Analysis of Quorn Mycoprotein Derived Products from Petri Dish to Plate

S184758

2017/18

Introduction

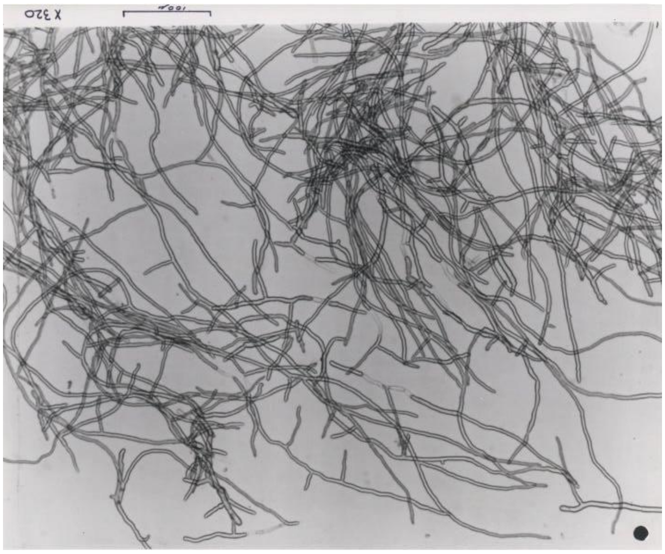

Fig 1. *The appearance of Fusarium venenatum A3/5 as collected from the outlet of the Quorn™ fermenter. Photographprovided by Marlow Foods (Ugalde and Castrillo, 2002).*

Quorn is a meat substitute that was developed by Marlow Foods Ltd, it contains a protein that is derived from the fungi *Fusarium venenatum A3/5 (Fig 1)*, the resulting protein that is made from this fungus is classed as a mycoprotein which literally means 'fungal protein'. What initially sparked the need for an alternative protein source was the growing concern that traditional protein sources like meat would not be able to meet the demand globally. There was also a protein malnutrition problem within underdeveloped countries that caused various childhood diseases. In 1955, the Protein Advisory Group (PAG) was created to help the World Health Organisation (WHO) advise the UN Food and Agricultural Organisation (FAO) and United Nations International Children's Emergency Fund (UNICEF) on new protein foods for their safety, nutritional quality and palatability for human consumption (Trinci, 1992). After 12 years of intensive research it was released for human consumption by Marlow Foods in 1985 and later available for UK distribution in 1993 (Wiebe, 2002). All the products from Quorn share a similar process and the difference between each product is the additives and how they are pressed or formed, egg albumin is added to dried mycoprotein to allow it to bind together and improve the protein quality of the product.

Mycoprotein is made through a fermentation process similar to the way beer is brewed, with the introduction of a carbohydrate and micronutrient source that the fungi feeds on and with a particular environment that allows for optimal growth and yield that is influenced by various factors like temperature and pH. After the fermentation process, there are steps to isolate the protein to improve its quality and safety for consumption. Following that, there are additives that are used to improve qualities such as nutritional value and texture which helps in the formation of the final product and different product varieties produced by Quorn can be made depending on what additives are introduced and how its finally formed for packaging. Quorn was not first marketed as a vegetarian alternative to meat but only to solve the future protein demand, it has become popular as a substitute with many vegetarians over recent years and in some metrics its nutritionally superior to some of its meat alternatives. It has a low-calorie density (80kcal/100g), its low in saturated fat and high in dietary fibre. It also has a protein content that is comparable of milk and contains all eight essential amino acids, but it lacks in methionine and cysteine in relation to the FAO/WHO reference (Sadler, 1988).

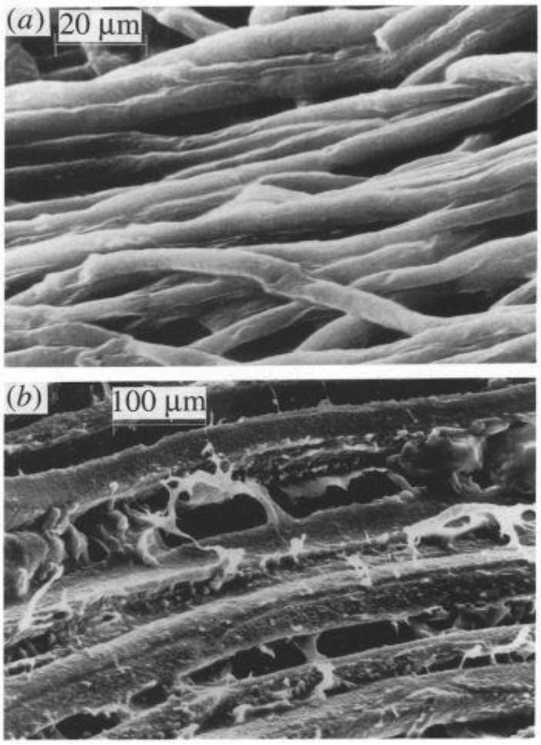

Fig. 2. *SEM image of (a) myco-protein prepared from F. venenatum A3/5, and (b) beefsteak. Photograph provided by Dr R. Angold (The Lord Rank Research Centre, High Wycombe) (Trinci, 1992).*

Its rich in biotin and contains all B vitamins apart from B12, it has a similar mineral content to meat (Sadler, 1988). The microfilaments of Quorn are similar to meat compared to other non-meat protein sources like soya, which gives it a better mouth feel and texture (Fig 2). The shelf life is also comparable to fresh meat (Sadler, 1988).

Despite some of the nutritional advantages of Quorn over meat, there has been various controversies surrounding the product in recent years in terms of its safety for consumption and allergy risk.

The objective of this report was to analyse Quorn and the products they produce from the petri dish to when the food reaches the consumers plate. It outlines the nutritional advantages and disadvantages compared to other alternative protein sources and reviews the safety of Quorn for human consumption.

Processes

Quorn starts its life off in a 140,000L air-lift/pressure-cycle fermenting vessel as a fungus called *Fusarium venenatum A3/5* (Trinci, 1994). The vessel is initially sterilised and filled with water, glucose, vitamins, minerals and ammonium are then added to act as the nutrition to provide the growth of *F. venenatum A3/5* into the mycoprotein that is later used as the raw material for Quorn. Temperature and pH is regulated at 28-30°C and 6.0 respectively, which provides *F. venenatum A3/5* a growth rate of 0.17-0.20 h^{-1} under these conditions and produces 300-350 kg of biomass/h over a 6-week period (Wiebe, 2002). The RNA content is reduced from 9% to 1% (Trinci, 1994) after the fermentation process to meet food safety standards (Edelman, Fewell and Solomons, 1983). This is done by heating the product up to 64-65°C for up to 45 minutes (Towersey, Longton and Cockram, 1977; Solomons, 1984) which allows the RNA to be degraded, separated from the cells. After the RNA reduction process, the biomass is transferred into a centrifuge and heated to 90°C which enables the RNA material to be separated, the resulting paste is then drawn off and cooled down to 4°C which is the raw material used for human consumption in Quorn (Wiebe, 2002). This raw material is then mixed with egg albumin to bind it and give it a more fibrous texture to imitate meat like properties, additives are added depending on what product type is being made and after it is steam cooked for 30 minutes and subsequently chilled until it gets formed and shaped using standard food processing technologies (Wiebe, 2002). Freezing of the product is the last process before it gets packaged, this helps to push the fibres together in groups so that it is more analogous of a real meat product (Mycoprotein.org, 2018).

Testing for microbial bacteria and toxins are carried out at 6-hour intervals throughout the whole production process. An overview of the entire production process can be seen in Fig 3.

Within the FAQ on the Quorn website, they claim that all their products can be cooked using an oven, grill, stove or microwave (Quorn, 2018), there is no information on special considerations when cooking Quorn specifically so general cooking safety guidelines should be followed.

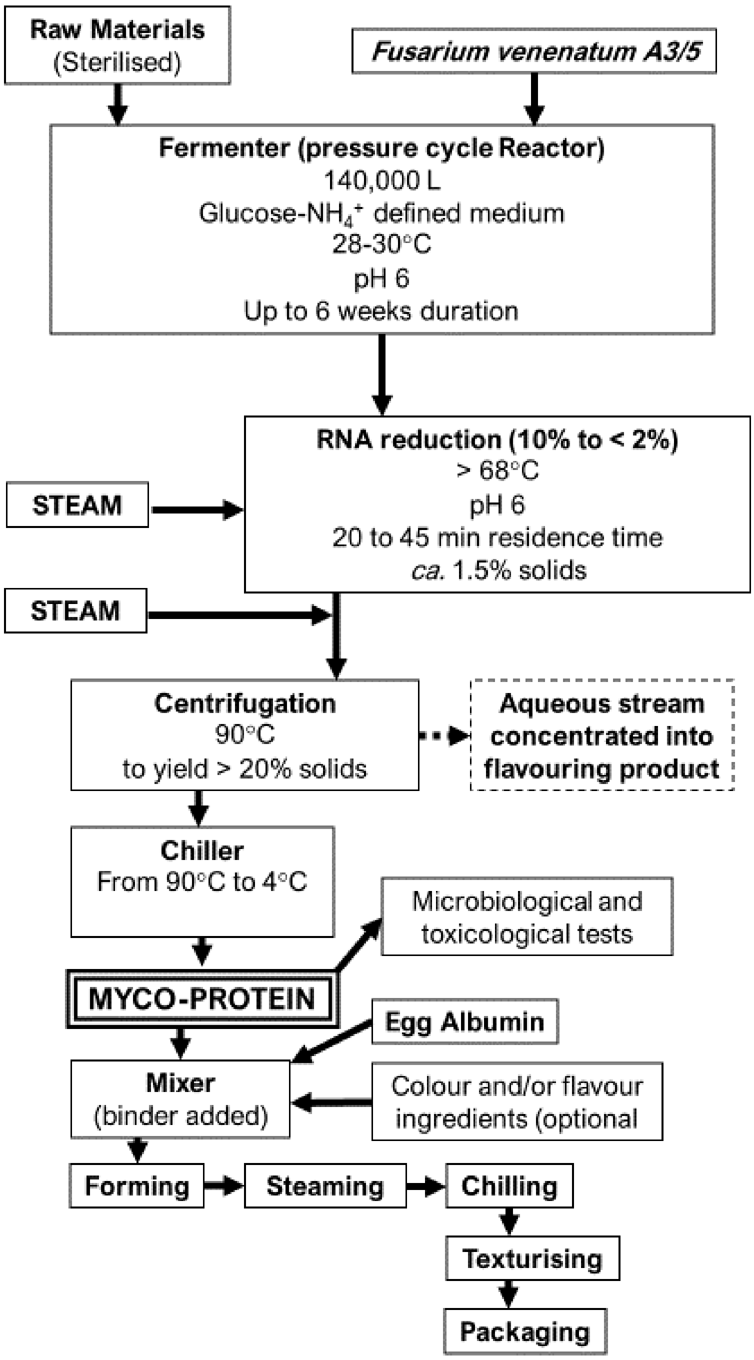

Fig. 3 *Flow chart representation of the process of Quorn from F. venenatum A3/5 to the finished product (Wiebe, 2002).*

Nutritional Analysis

There was a strain selection process that was carried out to get to the fungi strain that is used to make the mycoprotein in the Quorn products produced today and there was a criterion of characteristics that needed to be met so that the suitable strain could be decided on. This included safety (non-toxic), nutritional value (protein content of 45% w/w of biomass, a complete amino acid composition and a minimum Net Protein Utilisation (NPU) value of 75 which is equivalent to milk), an adequate growth rate and yield coefficient (= unit biomass produced: unit of carbohydrate consumed for growth) and organoleptic properties (mouth feel, taste, smell etc) (Trinci, 1992). *F. venenatum A3/5* was the fungal strain that was settled upon, it has a minimum protein content of 42% w/w, a maximum specific growth rate of 0.28 h^{-1}, converts 1kg of carbohydrate into 136g of protein (which is approximately 3 times more efficient at converting carbohydrate into protein than chicken, which only converts at: 49g/kg) and a favourable protein utilisation, especially and after the supplementation of 0.2% (w/w) methionine. Extensive research by MAFF (Ministry of Agriculture, Fisheries and Food) was carried out showing that the strain when used to produce mycoprotein is non-toxic for animal and human consumption.

Protein

The total protein content of mycoprotein in Quorn products is dependent on the specific product, some of them have higher protein per gram due to the addition of egg albumin (Quorn Pieces – Fig 4), although they are still less than lean meats in comparison (Chicken, Beef (lean), Ground Beef (lean) – Fig 4.). Quorn pieces are 15.22% protein per kcal which is higher than any of the other protein sources apart from Chicken (skinless) which is 17.98% of protein per kcal.

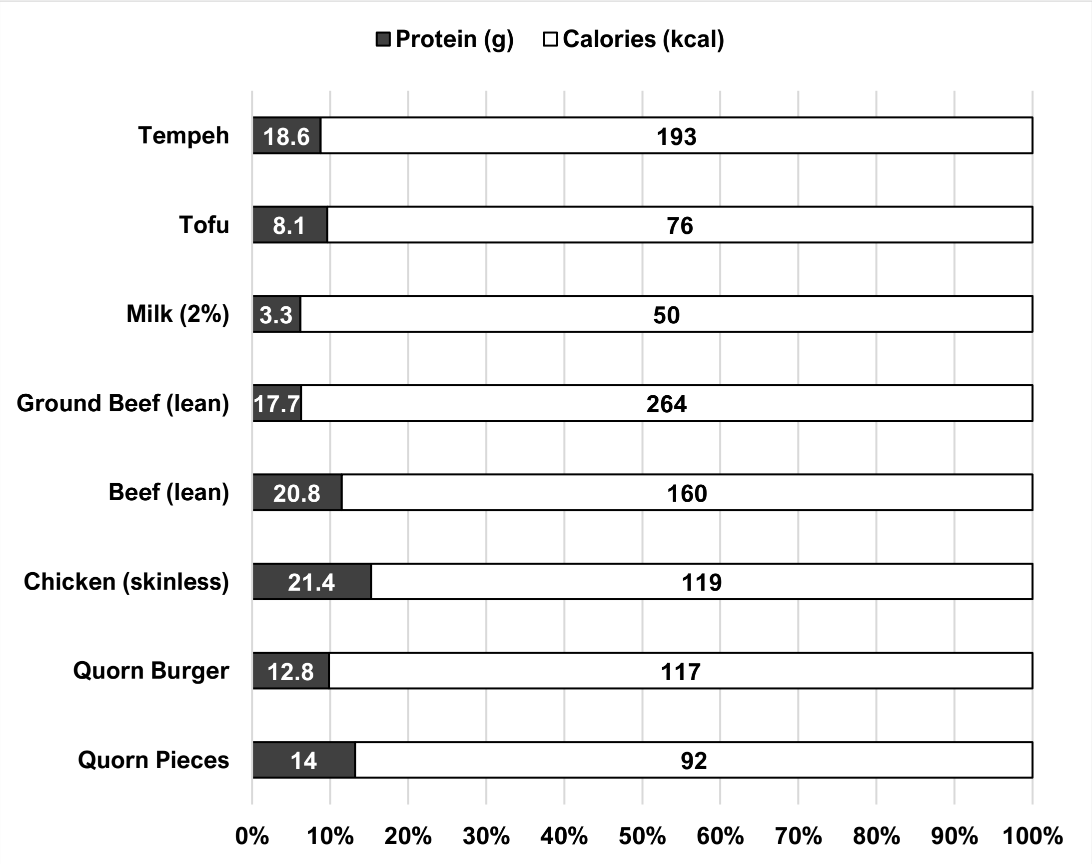

Fig 4. *Protein (g) and calorie (kcal) amount per 100g of raw product. (Wiebe, 2002)*

The Essential Amino Acid (EAA) profile of Quorn products is complete with the exception of methionine and cystine, which is slightly lower compared with the FAO/WHO reference value, even after the supplementation of methionine. Although it does presents higher values of the EAAs: threonine and valine when compared with beef, which are used for the biosynthesis of proteins (Fig 5).

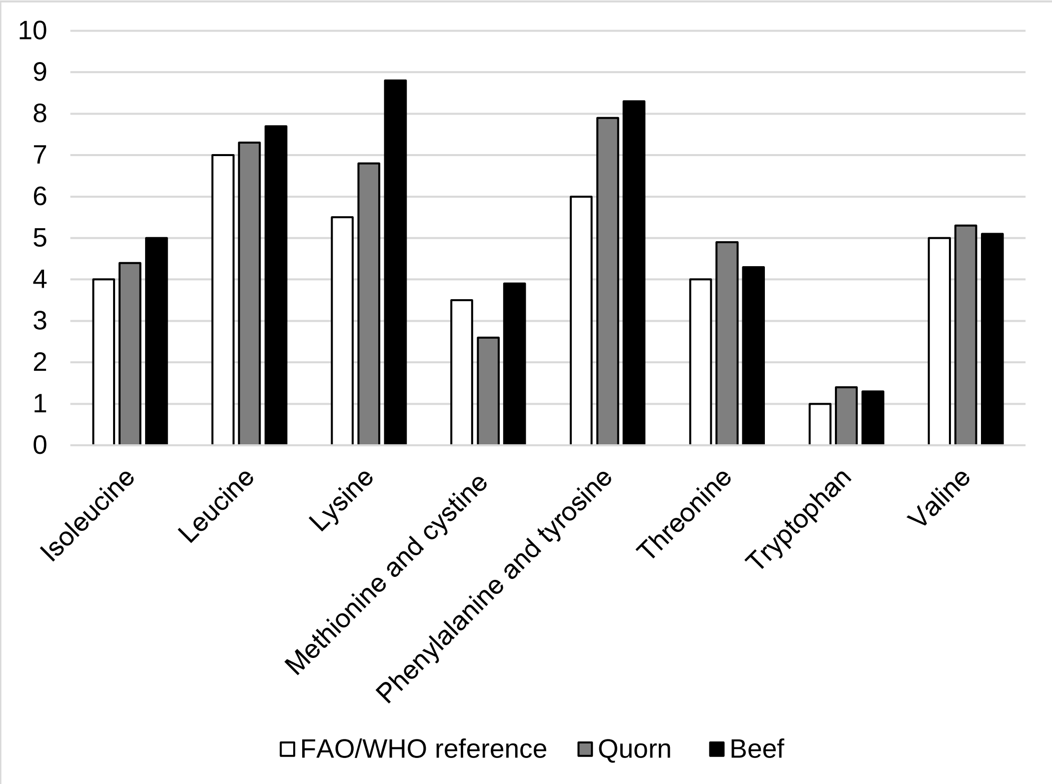

Fig 5. *Amino Acid Profile of Mycoprotein compared to beef (grams per 100 grams of protein) (Sadler, 1990).*

Fig 6. Shows the whole amino acid composition of freeze dried mycoprotein compared to a milk protein concentrate, the milk protein concentrate had totals of 34.5g of EAA, 16.5 g of Branch Chain Amino Acids (BCAA) and 47g of Non-Essential Amino Acids (NEAA) compared to the mycoprotein that had total values of EAA (23.5g), BCAA (8.5g) and NEAA (27.5g).

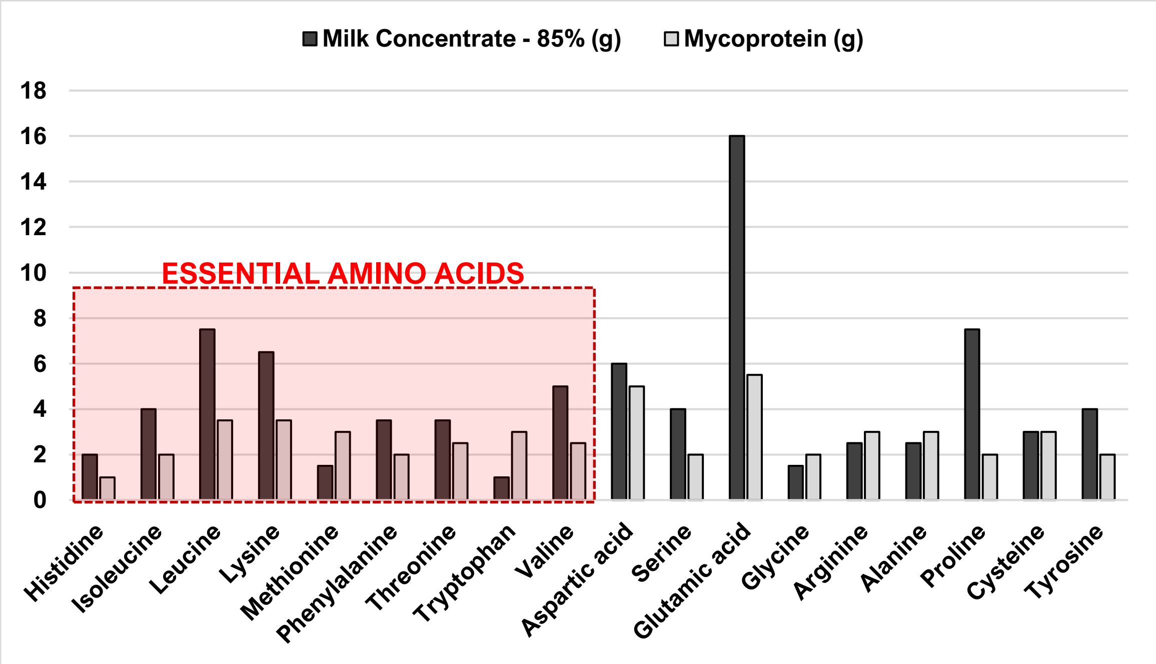

Fig. 6 *Amino acid profile comparison between g/100g of a milk protein concentrate (85%) and 100g of freeze dried mycoprotein. Dotted red box indicates the 9 EAAs (Dunlop et al., 2017).*

Net Protein Utilisation (NPU) is the ratio of amino acids that are converted to usable proteins within the body and the amount of amino acids that are supplied, it's used as a measure of 'Protein quality'. Quorn mycoprotein holds an NPU value of 75 but with the addition of methionine this increases to 100, which is considered 100% protein utilisation and is comparable to egg protein (Fig 7).

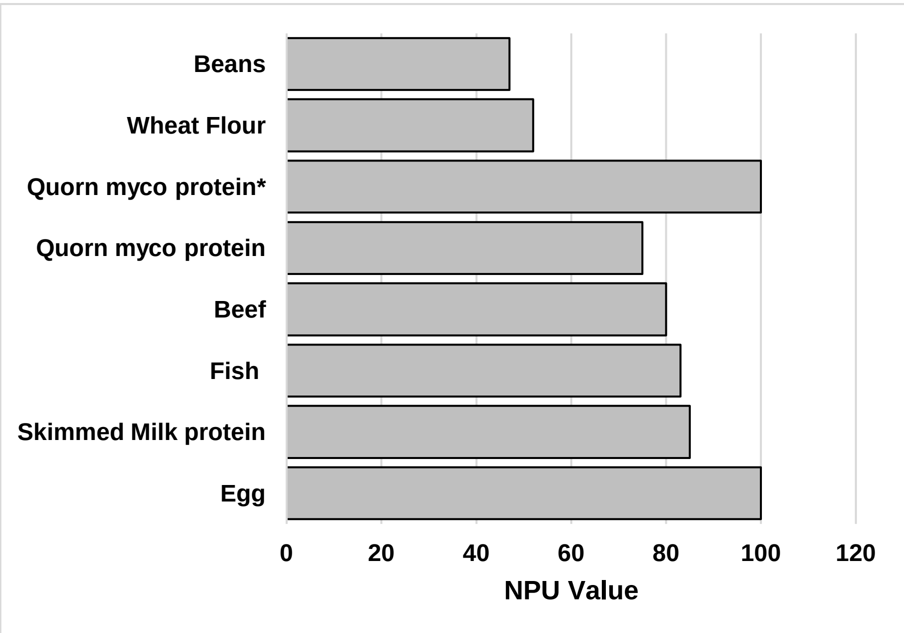

Fig 7. *Comparison of Net Protein Utilisation of Quorn myco-protein and some common food proteins (Trinci, 1992) * When supplemented with 0'2% (w/w) methionine, the NPU value of myco-protein is increased to 100.*

Protein quality can also be measured using the Protein Digestibility-Corrected Amino Acid Score (PDCAAS) which is now the preferred method of measuring protein quality. It is measured by comparing the amino acid profile of the test protein against a standard reference amino acid profile and then adjusted by a faecal true digestibility percentage (Schaafsma, 2000).

Mycoprotein within Quorn products scores higher than beef on the PDCAAS scale, and when egg albumin is added like in the product Quorn Pieces its score is comparable to egg whites (Table 1).

Table 1. *Protein Digestibility Corrected Amino Acid Score (PDCAAS) of Selected Food Proteins (*) - (FAO/WHO Joint Report, 1991), (**) - (Edwards and Cummings, 2010).*

Protein Source	PDCAAS
Quorn pieces**	1
Casein*	1
Egg white*	1
Mycoprotein**	0.99
Beef*	0.92
Pea flour*	0.69
Kidney beans (canned)*	0.68
Rolled oats*	0.57
Lentils (canned)*	0.52
Peanut meal*	0.52
Whole wheat*	0.4
Wheat gluten*	0.25

Fat

Quorn has a low-fat content (3%) and is very low in saturated fat (0.6%) (Fig 9), this is due to the fact the fungi cells are unable to store fat because of their rapid growth rate (Sadler, 1988). It also contains no trans fats or cholesterol but has some levels of polyunsaturated fat which is added to improve sensory qualities giving it a Poly/Saturated (P/S) ratio value of 2.5. This shows it could be a favourable protein alternative to populations who have higher cholesterol and require ways to limit their intake of saturated fat and cholesterol. Studies have shown the consumption of mycoprotein over meat improved blood lipids (Turnbull, Leeds and Edwards, 1990, 1992).

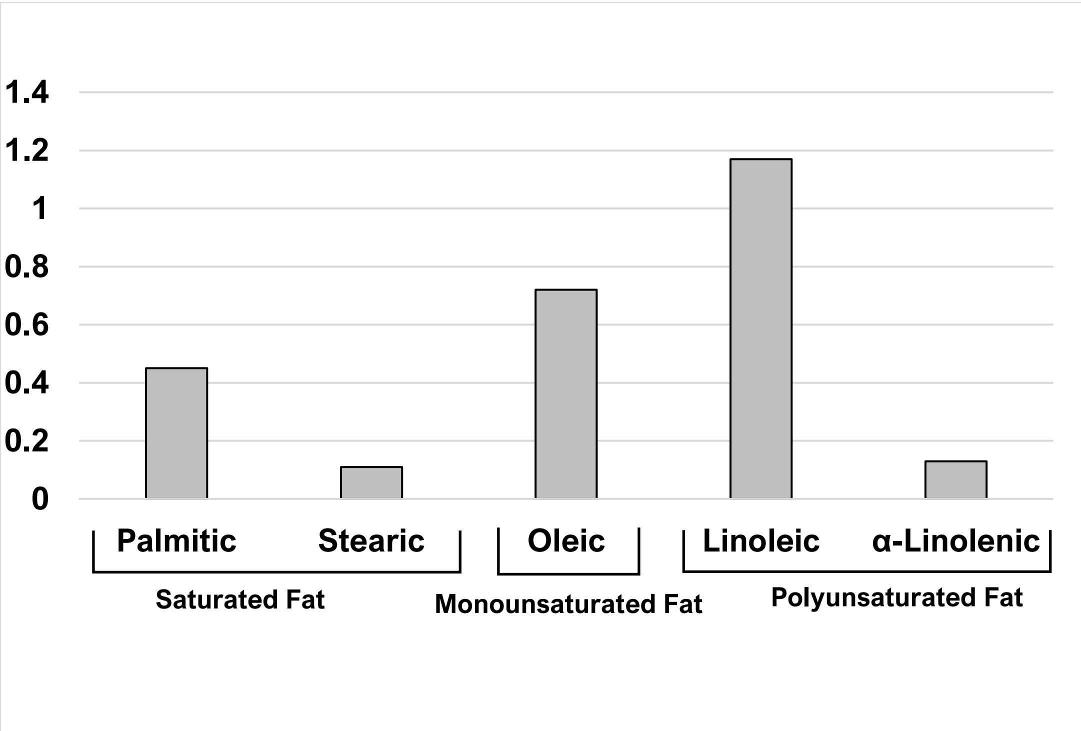

Fig 9. *Fat profile of Quorn (g/100g) (Sadler, 1988).*

Table 2 shows a comparison of fat of other common protein sources compared to Quorn products. Quorn has less total fat than most animal-based proteins apart from chicken, it also has less cholesterol than any other animal-based proteins. This makes it low in calories as dietary fat is the most energy dense macromolecule.

Table 2. *Total fat (g), saturated fat (g) and cholesterol (mg) of mycoprotein products and common protein sources. Values given from 100g of raw product (Wiebe, 2002).*

	Total fat (g)	Saturated fat (g)	Cholesterol (mg)
Quorn Pieces	3.2	0.6	0
Quorn Burger	4.6	2.3	0
Chicken (skinless)	3.1	0.8	70
Beef (lean)	7.8	2.8	62
Ground Beef (lean)	20.7	8.3	75
Milk (2%)	1.9	1.2	7.5
Tofu	4.8	0.7	0
Tempeh	10.8	2.2	0

Fibre & Carbohydrates

Quorn is also high in fibre, which consists of chitin (35%) and β-glucan cell wall material (65%), studies have shown the cholesterol-lowering effects of β-glucan, improving LDL without changing HDL (Othman, Moghadasian and Jones, 2011; Whitehead et al., 2014), although the sample sizes were small and study duration was short. It contains dietary fibre higher than many vegetables (Fig 11) and consuming Quorn as a primary protein source over meat would present a significant difference in total fibre intake (Sadler, 1990).

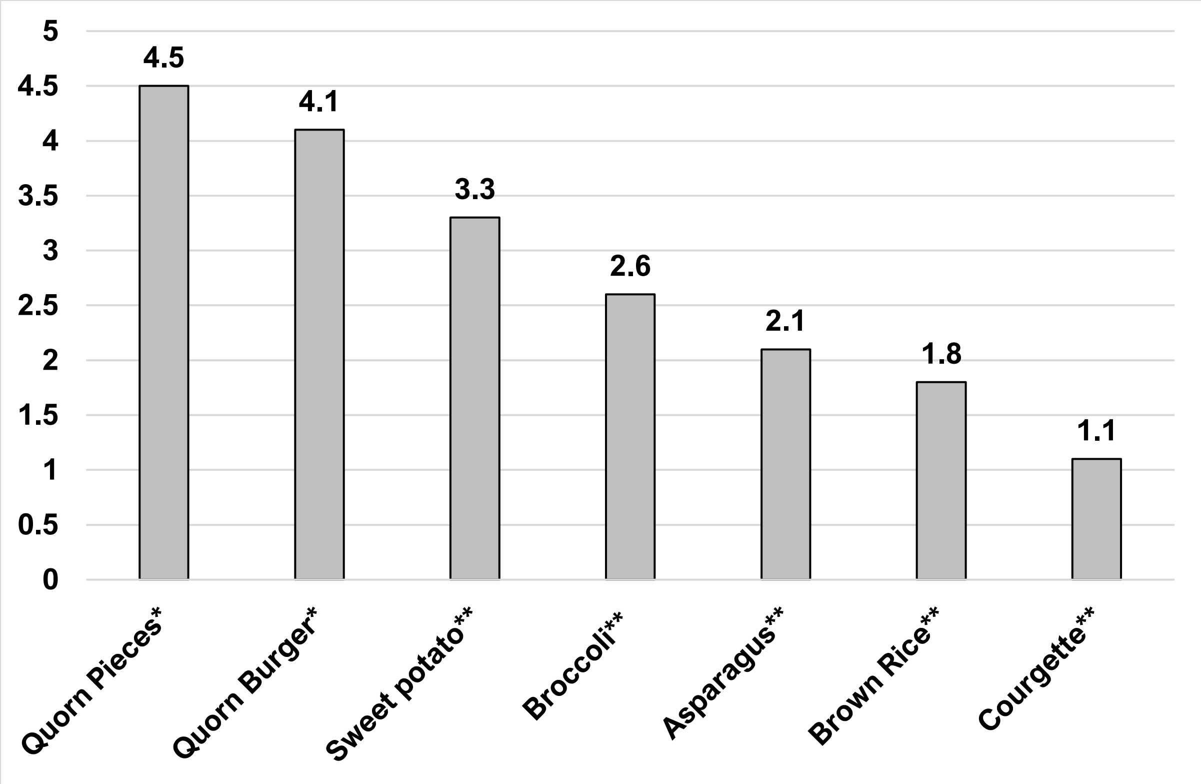

Fig 11. *Fibre content (g/100) of Quorn products and common fibre sources. *(Nutritiondata.self.com, 2018), **(Wiebe, 2002).*

Carbohydrate and sugar content in Quorn products are relatively low gram for gram, similar to other non-meat-based protein sources (Table 3), which may lend it to be a suitable food for the management of Type 2 Diabetes as it appears to show beneficial effects on glycaemia and insulinaemia. A study by Turnbull and Ward, (1995) showed anti-glycaemic effects of mycoprotein post prandial during an oral glucose tolerance test compared to a control. Although these effects may be due to the reduced rates of gastric emptying that fibre will bring by slowing the passage of food into the small intestine (Leclère et al., 1994), which in turn will reduce the absorption of glucose.

Table 3. *Carbohydrate and sugar content (g/100) of Quorn products and common protein sources (Wiebe, 2002).*

	Total Carbohydrate (g)	Sugars (g)
Quorn Pieces	1.8	0.8
Quorn Burger	5.8	2.5
Chicken (skinless)	0	0
Beef (lean)	0	0
Ground Beef (lean)	0	0
Milk (2%)	4.8	4.8
Tofu	1.9	1.5
Tempeh	9.4	4.6

Vitamins & Minerals

Quorn has high levels biotin and folic acid, this is due to the addition of these nutrients during the fermentation process, they provide optimal growth during fermentation for the fungi. It also contains no vitamin B12, and niacin is considerably lower than can be seen in beef (Fig 12.)

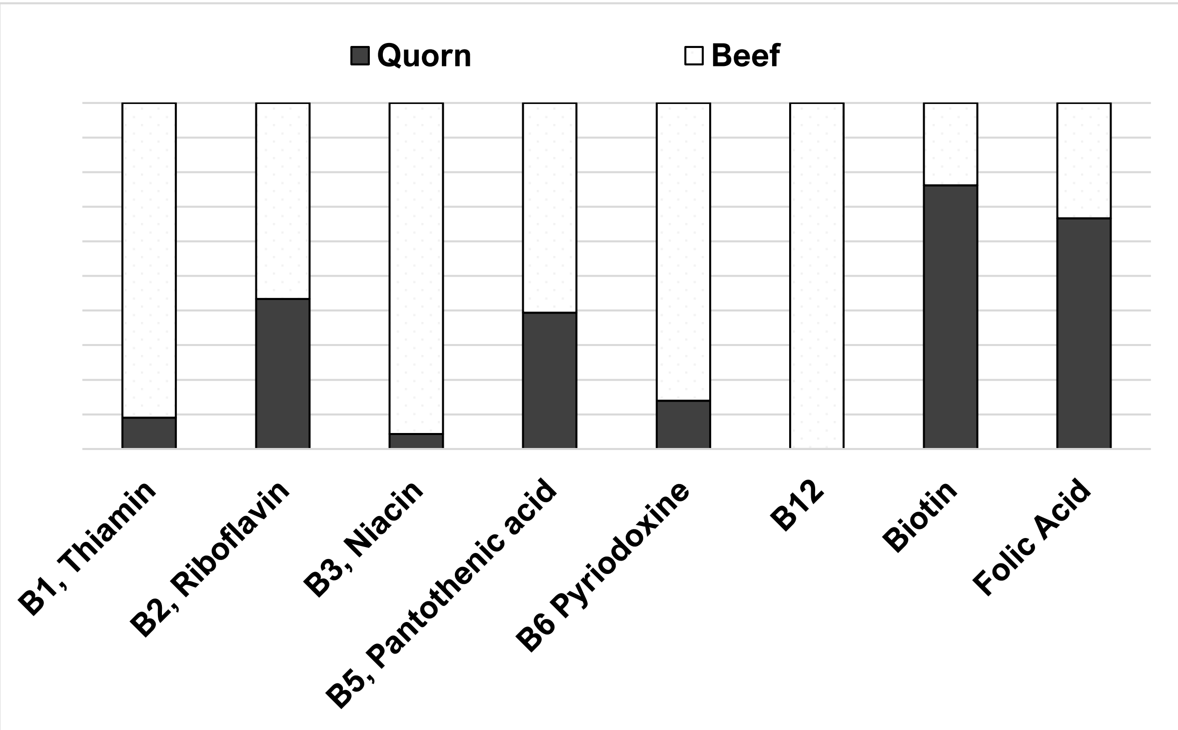

Fig 12. *B Vitamins comparison between Quorn and Beef (g/100) (Sadler, 1988).*

Zinc is relatively high within mycoprotein and calcium, magnesium and copper are comparatively higher than in beef (Table 4.) The inorganic form of iron (non-heme) that is contained in Quorn is also low, making a switch from meat-based proteins to just Quorn increasing the risk of iron deficiency anaemia not by just a lack or bioavailable iron but also a lack of vitamin B12. Both these nutrients contribute to proper red blood cell function and if the protein portion of a diet primarily comprised of only Quorn based products, the need for supplementation to avoid blood related health issues would increase.

Table 4. *Mineral comparison between Quorn and beef (g/100) (Sadler, 1988).*

	Quorn (g)	Beef (g)
Calcium	32	16
Magnesium	32	15
Potassium	85	384
Sodium	6	67
Iron	1.3	2.9
Zinc	19	4.5
Copper	1	0.1
Phosphorus	212	270

Food Safety & Hazards

The mycoprotein based product Quorn was Generally Recognised as Safe (GRAS) by the Food and Drug Administration (FDA) for production in the United States (Rulis, 2001). An extensive programme of animal feeding tests in 1970 was carried out showing that even high levels of mycoprotein can be fed safely to animals (mice, rate, rabbits, calves, pigs, turkeys, chickens and baboons) and later to human volunteers. Clearance was then given by the MAFF for test-marketing of food products containing mycoprotein for the European market (Edelman, Fewell and Solomons, 1983).

Mycotoxins

Multiple studies have shown that strains of *Fusarium* species can produce certain mycotoxins (Miller et al., 1991), but only under specific conditions where growth is limited, and nutrients are not easily metabolised, or physical conditions such as high ratio of carbon to nitrogen is the risk high enough to produce levels of mycotoxins to cause food safety concerns (Ueno, Sawano and Ishii, 1975; Miller and Greenhalgh, 1985). Further research has been done into testing the presence of mycotoxins within different strains of *Fusarium,* such as *F. venenatum NRRL 22198*, which was found to produce type-A trichothecenes, including diacetoxyscirpenol (DAS), scirpentriol, 15-acetoxyscirpenol and 4-monoaceytoxyscirpenol (O'Donnell, Cigelnik and Casper, 1998). Isotrichodermin, isotricodermol, sambucinol, apotrichothecen, culmorin, culmorone and enniatin B have been found to be present in other *F. venenatum* strains (Miller and MacKenzie, 2000) but the specific strain used for the production of the mycoprotein in Quorn did not produce mycotoxins in optimal growth conditions for mycoprotein production (Miller and Greenhalgh, 1985; O'Donnell, Cigelnik and Casper, 1998).

A study was carried out to show the possible adverse allergen effects of mycoprotein using the skin-prick test in human subjects, yielding negative results and further supporting the consumption of mycoprotein as safe (Tee et al., 1993). Another study compared human tolerance for the consumption of mycoprotein, a single celled protein from a different microfungal source (*Paecilomyces variotii)* and cows milk. There was no significant difference in tolerance and both microfungal foods were deemed safe for human consumption (Udall et al., 1984). There has been some other cases and reports of adverse allergic reactions relating to mycoprotein, a subject suffered rhino-conjunctivitis, urticaria/angioedema, laryngeal edema, and an asthma attack after the consumption of a Quorn product. The study concluded: "These symptoms probably are the result of cross-reactivity between the mycoprotein derived from *F. venenatum* and the 60S acidic ribosomal protein P2, which we identified as allergen Fus c 1 from *Fusarium culmorum*." (Hoff et al., 2003). There was also a postscript written by Katona and Kaminski (2002) reporting that a female subject had an allergic reaction after consuming a Quorn burger.

In addition, there have been many anecdotal cases that have been reported by the Center for Science in the Public Interest (CSPI) since 2002 detailing complaints about the allergic adverse effects that Quorn products present to some of the population and sponsored a survey in the United Kingdom that found the percentage of the population that are sensitive to Quorn is probably as great as, or greater than soy, milk, nuts or other common food allergens (Cspinet.org, 2015).

Marlow Foods Ltd have stated they have “received 92 communications regarding adverse events in 1999, and 89 such communications in 2000. Marlow calculates that these figures equate to an incidence rate per the estimated number of consumers of 1 in 130,000 and 1 in 146,000 and compares these estimated rates to published estimates of the rates of adverse reactions in the United Kingdom to soy (1 in 350) and to fish/shellfish (1 in 35).” (Rulis, 2001). Tee et al., (1993) suggested that the risk of sensitivity to Quorn was low but subjects that were allergic to mould might experience severe adverse reactions when inhaled or ingested.

Detection methods are in place and used during the production of Quorn for trichothecenes mycotoxins, which is based on the detection of trichothecenes in cereals. Detection limits for trichothecenes are no greater than 2 micrograms per kilogram (wet weight). High performance liquid chromatography with mass spectrometric detection is used to determine levels fusarin mycotoxins. Detection limits for fusarin are no greater than 5 micrograms/kg (wet weight) (Rulis, 2001).

RNA Reduction

Proteins derived from microorganisms with a high growth rate have high levels of RNA, this is broken down into purines and pyrimidines in the human body. Purine gets converted into uric acid and the consumption of purine rich foods (high RNA content) can add to serum levels of uric acid (Villegas et al., 2012; Zhang et al., 2012). Elevated levels of uric acid in the blood can lead to crystalline deposits in joints and tissues, which can result in gout and calculi in the urinary tract (Riese and Sakhaee, 1992; Perez-Ruiz, Dalbeth and Bardin, 2014). The PAG recommends that single celled proteins for human consumption should not exceed 2g of RNA per day (Rulis, 2001), this led Marlow Foods Ltd to create the specification that RNA levels must not exceed 2% (dry weight) (Wiebe, 2002). Of which is achieved by heating the product above 68ºC for 45 minutes to reduce the RNA content from 10% down to <2% (Fig 3).

Other controls on heavy metals including: lead, arsenic, mercury and cadmium should be no greater than 0.1 mg/kg (dry weight) and ash content no greater than 5% (Rulis, 2001).

Conclusion

Quorn products have been on the market for many years and have undergone rigorous testing in terms of its safety and nutritional value, it is also sustainable and environmentally friendly. Quorn provides a complete amino acid profile with good protein digestibility, it is low in saturated fat and high in cholesterol-lowering fibre and although it covers most of the micronutrients that are essential for health, it is lacking in B12 and a bioavailable iron. The current evidence shows that mycoprotein is safe for human consumption, with limited non-anecdotal evidence to support that it poses a danger to humans beyond rare cases, that have the potential of an allergic response. Quorn can be consumed within a healthy balanced diet, but it should not comprise all the protein within it, a mix of protein sources ensures no holes are left nutritionally, supplementation of B12 and an organic form of iron should be considered when consuming a diet that includes mycoprotein frequently.

Appendices

Appendix 1 – Raw data for Figures

Fig 4

	Protein (g)	Calories (kcal)
Quorn Pieces	14	92
Quorn Burger	12.8	117
Chicken (skinless)	21.4	119
Beef (lean)	20.8	160
Ground Beef (lean)	17.7	264
Milk (2%)	3.3	50
Tofu	8.1	76
Tempeh	18.6	193

Fig 5

	FAO/WHO ref (g)	Quorn (g)	Beef (g)
Isoleucine	4	4.4	5
Leucine	7	7.3	7.7
Lysine	5.5	6.8	8.8
Methionine and cystine	3.5	2.6	3.9
Phenylalanine and tyrosine	6	7.9	8.3
Threonine	4	4.9	4.3
Tryptophan	1	1.4	1.3
Valine	5	5.3	5.1

Fig 6

Amino Acid	Milk Concentrate - 85% (g/100g)	Mycoprotein (g/100g)
Histidine	2	1
Isoleucine	4	2
Leucine	7.5	3.5
Lysine	6.5	3.5
Methionine	1.5	3
Phenylalanine	3.5	2
Threonine	3.5	2.5
Tryptophan	1	3
Valine	5	2.5
Aspartic acid	6	5
Serine	4	2
Glutamic acid	16	5.5
Glycine	1.5	2
Arginine	2.5	3
Alanine	2.5	3
Proline	7.5	2
Cysteine	3	3
Tyrosine	4	2

Fig 7

	NPU
Egg	100
Skimmed Milk protein	85
Fish	83
Beef	80
Quorn mycoprotein	75
Quorn mycoprotein*	100
Wheat Flour	52
Beans	47

Fig 9

Fatty Acid	Quorn (g)
Palmitic	0.45
Stearic	0.11
Oleic	0.72
Linoleic	1.17
α-Linolenic	0.13

Fig 11

	Fibre (g)
Quorn Pieces*	4.5
Quorn Burger*	4.1
Sweet potato**	3.3
Broccoli**	2.6
Asparagus**	2.1
Brown Rice**	1.8
Courgette**	1.1

Fig 12

Vitamin	Quorn	Beef
B1, Thiamin	0.01	0.1
B2, Riboflavin	0.23	0.3
B3, Niacin	0.36	7.9
B5, Pantothenic acid	0.26	0.4
B6 Pyriodoxine	0.13	0.8
B12	0	0.002
Biotin	0.016	0.005
Folic Acid	0.01	0.005

References

Cspinet.org. (2015). *The Dangers of Quorn Products* | *Center for Science in the Public Interest*. [online] Available at: https://cspinet.org/tip/dangers-quorn-products [Accessed 7 May 2018].

Dunlop, M., Kilroe, S., Bowtell, J., Finnigan, T., Salmon, D. and Wall, B. (2017). Mycoprotein represents a bioavailable and insulinotropic non-animal-derived dietary protein source: a dose–response study. *British Journal of Nutrition*, 118(09), pp.673-685.

Edelman, J., Fewell, A. and Solomons, G. (1983). Myco-protein – a new food. *Nutr Abstr Rev Clin Nutr*, 53, pp.471–480.

Edwards, D. and Cummings, J. (2010). The protein quality of mycoprotein. *Proceedings of the Nutrition Society*, 69(OCE4).

FAO/WHO Joint Report (1991). *Protein quality evaluation : report of the Joint FAO/WHO Expert Consultation, Bethesda, Md., USA, 4-8 December 1989*. Rome: FAO.

Hoff, M., Trüeb, R., Ballmer-Weber, B., Vieths, S. and Wuethrich, B. (2003). Immediate-type hypersensitivity reaction to ingestion of mycoprotein (Quorn) in a patient allergic to molds caused by acidic ribosomal protein P2. *Journal of Allergy and Clinical Immunology*, 111(5), pp.1106-1110.

Katona, S. and Kaminski, E. (2002). Sensitivity to Quorn mycoprotein (Fusarium venenatum) in a mould allergic patient. *J Clin Pathol*, pp.876–879.

Leclère, C., Champ, M., Boillot, J., Guille, G., Lecannu, G., Molis, C., Bornet, F., Krempf, M., Delort-Laval, J. and Galmiche, J. (1994). Role of viscous guar gums in lowering the glycemic response after a solid meal. *The American Journal of Clinical Nutrition*, 59(4), pp.914-921.

Miller, J. and Greenhalgh, R. (1985). Nutrient Effects on the Biosynthesis of Trichothecenes and Other Metabolites by Fusarium graminearum. *Mycologia*, 77(1), p.130.

Miller, J. and MacKenzie, S. (2000). Secondary Metabolites of Fusarium venenatum Strains with Deletions in the Tri5 Gene Encoding Trichodiene Synthetase. *Mycologia*, 92(4), p.764.

Miller, J., Greenhalgh, R., Wang, Y. and Lu, M. (1991). Trichothecene Chemotypes of Three Fusarium Species. *Mycologia*, 83(2), p.121.

Mycoprotein.org. (2018). *Product process*. [online] Available at: http://www.mycoprotein.org/what_is_mycoprotein/product_process.html [Accessed 4 Apr. 2018].

Nutritiondata.self.com. (2018). *SELF Nutrition Data* | *Food Facts, Information & Calorie Calculator*. [online] Available at: http://nutritiondata.self.com/ [Accessed 8 May 2018].

O'Donnell, K., Cigelnik, E. and Casper, H. (1998). Molecular Phylogenetic, Morphological, and Mycotoxin Data Support Reidentification of the Quorn Mycoprotein Fungus asFusarium venenatum. *Fungal Genetics and Biology*, 23(1), pp.57-67.

Othman, R., Moghadasian, M. and Jones, P. (2011). Cholesterol-lowering effects of oat β-glucan. *Nutrition Reviews*, 69(6), pp.299-309.

Perez-Ruiz, F., Dalbeth, N. and Bardin, T. (2014). A Review of Uric Acid, Crystal Deposition Disease, and Gout. *Advances in Therapy*, 32(1), pp.31-41.

Quorn. (2018). *FAQ Product*. [online] Available at: https://www.quorn.co.uk/faqs/product [Accessed 4 Apr. 2018].

Riese, R. and Sakhaee, K. (1992). Uric Acid Nephrolithiasis: Pathogenesis and Treatment. *The Journal of Urology*, 148(3), pp.765-771.

Rulis, A. (2001). *Agency Response Letter GRAS Notice No.*. [Letter] https://wayback.archive-it.org/7993/20171031023444/https://www.fda.gov/Food/IngredientsPackagingLabeling/GRAS/NoticeInventory/ucm154623.htm.

Sadler, M. (1988). QUORN. *Nutrition & Food Science*, 88(3), pp.9-11.

Sadler, M. (1990). Myco-protein —a new food. *Nutrition Bulletin*, 15(3), pp.180-190.

Schaafsma, G. (2000). The Protein Digestibility–Corrected Amino Acid Score. *The Journal of Nutrition*, 130(7), pp.1865S-1867S.

Solomons, G. (1984). Production of biomass by filamentous fungi. *Comprehensive bio- technology*, 3, pp.483–505.

Tee, R., GORDON, D., WELCH, J. and TAYLOR, A. (1993). Investigation of possible adverse allergic reactions to mycoprotein (‘Quorn’). *Clinical & Experimental Allergy*, 23(4), pp.257-260.

Towersey, P., Longton, J. and Cockram, G. (1977). PRODUCTION OF EDIBLE PROTEIN-CONTAINING SUBSTANCES.

Trinci, A. (1992). Myco-protein: A twenty-year overnight success story. *Mycological Research*, 96(1), pp.1-13.

Trinci, A. (1994). Evolution of the Quorn(R) myco-protein fungus, Fusarium graminearum A3/5: The 1994 Marjory Stephenson Prize Lecture:(Delivered at the 128th Ordinary Meeting of the Society for General Microbiology, 29 March 1994). *Microbiology*, 140(9), pp.2181-2188.

Turnbull, W. and Ward, T. (1995). Mycoprotein reduces glycemia and insulinemia when taken with an oral-glucose-tolerance test. *The American Journal of Clinical Nutrition*, 61(1), pp.135-140.

Turnbull, W., Leeds, A. and Edwards, D. (1992). Mycoprotein reduces blood lipids in free-living subjects. *The American Journal of Clinical Nutrition*, 55(2), pp.415-419.

Turnbull, W., Leeds, A. and Edwards, G. (1990). Effect of mycoprotein on blood lipids. *The American Journal of Clinical Nutrition*, 52(4), pp.646-650.

Udall, J., Lo, C., Young, V. and Scrimshaw, N. (1984). The tolerance and nutritional value of two microfungal foods in human subjects. *The American Journal of Clinical Nutrition*, 40(2), pp.285-292.

Ueno, Y., Sawano, M. and Ishii, K. (1975). Production of Trichothecene Mycotoxins by Fusarium Species in Shake Culture. *Appl Microbiol*.

Ugalde, U. and Castrillo, J. (2002). Single Cell Proteins from Fungi and Yeasts. *Applied Mycology and Biotechnology*.

Villegas, R., Xiang, Y., Elasy, T., Xu, W., Cai, H., Cai, Q., Linton, M., Fazio, S., Zheng, W. and Shu, X. (2012). Purine-rich foods, protein intake, and the prevalence of hyperuricemia: The Shanghai Men's Health Study. *Nutrition, Metabolism and Cardiovascular Diseases*, 22(5), pp.409-416.

Whitehead, A., Beck, E., Tosh, S. and Wolever, T. (2014). Cholesterol-lowering effects of oat β-glucan: a meta-analysis of randomized controlled trials. *The American Journal of Clinical Nutrition*, 100(6), pp.1413-1421.

Wiebe, M. (2002). Myco-protein from Fusarium venenatum : a well-established product for human consumption. *Applied Microbiology and Biotechnology*, 58(4), pp.421-427.

Zhang, Y., Chen, C., Choi, H., Chaisson, C., Hunter, D., Niu, J. and Neogi, T. (2012). Purine-rich foods intake and recurrent gout attacks. *Annals of the Rheumatic Diseases*, 71(9), pp.1448-1453.