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Myco-protein from *Fusarium venenatum*: a well-established product for human consumption

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Abstract *Fusarium venenatum* A3/5 was first chosen for development as a myco-protein in the late 1960s. It was intended as a protein source for humans and after 12 years of intensive testing, *F. venenatum* A3/5 was approved for sale as food by the Ministry of Agriculture, Fisheries and Food in the United Kingdom in 1984. Today, myco-protein is produced in two 150,000 l pressure-cycle fermenters in a continuous process which outputs around 300 kg biomass/h. The continuous process is typically operated for around 1,000 h. One factor which has limited the length of production runs was the appearance of highly branched mutants in the population. Several factors affect the time of appearance of such mutants and a number of strategies for delaying their appearance have been investigated. After reduction of the RNA content, the fungal biomass is mixed with egg albumin and made into a variety of products. Consumption of these can lead to reduced blood cholesterol and to lower energy intake in a subsequent meal. *F. venenatum* myco-protein is now used in products available in six European countries and there are plans for it to be sold in France, the United States and Germany.

Introduction and historical perspective

Concern that animal protein sources would be insufficient to meet man's requirements for protein has led to the search for suitable, high-protein, microbial substitutes. Initially this search focused on the use of various yeasts, including brewers' and bakers' yeast (*Saccharomyces cerevisiae*), *Torula* sp. and *Candida utilis*, and food yeast was able to provide a substantial contribution to human diets during both world wars. Later, this interest spread to the use of both bacteria and filamentous fungi, and to the use of a wide variety of waste products

as the primary substrate. Much of the research, however, has focused on the production of microbial protein for use in animal feed rather than for human consumption.

Fusarium venenatum A3/5 (ATCC PTA-2684, formerly identified as *Fusarium graminearum* A3/5, O'Donnell et al. 1998; Yoder and Christianson 1998) was first investigated as a potential protein source for human consumption during the late 1960s by the British company Rank Hovis McDougall (RHM). RHM was seeking to develop a microbial protein source which would be cheap and easy to produce from starch- or glucose-based media, but which would also be palatable. They found that filamentous fungi provided a suitably textured product and *F. venenatum* A3/5 was selected as the best fungus for further product development after 3 years of screening approximately 3,000 different fungi (Anderson and Solomons 1984).

In order to bring myco-protein from *F. venenatum* A3/5 onto the market, it was necessary for RHM to invest 12 years in researching the safety of the organism (as a potential plant pathogen) and of the final product (Edelman et al. 1983; Anderson and Solomons 1984; Solomons 1986), making myco-protein the most carefully tested food product on the European market. Myco-protein produced from *F. venenatum* A3/5 was approved by the Ministry of Agriculture, Fisheries and Food (MAFF) for sale in the United Kingdom in 1984, but toxicity testing has continued (Miller and Dwyer 2001), as have investigations into allergic reactions (Tee et al. 1993). Some strains of *F. venenatum* (e.g. NRRL 22198) are known to produce type A trichothecenes, including diacetoxyscirpenol (DAS), scirpentriol, 15-acetoxyscirpenol and 4-monoacetoxyscirpenol (O'Donnell et al. 1998). Isotrichodermin, isotricodermol, sambucinol, apotrichothecen, culmorin, culmorone and enniatin B have also been detected in cultures of *F. venenatum* (Miller and MacKenzie 2000). However, the strain used for myco-protein production, ATCC PTA-2684 (formerly NRRL 26139 = ATCC 20334), did not produce myco-toxins when grown in conditions which induced myco-toxin production in the strain NRRL 22198 (O'Donnell

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et al. 1998), and the growth conditions used for production are not suitable for mycotoxin production (Johnstone 1998). Nonetheless, mycotoxins are tested for at 6-h intervals during the production process, to ensure that myco-protein is mycotoxin-free. While the safety of the product was being investigated, a cultivation process was developed in which *F. venenatum* A3/5 is grown in continuous flow culture.

The process of development of myco-protein from *F. venenatum* has been reviewed by Edelman et al. (1983), Angold et al. (1989) and Trinci (1992).

The production process

Myco-protein from *F. venenatum* A3/5 is produced in 150,000 l pressure-cycle reactors (Fig. 1) in a continuous flow process (Trinci 1994). Since the product is the fungal biomass itself, a continuous flow process operated at a high dilution rate is the most economic production system (Pirt 1975; Edelman et al. 1983). Glucose is provided as the carbon source and ammonium as the nitrogen source, but the process is operated with all nutrients (including glucose) in excess. The CO₂ evolution rate, reflecting the biomass concentration, determines the flow rate (Rodger 2001). Both temperature (28–30°C) and pH (6.0) are controlled. Under these conditions, *F. venenatum* A3/5 has a specific growth rate of 0.17–0.20 h⁻¹ and 300–350 kg biomass/h can be produced.

The RNA content of the fungal biomass must be reduced in order to meet required safety standards (Edelman et al. 1983). This reduction was achieved by subjecting the biomass to a heat shock at 64–65°C (Towersey et al. 1977) in a separate stirred reactor and maintaining the biomass at this temperature for 20–30 min (Anderson and Solomons 1984). At this temperature, RNA is degraded into monomers which can diffuse out of the cells. Unfortunately, other cell components also diffuse out of the cells under these conditions and there is a net loss of biomass (a reduction of approximately 35–38%; Ward 1998) and proteinaceous material. Recently, Zeneca have patented a modification of this process in which the fungal biomass is rapidly heated to temperatures above 68°C (optimum 72–74°C) for 30–45 min (Ward 1998). The modified treatment results in less loss of biomass (30–33% loss) and greater retention of proteins.

After the RNA content of the cells has been reduced, the mycelial suspension is heated to 90°C before collection of the biomass by centrifugation and subsequent cooling (Marlow Foods Limited 1997). Knight et al. (2001) have demonstrated that heat preservation of processed myco-protein at 90°C does not significantly affect the fibrous nature or the acceptability of the product. Centrifugation removes the mononucleotides which were released by the RNA reduction treatment and concentrates the mycelia from approximately 1.5% (w/v) solids to a paste containing greater than 20% (w/w) solids



Fig. 1 The myco-protein production plant at Marlow Food's Belasis site in Billingham, UK. (Photograph provided courtesy of Marlow Foods)

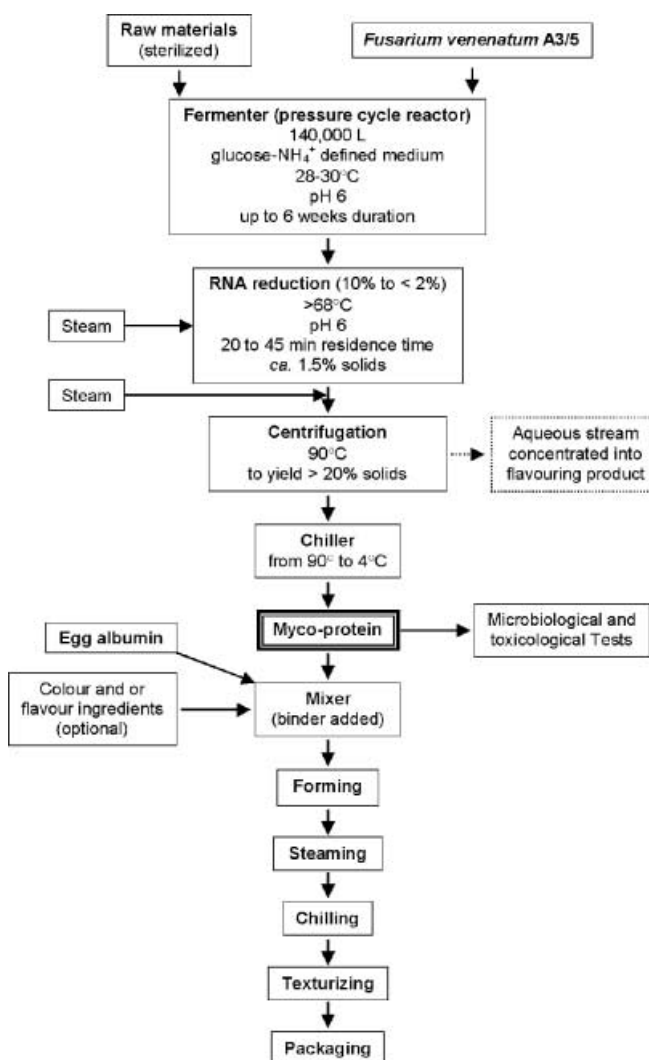


Fig. 2 Diagrammatic representation of the process for producing myco-protein from *Fusarium venenatum* A3/5. The source of the new flavouring product (Quessent) is also shown (dotted arrow and box)