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FINAL REPORT

PROJECT No. I-381-81

Nutrition-Physiology-Environment Interactions in Turkeys

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630.72
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1986

Standard BARD Cover Page for Technical Reports Date: March 1, 1986

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Bet Dagan, ISRAEL

BARD No of Proposal: I-381.81

Title of Proposed Research: Nutrition -Physiology - Environment
Interactions in Turkeys

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Project's starting Date: November, 1983

Type of Report: Final

Signature

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Turkeys

Turkeys - Growth

Turkeys - Feeding and feeds

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P"317 8132

Oils and nuts in animal nutrition

Amino acids in animal nutrition

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Energy metabolism - 636.089.257

Hormones 636.089.240.5

Protective atmospheres 697.931

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: 636.592 : 636.085 : 636.089.257 :

636.089.240.5 : 697.931

ACKNOWLEDGMENTS

The principal and cooperating investigators express their appreciation to the team responsible for animal care:

Ilan Ben Gal
Ofer Amir
Eliahu Wax
Yakob Meister

Thanks are also extended for laboratory technical assistance to:

Yehudith Nissenbaum
Miriam Ben Moshe
Miriam Cotter

Dr. Yoram Weisman, Head of Avian Disease Laboratory, The Veterinary Institute, supplied help and supervision in keeping the Turkey Experimental Farm free of infectious disease.

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ABSTRACT

Results of experiments with growing turkeys conducted in temperature-controlled chambers, showed that growth and feed efficiency were improved by dietary energy, regardless of age or environmental temperature. In addition to its effect as an energy source, dietary fat per se improved growth and feed efficiency of the older (9-12 weeks old) but not of the young (1-3 weeks old) turkey. In the older turkey only, dietary fat also caused an increase in carcass fat. The response of weight gain and feed efficiency to dietary fat was parallel at 10° and 27°, but the efficacy of dietary glucose was greater at the lower than at the higher temperature.

Plasma hormones were measured in turkeys kept between 5° and 35°, in addition to measurements of growth and feed intake. Corticosterone was high at the high environmental temperature. Thyroxine (T_4) did not consistently vary with temperature, but triiodothyronine (T_3) progressively decreased when environmental temperature exceeded 20°. Plasma growth hormone was not significantly affected by environmental temperature, but the response of the hormone to a single injection of thyrotropin-releasing hormone (TRH) was greater at 27° and 33° than at 20°. At all temperatures, growth was inversely related to plasma growth hormone concentration. The decline of weight gain at temperatures above 27° could be explained by the reduction in T_3 . No consistent response of various hormones to source and level of dietary energy could be documented.

Chicken kidney cells monoiodinated T_4 to form T_3 in vitro. The activity of this conversion was formulated into a model describing relationship between T_4 and T_3 in vivo, which was validated by measuring hormone kinetics after a T_3 administration in vivo.

In chicken adrenal cells in vitro, aldosterone and corticosterone secretion were stimulated by ACTH and by cAMP generating substances. In vivo, both hormones were stimulated by acute stress, but only aldosterone was stimulated by a low-Na diet. Plasma sodium appeared to be regulated by aldosterone; once the hormone was maximally suppressed, plasma sodium varied proportionally to sodium intake.

The allocation of feed protein and energy to the different carcass components was formulated into a dynamic model, based on Markov mathematics. This model can now be used to predict growth and carcass composition, under variable dietary conditions.

Models which simulate performance of chickens or turkeys, kept under variable environmental and dietary condition, were programmed for computer use to optimize profitability of farm operations. One version "TURKS" as modified by a Minnesota team, is distributed in the U.S. A Hebrew version was written and modified for general use in Israel.

New equations generated recently, are incorporated in a more detailed model which can also design the optimal dietary regime, give the composition of diets for the entire rearing period, and optimize environmental temperature, taking into account the interactions determined experimentally.

OBJECTIVES

1. To determine minimal concentrations of dietary energy and amino acids needed by turkeys, at different environmental temperatures.
2. To determine specific values of fats, carbohydrates and amino acids as sources of energy at different temperature.
3. To obtain temperature-diet functions of circulating key-hormones for growth and energy utilization, in an effort to understand the control of energy utilization and growth at changing environments.
4. To use experimentally determined parameters in a simulation model to be consequently used in implementation of the results.

DIETARY ENERGY x TEMPERATURE INTERACTIONS

Response of Growing Turkeys to Dietary Fat*

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* Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel, No. 1622-E, 1985 Series. Supported by a grant from the United States-Israel Binational Agricultural Research and Development fund (BARD).

ABSTRACT Growth, feed efficiency and carcass fat were evaluated in turkeys fed diets in which fat was added isocalorically, or while increasing dietary energy concentration and keeping a constant protein/calorie ratio. In the 1-3-week-old turkey, growth and feed efficiency increased with dietary energy, but did not change significantly when fat was added isocalorically. On the other hand, the 12-week-old turkey responded by improved growth and feed efficiency when dietary fat was added either isocalorically or with increasing energy density. However, the response to the isocaloric fat addition was smaller in magnitude than when added without calorie adjustment. No difference could be detected in the performance response between tallow and soybean oil, in 12-week old turkeys. Carcass fat deposition increased with dietary fat supplementation, regardless of the caloric change. The results suggest that in the midterm of development of the growing turkey, fat per se affects growth, feed efficiency and carcass fat. The growth and feed efficiency response to nutrient density occurs in both young and older birds.

INTRODUCTION

A growth and feed efficiency response of the turkey to dietary fat supplementation is well documented (Yacowitz et al., 1956; Potter et al., 1974; Sell and Owings, 1981; Moran, 1982). The magnitude of this response was found to increase with age (Potter et al., 1974; Salmon and O'Neil, 1973). It can be postulated that this age-dependent response is due to the increase in adiposity with age (Leeson and Summers, 1980b; Hurwitz et al., 1983b) and the greater efficiency of the direct transfer of absorbed fatty acids into adipose tissue (Borron and Britton, 1977). In agreement with this postulation, Sell and Owings (1981) found an effect of fat on body weight and feed efficiency irrespective of metabolizable energy. However, several studies with the turkey as well as with the chicken (Waldroup et al., 1976; Coon et al., 1981; Hurwitz et al., 1983a; Owen et al., 1981; Summers et al., 1985) show a general growth and feed efficiency response to increased energy or nutrient density in the diet. Earlier work of Jensen et al. (1970) and Jensen and Fallen (1973) agreed with such caloric effects of fat in turkey diets but suggested in addition, an extracaloric effect. Thus, the hierarchy of the effects of fat per se and the effect of fat as an energy supplement has not been elucidated.

Effects of dietary fat on carcass fat content are quite contradictory. In broiler chicks, some investigators found an increase in carcass fat (Salmon, 1974; Deaton et al., 1981), little or no significant change (Bartov et al., 1974; Coon et al., 1981), or a decrease in carcass fat (Alao and Balnave, 1984), in response to supplementary dietary fat. Some of the contradictions may have resulted from the differences in the experimental approach- dietary supplementation of fat only, in contrast to the maintenance of a constant energy:protein ratio during fat supplementation (Bartov et al., 1974). In turkeys, the effect of dietary fat on carcass composition has been investigated in a few studies only. Salmon et al. (1974) and Sell

et al. (1985) found an increase in carcass fat with supplementary dietary fat, whereas Summers et al. (1985) could not demonstrate any significant effect of dietary energy on carcass composition. In the present study, an attempt was made to separate the effects of energy and fat on growth, feed efficiency and carcass fat in turkeys.

METHODS AND RESULTS

Male BUT (British United Turkeys) day-old turkeys were obtained from a commercial hatchery and raised for 5 weeks in battery brooders situated in a temperature controlled room, at 24°. The experiment within this time period was conducted in these brooders. The chicks were then transferred to individual cages kept at the same room temperature. Feed in mash form was provided ad libitum at all times. Artificial illumination was provided continuously.

For the experiments, birds were separated into weight groups. One third of the birds, the lightest and the heaviest, were discarded. The rest were assigned to the experimental lots according to weight, with equal representation of each weight range in each group. Each treatment was applied to five replicate groups. The number of birds in each replicate was 10 and 6, for ages younger and older than 5 weeks, respectively.

At the end of the trials, 6-8 birds of each treatment were killed and defeathered by scalding. The carcass was then autoclaved for 2h, and homogenized. Fat was determined gravimetrically in the dried sample of the homogenate, after extraction with a mixture of chloroform : methanol (2:1).

The diets were designed to satisfy NRC (1977) recommendations. A CDC Cyber computer and LP-1 program were used for diet computations.

Trial 1: The purpose of this trial was to evaluate dietary fat in young chicks. The experiment was started with 1-week-old birds, lasted 3 weeks, and included seven dietary treatments (Table 1).

The first four treatments represent increasing concentrations of fat, at increments of 25 kg/ton, together with increased energy at increments of 100 kcal/kg. Treatments 5-7 contained the fat supplementaion at levels corresponding to treatments 2-4, but added isocalorically to diet 1. A constant protein and amino acid ratio to energy was maintained in the restrictions used to compute the diets.

Results (Table 1), indicate that weight gain and feed efficiency were significantly improved when fat was added together with energy (groups 1-4). There was no consistent effect of fat when added to the diets isocalorically (Group 1 and 5-7). Trial 2. The purpose of this trial was to evaluate fat supplementation in birds at the midterm of the growing period. The experiment was started with 12-week old birds and continued for 2 weeks.

Of the experimental diets (Table 3), diet 1 contained 2% supplementary oil and served as the control. Six percent of fat was added, isocalorically in diet 2 and together with 250 kcal/kg in diet 3. The ratio of protein and amino acids to energy was maintained in the restrictions used in diet formulation.

The results (Table 4), show that growth and feed efficiency were significantly ($P < 0.05$) improved by the isocaloric addition of fat (Lot 2). A further increase in both was observed in Lot 3, in which an increase in dietary nutrient density accompanied the addition of fat. Carcass fat was significantly ($P < 0.05$) increased by dietary fat, with no further increase due to nutriet density.

TABLE 1. Composition of the experimental diets, trial 1.

Ingredient	Diet No.						
	1	2	3	4	5	6	7
	<u>kg/ton</u>						
Soybean oil meal	501	535	571	606	495	489	484
Fishmeal	10	10	10	10	10	10	10
Wheatbran	17	17	17	17	93	170	248
Soybean oil	20	32.5	45	57.5	32.5	45	57.5
Tallow	-	12.5	25	37.5	12.5	25	37.5
Sorghum grain	408	348	285	223	314	220	124
Dicalcium phosphate	20.8	22.3	23.7	25.0	17.9	15.0	12.0
Calcium carbonate	13.8	14.0	14.0	14.0	15.4	16.9	18.4
Sodium chloride	4	4	4	4	4	4	4
Vitamin and mineral							
mixture ¹	3.5	3.5	3.5	3.5	3.5	3.5	3.5
DL Methionine	2.2	2.3	2.4	2.5	2.1	2.0	1.9
<u>Calculated composition</u>							
Metabolizable energy							
kcal/kg	2700	2800	2900	3000	2700	2700	2700
Protein, %	27.0	28.0	29.0	30.0	27.0	27.0	27.0
Fat, %	3.9	6.3	8.5	10.9	6.3	8.8	11.2

¹ Hurwitz et al. (1983b)

TABLE 2. Effect of supplementary fat on the performance of 7-day-old chicks (Trial 1).

No.	Fat	Energy	Weight gain	Feed intake	Efficiency ¹
	%	Kcal/kg	g/2 wk	g/2wk	
1	3.9	2700	353ab ²	596	0.592ab
2	6.3	2800	369ab	589	0.625ad
3	8.5	2900	384c	579	0.662cd
4	10.9	3000	388c	573	0.678c
5	6.3	2700	371bc	591	0.630ad
6	8.5	2700	352ab	563	0.625ad
7	10.9	2700	340b	594	0.573a
	SE ³		5	20	0.017

¹ g gain/g feed.

² Means of 5 replicates of 10 birds each. Values followed by different letters are significantly different ($P < 0.05$).

³ Pooled standard error, calculated from the analysis of variance.

TABLE 3. Composition of the experimental diets, trial 2.

Ingredient	Diet No.		
	1	2	3
	<u>kg/ton</u>		
Soybean oil meal	243	231	300
Fishmeal	10	10	10
Wheatbran	23	208	37
Soybean oil, refined	20	50	50
Tallow	-	30	30
Corn	200	200	200
Sorghum grain	471	241	338
Dicalcium phosphate	18	13	21
Calcium carbonate	7	10	7
Sodium chloride	3	3	3
Vitamin and mineral mix ¹	3.5	3.5	3.5
DL Methionine	0.9	0.6	0.9
L-Lysine.HCl	0.3	-	-
<u>Calculated composition</u>			
Metabolizable energy			
kcal/kg	3000	3000	3250
Protein, %	17.8	17.8	19.3
Fat, %	4.6	10.2	9.9

¹ Hurwitz et al. (1983b)

Trial 3. Since the results of the previous trial indicated effects on weight gain, feed efficiency and carcass fat, specifically attributable to dietary fat, it was hypothesized that the greater the similarity in the fatty acid composition between diet and the turkey carcass, the greater its expected effect.

The experiment was started with 12 week old birds and continued for 3 weeks. The experimental diets are given in Table 5. Diet 1, the control, contained 2% oil. Diets 2 and 3

contained an addition of 6% soybean oil and tallow, respectively. Here tallow was assumed to contain 9000 kcal/kg. Lot 4 contained the same amount of tallow, assuming a value for tallow of only 8100 kcal/kg. Lot 5 contained a supplement of 3% tallow and 3% soybean oil. The mixture was assumed to contain 8550 kcal/kg.

The results (Table 6), confirmed those of the previous trial in showing that the isocaloric addition of fat resulted in a significant ($P<0.05$) improvement in growth and feed efficiency. Carcass fat tended to increase in the same direction. However, there was no significant difference ($P<0.05$) between the various combinations of soybean oil and tallow in their promotion of growth, feed efficiency and carcass fat. In this experiment no significant difference could be detected between the diets designed according to a different metabolizable energy content of the tallow, and therefore including different amounts of wheat bran.

TABLE 4. Effect of supplementary fat on the performance of 12-week old turkeys (Trial 2).

<u>Treatment No.</u>	<u>1</u>	<u>2</u>	<u>3</u>	
Fat supplement, %	2.0	8.0	8.0	SE1
Dietary Energy, %	3000	3000	3250	
Dietary protein, %	17.8	17.8	19.3	
Body weight, initial, g	5671a ²	5675a	5627a	45
Weight gain, g/2 wks	1470a	1607b	1749c	42
Feed intake, g/2 wks	4649a	4728a	4605a	62
Feed efficiency	0.316a	0.340b	0.380c	0.008
Carcass fat, % ³	7.48a	8.57b	8.76b	0.33

1 Calculated from the analysis of variance.

2 Means of 5 replicates of 6 birds each. Values followed by different letters are significantly ($P<0.05$) different.

3 Average of 6 birds.

TABLE 5. Composition of the experimental diets, trial 3.

Ingredient	Diet No.				
	1	2	3	4	5
	<u>kg/ton</u>				
Soybean oil meal	235	224	224	230	227
Fishmeal	10	10	10	10	10
Wheatbran	16	200	200	160	181
Soybean oil, refined	20	80	20	20	50
Tallow	-	-	60	60	30
Sorghum grain	683	453	453	486	469
Dicalcium phosphate	19.1	13.4	13.4	14.0	13.7
Calcium carbonate	7.4	10.4	10.4	10.1	10.2
Sodium chloride	4	4	4	4	4
Vitamin and mineral					
mixture ¹	3.5	3.5	3.5	3.5	3.5
DL Methionine	1.0	0.8	0.8	0.8	0.8
L-Lysine.HCl	0.6	0.2	0.2	0.2	0.2
<u>Calculated composition</u>					
Metabolizable energy					
kcal/kg	3000	3000	3000	3000	3000
Protein, %	17.8	17.8	17.8	17.8	17.8
Fat, %	4.4	10.3	10.3	10.3	10.3

¹ Hurwitz et al. (1983b)

TABLE 6. Performance of 12-week-old turkeys fed different combinations of soybean oil and tallow (Trial 3).¹

Diet No.	1	2	3	4	5	SE ²
Fat supplement	Basal ³	Soy	Tallow	Tallow	Combined	
Fat level, %	4.4	10.3	10.3	10.3	10.3	
Body weight, initial, g	6160a ⁴	6148a	6187a	6139a	6090a	76
Weight gain, g/3 wk	1790a	2136b	1981ab	2073b	1933ab	94
Feed intake, g/3 wk	6451a	6942a	6800a	6991a	6660a	146
Feed efficiency	0.276a	0.308a	0.291a	0.296a	0.290a	0.011
Carcass fat, % ⁵	8.06a	8.89a	8.55a	8.76a	8.25a	0.45

¹ The caloric value of soybean oil was taken as 9000 kcal/kg. The value of tallow was taken as 9000 and 8100 in diet 3, and in diets 4 and 5, respectively.

² Calculated from the error term of the analysis of variance.

³ Contained 4.4% fat with 2% soybean oil.

⁴ Mean of 5 replicate groups of 6 birds each. Values followed by different letters are significantly different ($P < 0.05$).

⁵ Mean of 6 birds.

DISCUSSION

A comparison of the results of trial 1 and 2 showed that growth and feed efficiency were only slightly altered by fat per se in the young turkey, but were markedly improved by fat in the older bird confirming the results of Potter et al. (1974) which suggested an age-dependent response. However, a growth depression in the young bird (Table 2) by the high fiber content in diets 5-7 cannot be ruled out. Both young and older birds responded by improved growth and feed efficiency to an increase in dietary energy density, in agreement with previous results from this laboratory (Hurwitz et al., 1983a). Furthermore, in the

older bird, the growth and feed efficiency response to fat, appears to be the sum of the two effects: the direct one due to fat, and that of the increased energy density which occurs with fat supplementation. Results of trial 3, although with no significant effects of fat, suggest an equal response to fats with high or low content of polyunsaturated fatty acid. However, it is also possible that this experiment was not sensitive enough to detect such differences, due to the large variance in growth and feed efficiency in older birds.

The carcass fat response is of particular interest. In broilers, carcass fat increases with dietary energy in general, or fat in particular (Summers et al., 1965). However, this effect is abolished if protein is also added simultaneously, thus maintaining a constant protein/energy ratio (Bartov et al., 1974). The present results with the older turkey suggest that carcass fat increases with fat supplementation, even when added isocalorically (Table 3). The same response is obtained when nutrient density, including protein is increased together with fat supplementation. Thus, it may be suggested that in the turkey, carcass fat deposition is stimulated by fat per se. This is again in accord with the theory of direct utilization of dietary fatty acids by adipose tissue. It would be of interest to determine why this effect is observed in the turkey and not in the broiler chick, despite the fact that the chick deposits considerably more fat than the turkey (Plavnik and Hurwitz, 1983; Hurwitz et al., 1983b).

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Yacowitz, H., R.D. Carter, J. Wyne and M.G.M. Cartney, 1956.
Effect of varying protein and fat levels in a finishing ration
for turkey broilers. Poultry Sci. 35: 227-229.

**Differential Responses of Turkeys Kept at Various Environmental
Temperatures to Dietary Carbohydrates and Fat***

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* Contribution from the Agricultural Research Organization, The
Volcani Center, Bet Dagan, Israel, No. 1685-E, 1986 Series.
Supported by a grant from the United States-Israel Binational
Agricultural Research and Development Fund (BARD).

ABSTRACT Interactions of environmental temperature x dietary energy sources were evaluated in 9-12-week old turkeys using weight gain and feed efficiency, carcass fat and plasma glucose and hormones as response criteria. The dietary variables - soybean oil or glucose - were added at five or six levels, and the resulting diets were fed to birds kept at 10° and 27°C. In all cases, the amino acid and protein/ energy ratios were kept constant in the restrictions used in diet computations. Duplicate experiments were conducted for each mode of variable addition. Parallel responses of body weight gain and feed efficiency were obtained at the two temperatures when fat replaced carbohydrates, thereby raising dietary energy density. A similar response at the two temperatures was obtained also with a graded isocaloric addition of fat. A greater response of gain and feed efficiency to energy supplied by dietary glucose was obtained at 10°, as compared with 27°. Dietary fat supplementation resulted in increased deposition of carcass fat when given together with energy or isocalorically, regardless of environmental temperature. Carcass fat was increased by glucose-energy only at the low temperature. Plasma glucose and triiodothyronine were higher at the lower than at the higher temperature. No consistent response was found with thyroxine or corticosterone. The mechanism of the temperature-dependent differential response to dietary fats and carbohydrates and the practical implications of the results are discussed.

(Key words. Fat. carbohydrates. environmental temperature. carcass fat. turkey.)

INTRODUCTION

Dietary nutrient density and environmental temperature are important determinants of performance in birds. An increase in nutrient density led to improved growth and feed efficiency in turkeys and chicks (Waldroup et al., 1976; Coon et al., 1981; Owen et al., 1981; Sell et al., 1985; Summers et al. 1985). The magnitude of the growth increment was estimated to be approximately 1.7% per 100 kcal in turkeys (Hurwitz et al., 1983a). Some of the responses to the increase in dietary energy density have been attributed to specific "extracaloric" effects of fat rather than to a general energy effect (Jensen et al., 1970; Jensen and Fallen, 1973). It has also been suggested that in turkeys, the degree of stimulation of growth by fat increases with age (Salmon, 1974). Recently, Hurwitz et al. (1986) isolated specific from energy-related effects of fat and showed that growth and feed efficiency were promoted by the energy supplied with fat in both young (1-3 weeks old) and older (9-12 weeks old) turkeys, but when added isocalorically, fat improved growth and feed efficiency only in the older turkey. Furthermore, an increase in carcass fat could be attributed to dietary fat supplementation per se.

The mechanism of the response to fat has not been identified. Fuller (1977) explained the extracaloric value of fat on the basis of its lower heat increment (specific dynamic action) than that of carbohydrates, as reviewed by Brody (1945). However, the age dependence of the fat response as observed by Salmon (1974) and Hurwitz et al. (1986a), and the correlation between the occurrence of this response with the age-related increase in carcass fat deposition (Hurwitz et al., 1983b), favor the theory of a metabolic advantage to the direct transfer of fatty acids from feed to carcass fat.

Growth depression and reduced feed intake are consequences of environmental temperatures above 20°C in both growing chicks and turkeys (Hurwitz et al., 1980). This growth depression

cannot be overcome by increased concentrations of dietary protein (Cowan and Michie, 1978), or by increasing both protein and energy (Hurwitz et al., 1980; Charles et al., 1981). In considering sources of dietary energy, Lipstein and Bornstein (1975) proposed that the expression of the extracaloric action of fat may be more pronounced during hot weather. This suggestion was not confirmed by Dale and Fuller (1979) and Sinuart and Balnave (1985) who found that the beneficial effect of dietary fat in chickens was independent of temperature, nor by Charles et al. (1981) and Sell and Owings (1981), who used fat to raise the level of energy in chicken diets.

Thus, there is no agreement on the existence of any nutrient density x temperature interactions. Furthermore, carbohydrates are known to have a relatively high specific dynamic action (Brody, 1945). More heat is produced from a high carbohydrate than from a high fat diet in the chicken (Dale and Fuller, 1979) as well as in the human (Schwartz et al., 1985). However, to the best of our knowledge, there is no indication if use can be made of this thermic effect of dietary carbohydrate.

In the present study the response of growing turkeys, in terms of growth, feed efficiency, carcass fat, plasma glucose and some hormones to dietary fat and carbohydrates, was evaluated.

MATERIALS AND METHODS

Birds: Male BUT turkeys were obtained from a commercial hatchery and raised for 4-5 weeks in battery brooders situated in a temperature controlled room, at 24°. They were then transferred to individual cages kept at the same room temperature. Two weeks prior to the experiment, they were transferred to individual cages situated in temperature chambers at 20°. The temperatures in the four chambers were gradually changed to reach the desired temperature within one week. Two chambers were assigned to each temperature. Each treatment included eight birds, four in each room. During the experiment, body weight and feed intake were

recorded individually on a weekly basis. Diets designed to satisfy NRC (1977) recommendations, were provided ad libitum at all times. Artificial illumination was provided continuously.

Biochemical assays: In some experiments, blood was obtained in heparinized syringes, cooled on ice, and centrifuged. The plasma samples were then taken for glucose assay (Johnson et al., 1963), and for triiodothyronine (T_3), thyroxine (T_4) and corticosterone radioimmunoassays.

At the end of some of the trials, the birds were killed and defeathered by scalding. The carcass was then autoclaved for 2 hours, and homogenized. Fat was determined gravimetrically after extraction with a 2:1 mixture of chloroform:methanol.

For radioimmunoassays, antibodies against T_3 and T_4 were obtained from Bio-Yeda (Rehovot, Israel). ^{125}I -labeled T_3 and T_4 were obtained from The Radiochemical Centre (Amersham, England).

T_3 and T_4 were obtained from Sigma (St. Louis, MO).

^{125}I was counted in an Autogamma spectrometer and tritium in a TriCarb liquid scintillation spectrometer (Packard Corp., Downers Grove, IL), with the appropriate corrections for chemical luminescence and quenching.

T_3 and T_4 radioimmunoassays were made in 0.2M barbital buffer with 0.5% bovine serum albumin, directly on plasma samples. The dilution of the antisera was 1:10,000 and 1:4,000 for T_3 and T_4 , respectively. The range of the assays was 7-1,000 pg/tube. Standards were prepared in stripped serum, previously treated with charcoal. The assay tubes were incubated overnight at 4° and separation between the antibody-bound and the free ligand was made by the addition of a suspension of ghosts of Staphylococcus aureus, followed by centrifugation, as described previously (Bar and Hurwitz, 1979).

Numerical analysis: Diets were formulated using MINOS (Murtagh and Saunders, 1983). Results were subjected to analysis of variance according to Snedecor and Cochran (1967) and Duncan (1955) multiple comparison tests. Covariance analysis, for the comparison of the response to energy, at the two temperatures,

was performed by using the General Linear Model of SAS (Cohen, 1983). Computations were made in Rainbow-100 and VAX (Digital Equipment Corp.)

Trials 1 and 2: The purpose of these trials was to evaluate the effect of environmental temperature on the utilization of dietary fat. Dietary energy density was changed parametrically by fat supplementation. A constant ratio of protein and amino acid/energy was maintained in the minima set for diet formulation (Tables 1 and 2). In both trials, refined soybean oil and soybean oil meal replaced corn thereby increasing both energy and protein. NRC (1977) recommendations for the age of 4- 8 weeks, and for 8-12 weeks were used in Trial 1 and Trial 2, respectively. The level of wheat bran was held constant in all diets, in both experiments. Trial 1 included six dietary treatments, with energy concentrations ranging from 2400 to 3000 kcal/kg. The range was narrower - 2500-2900 kcal/kg - in the five diets of trial 2.

Trials 3 and 4: In these trials, fat was added to the diets isocalorically, in order to evaluate any effect of temperature on the utilization of fat per se. The isocaloric inclusion of fat was achieved by replacement of corn by oil and wheat bran in trial 3, and the addition of oil and soybean hulls, at the expense of glucose, in trial 4 (Tables 3 and 4). The energy level was taken as 9000 kcal/kg for refined soybean oil, 1300 kcal/kg for wheat bran, 660 kcal/kg for soybean hulls, and 3350 kcal/kg for glucose monohydrate. The levels of sulfur amino acids and lysine were adjusted by supplementation with the crystalline amino acids.

Trials 5 and 6: The purpose of these trials was to evaluate the effect of temperature on utilization of energy supplied by carbohydrates. In these duplicate trials dietary energy was changed by replacing soybean hulls with glucose, while maintaining the protein and amino acids ratio to energy constant in the minima set for the design of the diets (Table 5).

TABLE 1.- Composition of the experimental diets, trial 1

Ingredient	Diet No					
	1	2	3	4	5	6
	kg/ton					
Soybean oil meal	249	310	342	373	403	433
Fishmeal	50	50	50	50	50	50
Wheat bran	300	300	300	300	300	300
Soybean oil, refined	10	59	84	109	134	156
Corn	349	239	181	125	71	18
Dicalcium phosphate	15	15	15	15	15	15
Calcium carbonate	20	20	20	20	20	20
Sodium chloride	4	4	4	4	4	4
Vitamin and mineral mix ¹	3.5	3.5	3.5	3.5	3.5	3.5
DL Methionine	-	.2	.3	.4	.5	.6
<u>Calculated composition</u>						
Metabolizable energy						
kcal/kg	2400	2600	2700	2800	2900	3000
Protein	21.5	22.8	24.2	25.2	26.0	26.9
Fat,%	3.9	8.5	10.8	13.1	15.4	17.6

¹ Hurwitz et al. (1978).

TABLE 2.- Composition of the experimental diets, trial 2.

Ingredient	Diet No.				
	1	2	3	4	5
	kg/ton				
Soybean oil meal	212	242	272	302	332
Fishmeal	30	30	30	30	30
Wheat bran	270	270	270	270	270
Soybean oil, refined	12.0	37.3	62.6	88.0	113.4
Corn	454	398	342	286	230
Dicalcium phosphate	8.5	9.0	9.5	10.0	10.5
Calcium carbonate	5.5	6.0	6.5	7.0	7.5
Sodium chloride	3.0	3.0	3.0	3.0	3.0
Vitamin and mineral mixture ¹	3.5	3.5	3.5	3.5	3.5
DL Methionine	-	.05	.14	.23	.31
L-Lysine.HCL	1.55	1.27	1.00	.73	.44
<u>Calculated composition</u>					
Metabolizable energy					
kcal/kg	2500	2600	2700	2800	2900
Protein, %	18.3	19.0	19.8	20.5	21.2
Fat, %	4.2	6.6	8.9	11.3	13.6

¹ Hurwitz et al. (1978).

TABLE 3.- Composition of the experimental diets, trial 3.

Ingredient	Diet No.				
	1	2	3	4	5
	kg/ton				
Soybean oil meal	320	313	307	301	298
Fishmeal	30	30	30	30	30
Wheat bran	24	84	144	203	255
Soybean oil, refined	10	30	50	70	90
Corn	588	516	443	371	299
Dicalcium phosphate	18	18	18	18	18
Calcium carbonate	5	5	5	5	5
Sodium chloride	4	4	4	4	4
Vitamin and mineral mix ¹	3.5	3.5	3.5	3.5	3.5
DL Methionine	.24	.22	.21	.19	.18
L-Lysine.HCl	.28	.33	.37	.39	.39
<u>Calculated composition</u>					
Metabolizable energy					
kcal/kg	2900	2900	2900	2900	2900
Protein, %	21.3	21.3	21.3	21.3	21.3
Fat, %	3.8	5.7	7.6	9.6	11.5

¹ Hurwitz et al. (1978).

TABLE 4.- Composition of the experimental diets, trial 4

Ingredient	Diet No.				
	1	2	3	4	5
	kg/ton				
Soybean oil meal	381	377	373	368	364
Fishmeal	30	30	30	30	30
Soybean hulls	16	54	92	130	168
Soybean oil, refined	10	30	50	70	90
Corn	295	295	295	295	285
Glucose monohydrate	234	180	126	73	19
Dicalcium phosphate	21	21	21	21	21
Calcium carbonate	5	5	5	5	5
Sodium chloride	4	4	4	4	4
Vitamin and mineral mix ¹	3.5	3.5	3.5	3.5	3.5
DL Methionine	.55	.61	.66	.72	.78
<u>Calculated composition</u>					
Metabolizable energy					
kcal/kg	2900	2900	2900	2900	2900
Protein, %	21.3	21.3	21.3	21.3	21.3
Fat, %	2.8	5.1	7.4	9.7	12.0

¹ Hurwitz et al. (1978).

TABLE 5.- Composition of the experimental diets, Trials 5 and 6

Ingredient	Diet No.				
	1	2	3	4	5
	kg/ton				
Soybean oil meal	312	355	399	442	485
Fishmeal	30	30	30	30	30
Soybean hulls	377	288	198	109	20
Soybean oil, refined	81.5	81.8	82.1	82.4	82.7
Glucose monohydrate	173	217	261	304	345
Dicalcium phosphate	15	17	19	21	23
Calcium carbonate	5.7	5.8	5.8	5.9	6.0
Sodium chloride	4	4	4	4	4
Vitamin and mineral mix ¹	3.5	3.5	3.5	3.5	3.5
DL Methionine	1.2	1.1	1.1	1.0	1.0
<u>Calculated composition</u>					
Metabolizable energy					
kcal/kg	2400	2600	2800	3000	3200
Protein, %	17.6	19.1	20.5	22.0	23.5
Fat, %	10.0	10.0	10.0	10.0	10.0

¹ Hurwitz et al. (1978).

RESULTS

Response to dietary energy increase by fat supplementation: The results of trials 1 and 2 as illustrated in Fig. 1 are similar and indicate a linear increase in growth and feed efficiency response to fat-energy supplementation of up to 7% of the diet. At the upper level of supplementation (9%), at 3000 kcal/kg or at 2900 kcal/kg diet in trials 1 and 2, respectively, a decrease occurred in growth and/or feed efficiency. The same level of supplementation also caused a reduction in growth and feed efficiency when added isocalorically in trials 3 and 4.

Therefore, the results for the 9% fat level were not included in the response functions. The results in Fig. 1, also show that growth was significantly ($P < 0.05$) greater at 10° than at 27° , but feed efficiency was greater ($P < 0.05$) for the birds kept at 27° . There were no temperature $\times$ fat interactions, and the response functions do not differ significantly ($P > 0.05$) from each other.

Fig 1. Effect of dietary energy, supplied by fat, on the performance of turkeys kept at 10° (—○—) and 27° (—△—).

Upper graphs, feed efficiency (weight gain/feed intake). Lower graphs, weight gain, g/2 weeks. Left, trial 1; right, trial 2. Standard errors or represented by vertical bars.

Plasma hormone concentrations for the lower and upper energy levels of trial 1 are given in Table 6. T_4 did not show any consistent tendency ($P>0.05$). T_3 was higher at the low than at the high temperature ($P<0.05$). Similarly, corticosterone level was significantly ($P<0.05$) higher at 10° than at 27°. Neither of the hormones was affected significantly by diet, although a significant energy x temperature interaction was recorded for T_3 ($P<0.05$).

Table 6. Plasma glucose and hormones, and carcass fat, as affected by dietary energy supplied by fat (trial 1)

Ambient temperature, °C	10		27		SE ¹
Dietary Energy, kcal/kg	2400	3000	2400	3000	
Dietary Fat, %	3.9	17.6	3.9	17.6	
Plasma T_3 , ng/ml	.674a	.924b	.442c	.289c	.051
Plasma T_4 , ng/ml	5.06 ab	4.53 b	6.06 a	6.16 a	.48
Plasma corticosterone,					
ng/ml	7.54 a	5.63 a	3.24 ab	2.92 b	1.52
Carcass fat, %	4.02 a	7.12 b	5.28 a	7.93 b	.53

¹ Calculated from the analysis of variance table. Means designated by different letters are significantly different ($P<0.05$).

Carcass fat concentration was significantly increased by energy/fat supplementation ($P<0.05$), with no significant effect of temperature or temperature x diet interaction.

Response to isocaloric addition of fat: Results of trials 3 and 4 are given in Table 7. In both trials, growth was stimulated by an increase in fat supplementation from 1 to 3%, with no significant effect at higher levels of supplementation. The effect was however, not significant at 10°. At the higher temperature in both trials and also at the lower temperature in

trial 4, growth tended to decrease at the highest level of fat supplementation. Growth was significantly ($P<0.05$) higher at 10° than at 27°, with no significant diet x temperature interaction. Feed efficiency was higher at 27° than at 10°; it tended to be stimulated between 1 and 3% fat supplementation. Feed efficiency decreased when fat supplementation reached 9%.

TABLE 7- The effect of fat levels in isocaloric diets¹ on the performance of turkeys kept at different environmental temperatures (trials 3 and 4)

Temperature °C	Dietary fat %	Weight gain ²		Feed efficiency ³	
		Trial 3	Trial 4	Trial 3	Trial 4
10	1	1520abc	2499a	.342c	.358b
	3	1645a	2565a	.361bc	.375b
	5	1467abc	2532a	.383bc	.377b
	7	1611ab	2619a	.390b	.385b
	9	1679a	2521a	.399b	.390a
27	1	1283c	1961c	.384bc	.370b
	3	1582ab	2345ab	.420ab	.439a
	5	1525abc	2356ab	.439ab	.415a
	7	1666a	2331ab	.457a	.419a
	9	1332bc	2037bc	.381bc	.386b
SE ⁴		79	131	.017	.017

¹ Caloric density was adjusted by wheat bran and soybean hulls, in trial 3 and Trial 4, respectively.

² g/2 weeks and g/3 weeks in trials 3 and 4, respectively.

³ Weight gain/feed intake.

⁴ Calculated from the analysis of variance table.

Carcass fat (Table 8) was significantly increased by dietary fat, with no significant effect of temperature or temperature x diet interaction ($P>0.05$).

TABLE 8 - The effect of dietary fat, added isocalorically¹, on
Carcass fat in turkeys (trial 3)

Temperature oC	Dietary Fat supplement, %	Carcass fat %
10	1	5.28a
	9	6.75b
27	1	5.43ab
	9	6.56ab
SE ²		.48

¹ Caloric density was adjusted by soybean hulls.

² Calculated for the analysis of variance table.

Response to energy added as carbohydrate: Results of the growth and feed efficiency of the two duplicate experiments are shown in Fig. 2. In almost all cases, growth was greater and feed efficiency was lower at the low (10°) compared with the high (27°) temperature. Both weight gain and feed efficiency increased as the dietary glucose-energy increased. However, the response to energy was greater at the low than at the high temperature. This interaction was significant in trial 5, but less pronounced in trial 6. Analysis of the combined results by the SAS program, indicated that the interaction was significant ($P < 0.05$) for both growth and feed efficiency.

Plasma glucose (Table 9) was significantly ($P < 0.05$) higher at 10° than at 27°, without any difference due to diet. Plasma corticosterone was not affected by any of the treatments.

Fig 2. Effect of dietary energy supplied as glucose on the performance of turkey poults kept at 100(—○—) and 270(—△—). Upper graphs, feed efficiency (weight gain/feed intake); lower graphs, weight gain, g/2 weeks. Left, trial 5; right, trial 6. Standard errors are represented by vertical bars.

Carcass fat (Table 10) of birds of both trials was not significantly affected by temperature, and was increased by glucose-energy only at the lower temperature (100). This interaction was significant in both trials.

TABLE 9 - Plasma glucose and corticosterone in turkeys as influenced by dietary carbohydrate level and ambient temperature, Trial 5.

Temperature	10o		27o		SE1
Dietary glucose	17.3%	34.5%	17.3%	34.5%	
Plasma glucose, mg/dl	299a ²	293a	269b	270b	10
Corticosterone, ng/ml	4.01a	3.64a	3.89a	3.88a	0.67

¹ Pooled standard error, from the analysis of variance table.

² Means designated by different letters are significantly different ($P < 0.05$).

TABLE 10 - Effect of ambient temperature and dietary energy, provided by glucose on carcass fat (trials 5 and 6)

Temperature °C	Energy kcal/kg	<u>Carcass fat, % of weight</u>	
		Trial 5	Trial 6
10	2400	5.81b ¹	4.82c
10	3200	8.77a	7.22a
27	2400	7.28ab	5.77bc
27	3200	6.75b	6.12ab
	SE ²	0.62	0.39

¹ Means designated by different letters are significantly different ($P < 0.05$); $n=6$.

² Calculated from the error term of the analysis of variance

DISCUSSION

The present results confirm those of our previous study (Hurwitz et al., 1986a) which showed that (a) both growth and feed efficiency in turkeys are increased by dietary fat supplementation; (b) the growth and feed efficiency response to dietary fat is the sum of its effect as an energy supplement and as fat per se; and (c) the increase in carcass fat in turkeys, observed with high-energy diets is the result of fat per se, rather of energy. The evidence for this conclusion in the present study is the response to dietary fat added inclusive of energy (Table 6) or isocalorically (Table 8). The same tendency is apparent in the results of Summers et al. (1985), who used fat to balance the energy when dietary protein was raised.

The growth, feed efficiency and carcass fat response to the isocaloric addition of fat, aimed at illustrating the "extracaloric" effects of fat (Jensen et al., 1970), is subject to the assumption concerning the validity of the values used for metabolizable energy of the feedstuffs in this study. Evidence pointing to the applicability of these energy values is the general good agreement between these values and those determined empirically in many earlier studies and the age-dependent improvements in growth and feed efficiency due to the isocaloric addition of fat (Hurwitz et al., 1986a). Regardless of the validity of the assumption, the results of trials 3 and 4 (Table 7), and especially those of trials 1 and 2 (Fig 1), suggest that the general effect of fat including the "extracaloric" responses, are not temperature dependent. Therefore, these results do not confirm the suggestion of Lipstein and Bornstein (1975) that the extracaloric effect of fat was more pronounced during warm weather at least for the growing turkey, but are in agreement with Dale and Fuller (1979), Charles et al. (1981) and Sinuart and Balnave (1985), who found no fat x temperature interactions. It should be pointed out, however, that both the high and the low temperature used in the present study at a steady state may be

considered "mild". Different results may be obtained either under more extreme - cold and hot - temperatures, or with acute temperature changes. It should be pointed out also that, in all four experiments, fat replaced carbohydrates, and different results might have been obtained if carbohydrate concentration was held constant.

In trials 1-4, the high soybean oil supplementation of 9% depressed growth and/or feed efficiency. This effect appears to be independent of the level of energy (2900 kcal/kg in one experiment and 3000 kcal/kg in another), and of the mode of addition (with calories or isocaloric). Therefore, it may be suggested that the depressed performance could be related to the fat addition itself, possibly by adverse effects on diet consistency.

Only a small part of the greater feed consumption at the low as compared with the high temperature may be attributed to the difference in growth rate. Most of the additional energy consumed at the low temperature is the physiological answer to the higher energy production at the low temperature (Barrot and Pringle, 1946), due to the need for maintenance of body temperature (adaptive heat). The greater response of performance to dietary carbohydrate at low than at high temperature (trials 5 and 6) may be related to the efficient use of the high heat increment due to carbohydrates (Brody, 1945; Dale and Fuller, 1979; Schwartz et al., 1985), and/ or to the use of carbohydrate in generating the "adaptive heat". An increase in glucose turnover at low temperature was observed by Riesenfeld et al. (1983). The higher glucose concentration at the lower temperature also hints at this mechanism.

In diet formulation, no differentiation is made in the energy values of feedstuffs used in cold and in hot weather. The present results suggest that while this practice may be valid for lipid-rich feedstuffs, an environmental-temperature dependence of the values assigned to carbohydrate-rich ingredients should be considered.

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COOPERATION

1. The approaches and general plans were coordinated throughout the study.
2. The mathematical approaches and models for broiler and turkey feeding, have been outlined during a visit of the principal investigator (Hurwitz) with H. Talpaz at Texas A&M. The result, written into a joint paper "DYNAMIC OPTIMIZATION MODEL FOR FEEDING OF BROILERS", has been submitted for publication.
3. During the BARD-supported visit of Dr. Colin Scanes to Israel, a collaborative experiment was conducted with turkeys. Growth hormone assays of blood plasma from this experiment were made at Dr. Scanes' Laboratory in New Brunswick NJ, by the Israeli graduate student J. Rosenberg.
4. Continuation of cooperation with Dr. P. Waibel, at University of Minnesota, resulted in software which is aimed at optimizing turkey production. The program written for a microcomputer is currently distributed in the U.S..

MAIN ACHIEVEMENTS

1. Elucidation of the greater value of carbohydrates at the lower than at the higher temperatures. This information will be used in diet formulation for different seasons and geographical locations, and provides a basis for a more efficient utilization of feed.
2. Elucidation of the age-dependent value of fat for improving feed efficiency and increasing carcass fat in turkeys, in contrast to broilers. Carcasses of turkeys contain less fat than desired for consumption and further processing.
3. Establishment of a basis for understanding of the hormonal mechanisms involved in growth and temperature adaptation.
4. Characterization of the mechanisms involved in the regulation of corticosteroid hormone secretion in birds.
5. Establishment of the avian dispersed kidney cells as a model for studies of thyroxine monodeiodination.
6. Development of theoretical models to simulate growth, feed intake and carcass composition.
7. Development of computer techniques which can be used in practice to continuously design optimal diets, and to optimize profitability.
8. Preparation for public use of computer programs to aid on-farm decisions for optimizing chicken-broiler and turkey operations, in user-friendly software in English and Hebrew.

LIST OF PUBLICATIONS

Papers bearing the titles as given in the report have all been recently submitted for publication.

So far, the following have been accepted:

1. Talpaz, H., J.R. de la Torre, P.J.H. Sharpe and S. Hurwitz (1986) Dynamic optimization model for feeding of broilers. Agricultural Systems, in press.
2. Rosenberg, J., M. Pines and S. Hurwitz (1986) Relationship between endogenous cyclic AMP production and hormone secretion in chick adrenal cells. Comparative Biochemistry and Physiology, in press.