practical rations. It has been suggested (Leeson and Summers, 1976; Sibbald, 1978) that fats increase dietary metabolizable energy beyond expectations because of a positive interaction of saturated fatty acids supplied by added fat with unsaturated fatty acids present in the ingredients of the diets by which micelle formation and digestibility of dietary fat are enhanced. This suggestion, however, does not explain satisfactorily why estimated ME of fats often is higher than the gross energy values (Cullen et al., 1962; Gomez and Polin, 1974; Whitehead and Fisher, 1975). It seems that when fat is supplemented, an improvement in the utilization of the energy of other nonlipid components of the diet takes place (Sibbald and Kramer, 1978; Sell et al., 1979). Indeed, Sell et al. (1976) and Sibbald and Kramer (1978) showed that the apparent ME of tallow varied with the grain used in the formulation of the basal diet. Recently, Mateos and Sell (1980) proposed that added fat could enhance the utilization of the energy of the diet by decreasing the rate of passage through the digestive tract, thereby increasing the digestibility of the basal portion of the diet.

The objective of our research was to determine the influence of graded amounts of yellow grease on the nitrogen-corrected metabolizable
energy (MEn) and true metabolizable energy (TME) of diets containing 20% sucrose, starch or rice hulls.
EXPERIMENTAL PROCEDURE

Single Comb White Leghorn hens, 80 weeks of age, were used. The hens were kept in wire laying cages equipped with trays for collection of excreta. The cages were located in an environmentally controlled room maintained at 26°C. Thirteen experimental groups were used, and four individually caged hens were assigned randomly to each group. One group of hens was used to determine the energy excreted during a 24-hour period of fasting. This energy excretion, which represented metabolic and endogenous energy, was used to determine TME's of diets by the method of Sibbald (1976).

The experiment was of a randomized design with 12 dietary treatments arranged in a 3 x 4 factorial. There were 3 series of diets, one for each test ingredient (sucrose, starch and rice hulls), and 4 levels of yellow grease (0, 4, 8 and 12%). The 3 series of diets had the same ingredient composition except for a 20% portion that was sucrose, corn starch or rice hulls, respectively. The fat supplemented diets were adjusted so that relatively constant metabolizable energy:protein and ME:methionine ratios were maintained for all diets (Table 1).

The energy values of the ingredients used to formulate the diets were MEn's listed by the National Research Council (1977) and the TME's presented by Sibbald (1977). These reference values were corrected according to moisture content of our ingredients. TME values of 3696 kcal/kg for starch and of 3730 kcal/kg for sucrose were used. The MEn and TME of yellow grease were 7900 and 8070 kcal/kg, respectively.
Table 1. Composition of the experimental diets

<table>
<thead>
<tr>
<th></th>
<th>Fat level, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Yellow corn</td>
<td>44.90</td>
</tr>
<tr>
<td>Soybean meal (48.5%)</td>
<td>24.60</td>
</tr>
<tr>
<td>Test ingredient&lt;sup&gt;a&lt;/sup&gt;</td>
<td>20.00</td>
</tr>
<tr>
<td>Yellow grease&lt;sup&gt;b&lt;/sup&gt;</td>
<td>-</td>
</tr>
<tr>
<td>DL-methionine, 98%</td>
<td>0.09</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.61</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.00</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.30</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>100.0</td>
</tr>
</tbody>
</table>

Calculated analysis<sup>d</sup>

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>MEn (kcal/kg)</td>
<td>2878</td>
</tr>
<tr>
<td>TME (kcal/kg)</td>
<td>3120</td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>15.88</td>
</tr>
<tr>
<td>Methionine, %</td>
<td>.35</td>
</tr>
</tbody>
</table>

<sup>a</sup>Three ingredients were used: starch, sucrose and rice hulls. The starch was obtained from Clinton Corn Processing Co., Clinton, IA 52732 and had a moisture content of 9.0% and a calculated MEn of 3660 kcal/kg. Sucrose (American Crystal Sugar Co., Moorhead, MN 56560) had no moisture content and a calculated MEn of 3680 kcal/kg.

<sup>b</sup>The yellow grease (National Byproducts Co., Des Moines, IA 50317) had a gross energy of 9372 kcal/kg. The fatty acid composition by analysis were: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linolenic, 0.6%; others, 0.4%.

<sup>c</sup>Supplied the following per kg of diet: Vit. A, 8000 I.U.; Vit. D<sub>3</sub>, 2400 I.U.; Vit. B<sub>12</sub>, 5 µg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg; and ethoxyquin, 11 mg.

<sup>d</sup>The calculated analyses correspond to the diets based on corn starch. Similar analyses must be expected for sucrose diets but substantial changes occurred when rice hulls were used.
The experiment consisted of two phases. In phase 1, the 12 diets were fed ad libitum to their respective groups for a 96-hour adaptation period. Afterwards, hens were fed the same diets for another 110 hours, and excreta were quantitatively collected from each hen every 55 hours. Excreta samples were freeze-dried, allowed to come to equilibrium with atmospheric moisture and analyzed for dry matter, heat of combustion and nitrogen. These data were used to calculate nitrogen-corrected, apparent metabolizable energy values (MEn) for all diets.

In phase II, the true metabolizable energy (TME) of the diets was determined using the same hens. The procedure described by Sibbald (1976) was used. All hens were fasted for 24 hours and then were force-fed 20 g of test diet. The excreta produced during the next 24 hours were collected quantitatively, dried and analyzed for heat of combustion.

MEn's and TME's of the diets were used to estimate the MEn and TME of the supplemental yellow grease. The regression of changes in ration MEn's or TME's with changes in level of supplemental fat was used for this purpose. The intercepts and slopes of the regression equations were analyzed statistically by the Fisher (.05) test as described by Snedecor and Cochran (1967).
RESULTS AND DISCUSSION

The MEn's and TME's of the diets, as measured experimentally, increased with each increment of supplemental yellow grease (Table 2). A comparison of the calculated and determined MEn's showed that changes in diet MEn's associated with supplemental fat were larger than expected in the three series of diets. The difference was largest in the sucrose-containing diets. Similar observations were made with TME's, although, in this instance, the differences between calculated and determined values were largest for both sucrose- and starch-containing diets.

To further assess this trend, the MEn and TME of the diets were regressed against the amount of supplemental fat. All the regression curves conformed to a linear model ($r^2 = .98$ for MEn and $r^2 = .95$ for TME) and were defined by the equations presented in Table 3. As far as MEn's were concerned, a comparison between calculated and determined regression equations confirmed that supplemental fat increased the metabolizable energy of the diet more than expected. However, the determined and calculated slopes were found different ($P < .01$), only for diets based on sucrose (47.47 vs. 37.50). These results illustrate that the MEn's of the test diets, as determined experimentally, were changed more by supplemental fat when sucrose constituted the main carbohydrate than when starch or rice hulls were used. Similar results were found for TME's, but in this instance the determined slopes of both sucrose and starch diets (52.73 and 53.59, respectively) were significantly higher ($P < .01$) than the calculated slope (40.00).
Table 2. Effect of supplemental yellow grease on the MEn and TME of the diets (kcal/kg as fed basis)

<table>
<thead>
<tr>
<th>Test ingredient</th>
<th>Level of supplemental fat, %</th>
<th>MEn Calculated</th>
<th>MEn Determined&lt;sup&gt;a&lt;/sup&gt;</th>
<th>TME Calculated</th>
<th>TME Determined&lt;sup&gt;a&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starch</td>
<td>0</td>
<td>2878</td>
<td>2902±12</td>
<td>3120</td>
<td>3126±46</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3028</td>
<td>3078±29</td>
<td>3279</td>
<td>3317±47</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3178</td>
<td>3207±7</td>
<td>3439</td>
<td>3437±8</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>3328</td>
<td>3406±20</td>
<td>3600</td>
<td>3800±35</td>
</tr>
<tr>
<td>Sucrose</td>
<td>0</td>
<td>2884</td>
<td>2851±15</td>
<td>3126</td>
<td>3074±34</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3034</td>
<td>3082±14</td>
<td>3285</td>
<td>3403±21</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>3184</td>
<td>3241±14</td>
<td>3447</td>
<td>3438±22</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>3334</td>
<td>3431±21</td>
<td>3606</td>
<td>3765±22</td>
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<tr>
<td>Rice hulls</td>
<td>0</td>
<td>2222</td>
<td>2268±34</td>
<td>2480</td>
<td>2585±61</td>
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<tr>
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<td>4</td>
<td>2372</td>
<td>2481±25</td>
<td>2639</td>
<td>2750±31</td>
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<td>8</td>
<td>2522</td>
<td>2577±33</td>
<td>2799</td>
<td>2894±32</td>
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<tr>
<td></td>
<td>12</td>
<td>2672</td>
<td>2779±17</td>
<td>2960</td>
<td>3087±44</td>
</tr>
</tbody>
</table>

<sup>a</sup>MEn of TME value ± standard error.
Table 3. Estimated MEn and TME of the diets according to the carbohydrate source and level of added fat

<table>
<thead>
<tr>
<th>Test ingredient</th>
<th>Calculated</th>
<th>Determined</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Interc</td>
<td>Slope</td>
</tr>
<tr>
<td>MEn (kcal/kg)^2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>Y = 2878 + 37.5X</td>
<td>Y = 2902.37 + 40.97X^a^d</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Y = 2884 + 37.5X</td>
<td>Y = 2866.65 + 47.47X^b</td>
</tr>
<tr>
<td>Rice hulls</td>
<td>Y = 2320 + 37.5X</td>
<td>Y = 2282.10 + 40.71X^a</td>
</tr>
<tr>
<td>TME (kcal/kg)^5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>Y = 3120 + 40X</td>
<td>Y = 3098.62 + 53.59X^d</td>
</tr>
<tr>
<td>Sucrose</td>
<td>Y = 3126 + 40X</td>
<td>Y = 3103.80 + 52.73X^d</td>
</tr>
<tr>
<td>Rice hulls</td>
<td>Y = 2480 + 40X</td>
<td>Y = 2581.97 + 41.24X^c</td>
</tr>
</tbody>
</table>

^1"As fed" basis.
^2r^2 = 0.98; CV = 1.53.
^3Where Y = Apparent or True Metabolizable energy of the diet in kcal/kg and X = percent of supplemental yellow grease.
^4Slopes with different superscript letter are significantly different (P < .05).
^5r^2 = 0.95; CV = 2.67.
Regression equations based on determined MEn's or TME's were used to estimate the metabolizable energy value of yellow grease. An assumption inherent in these calculations was that all the changes in dietary metabolizable energy were due to added fat exclusively. The methodology used to obtain these values will be presented with the sucrose diet series as an example. On a calculated basis, an increase of 37.50 kcal MEn per kg of diet was expected for each 1% of yellow grease included in the diet. Regression analysis of the determined MEn data, however, showed that each 1% fat increased MEn of the sucrose diet 47.47 kcal per kg. The calculated changes in MEn (37.50 kcal/kg) were made by using the conventional MEn value of the type of yellow grease used, 7900 kcal/kg. If total credit for the determined changes in dietary MEn associated with fat supplementation is given to yellow grease, then the MEn of yellow grease can be estimated:

\[ \text{MEn of yellow grease} = \left(47.47 - 37.50 \text{ kcal/% fat}\right) \times 100\% \text{ fat} + 7900 = 8897 \text{ kcal/kg yellow grease} \]

The MEn's and TME's of yellow grease estimated by the procedure just described for each of the three series of diets are presented in Figure 1. The highest MEn of yellow grease (8897 kcal/kg) occurred when this energy source was used in sucrose-containing diets. Values of 8247 and 8221 kcal/kg of yellow grease were estimated with diets containing starch and rice hulls, respectively. TME's derived for yellow grease were similar in sucrose- and starch-containing diets (9343 and 9429 kcal/kg, respectively) while a TME of 8194 kcal/kg was obtained with the rice hull diets.
Figure 1. Nitrogen-corrected metabolizable energy (MEN) and True Metabolizable energy (TME) of yellow grease as influenced by dietary carbohydrate source.
These results indicate that the MEn of yellow grease is higher than generally recognized. In addition, the data illustrate that the MEn of this fat source approached or exceeded its gross energy content, depending upon the carbohydrate components of the diet. These observations suggest that supplemental fat may enhance the utilization of energy contained in other components of the diet. For example, a favorable interaction between the saturated fatty acids of the supplemental fat and unsaturated fatty acids present in the other ingredients of the diet may enhance micelle formation and digestibility of supplemental fat (Leeson and Summers, 1975; Sibbald, 1978). This mechanism may partly explain why, in our experiment, fat supplementation improved MEn of the diets more than expected on the basis of reference values. For example, the determined MEn of the starch-containing diet with 12% supplemental fat was 3406 kcal/kg as compared with a calculated value of 3320 kcal/kg. Fatty acid synergism cannot explain, however, why the estimated contribution of yellow grease to the total MEn of the diet was larger in sucrose- than in starch-containing diets. This observation suggests that another mechanism may be involved.

Sucrose and starch are two carbohydrate sources readily utilized by the chick. It might be expected that their respective digestibility would be a function primarily of their rate of passage (Rutter et al., 1953; Entringer et al., 1975). Monson et al. (1950) indicated that the rate of passage of sucrose was faster than that of starch. Therefore, more available energy should be derived from starch than from sucrose. Indeed, reference values listed by National Research Council (1977) show that, on
a dry matter basis, the ME\textsubscript{n} of starch is higher than that of sucrose (4015 vs. 3680 kcal/kg).

On the other hand, numerous reports (Rogers and Harper, 1966; Hunt and Knox, 1968) showed that rate of food passage through the digestive tract can be modified by fat supplementation. Evidence has been presented by Duke and Evanson (1972) that the influx of fat into the duodenum of avians inhibits gastric emptying via a hormone feedback mechanism. Therefore, fat could enhance the utilization of dietary energy by slowing the rate of food passage (Rao and Clandinin, 1970). Theoretically, supplemental fat should have a relatively greater effect on energy utilization from diets that otherwise passed through the gastrointestinal tract rapidly (Mateos and Sell, 1980). In our experiment, when yellow grease constituted 0% or 12% of the diet, the respective determined ME\textsubscript{n}'s (kcal/kg) were 2902 and 3406 for starch- and 2851 and 3431 for sucrose-containing diets. The difference in favor of the latter could be explained on the basis that fat supplementation reduced the rate of passage of the sucrose-containing diets, thereby facilitating more complete energy utilization. On the other hand, energy utilization from starch-containing diets was near maximum in the presence or absence of added fat.

The TME data, however, do not completely corroborate this hypothesis. Yellow grease supplementation improved the utilization of energy of both sucrose- and starch-containing diets to a similar extent. An explanation for the discrepancy between the ME\textsubscript{n} and TME data in this regard may be found in the different experimental conditions used. The hens were provided feed on an ad libitum basis during the ME\textsubscript{n} determination. In
contrast, hens were fasted for 24 hours and then were force-fed a limited amount of test diet to facilitate TME determination. Research has shown that the presence of fat in the small intestine inhibits rate of food passage (Rogers and Harper, 1966; Hunt and Knox, 1968). There is a time lag, however, between the initial contact of fat with intestinal receptors and the hormone-mediated inhibition of food movement into the intestine (Duke and Evanson, 1972). Possibly, fat-containing ingesta passed through the gastrointestinal tract of the chickens that were fasted and given small amounts of feed in the TME segment of the present study too rapidly for manifestation of fat's inhibiting effect on food movement (Rogers and Harper, 1966; Hunt and Spurrell, 1951). Also, fasting followed by limited force-feeding may have resulted in erratic motility patterns in the gut (Rogers and Harper, 1966; Poulakos and Kent, 1973) whereby the influence of other stimuli, such as fat, were obscured. Under ad libitum feed intake, however, the differential influence of fat on energy utilization from sucrose- or starch-based diets was of detectable magnitude.

From the results reported herein, we suggest that the extrametabolic effect attributed to fat by several authors (Jensen et al., 1970; Mateos and Sell, 1980; Cullen et al., 1962; Gomez and Polin, 1974; Sibbald and Kramer, 1978) could be explained by the influence of fat on rate of food passage. The slower rate of passage caused by fat, would expose the ingesta to enzymes and absorptive surfaces for longer periods of time, and, therefore, the utilization of the energy contained in the ingredients of the diet would be enhanced. Also, this type of effect by fat could create a highly favorable situation for a more complete manifestation of an in-
teraction between saturated and unsaturated fatty acids on micelle formation and total fat absorption.
REFERENCES


SECTION III. INFLUENCE OF CARBOHYDRATE AND SUPPLEMENTAL FAT SOURCE ON THE METABOLIZABLE ENERGY OF THE DIET
INFLUENCE OF CARBOHYDRATE AND SUPPLEMENTAL FAT SOURCE ON THE METABOLIZABLE ENERGY OF THE DIET

Gonzalo G. Mateos
Jerry L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
SUMMARY

An experiment involving 60 SCWL laying hens was conducted to measure the influence of the carbohydrate source and supplemental fat on metabolizable energy (MEn) of the diet. Twelve diets with the same calculated metabolizable energy and protein levels were arranged in a 2 x 6 factorial composed of 2 yellow grease to soy oil ratios (6%:0% and 4%:2% of the diet) and 6 corn starch:sucrose ratios (from 49%:0% to 0%:49%). The diets were assayed for MEn content by using the total feces collection method. There was a positive linear relationship between sucrose level and MEn of the diet. When sucrose replaced corn starch, the MEn of the diets increased more than expected, and these increments were statistically significant (P < .01). The diets containing a mixture of yellow grease and soy oil had significantly higher MEn values than those in which supplemental fat was supplied exclusively as yellow grease (P < .05). A comparison of the "calculated" regression equation describing the expected dietary ME with changing sucrose and soy oil levels, Y = 3110 + 1.03 (% sucrose) + 9 (% soy oil), and the regression equation determined experimentally, Y = 3177 + 3.25 (% sucrose) + 18 (% soy oil), illustrates the relatively large increases in dietary ME caused by sucrose and soy oil. These effects of sucrose and soy oil were independent. These data support the concept that the addition of a relatively unsaturated fat (soy oil) to a saturated fat (yellow grease) enhances dietary MEn. Also, the data indicate that the presence of supplemental fat in the diet increases the utilization of energy from sucrose. Thus, the "extra-caloric" effect of fats on MEn may be the culmination of a favorable interaction between
supplemental fats and fats inherent in other diet components, and a benesficial influence of supplemental fats on energy utilization from certain nonlipid dietary constituents.
INTRODUCTION

The addition of fat to poultry diets is reported to increase the metabolizable energy (ME) of the diets more than expected from the additivity of the MEs of the individual ingredients (Cullen et al., 1962; Jensen et al., 1970; Sell, 1977; Mateos and Sell, 1980; Sell et al., 1979). Garrett and Young (1975), Leeson and Summers (1976) and Sibbald (1978) suggested that the "extra-caloric" effect of supplemental fats could be due to a positive interaction between unsaturated fatty acids present in the ingredients of the diet and the saturated fatty acids supplied by the added fat. There is, however, the possibility that supplemental fats also increase the utilization of other dietary components, thereby enhancing ME of diets.

Gomez and Polin (1974) and Sibbald and Kramer (1978) reported that fat supplementation seemed to improve the utilization of nonlipid constituents of diets. Horani and Sell (1977) observed differences in the effect of supplemental animal tallow, depending upon the cereal grain component of laying-hen diets. Recently, Mateos and Sell (Department of Animal Science, Iowa State University, unpublished data) obtained larger increases in MEs due to fat supplementation of corn-soy diets when sucrose was included in the mixture than when starch or rice hulls were used.

Kalmbach and Potter (1959) found differences in MEs for different fat sources when the glucose level of the diet was changed. Saxena et al. (1963), Bray (1964) and DalBorgo et al. (1967), using different fat levels, reported that the degree of utilization of energy from raw soy-
beans was influenced by the main carbohydrate constituent of the test diet.

These findings suggest an interrelationship between dietary carbohydrates and supplemental fat with respect to energy utilization, but definitive data are lacking. Therefore, the research reported herein was conducted to determine the influence of dietary corn starch and sucrose on the utilization of energy from laying-hen diets supplemented with yellow grease or yellow grease plus soy oil.
EXPERIMENTAL PROCEDURE

Single Comb White Leghorn hens, 75 weeks of age, were used. The birds were kept in individual, wire laying cages equipped with trays for collection of excreta. The cages were located in an environmentally controlled room maintained at 26°C. Five hens were assigned randomly to each of 12 experimental groups, and each group was allotted to one of the 12 experimental diets (Table 1). The 12 diets were arranged in a 2 x 6 factorial composed of two yellow grease to soy oil ratios (6%:0% and 4%:2% of the diet) and six corn starch to sucrose ratios (from 49%:0% to 0%:49% of the diet). Yellow grease, corn starch and sucrose were products of National Byproducts Co., Des Moines, Iowa, Clinton Corn Processing Co., Clinton, Iowa and American Crystal Sugar Co., Moorhead, Minnesota, respectively.

All the diets had the same calculated protein level (16.7%). The calculated metabolizable energy concentrations were similar except for slight differences due to the different corn starch:sucrose and yellow grease:soy oil ratios. The MEn value used for yellow grease, commensurate with its fatty acid composition, was 7900 kcal/kg and the MEn's listed by NRC (1977) were used for all other ingredients.

After a 6-day adaptation period, the hens were fed the appropriate ration ad libitum for another 5 days. Feed consumption was recorded, and excreta were collected every 60 hours on a quantitative basis from each hen. The excreta samples were freeze-dried, allowed to come to equilibrium with atmospheric moisture and then were analyzed for dry matter, heat of combustion and nitrogen content. These data were used to calculate
Table 1. Diet composition, %

<table>
<thead>
<tr>
<th>Ingredients</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean meal, 48.5%</td>
<td>34.46</td>
</tr>
<tr>
<td>Carbohydrate tested(^a)</td>
<td>49.00</td>
</tr>
<tr>
<td>Fat source(^b)</td>
<td>6.00</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.61</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>0.30</td>
</tr>
<tr>
<td>Vitamin premix(^c)</td>
<td>0.50</td>
</tr>
<tr>
<td>DL-methionine, 98%</td>
<td>0.13</td>
</tr>
</tbody>
</table>

100.00

Calculated analysis:
- Metabolizable energy (kcal/kg)\(^d\): 3103
- Crude protein, %: 16.71
- Methionine, %: 0.38

\(^a\)Six different combinations of sucrose and starch were used. The six ratios were 0:49, 10:39, 20:29, 30:19, 40:9 or 49:0. The starch was obtained from Clinton Corn Processing Co., Clinton, Iowa 52732 and had a moisture content of 11.7% and a gross energy value of 3720 kcal/kg. Sucrose (American Crystal Sugar Co., Moorhead, Minnesota 56560) had no moisture and a gross energy of 3930 kcal/kg.

\(^b\)Two combinations of fat, 6% of yellow grease or 4% of yellow grease + 2% of soy oil were used. The yellow grease (National Byproducts Co., Des Moines, Iowa 50317) had a gross energy of 9372 kcal/kg. The fatty acid composition, by analysis, was: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6%; others, 0.4%.

\(^c\)Supplied the following per kg of diet: vitamin A, 8000 I.U.; vitamin D\(_3\), 2400 I.U.; vitamin B\(_12\), 5 \(\mu\)g; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg; and ethoxyquin, 11 mg.

\(^d\)This MEn value corresponds to the diet without sucrose or soy oil added. The metabolizable energy of the other diets (MEn) varied with the percentage of sucrose (1.03 kcal per 1% of increase) and of soy oil (9 kcal per 1% of soy oil substituted for yellow grease). The MEn of starch and sucrose used for calculation were 3580 and 3680 kcal/kg, respectively.
nitrogen-corrected, metabolizable energy for all diets. The ME\textsubscript{n} values of the diets were used to estimate the ME\textsubscript{n} of yellow grease. Simultaneously, the degree of utilization of sucrose was estimated as compared with that of starch in fat-supplemented diets.
RESULTS AND DISCUSSION

The MEn's of the rations, as measured experimentally, increased with increasing concentration of sucrose ($P \leq .01$) and with the inclusion of soy oil ($P \leq .05$) (Table 2). A comparison between the calculated and determined MEn's indicated that changes in dietary MEn's associated with the increments of sucrose were larger in the latter instance. The same observation was made when yellow grease was partly replaced by soy oil. To further assess these trends, the MEn's of the diets were regressed against the level of sucrose for both 6% yellow grease and 4% yellow grease + 2% soy oil diets. The model used was $y = a + b_1X_1 + b_2X_2 + e$, where $X_1 = \%$ of soy oil and $X_2 = \%$ of sucrose in the ration. The predicted response was defined by the equation $\text{MEn (kcal/kg)} = 3177 + 18 (\% \text{ soy oil}) + 3.25 (\% \text{ sucrose})$. The quadratic component and interaction of fat source x carbohydrate were not significant. Both $b_1$ and $b_2$ of the regression equation, based on measured ME's, exceeded those of the regression equation appropriate for the calculated MEn values of the diets [$\text{MEn (kcal/kg)} = 3110 + 9 (\% \text{ soy oil}) + 1.03 (\% \text{ sucrose})$]. As far as the $b_2$-coefficients are concerned, the differences between the determined and the calculated value illustrate that the MEn of the diet, as determined experimentally, was changed more by sucrose increments than was predicted on the basis of reference MEn values of the ingredients of the diets. A similar trend was observed when the supplemental fat, yellow grease, was partly replaced by soy oil.

The regression equation based on determined MEn's values was used to obtain information needed to estimate the MEn of the supplemental yellow
Table 2. Effect of fat and carbohydrate source on the MEn of the diets (kcal/kg)\(^a\)

<table>
<thead>
<tr>
<th>Fat source</th>
<th>Sucrose:starch ratio</th>
<th>Calculated ME(b)</th>
<th>Determined ME(b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6% yellow grease</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0:49</td>
<td>3110</td>
<td>3205±13</td>
</tr>
<tr>
<td></td>
<td>10:39</td>
<td>3120</td>
<td>3194±22</td>
</tr>
<tr>
<td></td>
<td>20:29</td>
<td>3130</td>
<td>3250±53</td>
</tr>
<tr>
<td></td>
<td>30:19</td>
<td>3140</td>
<td>3289±40</td>
</tr>
<tr>
<td></td>
<td>40:9</td>
<td>3150</td>
<td>3324±51</td>
</tr>
<tr>
<td></td>
<td>49:0</td>
<td>3159</td>
<td>3343±15</td>
</tr>
<tr>
<td>4% yellow grease + 2% soy oil</td>
<td>0:49</td>
<td>3128</td>
<td>3231±26</td>
</tr>
<tr>
<td></td>
<td>10:39</td>
<td>3138</td>
<td>3237±21</td>
</tr>
<tr>
<td></td>
<td>20:29</td>
<td>3148</td>
<td>3305±28</td>
</tr>
<tr>
<td></td>
<td>30:19</td>
<td>3158</td>
<td>3306±48</td>
</tr>
<tr>
<td></td>
<td>40:9</td>
<td>3168</td>
<td>3350±42</td>
</tr>
<tr>
<td></td>
<td>49:0</td>
<td>3178</td>
<td>3389±24</td>
</tr>
</tbody>
</table>

\(^a\) "As fed" basis.

\(^b\) Metabolizable energy ± standard deviation.

grease. A general assumption inherent in the calculations of ME\(\text{n}\) of yellow grease has been that all the changes in ration ME\(\text{n}\) were due to lipid components exclusively. If we accept this hypothesis, the ME\(\text{n}\) value for yellow grease would vary from 8267 kcal/kg to 9717 kcal/kg when yellow grease constituted the only source of supplemental fat and, from 8475 kcal/kg to 10,650 kcal/kg, if 2% of soy oil was included in the diet (Table 3). However, our data indicate that supplemental fat may exert a twofold beneficial effect on the ME\(\text{n}\) of the diet. The replacement of 2% of yellow grease by soy oil increased the ME\(\text{n}\) of the diets 18 kcal/kg more
Table 3. Data used to estimate the MEn of yellow grease by assuming changes in ration MEn due exclusively to lipid components

<table>
<thead>
<tr>
<th>Fat source</th>
<th>Sucrose: starch ratio</th>
<th>Calculated MEn</th>
<th>MEn based on regression</th>
<th>Corrected calculated MEn</th>
<th>Col. D minus Col. E</th>
<th>Calculated MEn in diet from Y.G.</th>
<th>Total MEn of the diet as due to added Y.G.</th>
<th>Estimated MEn Y.G. kcal/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>6% yellow grease (Y.G.)</td>
<td>0:49</td>
<td>3110</td>
<td>3187</td>
<td>3187</td>
<td>-</td>
<td>474</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10:39</td>
<td>3120</td>
<td>3219</td>
<td>3197</td>
<td>22</td>
<td>474</td>
<td>496</td>
<td>8267</td>
</tr>
<tr>
<td></td>
<td>20:29</td>
<td>3130</td>
<td>3252</td>
<td>3207</td>
<td>45</td>
<td>474</td>
<td>519</td>
<td>8650</td>
</tr>
<tr>
<td></td>
<td>30:19</td>
<td>3140</td>
<td>3284</td>
<td>3218</td>
<td>66</td>
<td>474</td>
<td>540</td>
<td>9000</td>
</tr>
<tr>
<td></td>
<td>40:9</td>
<td>3150</td>
<td>3317</td>
<td>3228</td>
<td>89</td>
<td>474</td>
<td>563</td>
<td>9383</td>
</tr>
<tr>
<td></td>
<td>49:0</td>
<td>3159</td>
<td>3346</td>
<td>3237</td>
<td>109</td>
<td>474</td>
<td>583</td>
<td>9717</td>
</tr>
<tr>
<td>4% yellow grease + 2% soy oil</td>
<td>0:49</td>
<td>3128</td>
<td>3222</td>
<td>3222</td>
<td>-</td>
<td>316</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>10:39</td>
<td>3138</td>
<td>3255</td>
<td>3232</td>
<td>23</td>
<td>316</td>
<td>339</td>
<td>8475</td>
</tr>
<tr>
<td></td>
<td>20:29</td>
<td>3148</td>
<td>3287</td>
<td>3232</td>
<td>44</td>
<td>316</td>
<td>360</td>
<td>9000</td>
</tr>
<tr>
<td></td>
<td>30:19</td>
<td>3158</td>
<td>3320</td>
<td>3253</td>
<td>67</td>
<td>316</td>
<td>383</td>
<td>9575</td>
</tr>
<tr>
<td></td>
<td>40:9</td>
<td>3168</td>
<td>3352</td>
<td>3263</td>
<td>87</td>
<td>316</td>
<td>403</td>
<td>10075</td>
</tr>
<tr>
<td></td>
<td>49:0</td>
<td>3177</td>
<td>3382</td>
<td>3272</td>
<td>110</td>
<td>316</td>
<td>426</td>
<td>10650</td>
</tr>
</tbody>
</table>

a Predicted value from regression equation \( y = 3177 + 18 \text{ (% soy oil)} + 3.25 \text{ (% sucrose)} \).

b Because the determined MEn of the no-added-sucrose ration exceeded the calculated ME, all calculated MEn's of the rations were adjusted according to the ratios 3187 kcal/kg/3110 kcal/kg = 1.0248 for the 6% yellow grease series and 3222 kcal/kg/3128 kcal/kg = 1.03 for the 4% yellow grease + 2% soy oil series.

c Assuming an MEn value for yellow grease of 7900 kcal/kg.

d Sum of column F and G.

e \([\text{Column H divided by percentage of yellow grease in the diet}] \times 100\).
than expected. Because the only difference between diets was the source of fat, we can assume that the observed improvement was caused by an interaction between the relatively unsaturated fatty acids of soy oil and the saturated fatty acids of yellow grease whereby the absorption of the latter was enhanced (Lewis and Payne, 1966; Leeson and Summers, 1976). Thus, when soy oil was present, yellow grease contributed 18 kcal more of MEn per kg of diet than when soy oil was not added (Table 4). With this improvement, the MEn of yellow grease was approximately 8335 kcal/kg, a value that is 5.7% higher than the commonly recognized MEn of yellow grease.

On the other hand, in the presence of fat (whether yellow grease or yellow grease + soy oil), sucrose was utilized by the hens more efficiently than expected on the basis of data presented by NRC (1977). The regression of MEn of the diets against the level of dietary sucrose is shown in Figure 1. A comparison between calculated and determined MEn's of the diets (Table 4) showed a MEn for sucrose of about 3910 kcal/kg, whereas the expected value was 3680 kcal/kg (NRC, 1977). Simple sugars have a faster rate of passage along the digestive tract than does starch (Monson et al., 1950; Stokstad et al., 1953; Griminger and Fisher, 1963). Consequently, digestibility of simple sugars seems to be less than that of starch. For example, more undigested sucrose than starch has been detected in feces when high levels of these carbohydrates were used (Entringer et al., 1975). As a result, a decrease in the MEn of the ration might be expected when high levels of dietary sucrose were substi-
Table 4. Data used to estimate the MEn of yellow grease in the presence of soy oil and the MEn of sucrose in the presence of supplemental fat (kcal/kg)

| A   | B       | C       | D       | E       | F       | G       | H       | I       | J       | K       | L       |
|-----|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Fat | source  | Su­cro-| est: | Correct­ | ed | Col. D | Extra | value | of the diet | calu- | d as | supplied as | y. G. | the diet | Total | Total | Est. | Est. |
|     |         | role: | based on | cali­ | culated | due to | S.O. | Suppl. | calculated | su­ | bined | sucrose | c. | due to | MEn | MEn | MEn | MEn |
|     |         | starch | regres­ | ated | mnus | to | C | by Y. G. | ed as | cru- | due to | of | due to | of | of | of | of |
|     |         | ratio  | sion | MEn | Col. C | 474 | 474 | 474 | 474 | 474 | 474 | 7900 | 7900 | 3900 | 3900 | 3905 | 3905 | 3920 | 3920 | 3902 | 3902 | 3902 | 3902 |
| 6%  | yellow  | 10:39  | 3219  | 3197  | 22   | -    | 474  | -    | 474  | -    | 474  | 7900  | 7900  | 3900 | 3900 | 3905 | 3905 | 3920 | 3920 | 3902 | 3902 | 3902 | 3902 |
|     | grey    | 20:29  | 3252  | 3207  | 45   | -    | 474  | -    | 474  | -    | 474  | 781   | 781   | 3900 | 3900 | 3905 | 3905 | 3920 | 3920 | 3902 | 3902 | 3902 | 3902 |
|     | (Y.G.)  | 30:19  | 3284  | 3218  | 66   | -    | 474  | -    | 474  | -    | 474  | 781   | 781   | 3900 | 3900 | 3905 | 3905 | 3920 | 3920 | 3902 | 3902 | 3902 | 3902 |
|     |         | 40:9   | 3317  | 3228  | 89   | -    | 474  | -    | 474  | -    | 474  | 1561  | 1561  | 7900 | 7900 | 3905 | 3905 | 3920 | 3920 | 3902 | 3902 | 3902 | 3902 |
|     |         | 49:0   | 3346  | 3237  | 109  | -    | 474  | -    | 474  | -    | 474  | 1912  | 1912  | 7900 | 7900 | 3902 | 3902 | 3902 | 3902 | 3902 | 3902 | 3902 | 3902 |
| 4%  | yellow  | 10:39  | 3222  | 3222  | -    | 17.5 | 316  | -    | 316  | -    | 333.5 | 8337  | -    | 8337  | 8337 | 3910 | 3910 | 3900 | 3900 | 3900 | 3900 | 3907 | 3907 | 3907 |
|     | grey    | 20:29  | 3255  | 3232  | 23   | 17.5 | 316  | -    | 316  | -    | 333.5 | 333.5 | 391  | 333.5 | 333.5 | 3910 | 3910 | 3900 | 3900 | 3900 | 3900 | 3907 | 3907 | 3907 |
|     | + 2%    | 30:19  | 3287  | 3243  | 44   | 17.5 | 316  | -    | 316  | -    | 333.5 | 333.5 | 391  | 333.5 | 333.5 | 3910 | 3910 | 3900 | 3900 | 3900 | 3900 | 3907 | 3907 | 3907 |
|     | soy     | 40:9   | 3320  | 3253  | 67   | 17.5 | 316  | -    | 316  | -    | 333.5 | 333.5 | 391  | 333.5 | 333.5 | 3910 | 3910 | 3900 | 3900 | 3900 | 3900 | 3907 | 3907 | 3907 |
|     | oil     | 49:0   | 3352  | 3263  | 87   | 17.5 | 316  | -    | 316  | -    | 333.5 | 333.5 | 391  | 333.5 | 333.5 | 3910 | 3910 | 3900 | 3900 | 3900 | 3900 | 3907 | 3907 | 3907 |
| a   | Calculated as shown in Table 3, footnote b. |
| b   | Calculated by difference between diets containing the same sucrose to starch ratio but differing in the fat source and taking into account the difference in MEn between yellow grease (7900 kcal/kg) and soy oil (8820 kcal/kg). |
| c   | The metabolizable energy used for yellow grease was 7900 kcal/kg and for sucrose 3680 kcal/kg (NRC, 1977). |
| d   | Column I: sum of columns G and F; Column J: sum of columns E and H. |
| e   | [Column K divided by percentage of yellow grease in the diet] x 100. |
| f   | [Column L divided by percentage of sucrose in the diet] x 100. |
Figure 1. Metabolizable energy of the diet as influenced by carbohydrate and fat sources
tuted for starch. In the research reported here, substitution of sucrose for starch in diets containing supplemental fat did not decrease ME\(n\).

The presence of supplemental fats in the diet might be expected to exert a beneficial effect on energy utilization from sucrose. It has been shown in humans and other mammals (Guyton, 1977; Davenport, 1978) that the presence of fat in the duodenum depresses the activity of the pyloric pump, the main proposed mechanism for stomach emptying. If, as it seems (Duke and Evanson, 1972), an analogous feedback control also is present in avians, the addition of fat could slow the rate of passage of the diet along the digestive tract of the hen. In turn, this might result in a more complete digestion of the diet (Tuckey et al., 1958; Rao and Clandinin, 1970). Theoretically, a reduction in rate of passage would be more important for sucrose diets than for those based on starch, because under normal circumstances, the rate of passage is faster and the utilization of energy is lower for sucrose than for starch (Vohra, 1967). Another interesting possibility to explain the different behavior of sucrose versus starch in the presence of fat is that the former mixes well with fat while starch does not. When supplemental fat is added to a sucrose diet, the affinity of the sugar for water would decrease, and a slower rate of passage would be expected (Cunningham, 1959; Entringer et al., 1975; Summers and Leeson, 1979).

We conclude that the "extra-caloric" effect on ME\(n\) attributable to yellow grease supplementation of poultry diets should be subdivided into two singular mechanisms: synergism between saturated and unsaturated fatty acids that enhances the absorbability of yellow grease (Artman,
1964; Garrett and Young, 1975; Leeson and Summers, 1976) and a reduction in rate of food passage due to supplemental fat whereby the digestibility of the diet (especially of those ingredients with a fast rate of passage) is increased (Davenport, 1973; Sturkie, 1976).
REFERENCES


SECTION IV. INFLUENCE OF GRADED LEVELS OF FAT ON UTILIZATION OF SPECIFIC CARBOHYDRATES BY THE LAYING HEN
INFLUENCE OF GRADED LEVELS OF FAT ON UTILIZATION OF SPECIFIC CARBOHYDRATES BY THE LAYING HEN

Gonzalo G. Mateos
Jerry L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
SUMMARY

An experiment involving 140 SCWL laying hens was conducted to investigate the influence of graded levels of supplemental fat on the metabolizable energy (MEn) of diets containing different pure carbohydrates. Twenty-four diets with the same MEn:protein ratio were arranged in a 4 x 6 factorial composed of four levels of yellow grease (0, 3, 6 and 9%) and six carbohydrate sources (sucrose, starch, maltose, glucose, fructose and glucose + fructose). Four additional diets in which the pure carbohydrate was not included were formulated to facilitate the determination of the MEn of the pure carbohydrates. All diets were assayed for MEn by using the total collection method. The MEn of the diets was changed more by supplemental fat than was predicted on the basis of reference MEn of dietary ingredients. The energetic contribution of yellow grease to diets was estimated to be 8,600 kcal MEn/kg instead of 7,900 kcal MEn/kg as had been expected. The estimated MEn of each pure carbohydrate increased with each increment of supplemental fat. When yellow grease constituted 0 or 9% of the diet, the respective MEn's of the carbohydrates (kcal/kg), expressed in a relative index form, with the MEn of sucrose in nonadded fat diets set equal to 100, were 100 and 110 for sucrose; 96 and 103 for starch; 93 and 100 for maltose; 92 and 101 for glucose; 90 and 98 for fructose and 89 and 98 for the glucose + fructose mixture. The data indicate that supplemental fat enhanced the utilization of energy from non-lipid dietary constituents. The mechanism by which fat exerts this influence on utilization of dietary energy is not known, but the possible
relationship between decreased rate of food passage resulting from supplemental fat and energy utilization is discussed.
INTRODUCTION

Glucose, sucrose and starch are used as main sources of energy in reference diets for metabolizable energy determination of poultry feedstuffs. It is commonly accepted that the metabolizable energy contribution of these carbohydrates to the diet is consistent irrespective of ingredient composition of diets. Published data, however, suggest that the actual contribution each energy source makes to dietary metabolizable energy (MEn) varies with ingredient composition of diets. Vohra (1967) presented MEn for glucose, sucrose and starch ranging from 3,240 to 3,740; 3,680 to 3,900 and 3,700 to 4,120 kcal/kg, respectively. In the specific case of glucose, other researchers have reported values of 2,850 (Sibbald, 1976); 3,310 (Whitehead and Fisher, 1975); 3,351 (Sibbald and Slinger, 1962); 3,564 (Potter and Matterson, 1960); 3,640 (Anderson et al., 1958); and 3,730 kcal/kg of dry matter (Anderson, 1955). The reasons for the variability among MEn values of glucose determined at different laboratories are not well understood. A major contributing factor may be ingredient interaction in test diets whereby energy is utilized from various dietary constituents in a nonadditive manner.

The manifestations of ingredient interactions with respect to energy utilization seems to be especially important in the case of supplemental fats. In measuring MEn of fats, one substitutes the lipid into a diet at low levels. A direct measurement is then made of the MEn of the reference and test diets and the MEn of the fat is calculated by difference. An assumption inherent in this method is that differences in MEn's of the test diet, as compared with the reference diet, result exclusively from
fat. However, this supposition may be erroneous. Leeson and Summers (1976) suggested that a synergism between saturated fatty acids of a supplemental fat of animal origin and unsaturated fatty acid inherent in other ingredients of a diet may enhance the MEn of the supplemental fat. Sues (1974) reported that the MEn of tallow increased with the level of protein and decreased with the level of calcium of the diet. Sibbald and Kramer (1978) found that the MEn of animal fat depended on the constituents of the basal portion of the diet. The MEn obtained for tallow was greater in a corn diet than in a wheat diet.

Gomez and Polin (1974) found that the MEn of different types of fats varied with the level of dietary glucose replaced by a mixture of fat and cellulose. Other authors (Kalmbach and Potter, 1959; Cullen et al., 1962) have observed that the MEn of either saturated or unsaturated fats varied depending upon whether semipurified or practical-type diets were used. Rao and Clandinin (1970) indicated that a higher MEn for a given ingredient was obtained when practical diets were used as compared with purified diets. They proposed that the rate of passage of purified diets through the gut was considerably faster than that of practical diets. Consequently, the period of exposure of food to the enzymes of the gastrointestinal tract was longer and the utilization of nutrients and energy was greater from practical- than from semipurified-type diets. Based on changes observed in the MEn of sucrose- or starch-containing diets due to fat supplementation, Mateos and Sell (1980b) proposed that fats may enhance the overall utilization of dietary energy by slowing the rate of food passage.
The present study was conducted to determine the influence of fat supplementation on the MEn of diets containing high levels of selected monosaccharides, disaccharides or starch.
EXPERIMENTAL PROCEDURE

Single Comb White Leghorn hens, 35-weeks old, were kept in individual cages located in an environmentally controlled room at 25°C. Five hens were assigned randomly to each of 24 experimental diets. The trial was carried out as a randomized block design with 24 treatments arranged in a 4 x 6 factorial with four levels of yellow grease (0, 3, 6 and 9%) and six carbohydrate sources (starch, sucrose, maltose, glucose, fructose and glucose + fructose) included at 30% of the diet (Table 1). Appropriate adjustments were made in the corn, soybean meal and methionine levels of the fat-supplemented diets so that relatively constant MEn:protein and MEn:methionine ratios were maintained.

In addition to the 24 treatments mentioned, four experimental groups (one for each level of fat) were included to estimate the effect of the level of fat on the MEn of the diet in the absence of the pure carbohydrate. These diets (Table 2) will be referred to as basal diets. Because these basal diets were formulated without the test carbohydrates, the proportion of all other ingredients increased. Thus, the basal diets contained 0, 4.29, 8.57 and 12.86% of yellow grease, respectively, instead of 0, 3, 6 and 9% as in the test diets. Each 3% or 4.29% increment of fat in the diet increased the MEn of the test and basal diets by about 110 and 157 kcal/kg, respectively.

The same hens were used for each block (time). Before each period, all the hens were re-randomized and permitted to adjust to the new diet for 5 days. Then, a 5-day trial was initiated during which feed consumption was recorded and excreta were collected every 60 hours. The total
Table 1. Composition of the test diets

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>33.00</td>
<td>27.71</td>
<td>22.50</td>
<td>17.26</td>
</tr>
<tr>
<td>3% fat</td>
<td>26.48</td>
<td>28.77</td>
<td>30.97</td>
<td>33.20</td>
</tr>
<tr>
<td>6% fat</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>9% fat</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
</tr>
<tr>
<td>Yellow corn</td>
<td>33.00</td>
<td>27.71</td>
<td>22.50</td>
<td>17.26</td>
</tr>
<tr>
<td>Soybean mean, 48.5%</td>
<td>26.48</td>
<td>28.77</td>
<td>30.97</td>
<td>33.20</td>
</tr>
<tr>
<td>Yellow grease(^a)</td>
<td>-</td>
<td>3.00</td>
<td>6.00</td>
<td>9.00</td>
</tr>
<tr>
<td>Test ingredient(^b)</td>
<td>30.00</td>
<td>30.00</td>
<td>30.00</td>
<td>30.00</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
<td>1.61</td>
</tr>
<tr>
<td>Sodium chloride</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Vitamin premix(^c)</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>DL-methionine, 98%</td>
<td>.11</td>
<td>.11</td>
<td>.12</td>
<td>.13</td>
</tr>
</tbody>
</table>

Calculated analysis:

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEn (kcal/kg)(^d)</td>
<td>2915</td>
<td>3025</td>
<td>3135</td>
<td>3246</td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>15.75</td>
<td>16.39</td>
<td>17.00</td>
<td>17.62</td>
</tr>
<tr>
<td>Total sulfur amino acids, %</td>
<td>.60</td>
<td>.62</td>
<td>.64</td>
<td>.67</td>
</tr>
<tr>
<td>Calcium, %</td>
<td>3.47</td>
<td>3.47</td>
<td>3.47</td>
<td>3.48</td>
</tr>
</tbody>
</table>

\(^a\)The yellow grease (National Byproducts Co., Des Moines, Iowa 50317) had a gross energy of 9.372 kcal/g. The fatty acid composition by analysis was: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6%; others, 0.4%.

\(^b\)Six different carbohydrates were used. Corn starch had a moisture content of 10% and a calculated MEn of 3,650 kcal/kg. Values for the other ingredients were: D-glucose, no moisture, 3,500 kcal/kg; β-D-levulose (fructose), .9% moisture, 3,325 kcal/kg; D(+) maltose hydrate, .8% moisture, 3,580 kcal/kg; sucrose, no moisture, 3,680 kcal/kg. All these ingredients except sucrose were obtained from United States Biochemical Corporation, Cleveland, Ohio 44122. Sucrose was produced by American Crystal Sugar Co., Moorhead, Minnesota 56560.

\(^c\)Supplied the following per kg of diet: vit. A, 8000 I.U.; vit. D\(_3\), 2400 I.U.; vit. B\(_12\), 5 μg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg and ethoxyquin, 11 mg.

\(^d\)These MEn's correspond to corn starch-containing diets. The MEn's of the other diets varied with the carbohydrate used. The MEn's of yellow corn and soybean meal used for calculations were 3,472 and 2,500 kcal/kg, respectively. These values correspond to those listed by NRC (National Research Council, 1977) after appropriate adjustments for moisture contents were made.
Table 2. Composition of the basal diets

<table>
<thead>
<tr>
<th></th>
<th>A Control</th>
<th>B 4.29% fat</th>
<th>C 8.57% fat</th>
<th>D 12.86% fat</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Yellow corn</strong></td>
<td>47.14</td>
<td>39.58</td>
<td>32.15</td>
<td>24.65</td>
</tr>
<tr>
<td><strong>Soybean meal, 48.5%</strong></td>
<td>37.83</td>
<td>41.10</td>
<td>44.24</td>
<td>47.43</td>
</tr>
<tr>
<td><strong>Yellow grease</strong>(^a)</td>
<td>-</td>
<td>4.29</td>
<td>8.57</td>
<td>12.86</td>
</tr>
<tr>
<td><strong>Calcium carbonate</strong></td>
<td>11.43</td>
<td>11.43</td>
<td>11.43</td>
<td>11.43</td>
</tr>
<tr>
<td><strong>Dicalcium phosphate</strong></td>
<td>2.30</td>
<td>2.30</td>
<td>2.30</td>
<td>2.30</td>
</tr>
<tr>
<td><strong>Sodium chloride</strong></td>
<td>.43</td>
<td>.43</td>
<td>.43</td>
<td>.43</td>
</tr>
<tr>
<td><strong>Vitamin premix</strong>(^b)</td>
<td>.71</td>
<td>.71</td>
<td>.71</td>
<td>.71</td>
</tr>
<tr>
<td><strong>DL-methionine, 98%</strong></td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
<td>.16</td>
</tr>
<tr>
<td><strong>Calculating analysis:</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEn (kcal/kg)</td>
<td>2585</td>
<td>2744</td>
<td>2902</td>
<td>3060</td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>22.49</td>
<td>23.42</td>
<td>24.29</td>
<td>25.17</td>
</tr>
<tr>
<td><strong>Total sulfur amino acids, %</strong></td>
<td>.87</td>
<td>.90</td>
<td>.92</td>
<td>.97</td>
</tr>
<tr>
<td><strong>Calcium, %</strong></td>
<td>4.93</td>
<td>4.94</td>
<td>4.95</td>
<td>4.96</td>
</tr>
</tbody>
</table>

\(^a\)The yellow grease (National Byproducts Co., Des Moines, Iowa 50317) had a gross energy of 9.372 kcal/g. The fatty acid composition by analysis was: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6%; others, 0.4%.

\(^b\)Six different carbohydrates were used. Corn starch had a moisture content of 10% and a calculated MEn of 3,650 kcal/kg. Values for the other ingredients were: D-glucose, no moisture, 3,500 kcal/kg; D-levulose (fructose), 9% moisture, 3,325 kcal/kg; D(+) maltose hydrate, .8% moisture, 3,580 kcal/kg; sucrose, no moisture, 3,680 kcal/kg. All these ingredients except sucrose were obtained from United States Biochemical Corporation, Cleveland, Ohio 44122. Sucrose was produced by American Crystal Sugar Co., Moorhead, Minnesota 56560.

The excreta collection method was employed to avoid some of the problems associated with the index method of determining MEn (Vohra, 1972). The 140 excreta samples were freeze-dried, allowed to come to equilibrium with atmospheric moisture and analyzed for dry matter, heat of combustion and nitrogen content. These data were used to calculate the nitrogen-corrected metabolizable energy (MEn) for all diets. Regression equations re-
lating calculated or determined MEn to dietary levels of fat were used to estimate the MEn of yellow grease and each carbohydrate source according to procedures used by Mateos and Sell (1980a). The intercepts and slopes of the regression equations were analyzed statistically by means of the Fisher (.05) test as described by Snedecor and Cochran (1967).
RESULTS AND DISCUSSION

The MEn's of the diets, as measured experimentally, increased with each increment of supplemental fat (Table 3). A comparison of the calculated and determined MEn's of the diets indicated that changes in dietary MEn's associated with supplemental fat were larger for the determined MEn's. However, the magnitude of the increases in MEn varied with the type of diet used, being greater for those diets containing a pure carbohydrate source. For example, the MEn of the sucrose diet with 3% fat and the basal diet containing 3% of fat were calculated to have 110 and 157 kcal/kg more MEn, respectively, than the same type of diets without added fat. However, the differences determined experimentally were 154 and 162 kcal/kg, respectively. To further assess this trend, the MEn's of the diets were regressed on the level of supplemental fat. The regression curves obtained were defined by the equations shown in Table 4. All of them conformed to a linear model. An analysis of the intercepts (a factors) did not reveal any significant difference between calculated and determined values for any of the diets except for the basal diets. The determined MEn's for the basal diets were significantly lower (P < .05) than the calculated MEn's for the same diets. The lower determined MEn for the basal diets may have been because of an adverse effect of the unusually high nutrient density of this diet (22.49% CP and 4.93% calcium) on energy utilization (Sues, 1974; Baldini, 1960; Sibbald et al., 1960, 1961; Mattson et al., 1979; Fedde et al., 1959).

An analysis of the regression coefficients showed that the slopes of the determined equations exceeded those of the regression equations
Table 3. Effect of supplemental yellow grease on the MEn of the diets as determined experimentally

<table>
<thead>
<tr>
<th>Carbohydrate in diet</th>
<th>0</th>
<th>3</th>
<th>6</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td>2831&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3024</td>
<td>3192</td>
<td>3327</td>
</tr>
<tr>
<td>Fructose</td>
<td>2809</td>
<td>2995</td>
<td>3151</td>
<td>3305</td>
</tr>
<tr>
<td>Glucose + fructose (50:50)</td>
<td>2798</td>
<td>2992</td>
<td>3170</td>
<td>3209</td>
</tr>
<tr>
<td>Maltose</td>
<td>2868</td>
<td>2999</td>
<td>3206</td>
<td>3326</td>
</tr>
<tr>
<td>Starch</td>
<td>2918</td>
<td>3033</td>
<td>3109</td>
<td>3396</td>
</tr>
<tr>
<td>Sucrose</td>
<td>2951</td>
<td>3105</td>
<td>3258</td>
<td>3455</td>
</tr>
<tr>
<td>Basal diet</td>
<td>2512</td>
<td>2674</td>
<td>2876</td>
<td>3063</td>
</tr>
</tbody>
</table>

<sup>a</sup>MEn (kcal/kg), "as fed" basis; pooled SE = 17.

appropriate for the calculated MEn's. The level of significance was higher for the series of diets containing a pure carbohydrate (P < .001) than for the basal diets (P < .05). These data illustrate that the MEn's of the diets, as determined experimentally, were changed more by supplemental fat than was predicted on the basis of reference MEn values of the dietary ingredients. Moreover, the extent to which supplemental fat enhanced the MEn of the diet depended on its composition. This observation agrees with those of other authors (Sibbald and Kramer, 1978; Sibbald et al., 1960; Horani and Sell, 1977; Sell et al., 1979) who showed that the MEn of the supplemental fat varied with the composition of the basal diet.

If one assumes that all changes in the determined MEn's of the diets tested herein could be assigned legitimately to supplemental yellow grease, then our data also indicate that the MEn of the fat source varied with ingredient composition of the diet. Using the above assumption and
Table 4. Regression equations relating calculated and determined MEn's of diets to level of supplemental yellow grease

<table>
<thead>
<tr>
<th>Carbohydrate in diet</th>
<th>Calculated MEn's</th>
<th>Determined MEn's</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a = intercept</td>
<td>b = slope</td>
</tr>
<tr>
<td>Glucose</td>
<td>( Y = 2,869 ) +</td>
<td>36.67X</td>
</tr>
<tr>
<td>Fructose</td>
<td>( Y = 2,808 ) +</td>
<td>36.67X</td>
</tr>
<tr>
<td>Glucose + fructose (50:50)</td>
<td>( Y = 2,838 ) +</td>
<td>36.67X</td>
</tr>
<tr>
<td>Maltose</td>
<td>( Y = 2,885 ) +</td>
<td>36.67X</td>
</tr>
<tr>
<td>Sucrose</td>
<td>( Y = 2,915 ) +</td>
<td>37.67X</td>
</tr>
<tr>
<td>Starch</td>
<td>( Y = 2,906 ) +</td>
<td>36.67X</td>
</tr>
<tr>
<td>Basal diet</td>
<td>( Y = 2,585 ) +</td>
<td>36.67X</td>
</tr>
</tbody>
</table>

1. \( r^2 = .96 \).

2. \( Y = \) MEn of the diet in kcal/kg; \( X = \) percent of supplemental yellow grease.

3. Means in the same column, not followed by the same superscript letter, are significantly different (\( P < .05 \)).
the regressions of dietary MEn vs. supplemental fat level, the MEn of yellow grease was estimated by the procedure of Mateos and Sell (1980a). The MEn's obtained were 8600, 9783, 9750, 9715, 9753, 9536 and 9510 kcal/kg of yellow grease when the fat source was tested in the basal, sucrose-, glucose-, fructose-, glucose + fructose-, starch- and maltose-containing diets, respectively. These data show that, in terms of energy contribution to the diet, the MEn of yellow grease approached or exceeded diet gross energy content (9372 kcal/kg), depending on the composition of the diet.

Others (Sibbald and Kramer, 1978; Gomez and Polin, 1979; Horani and Sell, 1977; Sell et al., 1979; Carew and Hill, 1964; Jensen et al., 1970) also have reported that, when supplemental fats are given full credit for changes in MEn of diets in which they are included, the MEn's of these energy sources exceeded their gross energy values. Because it is thermodynamically impossible for the MEn of fat to exceed its gross energy concentration, supplemental fat must have exerted an energetically favorable effect on digestibility and/or utilization of other dietary constituents. At least two mechanisms for fats influence on dietary energy utilization seem possible (Mateos and Sell, 1980b). The fatty acids of the supplemental fat may interact synergistically with those of the fat inherent in other diet constituents so that micelle formation and utilization of dietary energy are improved (Leeson and Summers, 1976; Mateos and Sell, 1980a; Lewis and Payne, 1966). Also, supplemental fat may decrease rate of food passage, thereby increasing overall energy utilization. Or, fat may be responsible for a combination of the above.
To further assess the effects of supplemental fat on energy utilization from diets containing various pure carbohydrates, it was assumed that the MEEn of yellow grease, as determined with the basal diet (8600 kcal/kg), would be representative of this fat when the pure carbohydrates were included in the diet. This assumption seems justified on the basis that the magnitude of any interaction between the supplemental fat and other dietary ingredients of the basal diet should be the same across all diets, because the ratio between added fat and each basal diet constituent remained constant within each level of added fat, irrespective of pure carbohydrate level.

Using the above rationale, the MEEn of each carbohydrate was estimated for each level of supplemental fat. Two methods of estimation were used. In the first method, the regression equations relating calculated and determined dietary MEEn's to level of supplemental fat for each carbohydrate series were used. The differences between the calculated and determined dietary MEEn's were assumed to be attributed to the test carbohydrate present in the diet. In the method of estimation, the sucrose, no-added fat diet and the MEEn for sucrose listed by National Research Council (1977) were used to calculate the portion of MEEn contributed by dietary ingredients other than fat and the carbohydrate source. Sucrose was chosen as the reference carbohydrate because estimates of its MEEn (Vohra, 1967; Potter and Matterson, 1960; Anderson, 1955) were less variable than those reported for other carbohydrates (Vohra, 1967; Sibbald, 1976; Potter and Matterson, 1960; Anderson, 1955). It should be emphasized that the MEEn's obtained as described below may not be absolute for the pure carbo-
hydrates but are relative to the MEn of sucrose. Nevertheless, these MEn's serve as a basis for comparing the effects of supplemental fats on energy utilization from the different carbohydrates.

The MEn of the basal fraction of the 30% sucrose, no-added fat diet was estimated to be:

\[
\text{Determined MEn of sucrose - contribution = MEn of basal fraction diet by sucrose}
\]

\[
2941 - (0.3 \times 3680) = 1837 \text{ kcal/kg}
\]

The MEn value obtained in this way for the basal fraction of each test diet was used to estimate the MEn of the other pure carbohydrates as determined with diets containing no added fat. The MEn of starch was estimated to be \((2896 - 1837)/.3 = 3.530 \text{ kcal/kg.} \)

The MEn's of the carbohydrates in diets containing supplemental yellow grease were estimated in an analogous manner using an MEn for yellow grease of 8600 kcal/kg as determined with the basal diet series.

The MEn's of each carbohydrate increased with each increment of supplemental fat (Table 5). When yellow grease constituted 0 or 9% of the diet, the respective MEn's (kcal/kg) were 3680 and 4023 for sucrose, 3530 and 3813 for starch, 3416 and 3700 for maltose, 3440 and 3793 for glucose, 3270 and 3603 for fructose, and 3257 and 3613 for glucose + fructose.

Similar results were obtained when a second method of estimating MEn's was used. This method utilized the differences observed between determined MEn's of the basal diets and the MEn's of the carbohydrate test diets (Table 6). Each level of supplemental fat increased the MEn of the carbohydrates. The relative magnitudes of the improvements were compara-
### Table 5. Estimate of the MEn of the carbohydrates (CHO) tested (kcal/kg)\(^a\)

<table>
<thead>
<tr>
<th>Diet CHO</th>
<th>Yellow grease %</th>
<th>Determined MEn of the diet</th>
<th>Calculated MEn</th>
<th>Corrected calculated MEn</th>
<th>Columns B-D</th>
<th>Calculated MEn of the CHO due to the diet</th>
<th>Determined MEn of the diet due to the CHO</th>
<th>Estimated MEn of the CHO (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>0</td>
<td>2941</td>
<td>2915</td>
<td>2941</td>
<td>-</td>
<td>1104</td>
<td>1104</td>
<td>3680</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3107</td>
<td>3046</td>
<td>3073</td>
<td>34</td>
<td>1104</td>
<td>1138</td>
<td>3793</td>
</tr>
</tbody>
</table>

\(^a\)Calculations based on differences between determined and calculated regression equations of the test diet (Table 4).

\(^b\)Values obtained from regression equations of determined values versus level of yellow grease (Table 4).

\(^c\)Values obtained from calculated regression equation (Table 4) and assuming that the MEn of yellow grease = 8600 kcal/kg. MEn of the sucrose diet: \( Y = 2915 + [8600 - 7900/100 + 36.67] \times \% \) yellow grease; \( Y = 2915 + 43.67x \times \% \) yellow grease.

\(^d\)Because the determined MEn of the no-added fat diet exceeded the calculated MEn, all calculated MEn's of the rations were adjusted according to the ratios 2941 kcal/kg/2915 kcal/kg = 1.0089 for the sucrose containing diets and 2896 kcal/kg/2906 kcal/kg = 0.9966 for the starch containing diets.

\(^e\)Assuming an MEn for sucrose in no-added fat diet of 3680 kcal/kg. MEn of basal fraction = determined MEn of sucrose diets - MEn contributed by sucrose = 2941 - (.3 \times 3680) = 1837 kcal/kg. MEn of the diet due to starch in no-added fat diets = Column B - 1837.

\(^f\)Sum of Columns E and F.

\(^g\)Column G divided by percentage of pure carbohydrate in the diet x 100.
Table 5. (Continued)

<table>
<thead>
<tr>
<th>Diet CHO</th>
<th>Yellow grease %</th>
<th>Determined MEn of the diet</th>
<th>Calculated MEn</th>
<th>Corrected calculated MEn</th>
<th>Columns B-D</th>
<th>Calculated MEn of the diet due to the CHO</th>
<th>Determined MEn of the diet due to the CHO</th>
<th>Estimated MEn of the CHO (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>3274</td>
<td>3177</td>
<td>3205</td>
<td>69</td>
<td>1104</td>
<td>1173</td>
<td>3910</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3440</td>
<td>3308</td>
<td>3337</td>
<td>103</td>
<td>1104</td>
<td>1207</td>
<td>4023</td>
<td></td>
</tr>
<tr>
<td>Starch&lt;sup&gt;h&lt;/sup&gt; 0</td>
<td>2896</td>
<td>2906</td>
<td>2896</td>
<td>-</td>
<td>1059</td>
<td>1059</td>
<td>3530</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3055</td>
<td>3037</td>
<td>3026</td>
<td>29</td>
<td>1059</td>
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<td></td>
</tr>
<tr>
<td>6</td>
<td>3214</td>
<td>3168</td>
<td>3157</td>
<td>57</td>
<td>1059</td>
<td>1116</td>
<td>3720</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>3373</td>
<td>3299</td>
<td>3288</td>
<td>85</td>
<td>1059</td>
<td>1144</td>
<td>3813</td>
<td></td>
</tr>
</tbody>
</table>

<sup>h</sup>MEn's (Column H) obtained for other carbohydrates by following the same procedure were:

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Yellow grease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Maltose</td>
<td>3416</td>
</tr>
<tr>
<td>Glucose</td>
<td>3440</td>
</tr>
<tr>
<td>Fructose</td>
<td>3270</td>
</tr>
<tr>
<td>Glucose + fructose (50:50)</td>
<td>3257</td>
</tr>
</tbody>
</table>
Table 6. Estimate of the MEn of the carbohydrates (CHO) tested (kcal/kg)\(^a\)

<table>
<thead>
<tr>
<th>Test diet</th>
<th>(\bar{v}.G.) level</th>
<th>(B^b)</th>
<th>Determined MEn of the test diet</th>
<th>MEn of the test diet, contributed basal part</th>
<th>MEn contributed by the pure carbohydrate</th>
<th>Estimated MEn of the carbohydrate (kcal/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sucrose</td>
<td>0</td>
<td>2941</td>
<td>1756</td>
<td>1185</td>
<td>3950</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3107</td>
<td>1887</td>
<td>1220</td>
<td>4067</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3274</td>
<td>2018</td>
<td>1256</td>
<td>4187</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3440</td>
<td>2149</td>
<td>1291</td>
<td>4303</td>
<td></td>
</tr>
<tr>
<td>Starch(^f)</td>
<td>0</td>
<td>2896</td>
<td>1756</td>
<td>1130</td>
<td>3800</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>3055</td>
<td>1887</td>
<td>1168</td>
<td>3893</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>3214</td>
<td>2018</td>
<td>1196</td>
<td>3987</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3373</td>
<td>2149</td>
<td>1224</td>
<td>4080</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\)Calculations based on differences between determined regression equations of test and basal diets (Table 4).

\(^b\)Same as Column B in Table 5.

\(^c\)\(\text{MEn of the basal diet as determined by regression equation in Table 4)}\times 70/100. For sucrose-containing, nonadded fat: \(\text{MEn} = 2508.2 \times 70/100 = 1756\ \text{kcal/kg}.

\(^d\)Difference between Column B and Column C.

\(^e\)\([\text{Column D divided by percentage of pure carbohydrate in the diet]}\times 100.

\(^f\)\(\text{MEn's in kcal/kg obtained for other carbohydrates by following the same procedure were:}\)

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Yellow grease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maltose</td>
<td>3687 3780 3870 3960</td>
</tr>
<tr>
<td>Glucose</td>
<td>3630 3743 3860 3973</td>
</tr>
<tr>
<td>Fructose</td>
<td>3540 3650 3763 3877</td>
</tr>
<tr>
<td>Glucose + fructose (50:50)</td>
<td>3526 3643 3757 3873</td>
</tr>
</tbody>
</table>
ble to those observed with the first method of calculation. It is noteworthy, however, that all MEn's of specific carbohydrates at each level of supplemental fat were higher than those of Table 5. We believe that these discrepancies were because of the unusually low MEn determined for the basal diets. The basal diets contained relatively high concentrations of protein and minerals, and these have been shown to have an adverse effect on MEn's of a diet (Sues, 1974; Baldini, 1960; Sibbald et al., 1961; Fedde et al., 1959). The inclusion of a carbohydrate in the basal diet at a level of 30% may have nullified most of the adverse effect of the high nutrient concentration, resulting in an overall increase in the utilization of the energy as a consequence of the improved utilization of constituents of the basal diet. The second method of estimating MEn's of the carbohydrates gave full credit to the test carbohydrate for the energy increase resulting from better utilization of the basal diet fraction and that resulting from the presence of the carbohydrate being tested. Consequently, relatively high MEn's for all carbohydrates were obtained with the second method of estimation. Nevertheless, the main effect of supplemental fat on energy utilization from the various carbohydrates remains clear. Regardless of method of estimation, the inclusion of yellow grease in the diet increased the MEn of each carbohydrate. Expressing the MEn's of the carbohydrates, as estimated by the two procedures described, in a relative index form with the MEn's of sucrose set equal to 100 facilitated further comparisons (Table 7). For each level of fat, sucrose had a significantly (P < .05) higher MEn than did the other carbohydrates, including starch. The latter observation is contradictory to the MEn data for
Table 7. Relative ME values of pure carbohydrates at different levels of supplemental yellow grease$
\text{a}$

<table>
<thead>
<tr>
<th>Carbohydrate</th>
<th>Level of yellow grease, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Glucose</td>
<td>94$^b$</td>
</tr>
<tr>
<td></td>
<td>92</td>
</tr>
<tr>
<td>Fructose</td>
<td>89</td>
</tr>
<tr>
<td></td>
<td>90</td>
</tr>
<tr>
<td>Glucose + fructose (50:50)</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>89</td>
</tr>
<tr>
<td>Maltose</td>
<td>93</td>
</tr>
<tr>
<td></td>
<td>93</td>
</tr>
<tr>
<td>Starch</td>
<td>96</td>
</tr>
<tr>
<td></td>
<td>96</td>
</tr>
<tr>
<td>Sucrose</td>
<td>100</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

$^a$Assuming an index value of 100 for sucrose in the no-added fat diet.

$^b$First value represents ME values estimated from regression equations relating calculated or determined diet ME values to fat level. The second value was obtained using differences between ME values of test and basal diets as bases for estimation.

Sucrose and starch listed by National Research Council (1977). This disagreement may be attributable to the origin of the starch, the age of the animal (hens vs. chicks) or to the method of ME determination.

The mechanism(s) by which supplemental fat exerted a favorable effect on ME values of the test diets is not known. Positive effects of interactions among fatty acids of dietary constituents have been reported (Leeson and Summers, 1976; Mateos and Sell, 1980b; Lewis and Payne, 1966). In the case of carbohydrate x supplemental fat interaction, however, another mechanism must be involved. It has been shown with mammals (Roberts, 1930; Card,
1941; Thomas, 1957; Quigley and Louckes, 1962; Rogers and Harper, 1966; Davenport, 1978) and with avians (Duke and Evanson, 1972) that fats, through a neuro-hormonal mediated response, are powerful inhibitors of the gastric emptying. In turn, gastric emptying has been postulated to be the primary mechanism controlling rate of food passage and therefore rate of food utilization (Hunt and Knox, 1968; Rerat et al., 1976). Thus, fat could augment the utilization of energy from other dietary ingredients by slowing the rate of passage of the diet through the gut (Mateos and Sell, 1980b). In our study, energy utilization from sugars (glucose, fructose and sucrose) was increased more by fat supplementation than was that from starch and its derivative maltose (P < .05). Rerat et al. (1976) indicated that the rate of gastric emptying was decreased by corn starch because of a rapid release of glucose and a subsequent increase in osmotic pressure in the intestine. On the other hand, when a sugar such as sucrose is used in large quantities, hypertonic conditions in the intestinal lumen may result, causing hydration of ingesta (Cunningham, 1959; Rosenberg, 1953) and an increase in rate of food passage (Gonzalez and Ibanez, 1979). Thus, it might be expected that fat supplementation would increase the utilization of sucrose more than that of starch, as was observed in the current research.

When arranged according to the magnitude of the beneficial effect of yellow grease supplementation of ME'n's, the carbohydrates tested followed a descending order of sucrose, glucose and fructose, maltose, starch and the practical ingredient mixture. Reports by several authors (Vohra, 1967; Rao and Clandinin, 1970; Monson et al., 1950; Stokstad et al., 1953;
Griminger and Fisher, 1963) suggested that an appropriate arrangement of
the same ingredients from faster to slower rate of passage would be su-
crose, fructose, glucose, starch and a practical ingredient mixture.
These data are compatible with the concept that supplemental fat may im-
prove energy utilization by slowing rate of food passage, and that, rela-
tively speaking, this effect of fat would be most prominent with ingredi-
ents having a fast rate of passage through the gut.

We conclude that the "extracaloric" effect of supplemental fat on the
MEen of diets may result, in large measure, from a reduction in rate of
food passage, whereby the overall digestibility of the diet is increased.
This mechanism does not exclude the beneficial effects of synergism be-
tween saturated and unsaturated fatty acids, whereby micelle formation and
absorbability of total dietary fat are enhanced. In fact, a reduction in
rate of passage could augment this type of interaction.
REFERENCES


Quigley, J. P., and M. S. Louckes. 1962. Gastric emptying. Am. J. Dig. Dis. 7:672-676.


SECTION V. NATURE OF THE EXTRAMETABOLIC EFFECT OF SUPPLEMENTAL FAT USED IN SEMIPURIFIED DIETS FOR LAYING HENS
NATURE OF THE EXTRAMETABOLIC EFFECT OF SUPPLEMENTAL FAT USED IN SEMIPURIFIED DIETS FOR LAYING HENS

Gonzalo G. Mateos
Jerry L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
An experiment involving 20 birds was conducted to quantitate the extrametabolic effect of yellow grease used in semisynthetic diets for laying hens. Four diets were arranged as a 2 x 2 factorial with two levels of fat (0 and 7%) and two carbohydrate sources (sucrose and starch). The nitrogen-corrected metabolizable energy (MEn) of yellow grease was calculated from lipid digestibility data and from actual determination of dietary MEn. The MEn of yellow grease varied with the dietary carbohydrate source and with the procedure used for estimation. When yellow grease was added to a starch-containing diet, the MEn of the fat was 8497 and 9714 kcal/kg from the lipid digestibility data and actual MEn determination, respectively. In the sucrose-containing diet the MEn of yellow grease was 8210 and 10071 kcal/kg, respectively. The data suggest that supplemental fat facilitated energy utilization from nonlipid constituents of the diet. The mechanism is unknown but may be related to a decrease in rate of food passage as a consequence of fat supplementation.
INTRODUCTION

Dietary fats have been shown to improve efficiency of feed utilization of poultry diets (March and Biely, 1963; Vermeersch and Vanschoobroek, 1968). The improvement is attributed to the high energy concentration of fats. Recently, several reports indicate that the generally recognized metabolizable energy (ME) of supplemental fats underestimates the true energy contribution of fats to diets for growing poultry (Jensen et al., 1970; Whitehead and Fisher, 1975) and laying hens (Sell et al., 1979; Mateos and Sell, 1980a). In measuring the ME of fats, lipid is substituted for part of a reference diet at a specific level. Then, the ME's of the reference and test diets are measured, and the ME of fat is calculated by difference. It is assumed that interactions among ingredients are negligible and, therefore, that dietary constituents will be utilized in an additive manner. Several researchers (Gomez and Polin, 1974; Sell, 1977; Sibbald and Price, 1977; Halloran and Sibbald, 1979), however, have obtained ME values for supplemental fats that exceeded the gross energy of fats. It is thermodynamically impossible for the ME of a feed ingredient to exceed its gross energy. Thus, it is logical to suggest that supplemental fats improve the utilization of other dietary constituents, thereby increasing dietary ME beyond expectations. Also, it is evident that the ME of a diet supplemented with fat cannot be calculated accurately from the additive contributions of the individual ingredients.

Data presented by Young (1961), Lewis and Payne (1966), Leeson and Summers (1976) and Sibbald (1978) indicated that the presence of unsaturated fatty acids in diet constituents may improve the ability of chickens
to absorb supplemental fat. Thus, the extrametabolic effect of supplemental animal fats in poultry diets could be due to a synergism between the saturated fatty acids of the supplemental fat and the unsaturated fatty acids of vegetable origin whereby micelle formation and overall fat absorption are improved. Data obtained by Sibbald and Kramer (1978), indicating that the true metabolizable energy of tallow was greater in a corn- than in a wheat-based diet, support this hypothesis. Synergism among dietary fatty acids, however, cannot explain satisfactorily the entire extrametabolic effect attributable to vegetable oils (Cullen et al., 1962; Mateos and Sell, 1980b) or MEn of fats reported to be greater than their gross energy.

Kalmbach and Potter (1959) obtained higher ME values for corn oil and for tallow when these fats were added at expense of the basal diet than when they were added at expense of cerelose. Horani and Sell (1977) reported that the ME of tallow differed according to the cereal used as main ingredient in the diet. Recently, Mateos and Sell (1980c) found that the nitrogen-corrected metabolizable energy (MEn) of supplemental yellow grease varied with the specific carbohydrate used as a main dietary ingredient. In these experiments, it was assumed that all changes between test and control diets were exclusively the result of fat supplementation.

These data indicate that the extrametabolic effect of added fat may be the result of an improvement in overall energy utilization of the diet. More precise data is needed, however, about the nature of this extrametabolic effect of supplemental fat. Therefore, the research reported herein was conducted to quantitate and more closely define the extra-
metabolic effect of yellow grease when used in semisynthetic diets for laying hens in which either sucrose or starch constituted the main ingredient.
EXPERIMENTAL PROCEDURES

Single Comb White Leghorn hens, 60 weeks of age, were kept in individual cages located in an environmentally controlled room at 27°C. Feed and water were offered ad libitum. Twenty hens were used in a 2 x 2 factorial design with two levels of yellow grease (0 and 7%) and two carbohydrate sources (sucrose or starch). Although the diets containing supplemental fat had a greater energetic concentration than those with no added fat, appropriate adjustments were made in the corn, soybean meal and methionine levels to maintain the same MEn:protein and MEn:methionine ratios as in the diets not supplemented with fat (Table 1). After a 6-day adaptation period, the hens were fed their respective experimental diet for another 5 days. Feed consumption was recorded, and excreta were collected on a quantitative basis every 60 hours from each hen. The excreta samples were freeze-dried, allowed to come to equilibrium with atmospheric moisture and then were analyzed for dry matter, heat of combustion, nitrogen, chromic oxide, and total lipid content. Chromium was analyzed by atomic absorption spectrophotometry (Perkin-Elmer, Model 460) after wet ashing of samples. The MEn's of the diets were calculated from data obtained by both total collection and the chromic oxide index method. The average MEn of both methods obtained for each hen was used in subsequent calculations. Ten additional hens were used to determine the nitrogen-corrected metabolizable energy (MEn) of the corn and soybean meal used. Each of two diets containing exclusively corn and soybean meal as energy-contributing ingredients (Table 2) was fed to five hens, and excreta were collected and analyzed. The MEn of corn and soybean meal was
Table 1. Composition of the experimental diets, %

<table>
<thead>
<tr>
<th></th>
<th>Starch-no fat</th>
<th>Sucrose-no fat</th>
<th>Starch-added fat</th>
<th>Sucrose-added fat</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>St-0</td>
<td>Su-0</td>
<td>St-7</td>
<td>Su-7</td>
</tr>
<tr>
<td>Yellow corn</td>
<td>12.18</td>
<td>12.18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soybean meal, 48.5%</td>
<td>30.00</td>
<td>30.00</td>
<td>35.17</td>
<td>35.17</td>
</tr>
<tr>
<td>Sucrose(^a)</td>
<td>-</td>
<td>47.00</td>
<td>-</td>
<td>47.00</td>
</tr>
<tr>
<td>Starch(^a)</td>
<td>47.00</td>
<td>-</td>
<td>47.00</td>
<td>-</td>
</tr>
<tr>
<td>Yellow grease(^a)</td>
<td>-</td>
<td>-</td>
<td>7.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
</tr>
<tr>
<td>Salt</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Vitamin premix(^b)</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>DL-methionine, 98%</td>
<td>.12</td>
<td>.12</td>
<td>.13</td>
<td>.13</td>
</tr>
<tr>
<td>Chromic oxide</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
</tbody>
</table>

Calculated analysis:\(^c\)

<table>
<thead>
<tr>
<th></th>
<th>MEn (kcal/kg)</th>
<th>Crude protein, %</th>
<th>Total sulfur aminoacids, %</th>
<th>Methionine, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2869</td>
<td>15.82</td>
<td>.59</td>
<td>.36</td>
</tr>
<tr>
<td></td>
<td>2884</td>
<td>15.62</td>
<td>.59</td>
<td>.36</td>
</tr>
<tr>
<td></td>
<td>3130</td>
<td>17.26</td>
<td>.64</td>
<td>.38</td>
</tr>
<tr>
<td></td>
<td>3144</td>
<td>17.06</td>
<td>.64</td>
<td>.38</td>
</tr>
</tbody>
</table>

\(^a\)Sucrose was produced by American Crystal Sugar Co., Moorhead, Minnesota 56560, and had a gross energy of 3930 kcal/kg. Corn starch was obtained from United States Biochemical Corp., Cleveland, Ohio 44122, and had a gross energy of 3750 kcal/kg. The yellow grease (National Byproducts Co., Des Moines, Iowa 50317) had a gross energy of 9375 kcal/kg. The fatty acid composition by analysis was: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6%; others, 0.4%.

\(^b\)Supplied the following per kg of diet: vitamin A, 8000 I.U.; vitamin D\(_3\), 2400 I.U.; vitamin B\(_{12}\), 5 μg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg and ethoxyquin, 11 mg.

\(^c\)Based on National Research Council (1977) values.
Table 2. Composition of the diets used to determine the MEn of soybean meal and corn

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Diet A</th>
<th>Diet B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow corn</td>
<td>70.0</td>
<td>50.0</td>
</tr>
<tr>
<td>Soybean meal, 48.5% protein</td>
<td>20.0</td>
<td>40.0</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Salt</td>
<td>.3</td>
<td>.3</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;a&lt;/sup&gt;</td>
<td>.5</td>
<td>.5</td>
</tr>
</tbody>
</table>

<sup>a</sup>Supplied the following per kg of diet: vitamin A, 8000 I.U.; vitamin D<sub>3</sub>, 2400 I.U.; vitamin B<sub>12</sub>, 5 µg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg and ethoxyquin, 11 mg.

determined by resolution of simultaneous equations based on the data obtained.

The MEn's of the two carbohydrates used (sucrose and starch) were calculated by subtracting the MEn supplied by the corn and the soybean meal portion of the diets from the determined MEn of the diets not supplemented with fat (Su-0 and St-0). It was assumed that the MEn's of the dietary ingredients were additive.

The MEn of yellow grease was obtained by two different methods. In method 1, lipids from diets and feces were extracted by the procedure described by the Association of Official Analytical Chemists (Procedure 7047, AOAC, 1975). The apparent digestibility of yellow grease in both sucrose- and starch-containing diets (Su-7 and St-7, respectively) was calculated by using these data. The MEn of yellow grease was then calculated by multiplying the gross energy content of yellow grease times the apparent digestibility. In method 2, the MEn's of yellow grease were
calculated by subtracting the MEn supplied by the soybean meal and the specific carbohydrate from the MEn obtained experimentally for the fat-supplemented diets (Su-7 and ST-7). Again, it was assumed that MEn's of dietary ingredients were additive.

Analysis of variance for treatments arranged factorially was used to statistically analyze the data (Snedecor and Cochran, 1967).
RESULTS AND DISCUSSION

The MEn of the diets, as determined experimentally, increased with fat supplementation (Table 3). A comparison of the calculated and determined MEn's indicated that changes in dietary MEn associated with supplemental fat were greater in the latter instance. Also, the difference was larger for the sucrose-containing diet (445 kcal/kg) than for the starch-containing diet (416 kcal/kg). The calculated change, based on National Research Council (1977) values, was 264 kcal/kg in both instances.

The MEn's obtained for corn and soybean meal were 3415 and 2460 kcal/kg, respectively. These values were similar to those listed by the National Research Council (1977) (3430 and 2440 kcal/kg, respectively). Assuming additivity of MEn values of dietary ingredients, the MEn of the sucrose and starch was estimated by using the data obtained from diets not supplemented with fat. For example, the MEn of starch was calculated by subtracting the MEn supplied by the corn and the soybean meal (.1218 x 3415 + .30 x 2460 kcal/kg) from the calculated MEn of the St-0 diet (2811 kcal/kg). Thus, the energy supplied by starch to the diet was 2811 - 1154 = 1657 kcal, and the MEn of starch was 1657/47 x 100 = 3525 kcal/kg. By the same method of calculation, the MEn of sucrose was estimated to be 3717 kcal/kg. Both MEn values are in the range reported in the literature for starch and sucrose (Vohra, 1967).

The MEn of yellow grease was estimated by two methods. In the first method, additivity of the MEn's contributed to the starch- or sucrose-containing diets by the carbohydrate and soybean meal was assumed. For example, in the St-7 diet, soybean meal supplied 865 kcal of MEn
Table 3. Nitrogen corrected-Metabolizable energy of the experimental diets (MEn) obtained by the total collection and by the chromic oxide index method (kcal/kg)

<table>
<thead>
<tr>
<th>Diet</th>
<th>Calculated&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Determined MEn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Total collection&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>St-0</td>
<td>2869</td>
<td>2831±31&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Su-0</td>
<td>2884</td>
<td>2918±42</td>
</tr>
<tr>
<td>St-7</td>
<td>3130</td>
<td>3197±57</td>
</tr>
<tr>
<td>Su-7</td>
<td>3144</td>
<td>3305±64</td>
</tr>
</tbody>
</table>

<sup>a</sup>National Research Council (1977).

<sup>b</sup>Main effects of fat supplementation and sucrose on MEn of diet were significant (P < .001).

<sup>c</sup>Mean ± standard deviation.

(0.3517 x 2460) and starch supplied 1657 kcal (0.47 x 3525) for a total of 2522 kcal/kg of diet. Because the determined MEn of the diet was 3202 kcal/kg, the MEn supplied by yellow grease would be the difference, 680 kcal (3202 - 2522 kcal). Therefore, the MEn of yellow grease in the starch-containing diets, assuming additivity of the MEn's from the carbohydrate and soybean meal, was 680/7 x 100 = 9714 kcal/kg. By the same procedure, the MEn of yellow grease in the sucrose-containing diet (Su-7) was calculated to be 10071 kcal/kg [(3317 - 865 - 1747)/7] x 100.

The MEn's of yellow grease, estimated in a conventional manner, exceeded the gross energy of this fat source by a considerable margin. Therefore, these results indicate that supplementation of starch- or sucrose-containing diets with yellow grease improved the utilization of
energy contained in the nonfat constituents of the diets as was suggested previously by Mateos and Sell (1980c).

The second method of estimating the MEn of yellow grease involved the use of the lipid digestibility data. The MEn of yellow grease was calculated by multiplying the apparent digestibility coefficients times the gross energy of yellow grease. The resulting MEn's were 8497 (0.9063 x 9375) and 8210 (0.8757 x 9375) kcal/kg for the starch- and sucrose-containing diets, respectively. These values were considerably lower than the values obtained by assuming additivity of MEn's of dietary ingredients (9714 and 10071 kcal/kg, respectively). Similar discrepancies have been reported by Whitehead and Fisher (1975) in turkeys and by Gomez and Polin (1974) in broilers.

In the starch diet, yellow grease contributed 680 kcal of MEn to the diet (.07 x 9714 kcal/kg), according to MEn of ingredient data, but yellow grease contributed only 595 kcal of MEn (.07 x 8497 kcal/kg) according to the lipid digestibility data. Thus, the difference between MEn's obtained by the two methods (680 - 595 = 85 kcal per 7% yellow grease) could represent the beneficial effect of supplemental fat on the utilization of the energy contained in the other ingredients of the St-7 diet (starch and soybean meal). In the sucrose diet, yellow grease contributed 705 kcal to the MEn of the diet (.07 x 10071 kcal/kg) on the basis of actual MEn determination. On the basis of lipid digestibility data, however, yellow grease supplied 575 kcal (.07 x 8210 kcal/kg). The difference between these two values (705 - 575 = 130 kcal) would be an estimate of the improvement in the utilization of energy of other dietary ingredients.
(soybean meal and sucrose) as a result of yellow grease supplementation to sucrose-containing diets.

If we assume, for comparative purposes, that supplemented fat benefitted carbohydrate utilization but not soybean meal utilization, then the MEn of starch and sucrose in fat-supplemented diets would be 3706 kcal/kg \([(1657 + 85)/47]\times 100 \text{ and } 3994 \text{ kcal/kg } [(1747 + 130)/47]\times 100, \text{ respectively.}

These last values contrast to the MEn of starch and sucrose obtained in the diets not supplemented with fat (3525 and 3717 kcal/kg, respectively). It would seem that fat supplementation of the semisynthetic diets tested here increased the MEn of starch and sucrose by 5.1 and 7.4%, respectively. Similar data were presented by Mateos and Sell (1980c) for sucrose and starch, on the basis of differences between calculated and determined MEn's of experimental diets.

These results and those reported by others (Gomez and Polin, 1974; Sibbald and Kramer, 1978; Mateos and Sell, 1980b,c,d) indicate that the extrametabolic effect of supplemental fats in poultry diets is mainly the result of improvements in the utilization of energy contained in other dietary ingredients. In the present study, yellow grease supplementation improved the utilization of the energy from diets containing sucrose more than from diets containing starch.

The mechanisms by which supplemental fat enhances energy utilization of dietary ingredients are not clear. Leeson and Summers (1976) and Sibbald and Kramer (1977) indicated that fatty acid synergism resulted in an extrametabolic effect of fats in poultry diets. Fatty acid synergism has been shown to improve digestibility of supplemental animal fats.
(Artman, 1964; Mattson et al., 1979). In the present study, the beneficial effect of fatty acid synergism on fat utilization may have resulted in an improved digestibility for yellow grease. Fatty acid synergism could explain the observation that MEn of yellow grease obtained from lipid digestibility data (8497 and 8210 kcal/kg in the starch- and in the sucrose-containing diets, respectively) were higher than expected on the basis of literature values (7900 kcal/kg). But the differences observed between the expected MEn of yellow grease and those obtained by assuming additivity of dietary constituents (7900 vs. 9714 and 10071 kcal/kg in starch- and sucrose-containing diets, respectively) cannot be rationalized on this basis.

It seems plausible that supplemental fat may have improved the utilization of energy from diets by reducing the rate of food passage, thereby facilitating more complete digestion and absorption (Mateos and Sell, 1980c). The exceptionally greater extrametabolic effect of yellow grease on MEn's of sucrose- vs. starch-containing diets support this hypothesis. Although fat supplementation improved MEn's of sucrose- and starch-containing diets, the largest change was observed with the former. The rate of passage of sucrose through the digestive tract has been shown to exceed that of starch (Monson et al., 1950; Mateos and Sell, 1981). Thus, a slowing in the rate of passage might be expected to be more beneficial for the utilization of sucrose-based diets than for diets based on starch. The results reported here show that supplemental fat exerted this effect with respect to energy utilization.
Table 4. Apparent digestibility of lipids of the experimental diets

<table>
<thead>
<tr>
<th>Diet</th>
<th>Total lipid intake, g/5 days</th>
<th>Apparent lipid(^a) digestibility, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>St-0</td>
<td>6.3±0.8(^b)</td>
<td>65.03±2.19</td>
</tr>
<tr>
<td>Su-0</td>
<td>5.0±1.6</td>
<td>58.48±3.01</td>
</tr>
<tr>
<td>St-7</td>
<td>28.9±7.4</td>
<td>90.63±2.75</td>
</tr>
<tr>
<td>Su-7</td>
<td>37.0±5.5</td>
<td>87.57±3.00</td>
</tr>
</tbody>
</table>

\(^a\)Significant main effects of supplemented fat (P < .001) and starch (P < .01) on lipid digestibility.

\(^b\)Mean ± standard deviation.
REFERENCES


SECTION VI. INFLUENCE OF FAT AND CARBOHYDRATE SOURCE ON RATE OF FOOD PASSAGE OF SEMIPURIFIED DIETS FOR LAYING HENS
INFLUENCE OF FAT AND CARBOHYDRATE SOURCE ON RATE OF FOOD PASSAGE
OF SEMIPURIFIED DIETS FOR LAYING HENS

Gonzalo G. Mateos
Jerry L. Sell

From the Department of Animal Science
Iowa State University, Ames, Iowa 50011
SUMMARY

An experiment was conducted with White Leghorn hens to determine the influence of supplemental yellow grease and carbohydrate source on rate of food passage (ROP). Two levels of yellow grease (0 and 7%) and two carbohydrate sources (sucrose and starch) were tested in a complete 2 x 2 factorial arrangement. ROP was determined utilizing either Cr$_2$O$_3$ or $^{144}$Ce as nonabsorbable markers. First appearance of the markers in the excreta and percentages of the markers ingested that were recovered in feces 9.5 to 11.5 hr after feeding were criteria used to determine ROP. ROP varied with the composition of the diet. Diets containing starch had a slower rate of passage than diets containing sucrose. First appearance time was 156 vs. 127 min, respectively. Also, yellow grease supplementation decreased ROP (150 vs. 133 min, respectively). The ROP of sucrose-containing diets was decreased more by fat supplementation than the ROP of starch-containing diets (32 vs. 3 min, respectively). Similar trends were observed when ROP was measured as percentage of marker recovered in feces 9.5 to 11.5 hr after feeding. The results show that supplemental fat decreased ROP in chickens. This observation may help in understanding the nature of the extrametabolic or extracaloric effect of fat in poultry diets. With decreased ROP, the diet will be more thoroughly digested and absorbed and thereby more energy may be derived from a diet if fat is added than if fat is not supplemented.
INTRODUCTION

Rate of food passage (ROP) through the digestive tract may be an important factor influencing the amount of energy that is derived from diets by monogastrics (Maner et al., 1962; Rao and Clandinin, 1970; Keys and DeBarthe, 1974; Kass et al., 1980). ROP may influence energy utilization of diets by: 1) changing the microbial population of the gut, 2) modifying feed intake capacity and 3) determining the length of time during which nutrients are exposed to the digestive enzymes and to the absorptive surfaces.

In the chicken, Monson et al. (1950) and Stokstad et al. (1953) observed that rate of food passage varied with the carbohydrate composition of the diet. Sucrose-containing diets had a faster rate of passage than starch-containing diets. There is not, however, any report in the literature clearly describing the effects of supplemental fat on rate of food passage. Duke and Evanson (1972) observed that corn oil placed in the small intestine of turkeys decreased stomach emptying contractions and thereby, speed of food passage was probably reduced. Tuckey et al. (1958), however, found inconsistencies in the effects of supplemental fat on first appearance of an indicator (ferric oxide) in chicken feces. Fats decreased rate of passage in some experiments but not in others. In the laying hen, fats are known to exert an extrametabolic effect on energy utilization (Horani and Sell, 1977; Mateos and Sell, 1980a). Indeed, Mateos and Sell (1980b) observed that yellow grease increased the nitrogen-corrected metabolizable energy (MEn) of diets containing single carbohydrates more than the MEn of diets containing practical ingredients.
Also, they observed that this effect of supplemental fat was of greater magnitude in sucrose-containing diets than in starch-containing diets. They suggested that fats may increase energy utilization of other dietary constituents by slowing the rate of food passage through the digestive tract. In view of these findings, the research reported herein was conducted to examine the influence of yellow grease supplementation and carbohydrate composition of the diet on rate of food passage. First appearance in feces of two markers (Cr$_2$O$_3$ and $^{144}$Ce) fed to laying hens and the percentage of the marker recovered in feces 9.50 to 11.50 hr after feeding were used as criteria for rate of food passage.
MATERIALS AND METHODS

Single Comb White Leghorn, 60 weeks of age hens, were kept in individual cages located in an environmentally controlled room at 27°C. Two levels of yellow grease (0 and 7%) and two carbohydrate sources (sucrose and starch) were tested in a complete 2 x 2 factorial arrangement. The composition of the four test diets is shown in Table 1. Each diet was assigned to five hens. After a 10-day adaptation period in which the hens received their respective diet without a marker, the rate of passage through the digestive tract was measured in four different periods.

Chromic oxide (Cr₂O₃, MW = 152.02) was used as a fecal marker for the first two periods. A radioactive rare earth element, Ce¹⁴⁴, that has been shown to flow through the digestive tract in close association with the indigestible feed residues (Huston and Ellis, 1965; Miller et al., 1967), was used in the last two periods.

In period 1, the hens were fasted for 30 min before they were fed their respective diets supplemented with .3% Cr₂O₃ as an indicator. Marked feed was supplied for 5 hr and then all birds were switched to the original diets without indicator. Time of first appearance of the marker in the feces, as detected by visual observation, was recorded for each hen. In addition, the percentage of the total marker ingested that was recovered in feces 5 hr after the withdrawal of the marked diet was determined. In period 2, a similar procedure to that of period 1 was followed except the birds were fasted for 14 hr before the marked feed was given.

In period 3, the hens were also fasted for 30 min, but Ce¹⁴⁴ rather than Cr₂O₃, was used as a fecal marker. The Ce¹⁴⁴ was added to the diet
Table 1. Composition of the experimental diets, %

<table>
<thead>
<tr>
<th></th>
<th>Starch- no fat (St-0)</th>
<th>Sucrose- no fat (Su-0)</th>
<th>Starch- added fat (St-7)</th>
<th>Sucrose- added fat (Su-7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow corn</td>
<td>12.18</td>
<td>12.18</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Soybean meal, 48.5%</td>
<td>30.00</td>
<td>30.00</td>
<td>35.17</td>
<td>35.17</td>
</tr>
<tr>
<td>Sucrose&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>47.00</td>
<td>-</td>
<td>47.00</td>
</tr>
<tr>
<td>Starch&lt;sup&gt;a&lt;/sup&gt;</td>
<td>47.00</td>
<td>-</td>
<td>47.00</td>
<td>-</td>
</tr>
<tr>
<td>Yellow grease&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
<td>7.00</td>
<td>7.00</td>
</tr>
<tr>
<td>Calcium carbonate</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Dicalcium phosphate</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
<td>1.60</td>
</tr>
<tr>
<td>Salt</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Vitamin premix&lt;sup&gt;b&lt;/sup&gt;</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
<td>.50</td>
</tr>
<tr>
<td>Chromic oxide</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
<td>.30</td>
</tr>
<tr>
<td>Calculated analysis:&lt;sup&gt;c&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MEn (kcal/kg)</td>
<td>2869</td>
<td>2884</td>
<td>3130</td>
<td>3144</td>
</tr>
<tr>
<td>Crude protein, %</td>
<td>15.82</td>
<td>15.62</td>
<td>17.26</td>
<td>17.06</td>
</tr>
<tr>
<td>Total sulfur amino</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>acids, %</td>
<td>.59</td>
<td>.59</td>
<td>.64</td>
<td>.64</td>
</tr>
<tr>
<td>Methionine, %</td>
<td>.36</td>
<td>.36</td>
<td>.38</td>
<td>.38</td>
</tr>
</tbody>
</table>

<sup>a</sup>Sucrose was produced by American Crystal Sugar Co., Moorhead, Minnesota 56560, and had a gross energy of 3930 kcal/kg. Corn starch was obtained from United States Biochemical Corp., Cleveland, Ohio 44122, and had a gross energy of 3750 kcal/kg. The yellow grease (National Byproducts Co., Des Moines, Iowa 50317) had a gross energy of 9375 kcal/kg. The fatty acid composition by analysis was: myristic, 1.8%; palmitic, 24.7%; palmitoleic, 2.6%; stearic, 15.8%; oleic, 44.4%; linoleic, 9.7%; linolenic, 0.6%; others, 0.4%.

<sup>b</sup>Supplied the following per kg of diet: vitamin A, 8000 I.U.; vitamin D<sub>3</sub>, 2400 I.U.; vitamin B<sub>12</sub>, 5 µg; riboflavin, 6.6 mg; pantothenate, 6.6 mg; niacin, 22 mg; choline, 440 mg; and ethoxyquin, 11 mg.

<sup>c</sup>Based on National Research Council (1977) values.
by adsorbing the isotope on 40 g of an anion exchange resin (Amberlite IRA-400, Mallinckrodt) and mixing this premix with 500 g of feed (Chandler and Cragle, 1962). The final concentration of $^{144}$Ce in each test diet was about 50 μCi per kg of diet. The radioactive feed was offered to the birds for 5.5 hours. Then, the hens were fed the original unmarked diets. Excreta from the hens were collected as produced from the beginning of $^{144}$Ce feeding and each sample was monitored for $^{144}$Ce activity using a Tracor Model 1197 gamma counter. The time after feeding required for the radioactivity level of the feces to reach 2000 disintegrations per minute (dpm) was used as an estimate of rate of passage of the diets. In addition, feces were collected 6 hours after withdrawing the marked diets (11.5 hours after marked feed was offered) and the percentage of the ingested $^{144}$Ce recovered in the total excreta was calculated for each hen.

In period 4, feces were collected as produced after the beginning of $^{144}$Ce feeding program. Excreta collection was continued until $^{144}$Ce had appeared in the excreta of each hen in at least 4 consecutive periods. First appearance of the marker in feces was calculated by regressing total $^{144}$Ce excreted vs. time of excreta sampling and extrapolating to zero $^{144}$Ce excretion. Blood samples were taken from each hen 8 hours post-$^{144}$Ce feeding by heart puncture to check for the presence of $^{144}$Ce that may have been absorbed.

Analysis of variance for treatments arranged factorially was used to statistically analyze the data (Snedecor and Cochran, 1967).
RESULTS AND DISCUSSION

Rate of food passage was affected by the composition of the diet (Table 2). Diets containing starch had a slower rate of passage than diets containing sucrose, according to all four methods of measurement of first appearance of the marker in the feces. On the average, the marker appeared 29 min later in excreta of hens receiving starch-containing diets than in excreta of hens fed sucrose-containing diets (156 vs. 127 min, respectively). The effect of carbohydrate composition of diet on rate of food passage was significant at $P \leq .01$ (Table 3).

Yellow grease supplementation increased the amount of time required after feeding for the marker to appear in feces (Table 2). Fat supplementation decreased rate of food passage by about 12% (133 vs. 150 min for the nonsupplemented and fat-supplemented diets, respectively). Although the addition of yellow grease to the diet decreased rate of passage of both sucrose- and starch-containing diets, this effect was greater for the diet containing sucrose. For example, fat decreased the average rate of passage of the starch diets by only 3 min but reduced the rate of passage of the sucrose diet by 32 min (Table 2). The interaction between fat supplementation and carbohydrate composition of diet was significant at $P = .09$ (Table 3).

Similar results also were observed when rate of passage was measured as percentage of the total marker ingested that was recovered in feces 9.5 to 11.5 hours after the markers were fed (Table 4). The variability among hens, however, was higher for the total recovery data than for the
Table 2. Influence of carbohydrate source and fat supplementation on time of first appearance of marker in excreta

<table>
<thead>
<tr>
<th></th>
<th>Cr_2O_3^a</th>
<th>144Ce^b</th>
<th>Average^c</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Period 1</td>
<td>Period 2</td>
<td>Period 3</td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No added fat</td>
<td>219(^d)</td>
<td>144</td>
<td>124</td>
</tr>
<tr>
<td>Sucrose</td>
<td>121</td>
<td>105</td>
<td>114</td>
</tr>
<tr>
<td>Starch</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7% added fat</td>
<td>202</td>
<td>159</td>
<td>140</td>
</tr>
<tr>
<td>Sucrose</td>
<td>166</td>
<td>138</td>
<td>135</td>
</tr>
<tr>
<td>Main effects:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>210</td>
<td>151</td>
<td>132</td>
</tr>
<tr>
<td>Sucrose</td>
<td>143</td>
<td>121</td>
<td>124</td>
</tr>
<tr>
<td>Added fat</td>
<td>184</td>
<td>148</td>
<td>137</td>
</tr>
<tr>
<td>No added fat</td>
<td>170</td>
<td>124</td>
<td>119</td>
</tr>
</tbody>
</table>

^aIn period 1 the birds were fasted for 30 min and then fed the marked diet. In period 2 the birds were fasted for 14 hr before feeding the marked diet.

^bIn periods 3 and 4 birds were fasted for 30 min and then fed the 144Ce marked diet. The criterion for first appearance was based on dpm > 2000 in period 3 and on regression equations in period 4.

^cAverages of four measurements per each hen.

^dMinutes after feeding.
Table 3. Statistical analysis of the data obtained by the first appearance of marker procedure

<table>
<thead>
<tr>
<th>Method</th>
<th>Fat</th>
<th>Starch vs. sucrose</th>
<th>Interaction</th>
<th>Pooled SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \text{Cr}_2\text{O}_3 )</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonfasting</td>
<td>NS</td>
<td>.001\textsuperscript{a}</td>
<td>.07</td>
<td>16.7</td>
</tr>
<tr>
<td>Fasting</td>
<td>.17</td>
<td>.09</td>
<td>NS</td>
<td>16.6</td>
</tr>
<tr>
<td>( \text{Ce}^{144} ) nonfasting dpm&gt;2000</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
<td>25.3</td>
</tr>
<tr>
<td>Reg. equation</td>
<td>.09</td>
<td>.11</td>
<td>.25</td>
<td>9.0</td>
</tr>
<tr>
<td>Average\textsuperscript{b}</td>
<td>.12</td>
<td>.01</td>
<td>.09</td>
<td>9.3</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Probabilities at which statistical significance was observed; NS = nonsignificant at \( P \geq .30 \).

\textsuperscript{b}Average of 4 measurements per each hen.

first appearance data. Consequently, fewer differences were statistically significant at \( P \leq .10 \) level (Table 5).

Recovery rate varied from 68.20 to 73.72% for the starch-containing diets and from 71.21 to 84.45% for the sucrose-containing diets, depending on the procedure used (Table 3). The percentage of marker recovered in the feces varied from 64.67 to 76.24% for the fat-supplemented diets and from 74.93 to 81.93% for the nonfat-supplemented diets.

Our results confirm those reported by Monson et al. (1950) showing that, in the chicken, sucrose had a faster rate of passage than starch. Also, our research confirms the suggestion of Mateos and Sell (1980b,c) that supplemental fat decreases rate of food passage and thereby it may improve energy utilization of diets for laying hens. Also, these
Table 4. Influence of carbohydrate source and fat supplementation on percentage of marker that was recovered in excreta, %

<table>
<thead>
<tr>
<th>Diet</th>
<th>( \text{Cr}_2\text{O}_3 )</th>
<th>( \text{Fasting}^b )</th>
<th>( \text{144Ce}^c )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Nonfasting(^a)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch - 0% fat</td>
<td>73.14</td>
<td>75.59</td>
<td>76.36</td>
</tr>
<tr>
<td>Sucrose - 0% fat</td>
<td>76.73</td>
<td>73.37</td>
<td>87.51</td>
</tr>
<tr>
<td>Starch - 7% fat</td>
<td>63.26</td>
<td>67.37</td>
<td>71.09</td>
</tr>
<tr>
<td>Sucrose - 7% fat</td>
<td>65.69</td>
<td>76.86</td>
<td>81.39</td>
</tr>
<tr>
<td><strong>Main effects</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starch</td>
<td>68.20</td>
<td>71.48</td>
<td>73.72</td>
</tr>
<tr>
<td>Sucrose</td>
<td>71.21</td>
<td>75.11</td>
<td>84.45</td>
</tr>
<tr>
<td>Added fat</td>
<td>64.47</td>
<td>72.11</td>
<td>76.24</td>
</tr>
<tr>
<td>No added fat</td>
<td>74.93</td>
<td>74.58</td>
<td>81.93</td>
</tr>
</tbody>
</table>

\(^a\)Hens were fasted for 30 min and the marked diet was fed for 5 hr. Excreta were collected for 10 hr after start of feeding.

\(^b\)Hens were fasted for 14 hr and then fed the marked diet for 4.5 hr. Excreta were collected for 9.5 hr after start of feeding.

\(^c\)Hens were fasted for 30 min and then fed the marked diet for 5.5 hr. Excreta were collected for 11.5 hr after start of feeding.

Results are consistent with those reported by Duke and Evanson (1972) showing that corn oil placed in the small intestine of turkeys decreased motility of the stomach. Recently, Borella and Lippmann (1980) have shown that sesame seed oil inhibited both stomach emptying and intestinal propulsion in the intact, conscious rat. Tuckey et al. (1958), however, reported inconsistencies in the effects of fat supplementation on rate of food passage in chickens. Fat retarded rate of passage in some experiments but not in others.
The results of the research reported herein illustrate that the addition of fat to the diet slows rate of food passage in chickens. This, in turn, would increase the time of exposure of feed to digestive processes and absorptive surfaces of the gastrointestinal tract. Therefore, the extrametabolic effect of fats reported by several authors (Gomez and Polin, 1974; Sibbald and Kramer, 1978) may be primarily the result of a better energy utilization of the diet as a consequence of reduced rate of food passage (Mateos and Sell, 1981).

In measuring rate of passage, variability of measurements among experimental animals treated alike is a major concern. The greater the variability, the more difficult becomes the detection of differences among treatments. The results of our research indicate that similar experimental errors were obtained when total recoveries of either $^{144}$Ce or $\text{Cr}_2\text{O}_3$ were used as criteria of food passage rate (Table 5). Similar results were found for the first appearance data (Table 4), although, in this

Table 5. Statistical analysis of the data obtained by the total recovery of marker procedure

<table>
<thead>
<tr>
<th>Method</th>
<th>Fat</th>
<th>Starch vs. sucrose</th>
<th>Interaction</th>
<th>Pooled SE</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{Cr}_2\text{O}_3$</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonfasting</td>
<td>.09</td>
<td>NS</td>
<td>NS</td>
<td>5.8</td>
</tr>
<tr>
<td>Fasting</td>
<td>.11</td>
<td>.27</td>
<td>NS</td>
<td>7.0</td>
</tr>
<tr>
<td>$^{144}\text{Ce}$</td>
<td>NS</td>
<td>.16</td>
<td>NS</td>
<td>7.4</td>
</tr>
</tbody>
</table>

$^a$Probabilities at which statistical significance was observed; NS = nonsignificant at $P > .30$. 
case, the pooled standard error was higher for the $^{144}\text{Ce}$ method (dpm > 2000) than for $\text{Cr}_2\text{O}_3$ methods (25.3 vs. 16.7 and 16.6, respectively). When the first appearance of the radioisotope was determined by using the regression equation of total dpm in feces vs. time after feeding, the variability was reduced (pooled standard error of 25.3 for the $^{144}\text{Ce}$ method based on dpm > 2000 vs. 9.0 for the $^{144}\text{Ce}$ method using regression equations.) Thus, the regression technique seemed to be a more sensitive criterion of rate of food passage than the classical first appearance procedures.

When first appearance of the marker in excreta was calculated by averaging the data obtained by the four methods used, the variability was reduced markedly (Table 4). Thus, the utilization of averages of repeated measurements by different methods seemed to be another reasonable procedure to determine ROP.

The use of either the regression equation technique or the average of four successive determinations reduced the variability of ROP estimates as compared with the individual determination procedures (Table 4). Thus, either of these approaches seemed to be suitable to estimate ROP on the basis of first appearance of a dietary marker in the excreta. The regression equation technique facilitates the most rapid collection of data, assuming that the marker used can be readily detected quantitatively by laboratory analysis.
REFERENCES


GENERAL SUMMARY

Six trials were conducted to study the nature of the extrametabolic effect of supplemental yellow grease in laying hen diets. In experiment 1, the nitrogen-corrected metabolizable energy (MEn) and the true metabolizable energy (TME) of corn-soybean meal diets supplemented with 0, 3, 6, 9, 12 or 15% yellow grease were determined and these data were used to estimate the MEn and TME of the fat. The MEn and TME of yellow grease were 9367 and 11567 kcal/kg, respectively, when the supplemental level was 3%. When yellow grease constituted 15% of the diet the values were 8653 and 8907 kcal/kg, respectively.

In experiment 2, the influence of different levels of yellow grease (0, 4, 8 or 12%) and three dietary carbohydrates (sucrose, starch and rice hulls) on energy utilization of the diet was studied. MEn and TME of the diets were determined and the data were used to estimate MEn and TME of yellow grease. The energetic contribution of yellow grease varied with carbohydrate composition of the diet. The energy of the fat was estimated to be 9343, 9429 and 8194 kcal TME/kg for sucrose-, starch-, and rice hulls-containing diets, respectively, instead of 8070 kcal TME/kg as expected on the basis of literature values. Similar values for MEn were 8897, 8247 and 8221 kcal/kg, respectively, instead of 7900 kcal/kg as expected.

In experiment 3, twelve diets with the same calculated MEn and protein levels were arranged in a 2 x 6 factorial composed of two yellow grease to soy oil ratios (6%:0% and 4%:2% of the diet) and six corn-starch:sucrose ratios (from 49%:0% and 0%:49%). The diets were assayed
for MEn content. There was a positive linear relationship between sucrose level and MEn of the diet ($P < .01$). When sucrose replaced cornstarch, the MEn of the diets increased more than expected. Also, the diets containing a mixture of yellow grease and soy oil had significantly greater MEn values than those in which supplemental fat was supplied exclusively as yellow grease ($P < .05$). The regression equation that best fit the results was $\text{MEn (kcal/kg)} = 3177 + 3.25 \% \text{ sucrose} + 18 \% \text{ soy oil}$ while the regression equation calculated from ingredient literature values was $\text{MEn (kcal/kg)} = 3110 + 1.03 \% \text{ sucrose} + 9 \% \text{ soy oil}$. These data show that the addition of a relatively unsaturated fat (soy oil) to a saturated fat (yellow grease) enhanced dietary MEn. Also, the results indicate that, in the presence of supplemental fat, energy utilization from sucrose was greater than expected.

In experiment 4, the influence of graded levels of supplemental yellow grease (0, 3, 6 and 9%) on energy utilization of diets containing selected carbohydrates (starch, sucrose, maltose, glucose, fructose and glucose + fructose) was determined. The MEn's of the diets were changed more by fat supplementation than was predicted on the basis of reference MEn's of the dietary ingredients. The MEn of yellow grease, estimated experimentally, was 8600 kcal/kg as compared with 7900 kcal/kg as listed in reference tables. The estimated MEn of each pure carbohydrate increased linearly with each increment of supplemental fat ($P < .05$). When yellow grease constituted 0 or 9% of the diet, the respective MEn's of the carbohydrates, expressed in a relative index form with the MEn of sucrose in nonadded fat diet set equal to 100, were 100 and 110 for su-
crose; 96 and 103 for starch; 93 and 100 for maltose; 92 and 101 for glucose; 90 and 98 for fructose and 89 and 98 for the glucose + fructose mixture. The results indicate that supplemental fat enhanced the utilization of energy from nonlipid dietary constituents and that the improvement varied with the carbohydrate source. Sugar-containing diets were benefitted more by yellow grease supplementation than starch-containing diets (P < .05).

In experiment 5, four diets were arranged as a $2 \times 2$ factorial with two levels of fat (0 and 7%) and two carbohydrate sources (sucrose and starch). The MEn of yellow grease was calculated from lipid digestibility data and from actual determination of dietary MEn. The MEn of yellow grease varied with the procedure used and with the carbohydrate composition of the diet. On the basis of digestibility data, the MEn of yellow grease was 8497 and 8210 kcal/kg for the starch- and the sucrose-containing diet, respectively. From actual MEn determination, the values obtained were 9714 and 10071 kcal/kg, respectively.

In experiment 6, the influence of supplemental fat and carbohydrate source of the diet on rate of food passage (ROP) was studied. Chromic oxide ($\text{Cr}_2\text{O}_3$) or $^{144}\text{Ce}$ cerium was used as a marker in four different periods. The first appearance of the marker in feces and the percentage of the total marker ingested recovered in feces 9.5 to 11.5 hr after feeding were used to estimate ROP through the digestive tract of the hen. Starch-containing diets had a slower ROP than sucrose-containing diets (156 vs. 127 min, respectively). Also, fat supplementation decreased ROP (150 vs. 133 min, respectively). There was a significant interaction (P = .09)
between fat and carbohydrate source on ROP. The ROP of sucrose-containing diets was decreased more by fat supplementation than the ROP of starch-containing diets (3 and 32 min, respectively). Within 9.5 to 11.5 hr after feeding, 71.21 to 84.45% of the marker had been excreted by hens fed the sucrose-containing diet while only 68.20 to 73.72% of the marker had been excreted by hens fed the starch-containing diets. Corresponding values for the nonadded and added fat diets varied from 74.58 to 81.93% and from 64.47 to 76.24%, respectively.

The data presented suggest that the extrametabolic effect of supplemental fat in poultry diets may be the result of 1) a synergism between the relatively unsaturated fatty acids present in the ingredients of practical poultry diets and those relatively saturated fatty acids supplied by the supplemental fat whereby micelle formation and fat absorption are enhanced, and 2) a better utilization of the energy contained in non-lipid dietary ingredients. The data also indicate that supplemental fat decreased ROP. Theoretically, a reduction in ROP would increase the time during which ingesta is subjected to digestion and absorption processes, and therefore a concurrent increase in utilization of energy contained in lipid and nonlipid constituents of the diet may be obtained. Decreased ROP may be the primary mechanism by which supplemental fats cause an extrametabolic effect in poultry diets.
LITERATURE CITED (IN GENERAL INTRODUCTION)

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