**Emerging Research Issues for Washington Agriculture**

**Proposal for 2021**

1. **Projective narrative**

**I. Title:** From waste to food: conversion of organic waste substrates into gourmet edible and medicinal mushrooms in Washington

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**II. Requested duration:** 2 years

**III.**  **Amount requested for:** 7/1/2021 - 6/30/2022: $50,000 **&** 7/1/2022 - 6/30/2023: $30,000

**IV. Project Abstract, including brief description of Emerging Issue(s) being addressed and the research strategy that is proposed (250 words) :**

Waste streams represent underutilized resources that merit increased emphasis in research in Washington. Stakeholders from agricultural, forestry, brewing, coffee, and restaurant industries have expressed the need for alternative waste disposal outlets. Fortunately, stakeholders from the gourmet mushroom cultivation industry have expressed the complementary need for such substrates in their operations. The goal of this project is to address this emerging issue of waste stream utilization with a biological solution: mushroom cultivation. To produce food from these wastes our objectives are to (i) investigate the cultivation of local mushrooms from regional wastes and (2) teach communities how to cultivate mushrooms. For objective 1, waste residues from the industries mentioned above will be obtained and prepared for mushroom cultivation. Five species of gourmet fungi will then be collected from around Washington. Cultures of these fungi will be maintained by the PIs and a graduate student. Substrates will then be inoculated with each of the five fungal species. To identify which combinations of fungal and waste residues generate the most potential profits, mushroom sporocarp biomass, quality, and production costs will be quantified and compared. Each treatment and trial will be replicated. For objective 2, the PIs will conduct workshops throughout Washington communities, share research results and demonstrate mushroom cultivation techniques. Surveys will be issued to stakeholders before and after workshops gauge the localized interest and adoption of gourmet mushroom cultivation. Ultimately, this research will help ameliorate the emerging issue of waste stream utilization while increasing the production of gourmet edible and medicinal mushrooms.

**Rationale & Significance of the problem from the perspective of Washington stakeholders. It should be made clear how the research conducted in this project will close existing gaps in our ability to conduct research that addresses an Emerging Issue for Washington’s stakeholders:**

The rationale and significance of this project are twofold. From the perspective of waste stream utilization, the rationale is to provide an outlet for organic wastes generated within Washington’s forestry, agricultural, brewing, coffee and restaurant industries. This is at once both a pragmatic endeavor- to reduce waste - and a transformative one since rigorous research in food production from waste streams is neglected compared to traditional agricultural research.

Further, from the perspective of gourmet mushroom cultivation the rationale is to generate the resources needed to successfully grow, sell, and conduct research on these fungi. The significance of this point should not be underestimated. Agriculture has traditionally focused efforts on plant and animal production. Mushroom cultivation is an age-old but under-researched frontier. Barriers to entry are largely informational and technical. Even with the development of cultivation kits for hobbyists, small to large scale mushroom cultivation is far from its potential. Thus, to provide the resources to stakeholders is to open the doors to an industry well positioned to flourish and prosper in Washington.

**Waste Stream Utilization:**

Mushrooms, which can be cultivated on a wide range of organic substrates, provide a solution to this issue by allowing us to reconsider waste as raw substrate **(Stamets, 2000).** For example, we can combine wood residues from sawmill waste with spent grain from breweries and spent coffee grounds from cafes and restaurants to produce nutritious mushroom cultivation substrates. Even in cases of extreme substrate characteristics (for example, with waste from oil spills or plastics), some species of fungi may thrive. In short, gourmet mushrooms can be cultivated on a variety of substrates from across commodities and industries while also functioning as profitable sink for agricultural waste.

An additional benefit of using organic waste in local mushroom cultivation is the production of Spent mushroom substrate (SMS), which is an excellent fertilizer. SMS provides organic matter, microbes, and water capacity, which are not benefits of most chemical fertilizers (**Grimm, 2018).** Retention of organic carbon may therefore make small-scale mushroom cultivation more appealing when compared to other uses for organic waste that remove carbon from the system such as ethanol and biofuel production.

**Types of waste.**

An attractive feature of increased mushroom cultivation is the outlet it provides for agricultural and restaurant waste. Organic materials produced as by-products of these industries usually have limited economic value and high transport and collection costs, which leads products being used locally. (FIND RESAERCH ON EACH)

* **Straw**

The average price of straw per ton in WA is $55 per ton (**“Livestock, Poultry & Grain Market News Moses Lake WA.” 2021).** Straw represents a significant amount of nutrients and organic carbon, making its removal from grain fields unsustainable in the long run and limiting the amount that is sold **(Reiter et. al, 2015).** This leads to a widely ranging price of straw depending on the yearly economic conditions.

* **Brewer’s Grain**

The average price per dry ton of Spent brewer’s grain is $134.10, which is generally more costly to acquire than other ligneous substrates **(Bluffington, 2014).** However, it’s use potential utility in mushroom cultivation is quite high, as grain is a commonly recommended as a substrate to produce spawn in commercial and hobby cultivation (**Staments, 2000**, other sources).

* **Coffee Grounds**

Spent coffee grounds (SCG) usually have minimal economic value and are usually not marketed (personal conversations). Due to their availability however, they are a popular substrate for mushroom production (**Staments, 2000)**

* **Sawdust.**

**Mushroom Cultivation: The industry,**

Although cultivation of edible and medicinal mushrooms has greatly expanded in recent decades, it is still far from its full potential. Global Mushroom cultivation increased 30-fold from approximately 1 billion kg in 1978 to 34 billion in 2013, with cultivated edible mushrooms accounting for a little over half of that (54%). **(Royse, Baars, & Tan, 2017).** This industry is estimated to be worth about $63 billion globally. Mushroom production and consumption are expected to keep expanding, with annual industry growth anticipated to be a little under 10% annually over the next decade (**Price, 2021).**

**Gaps in Research:**

**Number of species.**

Despite this enormous growth in economic value and bulk mushroom production, there is relatively low diversity in the strains of mushrooms commonly cultivated globally. 85% of global supply is dominated by 5 genera: *Lentinula* (shiitake)*, Pleurotus* (oyster)*, Auricularia* (wood ear)*, Agaricus,* and *Flammulina* (enoki)*;* with *Lentinula* alone making up 22% of all cultivated mushrooms **(Royse, Baars, and Tan. 2017).** Most research on mushroom cultivation focuses on these species, which represent only a small fraction of edible species and varieties. **We therefore surmise that there is high economic and research potential in studying agricultural techniques for some of the numerous other edible mushroom species not commercially cultivated.**

**Economics:**

While DIY mushroom growing kits have grown in popularity tremendously in recent decades, edible and medicinal mushroom production in the US is dominated by large, specialized farms. Small Businesses (>25 employed) made up less than 10% of the total market share in 2017, and the number of businesses overall declined between 2014 and 2017**. (*Mushrooms Profile*, 2018).** Most large production relies on dedicated equipment and space. Recommended equipment for mushroom growers includes large-scale compost turners, aerators, and HVAC systems (**Beyer, D. 2017).** This renders mushroom cultivation at significant outputs inaccessible to many people due to the high start-up costs. We wish to address the issues described above by designing easy-access cultivation techniques tailored for neglected strains and substrates. While it is unlikely for small-scale production to match the output or profitability of these industries, there is clearly the economic demand that would allow mushroom production to thrive on a smaller and more accessible scale.

**Intro. Conclusion:**

Stakeholders from disparate industries in Washington are well positioned to profit from the partnership of waste streams with gourmet edible and medicinal mushroom cultivation. The rationale of this project is to satisfy needs from both groups of stakeholders. Stakeholders from agricultural, forestry, brewing, coffee and restaurant industries need a home for their waste products. Fortunately, stakeholders from the gourmet mushroom industry need substrates for cultivation. By connecting these disparate industries we can solve problems for each. Lastly, the significance of this project lay not only solving problems but also in opening doors to fruitful research. Once reproducible methods for cultivating local species of gourmet mushrooms on local substrates are available, transformative research can proceed in many directions.

**Cultivation:**

**Need to find the right balance of nutrients in substate.**

One of the most important deciding factors in mushroom cultivation is the source of suitable substrates. Mushrooms, like all life, require a balanced source of chemical nutrients such as N, P, and S and a source of organic carbon, which must be present in the substrate. Many of these nutrients are commonly added in the form of manure supplements **(Jasińska et al. 2014)**

Anaerobically digested food waste (AD) releases some of these chemicals and also increases the pH (8.2), which is favorable to mushroom formation. **(Jasińska et al. 2014)**

The agarics and criminis are noted for being labor-intensive to cultivate compared to other species such as shiitake and oysters, and are thusly inaccessible to many smaller producers (*Mushrooms Profile*, 2018).

**Briefly describe Cultivation Techniques for each strain/Species.**

1. ***Hericium/ lion’s mane:(Ko et al. 2005)***
2. ***Pleurotus/ oyster:***
3. ***Gandoerma/ reishi:***
4. *Stropharia rugosoannulata* ***/ Wine cap***
5. ***Lentinula / shiitake***
6. ***Grifola fondosa/ Maitake:***
7. ***Agaricus:***

***Augustus***

***Avrensis***

**Provide summary of cultivation techniques**

Option: move to methods.

**Sources:**

**Beyer, D. (2017) Basic Procedures for *Agaricus* Mushroom Growing. Penn State Agricultural Research and Cooperative Extension. Accessed Sept. 9th, 2021. https://extension.psu.edu/basic-procedures-for-agaricus-mushroom-growing**

This paper gives good instructions for the process and rationale of growing mushrooms.

Phase I – initial compositing

Aerobic composting is recommended to keep the ammonia down and to reduce odor. The compost is aerated and mixed to improve airflow. Additives consist of N and gypsum. N is needed to be processed into the eventual food for the mycelium. This paper recommends 1.5-1.9 percent N by dry weight. This is usually added through horse or chicken manure, although brewer’s grain is also listed as a high-N waste product that may be used. Gypsum buffers the pH and “increases the flocculation of colloids in the compost”, preventing the straw from sticking together and helps increase air penetration. Gypsum can be added at 70-100 lbs/ton by dry weight. (all ingredients are dry).

More specific instructions are in the paper. Large-scale mushroom cultivation a lot of specialized equipment to process the compost and regulate temperature (HVAC). Ricks present a low-tech option, using convection to create a chimney effect and increase aeration. Also notes that there is much variation in systems used for phase I, so there is room for experimentation.

Phase II – secondary composting & pasteurization.

This is listed as usually the hardest part. The goals are pasteurization and composting the ammonia produced in phase I. This is critical as concentrations of ammonia above 0.05 % can inhibit mushroom growth. Pack the compost into the production trays, raise the temperature, and slowly lower it to allow desirable microbes to complete the composting process.

**Buffington, J. (2014). The economic potential of brewer’s spent grain (BSG) as a biomass feedstock. *Advances in Chemical Engineering and Science*, *2014*.**

“

1) Assuming 10% moisture content for other lignocelluloses, and 70% for BSG, the effective acquisition cost (in dry tons) for BSG is $134.10 in comparison to a range of $57.2 - $1718. This is assuming that the beer manufacturer will sell the co-product “as-is”.

2) If BSG co-product is assumed to be shipped “as-is”, the supply chain benefits of economies of scale (large US brewers) in well situated logistics origin points is negated through higher moisture rates (70% versus 10%), leading to a lower lignocellulose yield once dried.

3) On an aggregate supply chain standpoint, BSG is not found to be an optimal source of lignocellulose as a potential bio-feedstock.

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**Bradham, B. (2021) “**Labor Shortage Forces Pennsylvania Mushroom Farms to Dump Crops.” Bloomberg News. June 25, 2021. Retrieved Sept. 26th, 2021. [**https://www.bloomberg.com/news/newsletters/2021-06-25/labor-shortage-forces-pennsylvania-mushroom-farms-to-dump-crops**](https://www.bloomberg.com/news/newsletters/2021-06-25/labor-shortage-forces-pennsylvania-mushroom-farms-to-dump-crops)

**Coles, P. S., Nogin, G., Fidanza, M., & Roth, G. (2020). Evaluation of Fresh Mushroom Compost in a Field Corn Production System. *Compost Science & Utilization*, 1–11.** [**https://ntserver1.wsulibs.wsu.edu:2137/10.1080/1065657x.2020.1749184**](https://ntserver1.wsulibs.wsu.edu:2137/10.1080/1065657x.2020.1749184)

**Carrasco-Cabrera, C. P., Bell, T. L., & Kertesz, M. A. (2019). Caffeine metabolism during cultivation of oyster mushroom (Pleurotus ostreatus) with spent coffee grounds. *Applied Microbiology & Biotechnology*, *103*(14), 5831–5841.** [**https://ntserver1.wsulibs.wsu.edu:2137/10.1007/s00253-019-09883-z**](https://ntserver1.wsulibs.wsu.edu:2137/10.1007/s00253-019-09883-z)

Guide to growing oyster mushrooms *P. ostreatus* on coffee. Coffee was oven-dried, then mixed with sawdust and water in the correct proportions, then autoclaved all together in a bottle.

Caffeine inhibits mushroom growth, so composting may be essential to make commercial use viable. In concentrations of Spent Coffee Grounds above 25%, this research observed no mushroom growth. The author also hypothesizes that discussion of using coffee grounds may be more for marketing than anything else, and suggests that focusing on production and coffee husks may be more beneficial.

**Cotter, T. (2019). Coffee Ground Cultivation. *Mother Earth News*, *296*, 67–68.**

Coffee grounds make an excellent mushroom substrate due to their cheapness and avialibity in most locations. However, they do not produce as much as more conventional wheat-straw methods.

They also are usually best used fresh, as they spoil quickly.

**Grimm, D., Wösten, H.A.B. Mushroom cultivation in the circular economy. *Appl Microbiol Biotechnol* 102, 7795–7803 (2018).** [**https://doi.org/10.1007/s00253-018-9226-8**](https://doi.org/10.1007/s00253-018-9226-8)

**“Growing Edible Mushrooms For Profit: Crop Cycle, Yield, and Costs**.” **(2021) Fungi Ally. Retrieved Sept. 26, 2021.** [**https://www.fungially.com/blogs/growing-mushrooms/growing-edible-mushrooms-for-profit**](https://www.fungially.com/blogs/growing-mushrooms/growing-edible-mushrooms-for-profit)

Maximized yield occurs when environmental factors such as humidity and CO2 concentrations can be controlled. This entails growing mushrooms in an indoor setting, making the site one of the larger start-up costs.

Prices @ retail:

Oyster: $5-15 ~15 days to fruit.

Shiitake: $8-15. 50-60 days to fruit

**Hapuarachchi, K. K., Elkhateeb, W. A., Karunarathna, S. C., Cheng, C. R., Bandara, A. R., Kakumyan, P., ... & Wen, T. C. (2018). Current status of global Ganoderma cultivation, products, industry and market. *Mycosphere*, *9*(5), 1025-1052.**

**Jasińska, A. J., Wojciechowska, E., Krzesiński, W., Spiżewski, T., Stoknes, K., & Krajewska, K. (2014, August). Mushroom cultivation on substrates with addition of anaerobically digested food waste. In *XXIX International Horticultural Congress on Horticulture: Sustaining Lives, Livelihoods and Landscapes (IHC2014): 1123* (pp. *199-206).***

Gives a good description of testing different ratios of food waste for mushroom cultivation. This paper deals with the benefits of treating substrates through anaerobic digestion. AD contains N, P, and S needed for propogation of mushrooms, as well as a high pH of 8.2.

**Mixture:** AD was added in increments of 10% from 10 to 40. Straw and paper were added in a 1:2 ratio. Chicken manure and Gypsum were added at 3% each (all % in dry weight)

It was found that A. *bitorquis* had the best response to increased AD composition. This suggests that our research should focus on this species. “The availibility of the cultivation substrate components is one of the most important facotrs deciding their comercial utilization.”

**Kim, J. H., Choi, J. I., Chi, J. H., Won, S. Y., Seo, G. S., & Ju, Y. C. (2008). Investigation on favorable substrate formulation for bag cultivation of Grifola frondosa. *The Korean Journal of Mycology*, *36*(1), 26-30.**

**Ko, H. G., Park, H. G., Park, S. H., Choi, C. W., Kim, S. H., & Park, W. M. (2005). Comparative study of mycelial growth and basidiomata formation in seven different species of the edible mushroom genus Hericium. *Bioresource technology*, *96*(13), 1439-1444.**

**Labor, F., Face, C., Current, C. F., & Past, C. F. The Future of Mushroom Production in the United States: Fewer Producers and Expanding Output - Shannon Reid Hamm.**

**“Livestock, Poultry & Grain Market News Moses Lake WA.” (2021) Agricultural marketing Services, USDA. Retrieved Sept. 24, 2021.** [**https://www.ams.usda.gov/mnreports/lswfeedseed.pdf**](https://www.ams.usda.gov/mnreports/lswfeedseed.pdf)

Average price of straw per ton was $55

**“Mushrooms Profile.” (2018). Agricultural Marketing Resource Center. Retrieved Sept. 24th, 2021.** [**https://www.agmrc.org/commodities-products/specialty-crops/mushrooms-profile**](https://www.agmrc.org/commodities-products/specialty-crops/mushrooms-profile)

Small Businesses (>25 employed) make up less than 10% of the total market share in 2017.

Businesses of all kinds declining 2014-17

**Price, L. “Underground Tips for Starting a Mushroom Farm” (2021) Small Business Trends. Retrieved Sept. 26, 2021.** [**https://smallbiztrends.com/2021/06/mushroom-farm.html**](https://smallbiztrends.com/2021/06/mushroom-farm.html)

Industry predicted to grow 9.5% annually over the next decade.

Short shelf life.

Recommends indoor space.

**Reiter, M. S., Deitch, U. T., Frame, W. H., Holshouser, D. L., & Thomason, W. E. (2015). The nutrient value of straw. Virginia Cooperative Extension, Virginia Tech.**

Calculated value of the NUTRIENTS contained in straw to be ~25$ per ton.

**Robertson, J. A., I'Anson, K. J., Treimo, J., Faulds, C. B., Brocklehurst, T. F., Eijsink, V. G., & Waldron, K. W. (2010). Profiling brewers' spent grain for composition and microbial ecology at the site of production. *LWT-Food Science and Technology*, *43*(6), 890-896.**

Nutritional and microbial content of spent gain. This will be useful in deciding on a composition for the mixture.

**Royse, DJ. (2014) A GLOBAL PERSPECTIVE ON THE HIGH FIVE: AGARICUS, PLEUROTUS, LENTINULA, AURICULARIA & FLAMMULINA. Proceedings of the 8th International Conference on Mushroom Biology and Mushroom Products (ICMBMP8) 2014/11/19. https://scholar.google.com/citations?view\_op=view\_citation&hl=en&user=XUlt-fQAAAAJ&citation\_for\_view=XUlt-fQAAAAJ:SP6oXDckpogC**

Industrial descriptions of each:

Agaricus:

Pleurotus:

Lentinula:

Auricularia:

Flammulina:

**Royse, D.J., Baars, J. and Tan, Q. (2017). Current Overview of Mushroom Production in the World. In Edible and Medicinal Mushrooms (eds C.Z. Diego and A. Pardo-Giménez).** [**https://doi.org/10.1002/9781119149446.ch2**](https://doi.org/10.1002/9781119149446.ch2)

Global mushroom production has increased dramatically over the past few decades, increasing 30-fold from approximately 1 billion kg in 1978 to 34 billion in 2013. Of this, approximately 1 billion kg is produced in the US. This industry is estimated to be worth about $63 billion globally, with cultivated edible mushrooms accounting for a little over half of that (54%).

Global supply is dominated by the *Lentinula* (shiitake)*, Pleurotus* (oyster)*, Auricularia, Agaricus,* and *Flammulina* (enoki)genera, with Lentinula constituting 22% of all cultivated mushrooms. Most *Lentinula and Pleurotus* is cultivated on sawdust substrates with some additives such as wheat bran.

**Salmones, D., Mata, G., & Waliszewski, K. N. (2005). Comparative culturing of Pleurotus spp. on coffee pulp and wheat straw: biomass production and substrate biodegradation. *Bioresource Technology*, *96*(5), 537–544.** [**https://ntserver1.wsulibs.wsu.edu:2137/10.1016/j.biortech.2004.06.019**](https://ntserver1.wsulibs.wsu.edu:2137/10.1016/j.biortech.2004.06.019)

Oyster mushrooms are well-known as a robust and easy to cultivate species. There was increased biological activity for all strains tested when grown on wheat-straw, although this varied between varieties. *P. ostreatus* strain IE-49 showed the greatest biological activity, while *P. djamor* displayed the highest aptitude for growing on coffee pulp.

Research also indicates that *Pleurotus* does not have the ability to digest caffeine and the fruiting bodies may have absorbed trace amounts.

**Staments, P. (2000) “Growing Gourmet and Medicinal Mushrooms”**

Pg 167: encourages experimentation with different combonitions of agro-waste for cultivation. Development of different strains that normally grow on wood to be used on other substrates.

Methods: Hot water bath. Straw is submerged in 150-180 F water for one hour.

Good Summary of Species.

**Sokol, S., Golak-Siwulska, I., Sobieralski, K., Siwulski, M., & Górka, K. (2015). Biology, cultivation, and medicinal functions of the mushroom Hericium erinaceum. *Acta Mycologica*, *50*(2).**

**Zięba, P., Sękara, A., Sułkowska-Ziaja, K., & Muszyńska, B. (2020). Culinary and Medicinal Mushrooms: Insight into Growing Technologies. *Acta Mycologica*, *55*(2), 1–19.**

“A 500-square foot growing space should produce 12,000 pounds of mushrooms annually. The cost per pound of mushrooms can vary by type.”

**“What is the Value of Wheat Straw?” (FarmProgress)**

**https://www.farmprogress.com/grains/what-value-wheat-straw**

The largest concern for farmers is that the removal of straw amounts to a removal of essential nutrients. This leads to a widely ranging price of straw depending on the yearly economic conditions.