Mycoprotein reduces blood lipids in free-living subjects[1-3]

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ABSTRACT Mycoprotein is a food produced by continuous fermentation of *Fusarium graminearum* (Schwabe). A previous metabolic study showed that mycoprotein decreased total and low-density-lipoprotein (LDL) cholesterol and increased high-density-lipoprotein (HDL) cholesterol. This study was undertaken to determine the effects of mycoprotein under free-living conditions. Two groups of subjects with slightly raised cholesterol concentrations participated in the 8-wk study. The experimental group was fed cookies containing mycoprotein and the control group was fed a nutrient-balanced cookie without mycoprotein. After 8 wk of treatment total cholesterol was reduced by 0.46 mmol/L in the control group and 0.95 mmol/L in the mycoprotein group, and LDL was reduced by 0.34 mmol/L in the control group and 0.84 mmol/L in the mycoprotein group. All analysis of variance differences were statistically significant. This study confirms the metabolic-study results and we are now relatively confident that mycoprotein exerts a beneficial effect on blood lipids. *Am J Clin Nutr* 1992;55:415–9.

KEY WORDS Mycoprotein, *Fusarium graminearum*, blood lipids, lipoproteins, free-living study

Introduction

Mycoprotein is a food produced by continuous fermentation of *Fusarium graminearum* (Schwabe) on a carbohydrate substrate (glucose). After harvesting the biomass undergoes a short heat-treatment process to reduce the RNA content, which is achieved by activation of endogenous RNAase enzymes. Mycoprotein can be flavored and textured to resemble meat and has many potential applications. A detailed description of mycoprotein production has been given elsewhere (1, 2).

The protein quality of mycoprotein is high and close to that of skim milk (1) whereas the low fat content comprises predominantly unsaturated fatty acids, and it contains reasonable amounts of dietary fiber. Mycoprotein, under the brand name Quorn, is produced in the United Kingdom by Marlow Foods Ltd (Marlow, Buckinghamshire). It was approved for sale by UK authorities in 1983 and there is now a large variety of products available to the British public.

Previous animal and human studies designed to assess acceptability of mycoprotein gave some indication that there may be an effect on blood lipids (3–7). A recent metabolic study designed to investigate the effects of mycoprotein on blood lipids showed significant beneficial effects (8): significant reductions in total and low-density lipoprotein (LDL) cholesterol and an increase in high-density lipoprotein (HDL) cholesterol. Although these results are very good, this type of study took place under ideal scientific conditions.

The next logical step was to investigate the effects of mycoprotein under free-living conditions. The term free-living implies that subjects go about normal daily life and eat habitual diets but are given a supplement to consume with their normal food.

One problem with such a free-living study is subject compliance because there is no direct control over what a subject eats. The previous metabolic study lasted 3 wk and it was decided to investigate the free-living effects for 8 wk. To aid compliance for this considerable period of time, an easy to eat form of mycoprotein had to be given. To overcome this difficulty, cookies containing freeze-dried mycoprotein were prepared. The cookie solution was an ideal one as a control cookie was relatively easy to produce and the different varieties looked and tasted very similar. Previous studies using oat cookies demonstrated that this was a popular way of giving a fiber-containing food because cookies can be easily carried around and eaten throughout the day as a snack (9, 10).

This study investigated the effects of mycoprotein on blood lipids, lipoproteins, apolipoproteins A-1 (apo A-1) and B (apo B), and body weight taking experience from previous free-living studies (9, 10) into account.

Methods

To simplify the mode of administration of the mycoprotein, it was freeze-dried, mixed with other ingredients, and baked into cookies (**Table 1**). This freeze-dried mycoprotein differed slightly from the Quorn mycoprotein used in the previous metabolic study in that it was not bound with a small amount of albumen (not needed as a binding agent because the product was dried) and did not contain flavoring. The control cookies contained no mycoprotein but had the same macronutrient content. The basic ingredients of both cookies were flour (main ingredient), sugar, and vegetable margarine. Some soya concentrate (to balance the protein content) was included in the control cookies in place of mycoprotein and nutrient comparability was maintained by adjusting the proportions of the various ingredients.

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TABLE 1
Nutrient composition of mycoprotein

Protein (g/100 g)	12.1
Dietary fiber (g/100 g)	6.8
Total fat (g/100 g)	3.4
Fatty acids	
Saturated	0.5
Monounsaturated	0.3
Polyunsaturated	1.5
Total	2.3
Other lipid components	1.1
Total carbohydrate (g/100 g)	1.7
Sugars	0.8
Ash (g/100 g)	0.8
Sodium (g/100 g)	0.004
Cholesterol (g/100 g)	0.0
Water (g/100 g)	75.0
Energy	
(kJ/100 g)	360
(kcal/100 g)	86

The nutrient content for both cookies is shown in **Table 2.** The dietary fiber content of mycoprotein (25% of dry matter) is attributable to its cell-wall components, approximately one-third of which is chitin (poly *n*-acetyl glucosamine) and two-thirds insoluble β-glucan.

Three hundred staff and students of King's College London were screened by finger-prick blood sample (Reflotron, Boehringer Mannheim, Mannheim, FRG) to determine total cholesterol concentrations. Twenty-one subjects (7 female, 14 male, aged 25–61 y, body mass indices (in kg/m^2) 21.3–33.0) with blood cholesterol concentrations > 5.2 mmol/L were found suitable to participate in the study, having no indication of diabetes mellitus, kidney disease, or thyroid disorder and not using lipid-lowering drugs or other substances known to affect lipid metabolism. All subjects underwent further screening to establish that the first cholesterol reading was valid. This study was approved by the King's College ethical committee.

Two parallel groups of subjects (11 eating mycoprotein cookies and 10 eating control cookies) were randomly allocated to either mycoprotein or control groups (blind) for 8 wk. Subjects recorded their dietary intakes and were asked to continue with their habitual diets and to eat the cookie supplements spread out over the day. Blood samples were taken just before the start of the study, after 4 wk, and during the last days of the study. On each occasion subjects fasted overnight (12 h) before blood sampling and a second sample was taken within 3 d. Body weight was measured at the start and end of the study.

The following variables were measured: total cholesterol (enzymatic CHOD-PAP method, Boehringer Mannheim), triglycerides (Peridochrom GPO-PAP method, Boehringer Mannheim), LDL [calculated by the Friedwald et al formula (11)], HDL (HDL precipitant, Boehringer Mannheim), and apo A-1 and apo B (immunological turbidity method, Boehringer Mannheim). Three weighed, 5-d, dietary records were made (before the study started, after 4 wk of the study, and during the last week of the study) and analyzed by an individual not aware of the treatment sequence using a food tables computer database (12–14).

Three types of statistical analysis were performed on the data. Within each treatment group the initial values (before study) were compared with the values after 4 wk (midstudy) and the final values (end study) with a paired *t* test. The changes in the two groups over the period were compared by analysis of variance (ANOVA). The midstudy and the end-study values for the two groups were compared by analysis of covariance (ANCOVA) with the initial value used as a covariate (*GENSTAT 5*, Rothampstead Experimental Station, Harpenden, UK).

Results

Subjects in the control group consumed 8 cookies/d (range 6–10) and in the mycoprotein group 8.4 per day (range 7–12). The amount of mycoprotein consumed was 26.9 g dry wt/d (equivalent to $\approx$130 g Quorn at normal moisture content). There were no significant changes in body weight throughout the study.

Table 3 shows the mean nutrient intakes. The energy intake increased to a similar extent in both groups. There was no change in protein intake as a percentage of total energy during the study and carbohydrate intake as percent energy also did not change. Dietary fiber increased to the same extent in both groups. Dietary cholesterol intake was low and went even lower throughout the study in both groups.

Total fat intake increased in both groups similarly except for a slightly larger increase in the mycoprotein group at midstudy. There was only a small change in saturated fatty acid intake throughout the study period but the intake of polyunsaturated fatty acids doubled in both groups after the subjects began to eat the cookies and remained constant throughout the study period. The increase in polyunsaturated fatty acids was mainly due to an increase in linoleic acid (18:2). The intake of other fats including monounsaturated fatty acids in the control group was small and constant throughout, whereas there was a more marked increase after 4 wk and a slight reduction toward the end of the study in the mycoprotein group. There was virtually no change in the intake of saturated fatty acids when calculated as percent energy in either the control or mycoprotein group. The intake of polyunsaturated fatty acids calculated as percentage energy doubled after the start of cookie eating in both the control and mycoprotein groups and stayed unchanged throughout the study. There was virtually no change in the intake of other fats including monounsaturates when calculated as percentage energy

TABLE 2
Nutrient composition of experimental biscuits

	Control	Mycoprotein
	per 100 g	
Energy		
(MJ)	1.81	1.78
(kcal)	432	425
Protein (g)	13.0	12.9
Total fat (g)	22.6	22.7
Saturated fatty acids (g)	6.8	6.5
Polyunsaturated fatty acids (g)	6.2	5.5
Other fat including monounsaturated fatty acids (g)	9.6	10.7
Carbohydrate (g)	46.3	45.1
Dietary fiber (g)	6.2	5.5
Mycoprotein (g dry wt)	0	20.0

TABLE 3
Dietary intakes*

Variable	Before study	Midstudy	End study
Energy			
Control			
(MJ/d)	8.079 ± 2.82	8.778 ± 2.22	9.067 ± 2.61
(kcal/d)	1931 ± 674	2098 ± 531	2167 ± 623
Mycoprotein			
(MJ/d)	9.297 ± 2.16	10.22 ± 2.42	10.16 ± 1.67
(kcal/d)	2222 ± 516	2443 ± 578	2427 ± 400
Protein			
Control			
(g/d)	66.8 ± 16.1	71.6 ± 19.0	76.0 ± 19.6
(% energy)	14.5 ± 3.5	14.0 ± 3.3	14.4 ± 2.6
Mycoprotein			
(g/d)	81.7 ± 17.1	87.6 ± 19.0	86.8 ± 18.2
(% energy)	14.9 ± 2.3	14.6 ± 2.3	14.3 ± 1.4
Carbohydrate			
Control			
(g/d)	223 ± 77.1	247 ± 69.2	247 ± 69.1
(% energy)	43.7 ± 4.5	44.2 ± 3.7	43.3 ± 4.0
Mycoprotein			
(g/d)	243 ± 61.4	261 ± 67.2	271 ± 53.8
(% energy)	41.8 ± 8.6	40.5 ± 6.2	42.1 ± 6.4
Dietary fiber			
Control (g/d)	19.8 ± 6.3	25.0 ± 6.2	25.2 ± 4.4
Mycoprotein (g/d)	20.6 ± 5.5	26.0 ± 4.6	27.2 ± 5.9
Cholesterol			
Control (mg/d)	157 ± 119	107 ± 95	113 ± 47
Mycoprotein (mg/d)	216 ± 127	163 ± 96	120 ± 68
Alcohol			
Control			
(g/d)	6.7 ± 6.3	7.2 ± 9.4	5.8 ± 9.0
(% energy)	2.5 ± 2.9	2.2 ± 3.3	1.7 ± 2.6
Mycoprotein			
(g/d)	21.0 ± 17.4	14.8 ± 14.7	15.2 ± 14.7
(% energy)	6.3 ± 5.3	4.3 ± 4.4	4.4 ± 4.1
Total fat			
Control			
(g/d)	86.3 ± 38.3	92.0 ± 27.1	98.5 ± 32.4
(% energy)	39.0 ± 6.2	39.1 ± 4.7	40.5 ± 3.7
Mycoprotein			
(g/d)	92.9 ± 29.8	112.0 ± 34.5	106.4 ± 22.6
(% energy)	37.0 ± 4.8	40.6 ± 4.1	39.2 ± 3.2
Total saturates			
Control			
(g/d)	26.9 ± 14.1	24.5 ± 9.7	29.8 ± 10.3
(% energy)	11.9 ± 4.0	10.3 ± 2.7	12.2 ± 2.4
Mycoprotein			
(g/d)	30.0 ± 16.4	32.8 ± 14.4	31.1 ± 11.3
(% energy)	11.5 ± 4.4	11.7 ± 3.3	11.3 ± 2.8
Total polyunsaturates			
Control			
(g/d)	6.7 ± 3.1	12.5 ± 3.3	12.9 ± 4.2
(% energy)	3.1 ± 1.0	5.4 ± 1.0	5.4 ± 1.0
Mycoprotein			
(g/d)	6.6 ± 3.7	13.2 ± 5.0	13.5 ± 4.9
(% energy)	2.6 ± 1.2	4.9 ± 1.5	5.0 ± 1.0
Total other fats including monounsaturates			
Control			
(g/d)	52.8 ± 24.5	55.0 ± 18.1	54.9 ± 21.3
(% energy)	23.9 ± 4.7	23.3 ± 5.0	22.4 ± 3.2
Mycoprotein			
(g/d)	56.4 ± 17.9	66.0 ± 24.6	64.3 ± 15.8
(% energy)	22.8 ± 5.5	23.9 ± 5.4	24.1 ± 6.3

* $\bar{x}$ ± SD.

in either group. All supplementary data (dietary intakes, number of cookies eaten, age, sex, height, and weight) were not statistically significant with respect to the main blood responses.

All measured blood lipids are shown in **Table 4.** Total cholesterol was reduced by 10.4% in the mycoprotein group whereas there was a slight increase in the control group of 1.4%, producing an overall difference between the groups of 11.8% (ANOVA, $P < 0.01$) from start to midstudy. From start to end total cholesterol was reduced by 15.9% in the mycoprotein group but also reduced by 8.0% in the control group, producing an overall difference of 7.9% (ANOVA, $P < 0.05$) between groups from start to end study. HDL was fairly stable throughout and all differences were nonsignificant. LDL was reduced by 18.4% in the mycoprotein group and increased by 2.6% in the control group, producing an overall difference of 21% (ANOVA, $P < 0.01$) between groups from start to midstudy. From start to end study, there was a 21.5% LDL reduction in the mycoprotein group and an 8.9% reduction in the control group, producing an overall difference of 12.6% (ANOVA, $P < 0.05$) between groups. Triglycerides were stable throughout and all changes were nonsignificant. There was very little change in apo A-1 and apo B or in their ratio at any stage of the study. The ANCOVA showed very similar results to the ANOVA.

Discussion

The results of this study correlate very well with the previous metabolic study (8). In a free-living study there is little control over the participants' diets and, as might be expected, there were fluctuations in nutrient intakes in both groups of subjects. Even though dietary variables did change somewhat, the blood lipid

TABLE 4
Blood lipid results*

	Initial	Midstudy	End study
Cholesterol (mmol/L)			
Control	5.75 ± 0.96	5.83 ± 1.37	5.29 ± 1.25
Mycoprotein	5.97 ± 0.61	5.35 ± 0.50†	5.02 ± 0.46‡
HDL (mmol/L)			
Control	1.27 ± 0.34	1.22 ± 0.32	1.13 ± 0.29
Mycoprotein	1.45 ± 0.43	1.58 ± 0.48	1.29 ± 0.46
LDL (mmol/L)			
Control	3.81 ± 0.90	3.91 ± 1.20	3.47 ± 1.06
Mycoprotein	3.91 ± 0.72	3.19 ± 0.74†	3.07 ± 0.69‡
Triglycerides (mmol/L)			
Control	1.47 ± 0.72	1.52 ± 0.76	1.52 ± 0.82
Mycoprotein	1.35 ± 0.45	1.28 ± 0.51	1.45 ± 0.71
Apo A-I (g/L)			
Control	1.18 ± 0.17	1.19 ± 0.21	1.21 ± 0.18
Mycoprotein	1.41 ± 0.41	1.39 ± 0.34	1.31 ± 0.33
Apo B (g/L)			
Control	0.88 ± 0.12	0.91 ± 0.41	0.87 ± 0.10
Mycoprotein	0.93 ± 0.12	0.73 ± 0.23	0.89 ± 0.11
Apo B:Apo A-1			
Control	0.77 ± 0.19	0.81 ± 0.45	0.74 ± 0.15
Mycoprotein	0.72 ± 0.25	0.56 ± 0.23	0.72 ± 0.25

* $\bar{x}$ ± SD.

†‡ Significantly different from control: †$P < 0.01$; ‡$P < 0.05$ (ANOVA).

changes observed in this study follow a pattern similar to those demonstrated in the metabolic study. One exception was that the significant increase in HDL demonstrated in the metabolic study did not occur in this study.

The most likely explanation for the reduction in total and LDL cholesterol is that even though the total dietary fiber increased by the same amount in both groups, the type of dietary fiber found in mycoprotein could be responsible for the desirable effect on blood lipids. Looking closely at the dietary-analysis figures, it is evident that the changes, if any, were very small and similar in both the control and mycoprotein groups. Factors other than dietary intake may have been responsible for the cholesterol reduction in the control group toward the end of the study.

A number of vegetable-protein sources that have a cholesterol-lowering effect have been identified (15–20). Most of these protein sources are associated with various types of beans that in moderate to large amounts result in significant side effects in susceptible individuals.

No side effects of eating either the control or mycoprotein cookies were reported, and this may be because the subjects were asked to slowly increase cookie intake over the first 7 d of the study. A feeling of fullness was an advantageous side effect reported by subjects eating the mycoprotein cookies.

No attempt was made to address the question of mechanisms of action in this study because of the complications associated with measuring these variables, but there are a number of possible explanations. Decreased LDL synthesis and increased clearance in the liver and peripheral tissue may take place because of the dietary fiber fermentation and production of the short-chain fatty acids, such as butyrate, acetate, and propionate (21). Studies demonstrated that fiber can increase fecal bile acid excretion through binding them in the gut (22). Fiber substances can lower the activity of 7-α-hydroxylase, which would increase the conversion of cholesterol to bile acids. The fractional catabolism of LDL may be increased and the LDL receptor activity may be intensified. Propionate may reduce cholesterol synthesis via the inhibition of β-hydroxy-β-methylglutaryl coenzyme A (HMG-CoA) reductase, which is rate-limiting in cholesterol synthesis (23).

There was little difference in total fat intake between control and mycoprotein groups and there was no reduction in saturated fatty acid intake; therefore, Swain et al's (24) observation that dietary fiber and starch-containing foods replace saturated fatty acids causing the plasma cholesterol reduction does not hold for this study.

There are a number of ways of comparing the results of these two different mycoprotein studies, but the following was chosen as a reasonable method of comparison. By converting the freeze-dried mycoprotein into wet weight (25% solids) it is possible to make a direct comparison. Subjects participating in the metabolic study ate 190.6 g Quorn mycoprotein/d and in the free-living study ate 107.5 g mycoprotein/d (equivalent amount of Quorn mycoprotein) on average. **Table 5** shows a comparison of the effect of mycoprotein on blood cholesterol calculated on the basis of 100 g mycoprotein (wet wt) eaten. Because there was little change in the plasma cholesterol of the control group at 4 wk in the free-living study, the absolute value and difference between groups are very similar. The reduction in plasma cholesterol between weeks 4 and 8 in the free-living study shows a lesser reduction in terms of the difference compared with the absolute value because the cholesterol was reduced in the control group as well as in the mycoprotein group. There was already a considerable reduction in the mycoprotein group by week 4 in the free-living study, which accounts for the smaller reduction between weeks 4 and 8 because the scope for the reduction was smaller. The considerable reduction in plasma cholesterol between weeks 0 and 8 in the free-living study is reflected in the absolute change, whereas the reduction is less in the difference due to the reduction in the control group. The metabolic study, which lasted 3 wk, shows little difference between the two methods of comparison because the plasma cholesterol of the control group hardly changed.

TABLE 5
Cholesterol reduction (mmol/L) per 100 g of mycoprotein eaten (wet wt)

Study type and time into study*	Absolute change	Difference between groups
	mmol/L	
FL, 0–4 wk	0.58	0.65
FL, 4–8 wk	0.31	0.20
FL, 0–8 wk	0.88	0.46
M, 0–3 wk	0.38	0.41

* FL, free-living; M, metabolic.

The freeze-dried mycoprotein given in the free-living study may have been more effective when figures for cholesterol reduction per 100 g of mycoprotein on a wet-weight basis were used, but the time scale of the different studies poses a problem. The reduction after 4 wk of the free-living study was more pronounced, as might be expected, but the reduction did continue and might have continued even further if the study had been prolonged. It is even more difficult to persuade subjects to participate in longer-term metabolic studies than in free-living studies because of the very severe restrictions on normal lifestyle.

A very interesting analysis of data published over the last few years demonstrates that as initial plasma cholesterol concentrations are raised, the cholesterol lowering potential of oats increases (25). If this is so, then it strengthens the case to use subjects who would be targeted for dietary change and not to use normal individuals as many studies still do.

Participants of this study were not asked to make any dietary changes other than to eat cookies. The mean percentage energy from total fat in this study was higher than is recommended and it was previously shown that the effect of fiber is supplementary to the effect of lowering dietary fat intake (9, 10, 26, 27). There was thus further scope for reduction of blood cholesterol, and fiber should be seen as one of several ways of lowering blood lipids in the context of the overall diet.

Because of the versatility of mycoprotein, it can be used in a large variety of main-course dishes with a positive contribution to taste and quality, which is not always true for some other products. We are now reasonably confident that mycoprotein does exert an advantageous effect on dyslipidemia. It therefore appears to be a useful dietary means of improving blood lipid profiles.

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