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Soybean residue make a savory food source



By Raymond Gregory Tribdino

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EVERY DAY, makers of tofu, soymilk, and street foods like taho press mountains of boiled soybeans, leaving behind tons of wet, pale pulp. Known as okara, this fibrous residue packs abundant plant nutrients, yet it spoils within hours in tropical heat. Its coarse grit and sour edge mean most of it is discarded into municipal waste streams or hauled off as cheap feed for livestock.

Researchers at Nanyang Technological University, working alongside Japanese food manufacturing firm Ichimasa Kamaboko, have devised a solid-state fermentation technique using oyster mushroom mycelium to upcycle perishable okara into a high-protein, umamirich ingredient. The findings, published in the peer-reviewed journal Food Chemistry: X, suggest food processors could soon transform a stubborn industrial side stream into nutritious sustenance for humans.

William Chen, director of the Food Science and Technology Programme at NTU, explained that okara has long posed a puzzle for the food industry.

"Okara is a soybean by-product that is rich in nutrients, but its high fibre content, short shelf life and less appealing flavour have long limited its use in food products for people," said Chen, who led the investigation.

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To overcome those drawbacks, the researchers inoculated batches of fresh and dried okara with oyster mushroom mycelium, the vegetative fungal network that precedes the blooming of full mushrooms. Over an 11- day incubation window, the fungal threads spread aggressively, enveloping the moist soy pulp in dense white coverage.

As the fungus fed, its digestive enzymes dismantled stubborn, insoluble plant fibres.

The biochemical breakdown released simpler sugars, causing glucose levels to jump by 2.8 to 6.4 times baseline figures.

More importantly, the process boosted the material's total nutritional density. Laboratory testing showed that nitrogen concentrations rose substantially, translating to a final protein content ranging between 27.7 percent and 30.2 percent by dry weight. Beyond nutritional gains, the team set out to fix the unappealing taste profile that typically dooms okara in commercial test kitchens.

Using an electronic tongue, an analytical instrument that measures taste characteristics through specialized chemical sensors, the team observed a notable shift away from sourness toward a rich, savoury profile. Total free amino acids expanded anywhere from 2.2 to 6.6 times over unfermented baselines.

Concentrations of glutamic acid and aspartic acid, the two amino acids primarily responsible for the savory umami sensation, surged by as much as 4.1 times in the fresh pulp.

The fungal digestion also drove up complementary flavour enhancers known as 5 prime nucleotides by 3.2 to 6.3 times.

Meanwhile, succinic acid, another organic compound linked to rich flavours, multiplied up to 14.9 times to become the dominant organic acid in several test formulations.

At the same time, the sharp citric acid that contributes to okara's natural sourness fell.

The experiment was not entirely without hurdles. In some samples, the electronic tongue flagged a rise in bitterness and lingering dryness. The research team noted that these notes likely stem from specific bitter amino acids released during breakdown, some of which carry useful health attributes.

Fine-tuning the cultivation window and substrate blends will be crucial to strike a balanced profile before the public takes its first bite. Malsha Samarasiri, a research fellow at NTU and first author of the study, sees the fungal approach as a practical shift away from linear manufacturing habits.

”Rather than treating okara solely as a waste stream, our research demonstrates that mushroom fermentation can create new, high value opportunities to use this soybean by-product in food applications, contributing to a more circular and sustainable food system,” Samarasiri said.

The researchers note that scaling the method from laboratory benches to commercial factories will require further study.

The team plans to examine energy demands during pre-treatment, verify long-term shelf stability, run human sensory tasting panels, and test economic feasibility for industrial food manufacturers looking to keep valuable soy proteins on dinner tables.

By cultivating *Pleurotus ostreatus*, commonly known as the oyster mushroom, on moist okara beds, the researchers demonstrated that solidstate fungal fermentation can transform raw soy pulp into an ingredient with higher protein readings and a deep savoury profile.

In a written exchange detailing the study, the research team explained the biological mechanics, dietary limitations, and commercial realities of moving the technology from the bench to food producers.

The selection of the oyster mushroom was calculated. *P. ostreatus* ranks among the most widely cultivated edible mushrooms on the globe. It carries a long history of safe human consumption and produces robust lignocellulose-degrading enzymes capable of attacking tough, woody plant fibres. While other institutions have explored organisms like *Rhizopus oligosporus* for traditional tempeh, *Bacillus subtilis*, or medicinal fungi like *Ganoderma lucidum*, the NTU scientists noted that oyster mushroom mycelium had remained largely unexamined as a tool for valorizing okara.

During the 11-day laboratory incubation, the root-like fungal network colonizes the soy mass. The resulting composite material contains both the transformed okara and the dense fungal biomass that feeds upon it.

Addressing how much of the final protein boost stems from fungal tissue versus changes within the soy itself, the researchers clarified that their analytical testing measured the entire composite. The team measured total nitrogen as a standard proxy for crude protein, meaning the reported surge reflects both the biotransformation of the soy base and the physical growth of the fungal mycelium incorporating those nutrients. The study did not separate the fungal threads from the substrate to measure individual contributions, leaving exact biomass proportions for future evaluation.

The team also sounded a note of scientific caution regarding nutrition. While the process produced marked changes in free amino acid concentrations, the initial laboratory study did not test for protein digestibility or the bioavailability of essential

amino acids. Rising free amino acid counts cannot be taken automatically as proof of better nutritional uptake by the human body.

Similarly, the fate of the stubborn insoluble dietary fibre remains partially unmapped. Although the researchers observed a notable liberation of simple glucose across the fermentation cycle, demonstrating that fungal enzymes actively break down complex carbohydrates, the study did not measure specific individual fibre fractions. Further tests are required to quantify exactly how much insoluble fibre vanishes during the 11-day cycle. Soy allergens present another unanswered question. Although microbial fermentation is known to break down allergenic proteins and modify molecular binding sites in certain traditional foods, the NTU researchers did not evaluate soy allergenicity in this trial. Determining whether oyster mushroom mycelium can make soy products safer for allergic consumers will require dedicated immunological assays.

Where the technique made its clearest mark was in flavor chemistry. Unfermented okara often carries an unappealing sourness. The fungal treatment reversed that, driving up taste-active free amino acids, five-prime nucleotides, and succinic acid, an organic compound known for rich savory notes. Electronic tongue measurements confirmed a sharp spike in umami.

Yet the fungal activity also introduced unwanted bitter notes and drying sensations in certain test samples. The researchers attributed this astringency to the complex breakdown of soy components, which yields bitter-tasting peptides alongside bioactive compounds.

The scientists noted that desirable savory notes can sometimes mask or moderate perceived bitterness, but verifying that balance will require formal human tasting panels once complete toxicological and food safety clearances are met. Adjusting fermentation times and moisture levels could also help suppress bitter compounds before the ingredient reaches kitchen trials.

For micro-enterprises and community bean curd manufacturers, the prospect of turning wet waste into a salable food ingredient holds practical appeal. Okara is generated right at the press, eliminating the need to source external raw materials.

The researchers emphasized, however, that mushroom fermentation will not increase the actual yield of soymilk or tofu from a bushel of soybeans. Instead, it creates a secondary revenue opportunity from a material that otherwise incurs disposal costs. Moving the process into cottage industries will take deliberate engineering. The laboratory trials relied on tightly managed environmental chambers.

Practical deployment will require clean, low-cost incubation rooms capable of regulating ambient humidity and temperature while keeping wild molds and bacteria at bay. Before small-scale producers can start fermenting their own pulp, the research

team plans to focus on processing economics, shelf-life stability, energy requirements for pre-treatment, and human sensory acceptance. If those practical factors line up, the humble oyster mushroom could help close the loop on one of the soy industry's oldest waste challenges.