Northeast SARE Farmer/Grower Grant

FINAL REPORT

To: Dale I. M. Riggs, SARE Northeast, Farmer Grant Specialist
From: John Morelli, Project Leader
Date: December 19, 2006

Project Title: ***Increasing Production and Promoting Adoption of Organic King Oyster Mushrooms***

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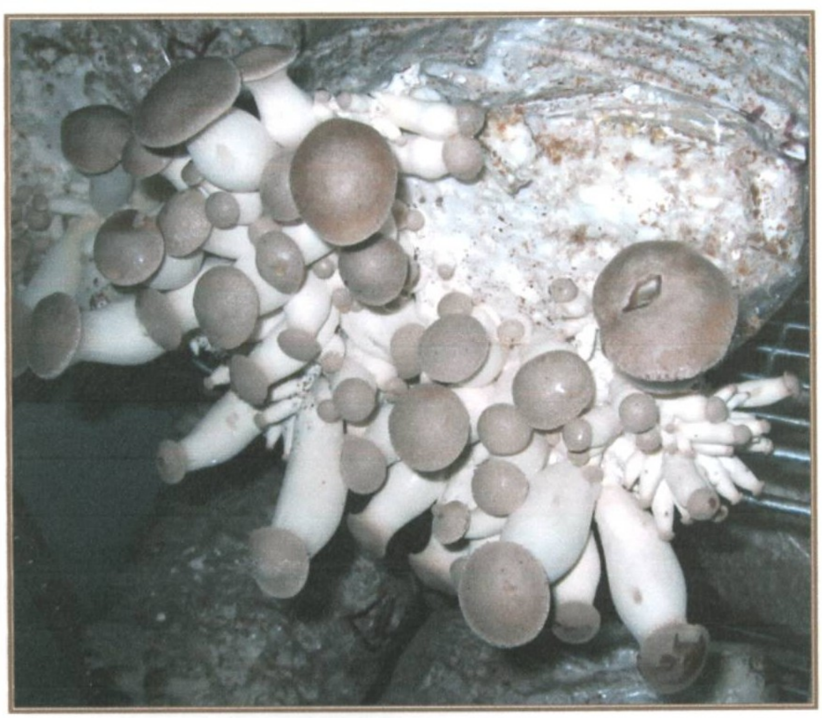

INCREASING PRODUCTION AND PROMOTING ADOPTION OF ORGANIC KING OYSTER MUSHROOMS

Final Report

to

Northeast SARE

by

Flower City Mushrooms LLC

John Morelli & Melissa Lamphron

December 8, 2006

FCM thanks Northeast SARE for its encouragement and support of this project, without which this work would not have been done. In designing and conducting the research described herein, FCM paid close attention to the principles of sustainability, particularly those espoused in the SARE Outcome Statement, to provide "healthful products to its customers", "manage resources wisely"; "live a more satisfying life", and "have a positive influence on their communities and the environment."

EXECUTIVE SUMMARY

A benchmark for the success of this project was to be able to economically produce a pound or more of King Oyster mushrooms per six pounds of substrate (i.e., the material upon which the mushrooms are grown) within a five-week period. The strategy employed to accomplish this goal was to explore the efficacy of a variety of substrate formulations, using locally produced agricultural products and by-products containing constituents previously demonstrated by others to be effective in growing these mushrooms.

Using an analysis of fiber and protein content in a successful control formulation developed and published by Royse and Sanchez-Vazquez[1], six additional mixtures of ground corncobs, hardwood sawdust, wheat straw, wheat bran, soy meal, millet spent brewery grain, grape pomace and other supplements, were formulated to duplicate, and in two cases enhance, constituent content. Two complete mushroom crop cycles were conducted using these formulations. A third crop cycle was run with the most successful formulation, R7, and with modified versions of the three next best formulations, R2, R3 & R4.

While all ten formulations were productive, R7 clearly met and, in fact, surpassed the established benchmark by producing 1.3 pounds of mushrooms per five-pound block in just over four weeks. Beyond this measure of success, were evaluations of quality, compatibility with the ongoing farm operations, availability of local resources, and cost.

Quality was evaluated quantitatively as the "sellable" percentage of the harvested crop after removing deformities and other debris. With only one exception, quality measured greater than 90% and for the R7 formulation, 91.7%. Even with this approximately 8% reduction in overall harvest quantity, the sellable portion of R7 still exceeded the production and timeframe benchmarks for success. Additionally, the chefs of four top Rochester restaurants and the produce buyer for a large, local natural food store, performed qualitative evaluations. Evaluators were asked to assess the quality of the mushrooms based on size, weight, shape, texture, flavor, ease of preparation and culinary versatility. In every case, assessments were positive with several indicating the highest rating in every category.

Flower City Mushrooms LLC (FCM) began and continues to operate principally as a grower of Shiitake mushrooms. Compatibility with current operations was thus evaluated on the bases of synergetic and competitive relationships regarding materials, procedures, equipment, labor, and space. The similarity of needs in each of these categories led to a favorable evaluation in this regard and considerations regarding competition were easily outweighed by gains associated with a shorter production cycle for the King Oysters and the benefits of offering an expanded crop variety.

FCM was successful in identifying and establishing satisfying working relationships with additional local resources for substrate materials, including a microbrewery, primary log mill, organic seed producer, organic wheat straw farmer, and winery. Additionally, FCM's customers were pleased with the expanded selection and most have indicated a commitment to continue to purchase King Oyster mushrooms. FCM believes that development of strong local relationships and exchange of by-products is key to sustainability and is especially pleased to have succeeded in this regard.

The result of a benefit-cost evaluation for growing King Oyster mushrooms as an FCM crop yielded a favorable 1.53 benefit-to-cost ratio. FCM now plans to run a batch of King Oyster blocks every four weeks thus comprising 1/12th of its overall production potential. This is anticipated to generate approximately $5,700 in revenue annually above total production costs (at standard labor rates).

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[1] Royse, D. J., and J. E. Sanchez-Vazquez. 1999. Effect of brewer's grain and delayed release nutrient supplementation on yield and size of *Pleurotus eryngii* (king oyster mushroom). *In*: A. Broderick and T. Nair (eds.). *Mushroom Biology and Mushroom Products, Proceedings of the 3rd Int. Conf.* Sydney, Australia (CD-ROM). 362-367.

Statement of the Problem Being Addressed

Of all the oyster mushroom varieties, the King Oyster mushroom (Pleurotus Eryngii) is often characterized as the best tasting and the best textured.[2] It is very popular in Europe and Japan and is in increasing demand by top chefs in the U.S. However, attempts to grow King Oysters commercially in the US have largely been unsuccessful as, up until recently, evidenced by their absence in super markets and natural food stores.

While a variety of standard substrate formulations exist for the most common oyster mushroom varieties, standard substrate formulations that produce comparable quantities of the King Oyster mushroom (Pleurotus Eryngii) have not yet been established. A benchmark for success is to be able to produce more than a pound of oyster mushrooms per six pounds of substrate (i.e., the material upon which the mushrooms are grown) over a four to five week period. This corresponds to the quantity and growth rate of the most common oyster mushroom, Pleurotus Ostreatus.[3] By comparison, productivity of the King Oyster ranges only from 0.66 to 0.99 pound of mushrooms per six pounds of substrate and taking up to twice as long to produce them.[4,5] Since the production effort and market value for all oyster varieties are similar, the farmer must decide which to grow based on other factors and while there appears to be growing interest in the King Oyster mushroom, unfortunately, the biological efficiency of King Oyster production (i.e., the fresh weight of mushrooms produced per dry weight pound of substrate) is less than that for the more common varieties[6, 7] and the production time is longer (28 to 30 days for incubation as compared to 18 days for the common oyster). Unless the King Oyster mushroom can be more competitively produced, it is unlikely to become a commercially viable organic crop.

Interestingly, since the time that this research was first proposed, King Oyster mushrooms have begun showing up in some supermarkets, challenging the assumption proffered by the researchers that they would not. However, these mushrooms are being offered at prices 50% higher than Shiitake of comparable quality. This will be a good situation for mushroom farmers if the market will bear it, however, the work reported upon herein may help keep the cost down while increasing profitability for farmers.

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[2] Golden Gourmet Mushrooms, http://www.goldengourmetmushrooms.com/oyster.html

[3] Shah, Z. A., M. Ashraf and M. Ishtiaq Ch., *Comparative Study on Cultivation and Yield Performance of Oyster Mushrooms (Pleurotus Ostreatus) on Different Substrates,* Pakistan Journal of Nutrition 3 (3): 158-160, 2004, Asian Network for Scientific Information, 2004

[4] Royse, Daniel J., *Effect of Brewers Grain and Delayed Release Nutrient Supplementation on Yield and Size of Pleurotus Eryngii,* http://www.mushworld.com/sub_en.html, 4/13/04.

[5] Maddau, Lucia, et. al., "Influence of Aeration on Development and Productivity of Edible and Medicinal Mushrooms Pleurotus Eryngii," International Journal of Medicinal Mushrooms, Volume 4, 2002

[6] The biological efficiency of the most common oyster mushroom, Pleurotus Ostreatus, grown on the most commonly used substrates, i.e., sawdust and wheat straw, ranges from 43.6 to 64.7. Source: Z.A. Shah, M. Ashraf and M. Ishtiaq Ch., *Comparative Study on Cultivation and Yield Performance of Oyster Mushrooms (Pleurotus Ostreatus) on Different Substrates,* Pakistan Journal of Nutrition 3 (3): 158-160, 2004, Asian Network for Scientific Information, 2004. *This translates to production rates between 0.96 and 1.37 pounds of mushrooms produced per ~ 6.3 pounds of substrate.*

[7] The biological efficiency of Pleurotus Eryngii, grown on oak sawdust, white millet and wheat bran, a common substrate, ranges from 30 to 45. Source: Royse, Daniel J., *Effect of Brewers Grain and Delayed Release Nutrient Supplementation on Yield and SIze of Pleurotus Eryngii,* http://www.mushworld.com/sub_en.html, 4/13/04. *This translates to production rates between 0.66 and 0.99 pounds of mushrooms produced per ~ 6.3 pounds of substrate.*

Research and Feasibility Study Design

A benchmark for the success of this project was to be able to economically produce a pound or more of King Oyster mushrooms per six pounds of substrate (i.e., the material upon which the mushrooms are grown) within a five-week period. This benchmark was established as comparable to production of other commercially produced oyster mushroom species. The strategy employed to accomplish this goal was to explore the efficacy of a variety of substrate formulations, using locally produced agricultural products and by-products containing constituents previously demonstrated by others to be effective in growing these mushrooms.

The Research and Feasibility Study Design task involved the review of published works focused on production of King Oyster mushrooms. These included works by Stamets, Royse & Sanchez-Vazquez, Luo & Hsu, and the Edible Fungi Institute. Each piece included a discussion of various substrate materials used during King Oyster mushroom production. Substrate is defined as straw, sawdust, compost, soil, or any organic material on which mushroom mycelium (the collection of filament cells that grow into the mushroom body) will grow.[8] Often, mushroom growers will use different substrate "formulas" for different species of mushroom. For example, mushroom growers often prefer a sawdust-based substrate formula for shiitake mushrooms, while a straw-based one is used in oyster mushroom production. These formulas usually include a combination of other materials, such as wheat bran or corn powder, for nutrient supplementation.

The technical advisor for this project, Dr. Robert King, suggested that FCM choose one control formulation for our experiment. The formulation ultimately selected was developed by Royse and Sanchez-Vazquez, as published in their article "Effect of Brewer's Grain and Delayed Release Nutrient Supplementation on Yield and Size of Pleurotus Eryngii". This formula was selected as an experimental control because:

- It reported biological efficiencies ranging from 30% to 54%[9], with 40% representing one pound of mushroom growth per six-pound substrate block on a wet-weight basis;
- A detailed breakdown of formulation content was available;
- The same strain of Pleurotus Eryngii spawn was available and would be used in FCM's research project; and
- All control formula materials were locally available to FCM.

FCM selected a quasi-experiment research design to measure and evaluate the feasibility of the various King Oyster production methods employed for this project. (Appendix A – Quasi-

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[8] Stamets, Paul, 2000. *Growing Gourmet and Medicinal Mushrooms*. Ten Speed Press, Berkley, California.

[9] Biological Efficiency (BE) is a measure of the ability of a mushroom strain to convert substrate materials into mushrooms. The "Biological Efficiency Formula" states that: 1 pound of fresh (i.e. wet) mushrooms grown from 1 pound of dry substrate equates to 100% biological efficiency. This formula assumes that most mushrooms have 90% water content at harvest. Because the biological efficiency of the control formula used in this research study has already been determined to range from 30% to 54% in a previous study (see Royse), this measure of yield will be used to compare the biological efficiencies of the test formulas with that of the control formula in order to assess their viability for commercial King Oyster production.

Experimental Design provides a more complete discussion of the research design and feasibility analysis.) Ultimately, economic feasibility is dependent upon production/quality, time to market, and production costs.

Process Design

Formulation Development

Because oyster mushrooms are degraders of cellulose and lignin, as well as users of protein, each substrate component in the control formulation was characterized by these elements and an overall formula characterization of percentage fiber and protein content was developed. A methodology was then developed, allowing overall fiber and protein percentage content to be varied by selection of various substrate material components. Using this methodology, six experimental formulations plus the one control formulation were developed and used in the first stage ("Stage One) of this project. After evaluating the production results of the Stage One formulas, four experimental formulas that appeared to exhibit the most promising results in terms of mushroom growth were selected for a second round of production ("Stage Two"). The discussion below provides a more detailed explanation of these project stages.

> "Stage One": Formula R1 was designated as the control formula, replicating the experiments of Royse and Sanchez-Vasquez. Formula R2 uses a sawdust-based bulk substrate (supplemented with wheat bran, soybean meal and calcium carbonate) to duplicate the overall fiber and protein content of the control formula. Formula R3 uses a corncob-based bulk substrate (supplemented by sawdust, millet, grape pomace and calcium carbonate) to duplicate the overall fiber and protein content of the control formula. Formula R4 uses a wheat straw-based bulk substrate (supplemented by sawdust, corncob, beet pulp, brewer's grain, grape pomace and calcium carbonate) to duplicate the overall fiber and protein content of the control formula.
>
> For the remaining formulas, the strategy was to vary specific substrate component percentages to correspond with reported successes. Formula R5 uses a sawdust-based substrate to increase overall lignin content, relative to the control formula, by 50%. Formula R6 also uses a sawdust-based substrate to increase overall lignin content by 35% and hemi-cellulose by 25%. Formula R7 essentially reproduces the control formula, but with the addition of 1% sucrose.
>
> The R2, R3 and R4 formulations attempted to duplicate the lignin, cellulose, hemicellulose, and protein content in the R1 control. The R5 and R6 variations are described above. (All formulations are described in Appendix B: Formulation Development.)
>
> "Stage Two": Due to their relative success in terms of mushroom growth (both quality and quantity), formulas R2, R3, R4 and R7 were selected to perform another sample set of experimental production. However, it was surmised that perhaps the presence of sucrose in the R7 formula was a significant factor in the success of the first sample set of King Oyster production, and therefore sucrose was added to formulas R2, R3, and R4 in the third sample set (i.e. Stage Two).

Production Design

Moisture determination. In order to determine biological efficiency (i.e., the ratio percentage of the wet weight of harvested mushrooms to the dry weight of the substrate from which they were harvested) the moisture content of all substrate materials was determined using the microwave oven drying method, which involved repeated 2 to 5 minute cooking intervals and weighing of substrate samples until successive measurements were within 0.001 lb. (see Appendix C: Moisture Determination).

Depending upon the size of the substrate blocks, FCM's sterilizer is capable of holding between 60 and 120 blocks. In order to ensure identical environmental conditions for each formulation throughout the research, all formulations needed to be mixed, sterilized, inoculated and incubated during the same time intervals. During Stage One of the project, the first sample set was mixed and inoculated during the week of 7/10 and the second sample set during the week of 7/24. During Stage Two of the project, the third sample set (consisting only of formula R7 and the sucrose-enhanced formulas R2, R3, and R4) was mixed and inoculated during the week of 9/4 and 9/11.

Substrate, Supplement and Spawn

Basal substrate materials were procured for this work included[10]:

- Organic corn cobs (Source: seed company in Ithaca, NY)
- Hardwood sawdust (maple/oak) (Source: log mill in Caledonia, NY)
- Organic red wheat straw (Source: organic farm in Albion, NY)

Supplement materials included:

- Brewer's grain (Source: brewery in Honeoye Falls, NY)
- Grape pomace (Source: vineyard in Hammondsport, NY)
- Wheat bran
- Soybean meal
- Millet
- Calcium Carbonate
- Beet pulp
- Sucrose (table sugar)

Spawn:

- 9 blocks, *Pleurotus eryngii* (King Oyster) – Strain 515 spawn from Northwest Mycological Consultants

[10] Note: Where indicated, procurement sources for basal substrate and supplemental materials are noted in parentheses. All other feed-quality materials were procured from a farm supply store in Avon, NY.

Substrate Preparation
"Stage One": Substrate preparation took place over two 1-week periods, "Run A" and "Run B" respectively. Basal substrate materials (corn cob, sawdust and wheat straw) were soaked overnight prior to substrate preparation. Batch One consisted of fifteen 5-pound blocks of substrate per formula, totaling 75 lb. wet substrate weight per formula. Batch Two consisted of sixteen 5-pound blocks of substrate per formula, totaling 80 lbs wet weight per formula. In order to eliminate suspicion of spawn as a source of contamination, should it occur, one block from each formula in Batch Two was used as a 'control' block and was not inoculated with spawn. The microwave method was used to determine formula dry weight prior to sterilization. This was later used to determine biological efficiency. Each block was inoculated with ½ cup of strain 515 *Pleurotus Eryngii* spawn. Batch number and unit number were recorded for future reference, if necessary. Each block was labeled by formula and date of inoculation. (See Appendix D: Production Worksheet 1 for more details on substrate preparation.)

"Stage Two": Substrate preparation took place over two 1-week periods, comprising "Run C". Main substrate materials (corn cob, sawdust and wheat straw) were soaked overnight prior to substrate preparation. Sixteen 5-pound blocks of substrate per formula were prepared for formulas R2, R3, and R4. In order to eliminate suspicion of spawn as a source of contamination, should it occur, one block from each of these formulas was used as a 'control' block and was not inoculated with spawn. Sixty 5-pound blocks of substrate were prepared for formula R7. All sixty blocks were inoculated with spawn. Each block was inoculated with ½ cup of strain 515 *Pleurotus eryngii* spawn. Batch number and unit number were recorded for future reference, if necessary. Each block was labeled by formula and date of inoculation. (See Appendix D: Production Worksheet 1 for more details on substrate preparation.)

Production Results

Production involved:

- Spawn run (i.e., the vegetative growth phase) of the inoculated blocks. The room temperature is maintained at 68 degrees and 12 hours of overhead fluorescent light. Weekly photographs were taken of spawn run blocks.
- Fruiting, harvesting, weighing and qualitative assessment. Production quantities and **initial quality assessments (i.e. "sellable" quantity)** are presented in Appendix E: Production Worksheet 2. Production data are linked to photos of harvested mushrooms.

The productivity results (i.e. cumulative "sellable" weight harvested as a function of time) are depicted for Run A, Run B and Run C, respectively, in Figures 1, 2 & 3 below. Summary data is reported in Tables 1, 2 & 3. Complete productivity tables for each run are presented in Appendix F: Productivity Results. The total experimental crop yielded 213 lbs of mushrooms, 197 lbs of which were considered "sellable".

As already mentioned, the benchmark for success was to be able to grow one or more pounds of King Oyster mushrooms on a six-pound block of substrate. A concept known as Biological Efficiency (BE), i.e., the ratio of the wet weight of harvested mushrooms divided by the dry weight of the substrate upon which they were grown, expressed as a percentage, is useful to more precisely measure this productivity for the sake of comparison. The moisture content of the control formulation used in the Royce experiment[11] was 59%. By comparison, the moisture content of the experimental formulations ranged from 54% to 61%. At 59% moisture, the six-pound substrate block formulation used in the Royce experiment contained 2.46 pounds of dry substrate. By comparison, the dry material in the five-pound substrate blocks used in these experiments ranged from 1.95 to 2.3 pounds.

RUN A

The Royce experiments produced between 0.738 and 1.328 pounds of mushrooms per six-pound block of substrate, yielding BE values ranging from 30% to 54%. The first run of the FCM experiments (i.e., Run A) produced between 0.33 and 1.48 pounds of mushrooms per five-pound block of substrate, yielding BE values ranging from 7% to 73%. FCM further refined its analysis to consider that not all harvested mushrooms were sellable. Considering only the sellable portion of each formulation, quantities ranged from 0.29 and 1.35 lb. per block and BE, from 7% to 67% (see Table 1.).

Table 1. Production Results, Quality Calculations, and Biological Efficiencies for Run A

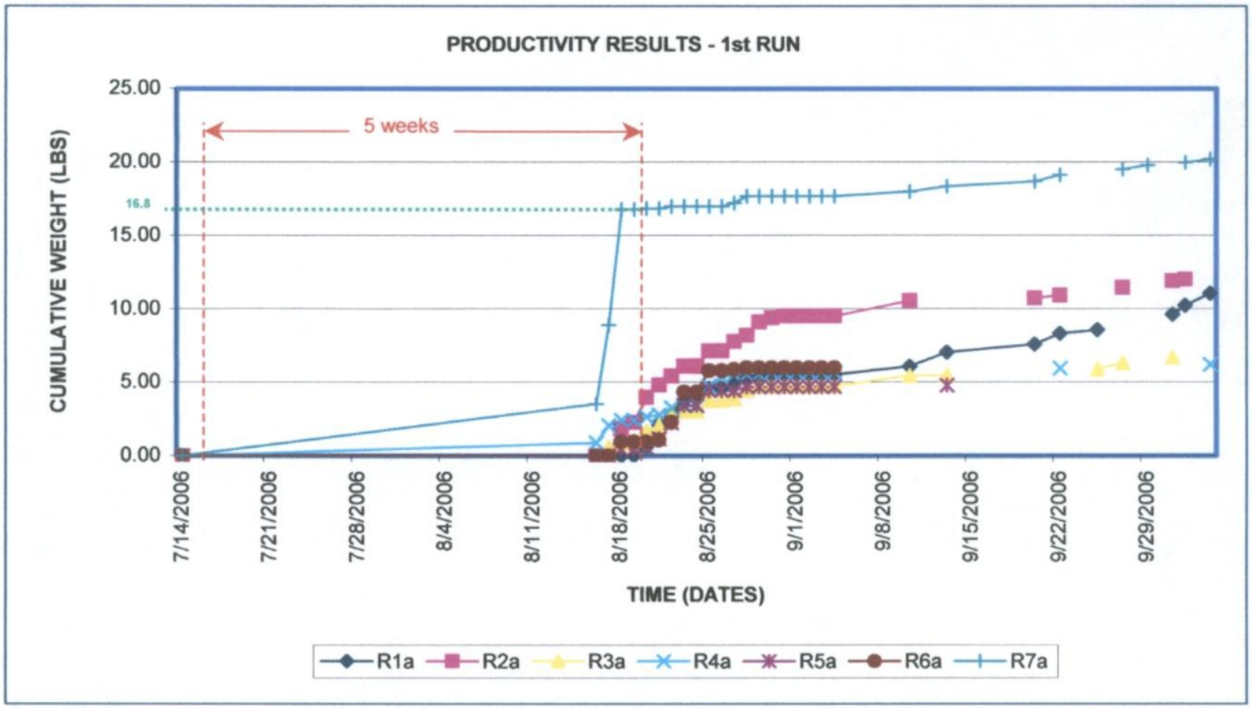
R1- Royse Sawdust Wheat bran Millet Brewer's grain Calcium Carbonate			R2 - Sawdust Sawdust Corncob Wheat bran Soybean meal Calcium Carbonate			R3 - Corncob Sawdust Corncob Millet Grape pomace Calcium Carbonate			R4 - Wheat straw (red) Sawdust Corncob Wheat Straw Beet pulp Brewer's grain Grape pomace Calcium carbonate		
date	harvest	sellable	date	harvest	sellable	date	harvest	sellable	date	harvest	sellable
Ttl lb.	11.904	11.040	Ttl lb.	12.716	12.007	Ttl lb.	7.038	6.689	Ttl lb.	6.763	6.205
Bio ζ %	39%	37%	Bio ζ %	40%	38%	Bio ζ %	25%	23%	Bio ζ %	30%	28%
Quality	0.927		Quality	0.944		Quality	0.950		Quality	0.917	

R5 - 50% lignin increase Sawdust Wheat bran Grape pomace Soybean meal			R6 - 35% lignin increase + 25% hemi-cellulose increase Sawdust Wheat bran Grape pomace Soybean meal			R7 - Royse + 1% sucrose Sawdust Wheat bran Millet Brewer's grain Calcium carbonate Sucrose		
date	harvest	sellable	date	harvest	sellable	date	harvest	sellable
Ttl lb.	4.930	4.793	Ttl lb.	8.477	5.973	Ttl lb.	22.193	20.201
Bio ζ %	7%	7%	Bio ζ %	25%	17%	Bio ζ %	73%	67%
Quality	0.972		Quality	0.705		Quality	0.910	

[11] Royse, D. J., and J. E. Sanchez-Vazquez. 1999. Effect of brewer's grain and delayed release nutrient supplementation on yield and size of *Pleurotus eryngii* (king oyster mushroom). *In*: A. Broderick and T. Nair (eds.). *Mushroom Biology and Mushroom Products, Proceedings of the 3rd Int. Conf.* Sydney, Australia (CD-ROM). 362-367.

Consistent with the quasi-experimental research design proposed for this project, Run A production was evaluated on a time basis as well as a quantity basis. FCM's time benchmark for success was to produce one or more pounds of mushrooms per block in five weeks or less. Of these seven formulations used in Run A, only one, R7, met this criterion, producing 1.12 lb. within five weeks (see Fig. 1).

Figure 1. Production Results: Run A



RUN B

FCM replicated the Run A formulations beginning approximately 2 weeks after the initial run but encountered HVAC malfunctions that very likely compromised the integrity of the second run. Run B production ranged from only 0.08 to 0.73 pounds per five-town block, with BE values ranging from 2% to 35% (See Table 2.).

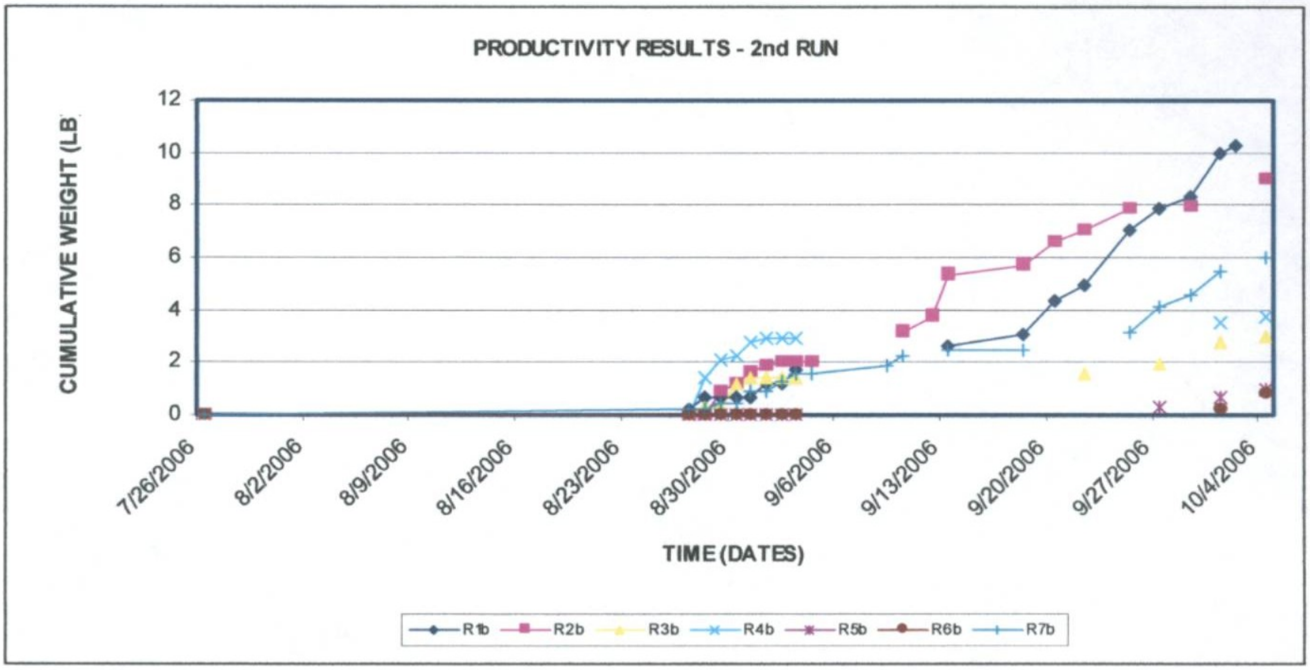
Table 2. Production Results, Quality Calculations, and Biological Efficiencies for Run B.

R1b- Royse			R2b - Sawdust			R3b - Corncob			R4b - Wheat straw (red)		
Ttl lb.	11.189	10.302	Ttl lb.	9.929	8.986	Ttl lb.	3.074	3.007	Ttl lb.	3.948	3.769
Bio ζ %	35%	32%	Bio ζ %	29%	26%	Bio ζ %	10%	10%	Bio ζ %	16%	16%
Quality	Quality:	0.921	Quality		0.905	Quality	0.978		Quality	0.955	

R5b - 50% lignin increase			R6b - 35% lignin increase + 25% hemi-cellulose increase			R7b - Royse + 1% sucrose		
Ttl lb.	1.292	0.980	Ttl lb.	0.903	0.807	Ttl lb.	8.111	6.004
Bio ζ %	2%	1%	Bio ζ %	3%	2%	Bio ζ %	27%	20%
Quality	0.759		Quality	0.894		Quality		0.740

Evaluation of the crop timing was unnecessary since production quantity never reached the benchmark for success.

Figure 2. Production Results: Run B



RUN C

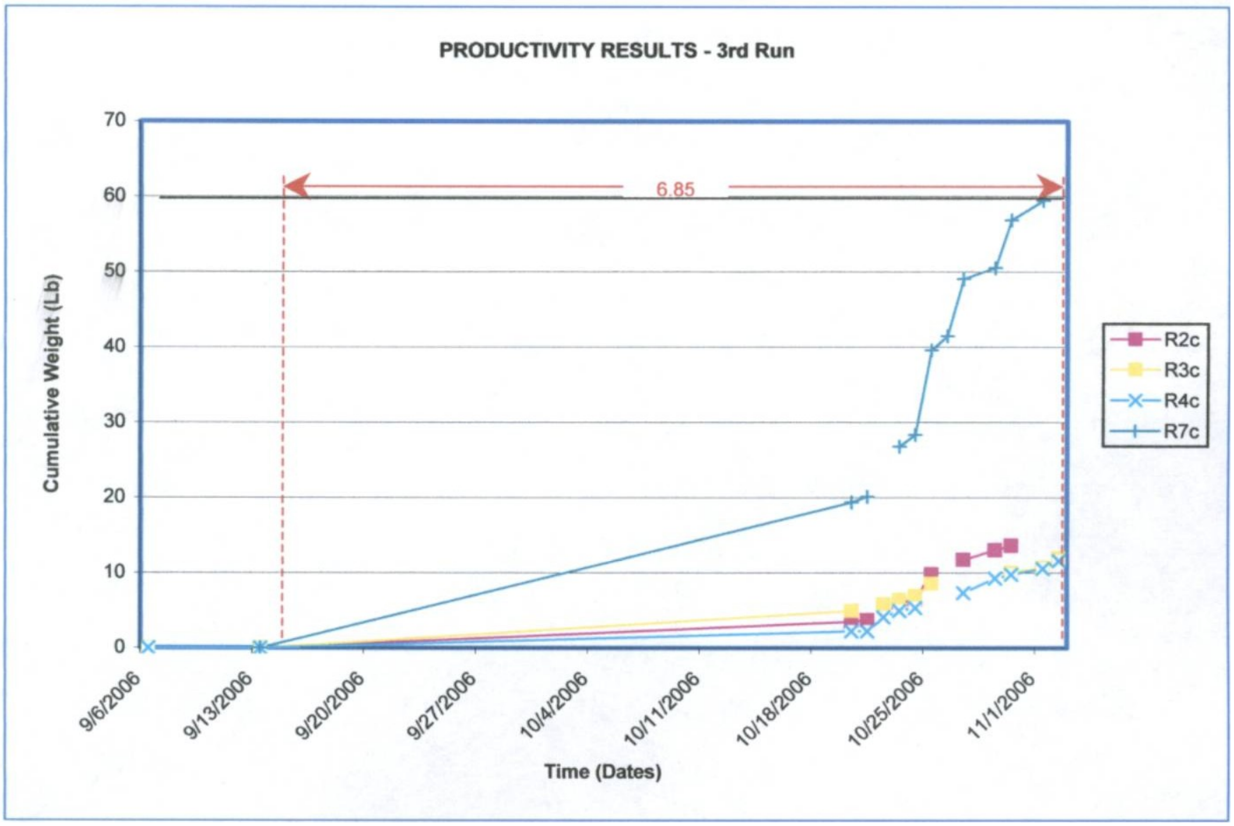
The final run was conducted when the results of Run A were obvious, as was the failure of Run B. Four formulations were used, representing those most successful in the initial run. R7c duplicated the original R7 formulation, except 60 blocks were prepared instead of the 16 originally used. R3c, R4c & R5c were similar formulations to their original counterparts but each was amended with an addition of 1% sucrose. Formulation R2c production achieved the quantity benchmark for success, growing over 14 pounds of mushrooms with a BE of 40% to 42%. Had six-pound blocks been prepared instead of five-pound blocks, this formulation clearly would have exceeded a production rate of 1 pound per block Formulation R7c again exceeded the production quantity benchmark, by growing an average 1 pound of mushrooms using only a 5 pound block. (See Table 3.).

Table 3. Production Results, Quality Calculations, and Biological Efficiencies for Run C.

R2c - Sawdust			R3c - Corncob			R4c - Wheat straw (red)			R7c - Royse + 1% sucrose		
date	harvest	sellable	date	harvest	sellable	date	harvest	sellable	date	harvest	sellable
Ttl lb.	14.420	13.622	Ttl lb.	12.589	11.981	Ttl lb.	12.082	11.606	Ttl lb.	62.265	59.516
Bioζ%	42%	40%	Bioζ%	44%	42%	Bioζ%	54%	52%	Bioζ%	51%	49%
Quality	0.945		Quality	0.952		Quality	0.961		Quality	0.956	

Both formulations R4c and R7c took over six weeks from the point of inoculation until final harvest. While this length of time did not meet the five-week benchmark, both formulations were yet determined viable for continued production. Environmental conditions were difficult to match identically among all the runs. Additionally, while FCM attempted to precisely replicate the formulations by using substrate components collected at the same time, from the same batch, some variation could not be avoided. That which stands in the forefront of concern in this regard is spent brewery grain. For example, spent brewery grain tends to sour if not used right away, so a new batch was acquired for each run. It was not until after the experiments had been conducted that FCM considered that it was likely that different beers were being brewed and consequently the spent grains had different component percentages. This variation has been identified for an area of follow-up research and, in fact, the R7 King Oyster formulation being incubated at the time of this writing is now identified as the English Pale Ale-R7 formulation. FCM will continue to keep track of and monitor production using spent grain from different brews in order to keep BEs high. (See Fig. 3.)

Figure 3. Production Results: Run C



Product Assessment

Quality was evaluated quantitatively as the "sellable" percentage of the harvested crop after removing deformities and other debris. With only one exception, quality measured greater than 90%.

Additionally, the chefs of four top Rochester restaurants and the produce buyer for a large, local natural food store performed qualitative evaluations. Evaluators were asked to assess the quality of the mushrooms based on size, weight, shape, texture, flavor, ease of preparation and culinary versatility. In every case, assessments were positive with several indicating the highest rating in every category.

Economic Analysis & Enterprise Budget

Actual costs and projected revenues were used as a basis for an enterprise budget analysis to help determine viability and sustainability.

- Determining the cost of formulation ingredients (e.g., spent brewery grain, wheat bran supplements, calcium sulfate, and calcium carbonate), classified as production materials, was fairly straightforward. Costs for full-scale operations were extrapolated from actual data collected.
- Labor costs for production using the experimental substrate material were equivalent to those associated with the current production schedule using traditional substrates.
- Non-substrate material, energy and supply costs, classified as facility overhead, are equivalent to those using traditional practices.

All costs associated with this project were extrapolated to full-scale and compared with those using current materials and methods to determine an overall benefit/cost ratio. The results of this analysis are provided in the chart below.

King Oyster Production Benefit/Cost Analysis	Annual	Monthly	Monthly King Oyster Production Cost (1/12th total monthly cost)	Monthly Totals	
Facility Overhead	$7,990	$666	$55	$55	Annual Revenue Basis: 1 run per 4 weeks 6 lb substrate/blk; 1.5 lb. King Oyster per block @ $6.5/lb
Production Materials				$76	$8,788
Labor (2 x $10/hr x 40 hr/wk)	$49,920	$4,160	$347	$347	Annual Cost
				$478	$5,738

Benefit/Cost Ratio
1.53

Business Plan

The result of the benefit-cost evaluation for growing King Oyster mushrooms as an FCM crop yielded a favorable 1.53 benefit-to-cost ratio. FCM now plans to run a batch of King Oyster blocks every four weeks, thus comprising 1/12th of its overall production potential.

Evaluation of spent substrate

The researchers met with Frank Ricotta, Regional Engineer, NYSDEC Region 8, and staff to assess the applicability of environmental regulations governing the composting of organic agricultural by-products. After reviewing FCM's activities, DEC determined that environmental regulations did not apply to the operation's composting activities associated with its spent substrate. FCM was also advised by Dr. Robert King, then Agricultural Specialist for Cornell Cooperative Extension that the Cooperative Extension holds a statewide permit for composting agricultural by productions and that anyone could use it. He advised that our composted substrate could be used and/or sold as an organic soil amendment.

Information Dissemination

- The researchers presented the findings of this project at the 9th Annual Organic Production and Marketing Program Work Team Meeting held at Cornell University on December 4th, 2006. To extend the reach of this conference beyond farmers and educators in Ithaca, this was convened as a videoconference to include farmers, researchers and Cornell Cooperative Extension agents from Monroe, Rensselaer, and Suffolk counties in New York State.
- As indicated by SARE's website, the final report will be reviewed by a regional SARE office and the results of this SARE-funded project will be made available on the organization's national database of projects.
- A third-party assessment of product quality for the King Oyster mushrooms grown during the course of this project was conducted by the chefs of four top Rochester restaurants and the produce buyer for a large, local natural food store. Evaluators were asked to assess the quality of the mushrooms based on size, weight, shape, texture, flavor, ease of preparation and culinary versatility. In every case, assessments were positive, with several indicating the highest rating in every category.
- The researchers have eagerly shared the results of this project with Joe & Angela Evans, owners of Oley Valley Mushrooms, a small, organic mushroom farm growing Oyster and Shiitake mushrooms in Pennsylvania. The Evans are currently attempting to duplicate the results of this project, as they share an interest in increasing production and promoting the adoption of organic King Oyster mushrooms in their region.
- These findings will be submitted for publication in mushroom grower publications including *The Mushroom Growers Newsletter*.
- Farm tours have been available on an on-going basis by request.

APPENDIX A: QUASI-EXPERIMENTAL RESEARCH DESIGN

Two classic quasi-experimental research designs were evaluated and combined for this work, the Comparison-Groups, Pretest-Posttest design, and the Regression Discontinuity Research Design.

The Non-Equivalent Group Design (aka, Comparison-Groups, Pretest-Posttest, Research Design). The non-equivalent group design is an intuitively sensible design and perhaps one of the most commonly used of the quasi-experimental research designs. It combines elements of the Static-Group Comparison and the One-Group Pretest-Posttest Pre-Experiment.

The *Comparison-Group Design* can be diagrammed as follows:

$$\begin{array}{llll} \mathbf{G_1} & \mathbf{O_{1\text{-}1}} & \mathbf{X} & \mathbf{O_{1\text{-}2}} \\ \mathbf{G_2} & \mathbf{O_{2\text{-}1}} & & \mathbf{O_{2\text{-}2}} \end{array}$$

Where: G ≡ The group. This can be an experimental or control group. Each group has its own line.

O ≡ An observation. This can be the result of a measurement, interview, survey, etc. $\mathbf{O}_{1\text{-}1}$ indicates a pre-treatment (or baseline) measurement for the experimental group, G_1; $\mathbf{O}_{1\text{-}2}$ is the post-treatment measurement. $\mathbf{O}_{2\text{-}1}$ and $\mathbf{O}_{2\text{-}2}$ are the corresponding measurements for the control group, G_2.

X ≡ A treatment or program. This represents some intervention, something that happened to the experimental group that did not happen to the control group. It could be the introduction of a new voluntary environmental policy, a large environmental regulatory fine, a death, a training program, etc.

- The timeline is from left to right.
- Vertical alignment of the symbols indicates that the measurements or treatments occur at the same time.
- Subscripts indicate subsets of measures.

A *Comparison-Group Design* to assess the effectiveness of different mushroom substrate formulations might look like this:

Group	O_1: Production Rate	Formulation	O_2: Production Rate
G_1	$O_{1\text{-}1}$: Mushroom Production (lb/day)	Standard	$O_{1\text{-}2}$: Mushroom Production (lb/day)
G_2	$O_{2\text{-}1}$: Mushroom Production (lb/day)	Standard	$O_{2\text{-}2}$: Mushroom Production (lb/day)
G_3	$O_{3\text{-}1}$: Mushroom Production (lb/day)	Standard	$O_{3\text{-}2}$: Mushroom Production (lb/day)
G_4	$O_{4\text{-}1}$: Mushroom Production (lb/day)	Increased lignin	$O_{4\text{-}2}$: Mushroom Production (lb/day)
G_5	$O_{5\text{-}1}$: Mushroom Production (lb/day)	Increased lignin	$O_{5\text{-}2}$: Mushroom Production (lb/day)
G_6	$O_{6\text{-}1}$: Mushroom Production (lb/day)	Increased lignin	$O_{6\text{-}2}$: Mushroom Production (lb/day)

The Regression-Discontinuity Research Design. The *Regression-Discontinuity Research* design is an expansion of the *Static-Group Comparison* pre-experimental design. It compares multiple rank-ordered groups with and without the treatment. A pre-treatment test is not used. However, a "phantom" pretest (signified by O) is assumed based on some criterion known to the researcher and upon which s/he makes the decision to treat or not treat the group. Because this design identifies differences among the groups at the outset, its long series of comparison groups helps the researcher rule out selection threats.

G_1	O	X	O_1
G_2	O	X	O2
G_3	O	X	O3
G_4	O	X	O4
G_5	O	X	O5
G_6	O		O_6
G_7	O		O_7
G_8	O		O_8
G_9	O		O_9
G_{10}	O		O_{10}

This design provides a cross-sectional examination of many groups all at the same time. The researcher has the opportunity to see how a variety of treated and non-treated groups differ.

Selected Experimental Design

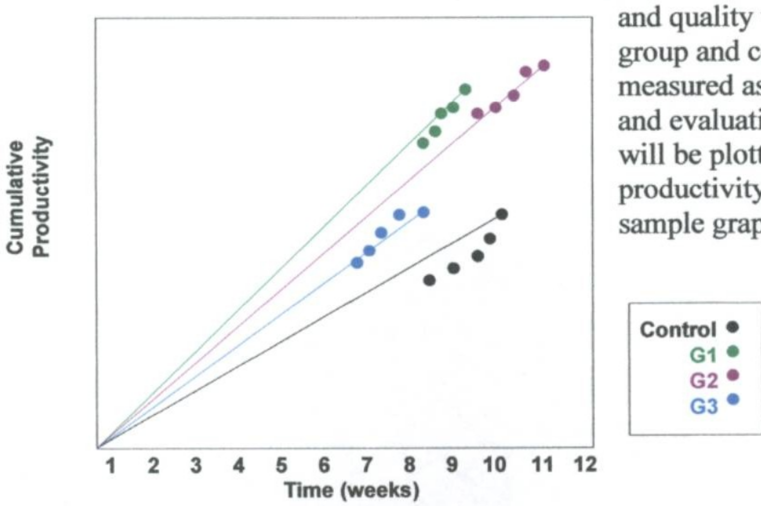
This research combined elements of the Comparison Design and the Regression Discontinuity Design. Consistent with the Regression-Discontinuity design, there was no pre-treatment test. A phantom pre-treatment test value of zero mushroom production was assigned to all groups. Non-equivalent group design was used to compare production rate (lbs/day) and duration (days) of each group.

Threats to Validity

- Selection threats: Differences among experimental and control groups were identified at the outset to eliminate selection threats.
- Environmental threats: Differences in the environment over time for each of the groups were minimized by minimizing the amount of time between preparation of successive groups, and monitoring and controlling CO_2/O_2, relative humidity, light, and temperature throughout successive stages of growth.

Productivity Analysis

In order to assess economic viability as well as productivity, a cost-benefit analysis of quantity and quality vs. time was conducted for each group and compared. Productivity results were measured as the product of mushroom weight and evaluation of their quality. These results will be plotted against time to provide an overall productivity relationship for each group. A sample graph is presented below.



Productivity (P) = Harvested Weight × Percent "Sellable"
Time (T) = Days from Inoculation

Criteria for evaluating quality are described below.

Quality Criteria

- % "Sellable"
  - 100% (1.0), 90% (0.9) etc.
    - Basis: Qualitative assessment of:
      - Size
      - Consistency
      - Moisture
      - Appearance

APPENDIX B: FORMULATION DEVELOPMENT

Substrate Materials	Lignin	Cellulose	Hemi-Cellulose	Crude Protein
Sawdust, oak	20	45	30	0
Sawdust, maple	20	45	30	0
Sawdust, other				
Corncob	4.767	30.447	30.482	5.231
Wheat straw	7.918	41.511	22.737	5.409
Oat straw				
Brewer's grain	6.152	17.35	26.678	25.955
Cottonseed hulls	23.718	41.328	14.609	8.359
Cottonseed meal	8.309	13.939	9.735	42.874
Supplements				
Wheat bran	4.155	10.18	26.65	17.635
Rice bran	12.619	9.309	11.543	13.36
Oat bran				
Millet	0.000	6.467	8.009	13.471
Beet pulp	3.587	21.998	16.265	9.644
Brewer's grain	6.152	17.35	26.678	25.955
Sucrose	0	0	0	0
Grape pomace	34.840	13.979	6.567	16.856
Soybean meal	1.373	7.069	4.658	51.264
Corn distillers grain	5.8	3.9	24.800	31.7

					Source
59% oak sawdust & 15% millet & 15% brewer's grain & 10% wheat bran & 1% calcium carbonate	13.1	31.1	37.1	7.7	Dan Royse: *Effect of Brewer's Grain and Delayed Release Nutrient Supplementation on Yield and Size of* Pleurotus eryngii
Royse control	13.1	31.1	25.6	7.7	
Composite from below	12.6	30.9	26.9	7.3	
Percentage difference	4.4%	0.7%	5.2%	4.7%	

		ALTERNATIVE SUBSTRATES DUPLICATING ROYSE										
	Calculator	Royse lbs & %	Sawdust Organic & Local (lbs)	%ages	Corncob Local (lbs)	%ages	Wheat Straw Local (lbs)	%ages	Sawdust Organic & Local (lbs)	%ages	Corncob Local (lbs)	%ages
Sawdust	20.00	59	60.00	65.2%	20.0	18.3%	15	14.7%	60.00	64.5%	20.0	18.1%
Corncob	62.50		7.00	7.6%	62.5	57.1%	27	26.5%	7.00	7.5%	62.5	56.6%
Wheat straw	0.00						34	33.4%				
Cottonseed hulls	0.00											
Wheat bran	0.00	10	15.00	16.3%					15.00	16.1%		
Rice Bran	0.00											
Sucrose	1.00								1.00	1.1%	1.0	0.9%
Millet	10.00	15			10.0	9.1%					10.0	9.0%
Corn distiller's grain	0.00											
Beet pulp	0.00						2	2.0%				
Brewer's grain	0.00	15					9	8.8%				
Brewer's yeast	0.00	0										
Grape pomace	16.00				16.0	14.6%	13.8	13.6%			16.0	14.5%
Soybean meal	0.00		9.00	9.8%					9.00	9.7%		
calcium carbonate	1.00	1	1.00	1.1%	1.0	0.9%	1	1.0%	1.00	1.1%	1.0	0.9%
calcium sulfate	0.00											
	110.50	100	92.00	100.0%	109.5	100.0%	101.8	100.0%	93.00	100.0%	110.5	100.0%
	COMPONENT	%	%		%		%					
	Lignin	13.1	13.1		12.6		12.4					
	Cellulose	31.1	31.3		30.9		33.0					
	Hemi-Cellulose	25.6	24.6		26.9		24.1					
	Crude Protein	7.7	7.6		7.3		8.1					

NOTE: Our strategy here is to create control groups for sawdust-based, wheatstraw-based, and corncob-based formulations by matching the fiber and protein content to Royse's sawdust-based formulation. Our rationale for using a sawdust-based formulation for wheat and corncob basal ingredients is that Royse's formulation came from the only study we found that used the CS 515 spawn as an inoculant.

	Royse lbs & %	50% lignin increase		35% lignin increase + 25% hemi-cellulose increase		Royse + 1% sucrose		
Sawdust	59	60	58.8%	70	59.8%	59	58.4%	
Corncob		0	0.0%	0	0.0%		0.0%	
Wheat straw		0	0.0%	0	0.0%		0.0%	
Cottonseed hulls		0	0.0%	0	0.0%		0.0%	
Wheat bran	10	20	19.6%	40	34.2%	10	9.9%	
Rice Bran		0	0.0%	0	0.0%		0.0%	
Millet	15	0	0.0%	0	0.0%	15	14.9%	
Corn distiller's grain		0	0.0%	0	0.0%		0.0%	
Beet pulp		0	0.0%	0	0.0%		0.0%	
Brewer's grain	15	0	0.0%	0	0.0%	15	14.9%	
Brewer's yeast		0	0.0%	0	0.0%	0	0.0%	
Grape pomace		21	20.6%	6	5.1%		0.0%	
Soybean meal		1	1.0%	0	0.0%		0.0%	
calcium carbonate	1	0	0.0%	1	0.9%	1	1.0%	
calcium sulfate		0	0.0%	0	0.0%		0.0%	
TOTAL	100	102	100.0%	117	100.0%	1	1.0%	< Sucrose
COMPONENT	%	%		%		101	100.0%	
Lignin	13.1	20.2		17.8		%		
Cellulose	31.1	32.2		36.4		13.1		
Hemi-Cellulose	25.6	24.8		32.1		31.1		
Crude Protein	7.7	7.6		8.1		25.6		
						7.7		

NOTE: Our strategy here is to vary specific substrate component percentages to correspond with reported successes.

APPENDIX C MOISTURE DETERMINATION

	Initial Wt. (lb)	Final Wt. (lb)	Moisture Content (%)	Initial Wt. (lb)*	Final Wt. (lb)*	Moisture Content (%)*
Sawdust	0.102	0.064	37.25%	0.106	0.038	64.15%
Corn cob	0.101	0.090	10.89%	0.172	0.058	66.28%
Wheat straw (red)	0.119	0.106	10.92%	0.201	0.045	77.61%
Grape pomace	0.100	0.047	53.00%			
Millet	0.111	0.102	8.11%			
Brewer's grain	0.107	0.029	72.90%			
Soybean meal	0.108	0.100	7.41%			
Beet pulp	0.108	0.098	9.26%			
Calcium carbonate	0.108	0.108	0.00%			
Sucrose	0.111	0.111	0.00%			
Wheat bran	0.101	0.088	12.87%			
Bag	0.023	0.023	0.00%			

*after overnight soak

	Physical Analysis			Calculated
	Initial Wt. (lb)	Final Wt. (lb)	Moisture Content (%)	Moisture Content (%)
R1-Royse	0.106	0.037	65.09%	59.80%
R2-Sawdust	0.113	0.045	60.18%	57.41%
R3-Corncob	0.088	0.033	62.50%	61.87%
R4-Wheat straw	0.099	0.028	71.72%	70.00%
R5-50% lignin increase	0.103	0.040	61.17%	56.79%
R6-35% lignin, 25% hemi-cellulose	0.107	0.046	57.01%	54.10%
R7-Royse + 1% sucrose	0.116	0.047	59.48%	59.55%

APPENDIX D: PRODUCTION WORKSHEET 1

R1- Royse	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	59.00	64.15%	164.57	49.63	17.79	59.00%	
Wheat bran	10.00	12.87%	11.48	3.46	3.02	10.00%	
Millet	15.00	8.11%	16.32	4.92	4.52	15.00%	
Brewer's grain	15.00	72.90%	55.35	16.69	4.52	15.00%	
Calcium Carbonate	1.00	0.00%	1.00	0.30	0.30	1.00%	
Total	**100.00**		**248.73**	**75.00**	**30.15**	**100.00%**	**59.80%**
			Target Weight:	75.00			

R2 - Sawdust	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	65.20	64.15%	181.87	58.09	20.83	65.20%	
Corncob	7.60	66.28%	22.54	7.20	2.43	7.60%	
Wheat bran	16.30	12.87%	18.71	5.98	5.21	16.30%	
Soybean meal	9.80	7.41%	10.58	3.38	3.13	9.80%	
Calcium Carbonate	1.10	0.00%	1.10	0.35	0.35	1.10%	
Total	**100.00**		**234.80**	**75.00**	**31.94**	**100.00%**	**57.41%**
			Target Weight:	75.00			

R3 - Corncob	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	18.30	64.15%	51.05	14.60	5.23	18.30%	
Corncob	57.10	66.28%	169.34	48.43	16.33	57.10%	
Millet	9.10	8.11%	9.90	2.83	2.60	9.10%	
Grape pomace	14.60	53.00%	31.06	8.88	4.18	14.60%	
Calcium Carbonate	0.90	0.00%	0.90	0.26	0.26	0.90%	
Total	**100.00**		**262.25**	**75.00**	**28.60**	**100.00%**	**61.87%**
			Target Weight:	75.00			

R4 - Wheat straw (red)	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	14.70	64.15%	41.00	9.22	3.31	14.70%	
Corncob	26.50	66.28%	78.59	17.68	5.96	26.50%	
Wheat Straw	33.40	77.61%	149.17	33.56	7.51	33.40%	
Beet pulp	2.00	9.26%	2.20	0.50	0.45	2.00%	
Brewer's grain	8.80	72.90%	32.47	7.31	1.98	8.80%	
Grape pomace	13.60	53.00%	28.94	6.51	3.06	13.60%	
Calcium carbonate	1.00	0.00%	1.00	0.22	0.22	1.00%	
Total	**100.00**		**333.38**	**75.00**	**22.50**	**100.00%**	**70.00%**
			Target Weight:	75.00			

R5 - 50% lignin increase	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	58.80	64.15%	164.02	53.16	19.06	58.80%	
Wheat bran	19.60	12.87%	22.50	7.29	6.35	19.60%	
Grape pomace	20.60	53.00%	43.83	14.20	6.68	20.60%	
Soybean meal	1.00	7.41%	1.08	0.35	0.32	1.00%	
Total	**100.00**		**231.42**	**75.00**	**32.41**	**100.00%**	**56.79%**
			Target Weight:	75.00			

R6 - 35% lignin increase + 25% hemi-cellulose increase	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	59.80	64.15%	166.81	57.42	20.58	59.80%	
Wheat bran	34.20	12.87%	39.25	13.51	11.77	34.20%	
Grape pomace	5.10	53.00%	10.85	3.74	1.76	5.10%	
Soybean meal	0.90	7.41%	0.97	0.33	0.31	0.90%	
Total	**100.00**		**217.88**	**75.00**	**34.42**	**100.00%**	**54.10%**
			Target Weight:	75.00			

R7 - Royse + 1% sucrose	Dry Weight (%)	Moisture (%)	Wet Weight (lb)	Adjusted Wet Weight (lb)	Adjusted Dry Weight (lb)	Adjusted Dry Weight (%)	Adjusted Total Moisture (%)
Sawdust	58.40	64.15%	162.90	49.37	17.70	58.34%	
Wheat bran	9.90	12.87%	11.36	3.44	3.00	9.89%	
Millet	14.90	8.11%	16.22	4.91	4.52	14.89%	

R1- Royse

Sawdust
Wheat bran
Millet
Brewer's grain
Calcium Carbonate

date	harvest	sellable	cumul
16-Aug	0.000	0.000	0.000
17-Aug	0.000	0.000	0.000
18-Aug	0.000	0.000	0.000
19-Aug	0.000	0.000	0.000
20-Aug	0.741	0.610	0.610
21-Aug	1.490	1.490	2.100
22-Aug	0.729	0.708	2.808
23-Aug	0.949	0.933	3.741
24-Aug	0.421	0.421	4.162
25-Aug	0.721	0.421	4.583
26-Aug	0.000	0.000	4.583
27-Aug	0.310	0.310	4.893
28-Aug	0.437	0.437	5.330
29-Aug	0.000	0.000	5.330
30-Aug	0.266	0.184	5.514
31-Aug	0.000	0.000	5.514
1-Sep	0.000	0.000	5.514
2-Sep			5.514
3-Sep			5.514
4-Sep			5.514
10-Sep	0.580	0.571	6.085
13-Sep	1.031	0.954	7.039
20-Sep	0.551	0.540	7.579
22-Sep	0.761	0.731	8.310
25-Sep	0.336	0.270	8.580
1-Oct	1.105	1.038	9.618
2-Oct	0.632	0.615	10.233
4-Oct	0.844	0.807	11.040
Ttl lb.	11.904	11.040	
Bio ζ %	39%	37%	
Quality	0.927		

R2 - Sawdust

Sawdust
Corncob
Wheat bran
Soybean meal
Calcium Carbonate

date	harvest	sellable	cumul
16-Aug	0.000	0.000	0.000
17-Aug	0.000	0.000	0.000
18-Aug	1.845	1.844	1.844
19-Aug	0.432	0.432	2.276
20-Aug	1.727	1.705	3.981
21-Aug	0.834	0.834	4.815
22-Aug	0.644	0.609	5.424
23-Aug	0.674	0.673	6.097
24-Aug	0.000	0.000	6.097
25-Aug	1.103	1.020	7.117
26-Aug	0.000	0.000	7.117
27-Aug	0.660	0.660	7.777
28-Aug	0.424	0.424	8.201
29-Aug	1.275	0.906	9.107
30-Aug	0.301	0.291	9.398
31-Aug	0.112	0.112	9.510
1-Sep	0.000	0.000	9.510
2-Sep			9.510
3-Sep			9.510
4-Sep			9.510
10-Sep	1.094	1.057	10.567
20-Sep	0.167	0.167	10.734
22-Sep	0.207	0.190	10.924
27-Sep	0.657	0.523	11.447
1-Oct	0.466	0.466	11.913
2-Oct	0.094	0.094	12.007
Ttl lb.	12.716	12.007	
Bio ζ %	40%	38%	
Quality	0.944		

R3 - Corncob

Sawdust
Corncob
Millet
Grape pomace
Calcium Carbonate

date	harvest	sellable	cumul
16-Aug	0.000	0.000	0.000
17-Aug	0.599	0.581	0.581
18-Aug	0.284	0.273	0.854
19-Aug	0.224	0.224	1.078
20-Aug	0.625	0.604	1.682
21-Aug	0.439	0.439	2.121
22-Aug	0.863	0.831	2.952
23-Aug	0.100	0.100	3.052
24-Aug	0.000	0.000	3.052
25-Aug	0.758	0.710	3.762
26-Aug	0.000	0.000	3.762
27-Aug	0.118	0.118	3.880
28-Aug	0.585	0.585	4.465
29-Aug	0.297	0.278	4.743
30-Aug	0.000	0.000	4.743
31-Aug	0.000	0.000	4.743
1-Sep	0.000	0.000	4.743
2-Sep			4.743
3-Sep			4.743
4-Sep			4.743
10-Sep	0.756	0.717	5.460
13-Sep	0.103	0.000	5.460
25-Sep	0.434	0.434	5.894
27-Sep	0.449	0.440	6.334
1-Oct	0.404	0.355	6.689
Ttl lb.	7.038	6.689	
Bio ζ %	25%	23%	
Quality	0.950		

R4 - Wheat straw (red)

Sawdust
Corncob
Wheat Straw
Beet pulp
Brewer's grain
Grape pomace
Calcium carbonate

date	harvest	sellable
16-Aug	0.874	0.874
17-Aug	1.209	1.171
18-Aug	0.359	0.359
19-Aug	0.000	0.000
20-Aug	0.245	0.245
21-Aug	0.132	0.132
22-Aug	0.497	0.489
23-Aug	0.123	0.123
24-Aug	0.000	0.000
25-Aug	1.641	1.352
26-Aug	0.592	0.592
27-Aug	0.190	0.190
28-Aug	0.104	0.000
29-Aug	0.045	0.000
30-Aug	0.156	0.148
31-Aug	0.000	0.000
1-Sep	0.000	0.000
2-Sep		
3-Sep		
4-Sep		
22-Sep	0.271	0.271
4-Oct	0.325	0.259
Ttl lb.	6.763	6.205
Bio ζ %	30%	28%
Quality	0.917	

R5 - 50% lignin increase Sawdust Wheat bran Grape pomace Soybean meal				R6 - 35% lignin increase + 25% hemi-cellulose increase Sawdust Wheat bran Grape pomace Soybean meal				R7 - Royse + 1% sucrose Sawdust Wheat bran Millet Brewer's grain Calcium carbonate Sucrose			
date	harvest	sellable	cumul	date	harvest	sellable	cumul	date	harvest	sellable	cumul
16-Aug	0.000	0.000	0.000	16-Aug	0.000	0.000	0.000	16-Aug	3.711	3.520	3.520
17-Aug	0.000	0.000	0.000	17-Aug	0.000	0.000	0.000	17-Aug	5.577	5.357	8.877
18-Aug	0.483	0.443	0.443	18-Aug	0.945	0.943	0.943	18-Aug	9.112	7.892	16.769
19-Aug	0.000	0.000	0.443	19-Aug	0.000	0.000	0.943	19-Aug	0.000	0.000	16.769
20-Aug	0.128	0.128	0.571	20-Aug	2.340	0.000	0.943	20-Aug	0.060	0.060	16.829
21-Aug	0.587	0.581	1.152	21-Aug	0.118	0.118	1.061	21-Aug	0.000	0.000	16.829
22-Aug	1.101	1.083	2.235	22-Aug	1.227	1.227	2.288	22-Aug	0.154	0.154	16.983
23-Aug	1.233	1.195	3.430	23-Aug	2.044	2.044	4.332	23-Aug	0.000	0.000	16.983
24-Aug	0.000	0.000	3.430	24-Aug	0.000	0.000	4.332	24-Aug	0.000	0.000	16.983
25-Aug	1.030	1.005	4.435	25-Aug	1.611	1.449	5.781	25-Aug	0.000	0.000	16.983
26-Aug	0.000	0.000	4.435	26-Aug	0.000	0.000	5.781	26-Aug	0.000	0.000	16.983
27-Aug	0.000	0.000	4.435	27-Aug	0.093	0.093	5.874	27-Aug	0.213	0.213	17.196
28-Aug	0.275	0.269	4.704	28-Aug	0.099	0.099	5.973	28-Aug	0.487	0.467	17.663
29-Aug	0.000	0.000	4.704	29-Aug	0.000	0.000	5.973	29-Aug	0.000	0.000	17.663
30-Aug	0.000	0.000	4.704	30-Aug	0.000	0.000	5.973	30-Aug	0.068	0.000	17.663
31-Aug	0.000	0.000	4.704	31-Aug	0.000	0.000	5.973	31-Aug	0.000	0.000	17.663
1-Sep	0.000	0.000	4.704	1-Sep	0.000	0.000	5.973	1-Sep	0.000	0.000	17.663
2-Sep			4.704	2-Sep			5.973	2-Sep			17.663
3-Sep			4.704	3-Sep			5.973	3-Sep			17.663
4-Sep			4.704	4-Sep			5.973	4-Sep			17.663
								10-Sep	0.436	0.323	17.986
13-Sep	0.093	0.089	4.793					13-Sep	0.444	0.357	18.343
								20-Sep	0.349	0.333	18.676
								22-Sep	0.432	0.432	19.108
								27-Sep	0.409	0.409	19.517
								29-Sep	0.323	0.270	19.787
								2-Oct	0.183	0.183	19.970
								4-Oct	0.235	0.231	20.201
Ttl lb.	4.930	4.793		Ttl lb.	8.477	5.973		Ttl lb.	22.193	20.201	
Bio ζ %	7%	7%		Bio ζ %	25%	17%		Bio ζ %	73%	67%	
Quality	0.972			Quality	0.705			Quality	0.910		

R1b- Royse				R2b - Sawdust			
date	**harvest**	**sellable**	**cumul**	**date**	**harvest**	**sellable**	**cumul**
27-Aug	0.252	0.252	0.252	27-Aug	0.000	0.000	0.000
28-Aug	0.461	0.421	0.673	28-Aug	0.000	0.000	0.000
29-Aug	0.000	0.000	0.673	29-Aug	0.879	0.879	0.879
30-Aug	0.000	0.000	0.673	30-Aug	0.340	0.300	1.179
31-Aug	0.000	0.000	0.673	31-Aug	0.467	0.467	1.646
1-Sep	0.536	0.536	1.209	1-Sep	0.230	0.230	1.876
2-Sep	0.000	0.000	1.209	2-Sep	0.129	0.129	2.005
3-Sep	0.630	0.522	1.731	3-Sep	0.000	0.000	2.005
				4-Sep	0.596	0.000	2.005
				10-Sep	1.150	1.150	3.155
				12-Sep	0.608	0.608	3.763
13-Sep	0.969	0.919	2.650	13-Sep	1.816	1.569	5.332
18-Sep	0.444	0.409	3.059	18-Sep	0.355	0.340	5.672
20-Sep	1.303	1.285	4.344	20-Sep	0.919	0.903	6.575
22-Sep	0.651	0.613	4.957	22-Sep	0.466	0.464	7.039
25-Sep	2.115	2.077	7.034	25-Sep	0.808	0.808	7.847
27-Sep	1.186	0.830	7.864				
29-Sep	0.445	0.445	8.309	29-Sep	0.142	0.135	7.982
1-Oct	1.840	1.639	9.948				
2-Oct	0.357	0.354	10.302				
				4-Oct	1.024	1.004	8.986
Ttl lb.	11.189	10.302		Ttl lb.	9.929	8.986	
Bio ζ %	35%	32%		Bio ζ %	29%	26%	
Quality	Quality:	0.921		Quality		0.905	

R3b - Corncob				R4b - Wheat straw (red)			
date	**harvest**	**sellable**	**cumul**	**date**	**harvest**	**sellable**	**cumul**
27-Aug	0.000	0.000	0.000	27-Aug	0.000	0.000	0.000
28-Aug	0.305	0.305	0.305	28-Aug	1.404	1.401	1.401
29-Aug	0.000	0.000	0.305	29-Aug	0.784	0.717	2.118
30-Aug	0.961	0.923	1.228	30-Aug	0.116	0.116	2.234
31-Aug	0.204	0.204	1.432	31-Aug	0.580	0.574	2.808
1-Sep	0.000	0.000	1.432	1-Sep	0.111	0.111	2.919
2-Sep			1.432	2-Sep			2.919
3-Sep			1.432	3-Sep			2.919
22-Sep	0.159	0.159	1.591				
27-Sep	0.345	0.326	1.917				
1-Oct	0.896	0.886	2.803	1-Oct	0.643	0.616	3.535
4-Oct	0.204	0.204	3.007	4-Oct	0.310	0.234	3.769
Ttl lb.	3.074	3.007		Ttl lb.	3.948	3.769	
Bio ζ %	10%	10%		Bio ζ %	16%	16%	
Quality	0.978			Quality	0.955		

RUN B (Cont'd.)

R5b - 50% lignin increase				R6b - 35% lignin increase + 25% hemi-cellulose increase				R7b - Royse + 1% sucrose			
date	harvest	sellable	cumul	date	harvest	sellable	cumul	date	harvest	sellable	cumul
27-Aug	0.000	0.000	0.000	27-Aug	0.000	0.000	0.000	27-Aug	1.052	0.252	0.252
28-Aug	0.000	0.000	0.000	28-Aug	0.000	0.000	0.000	28-Aug	0.350	0.000	0.252
29-Aug	0.000	0.000	0.000	29-Aug	0.000	0.000	0.000	29-Aug	0.175	0.175	0.427
30-Aug	0.000	0.000	0.000	30-Aug	0.000	0.000	0.000	30-Aug	0.000	0.000	0.427
31-Aug	0.000	0.000	0.000	31-Aug	0.000	0.000	0.000	31-Aug	0.480	0.463	0.890
1-Sep	0.000	0.000	0.000	1-Sep	0.000	0.000	0.000	1-Sep	0.000	0.000	0.890
2-Sep			0.000	2-Sep			0.000	2-Sep	0.543	0.366	1.256
3-Sep			0.000	3-Sep			0.000	3-Sep	0.303	0.303	1.559
								4-Sep	0.098	0.000	1.559
								9-Sep	0.340	0.330	1.889
								10-Sep	0.362	0.362	2.251
								13-Sep	0.249	0.247	2.498
								18-Sep	0.252	0.000	2.498
								25-Sep	0.673	0.651	3.149
27-Sep	0.286	0.275	0.275					27-Sep	1.040	0.981	4.130
								29-Sep	0.433	0.427	4.557
1-Oct	0.444	0.399	0.674	1-Oct	0.280	0.222	0.222	1-Oct	1.204	0.938	5.495
4-Oct	0.562	0.306	0.980	4-Oct	0.623	0.585	0.807	4-Oct	0.557	0.509	6.004
Ttl lb.	1.292	0.980		Ttl lb.	0.903	0.807		Ttl lb.	8.111	6.004	
Bio ζ %	2%	1%		Bio ζ %	3%	2%		Bio ζ %	27%	20%	
Quality	0.759			Quality	0.894			Quality		0.740	

APPENDIX E – PRODUCTION WORKSHEET 2 – RUN C

R3c - Sawdust				R3c - Corncob				R4c - Wheat straw (red)			
date	**harvest**	**sellable**	**cumul**	**date**	**harvest**	**sellable**	**cumul**	**date**	**harvest**	**sellable**	**cumul**
20-Oct	3.620	3.550	3.550	20-Oct	5.490	4.960	4.960	20-Oct	2.250	2.250	2.250
21-Oct	1.450	0.180	3.730					21-Oct	0.253	0.016	2.266
				22-Oct	0.865	0.865	5.825	22-Oct	1.923	1.855	4.121
23-Oct	2.416	2.333	6.063	23-Oct	0.591	0.591	6.416	23-Oct	0.881	0.843	4.964
24-Oct	0.370	0.370	6.433	24-Oct	0.498	0.498	6.914	24-Oct	0.399	0.399	5.363
25-Oct	3.392	3.390	9.823	25-Oct	1.703	1.674	8.588				
27-Oct	1.240	1.928	11.751					27-Oct	2.091	1.983	7.346
29-Oct	1.368	1.307	13.058					29-Oct	1.927	1.927	9.273
30-Oct	0.564	0.564	13.622	30-Oct	1.476	1.427	10.015	30-Oct	0.521	0.508	9.781
				1-Nov	0.703	0.703	10.718	1-Nov	0.783	0.771	10.552
				2-Nov	1.263	1.263	11.981	2-Nov	1.054	1.054	11.606
Totals (lbs)	14.420	13.622		Ttl lb.	12.589	11.981		Ttl lb.	12.082	11.606	
iciency (%)	42%	40%		Bio ζ %	44%	42%		Bio ζ %	54%	52%	
Quality	0.945			Quality	0.952			Quality	0.961		

HARVESTED	SELLABLE	BIOLOGICAL ζ %
213.823	197.896	1 TO 73

R7c - Royse + 1% sucrose			
date	**harvest**	**sellable**	**cumul**
20-Oct	19.670	19.370	19.370
21-Oct	1.920	0.770	20.140
23-Oct	6.947	6.667	26.807
24-Oct	2.010	1.560	28.367
25-Oct	11.255	11.255	39.622
26-Oct	2.190	1.918	41.540
27-Oct	7.808	7.538	49.078
29-Oct	1.494	1.467	50.545
30-Oct	6.365	6.365	56.910
1-Nov	2.606	2.606	59.516
Ttl lb.	62.265	59.516	
Bio ζ %	51%	49%	
Quality	0.956		