Depuration and Slaughter Techniques to Optimize Atlantic Salmon Product Quality from Land-Based Closed Containment Systems

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Introduction

- Increased use of recirculating aquaculture systems (RAS) to culture aquatic species, including Atlantic salmon

- Many advantages of RAS, but one drawback
  - Bioaccumulation of off-flavor compounds within fish flesh
  - Create an earthy or musty taste

- Caused by microbial metabolites produced by actinomycetes and cyanobacteria
  - 2-Methylisoborneol (MIB)
  - Geosmin
Introduction

- Off-flavor not reported for *A. salmon* cultured in ocean net pens but reported in *A. salmon* caught in freshwater rivers

- For RAS to be viable technology, methods for off-flavor removal are necessary

- Can be effectively accomplished using depuration process
  - Fish off feed
  - Clean/ biofilm-free system water
  - Flow Through or Partial Reuse System

- Ozone used at non-disinfecting dose did not remove off-flavor from trout from low exchange RAS (Schrader et al., 2010)

- Determined approximate amount of time and conditions for optimal depuration of A. salmon cultured in RAS
- Salmon cultured in RAS with 97% recycle rate (flow basis)
- Fed a commercial 44/29 diet
2-Methylisoborneol Levels in the Flesh of Salmon from a Flow-through System during Depuration Study

- Cited from Wolters et al., 2011. Weight Loss and Fillet Quality Characteristics of Atlantic Salmon after Purging for 5, 10, 15 or 20 days. Aquaculture Innovation Workshop I, Shepherdstown, WV.

- Optimal purge time = 10-15 days
Aquaculture Innovation Workshop #3
Seattle, WA

- Cited from Wolters et al., 2011.
- Salmon purged more effectively in geosmin/MIB-free RAS and flow through system

Burr et al. 2012 Results

Geosmin levels in flesh of salmon purged under various conditions

- Original RAS
- Flow Through w/ GAC
- Clean RAS
- Burr et al. 2012 Results

Mean Geosmin (ng/kg) in Salmon Fillets \( n = 12 \)

Time (d)

0 5 10 15
Burr et al. 2012 Conclusions

- 10-15 days optimal depuration time
- Taking salmon off feed prior to harvest shouldn’t be only method
- Recommend fish relocation to biofilm-free depuration system
- Fillet color not impacted during depuration
- Use of granular activated carbon to treat influent of depuration system appears to be beneficial
• A. salmon used for depuration and fillet quality studies harvested from commercial scale RAS

• Recycle Flow
  • 99.75% (flow basis)
  • 1500 gpm recycle

• Makeup Flow
  • < 5 gpm

• Fish Density - 50-60 kg/m³

• Feed Loading Rate –
  • 6-7 kg feed/ m³ makeup flow
Twelve 0.5 m³ circular single drain tanks

Prior to stocking salmon for depuration - equal numbers of rainbow trout cultured in tanks to establish biofilm

Partial reuse systems operated at appx. 92% recycle
- 26 gpm recycle flow
- 2 gpm makeup flow
- Hydraulic Retention Time > 1 Hr

Recycle water pumped from each tank through an aeration column containing random packing
0.5 m³ Experimental Partial Reuse Systems
## Salmon Depuration Experimental Design

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<th>Experimental Tanks per Treatment</th>
<th>Granular Activated Carbon (GAC)</th>
<th>Hydrogen Peroxide</th>
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Depuration Study Methods

- Rainbow trout removed 1 day prior to stocking salmon
- Six tanks treated with 1 hr static hydrogen peroxide
  - Target – 250 mg/L
- GAC turned on
- Systems allowed to flush 24 hrs
- Appx. 15 salmon stocked per tank next day
  - Trial 1 used 1-2 kg salmon (1 yr. old)
  - Trial 2 and 3 used 4-5 kg salmon
- Salmon remain off feed for study period
Granular Activated Carbon Filtration

- All makeup water entering six tanks assigned GAC treatment passed through GAC filter
Depuration Study Sampling Methods

- Fillet samples - Days 0, 2, 6, and 10
- Water and biofilm samples - Days 0, 2, 4, 6, 8, and 10
- All samples tested by Kevin Schrader, USDA ARS Microbiologist at University of Mississippi for off-flavor compounds – geosmin and MIB
MIB in Culture Water and Salmon Fillets

- MIB concentrations very low to begin in culture water and fillets
- MIB concentrations in water unaffected by treatment or time
- Depuration occurred for all treatments
- Lowest MIB in salmon harvested from $\text{H}_2\text{O}_2$ and GAC + $\text{H}_2\text{O}_2$ treated systems

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Geosmin in Culture Water & Salmon Fillets

- Geosmin concentrations in water declined over a 10-day period.

- Geosmin concentrations in fillets increased for all treatments except GAC + H₂O₂.

- Increase in off-flavor would not be expected in clean, biofilm-free depuration system.
- Results indicated 4-5% body weight lost from Day 0 to 10

- Later results showed fillet yield was not impacted by 10-day depuration

- Reducing depuration time from 10 days could be beneficial if off-flavor sufficiently reduced
Depuration Results

- Studies conducted with systems treated with various methods, but not brushed/cleaned prior to stocking for depuration to simulate worst case industry scenario

- Thorough pre-cleaning is critical so that depuration systems are clean/biofilm-free to begin

- Off-flavor concentrations in fillets can increase in “dirty” depuration systems with biofilm on walls of unit processes

- GAC combined with H₂O₂ disinfection appears to be best treatment option

- H₂O₂ disinfection alone was also effective
Biofilters & aeration columns can harbor off-flavor producing bacteria

Depuration time could be reduced from 10 days if:
- starting with clean/biofilm free systems
- avoid aeration columns or using columns with no packing
- use fish with inherently low initial off-flavor concentrations

Results from Study 2 using 4 kg salmon pending
Marketing research using optimal depuration techniques indicates success!

Blind taste tests of 2 panels of seafood professionals in Seattle indicated preference for Freshwater Institute salmon cultured in RAS and depurated 10 days vs. commercially available ocean-raised A. salmon

- Cooked flavor
- Cooked smell
- Cooked texture
"It was the first closed contained fish which we’ve sampled that not only tasted great and entirely lacked any muddy, earthy, plastic, or metallic taste whatsoever. So whatever [they] are doing with respect to recirculation systems, feed formulae, depuration, etc., the rest of the closed contained fish farming community should take note because [they] appear to have nailed the recipe."

-Dane Chauvel, Organic Ocean
Evaluation of Humane Slaughter Techniques

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Four techniques compared using depurated and non-depurated salmon from grow-out:

1. Humane Stunner Technology with bleeding
2. Humane Stunner Technology without bleeding
3. Carbon Dioxide and Ice Slurry with bleeding
4. Carbon Dioxide and Ice Slurry without bleeding

Six salmon randomly selected and euthanized using each slaughter technique
- Males and obviously mature fish excluded
- 4-5 kg fish targeted

For groups assigned bleeding, gills manually cut just after euthanasia
Fillet Quality Measurements

- Length/ whole Body Weight
- Fillet weights and yields
- Gonadosomatic Index
- Fillet temperature, pH
- Fillet texture and color
- Proximate analysis and fatty acids
Post-Harvest Slaughter

Rapid & Humane
- Percussive Stunning
  - MODEL SI-7 Stunner
    (Seafood Innovations)
Fillet Quality - Temperature

Muscle Temperature (°C)

Hours Post Slaughter

- Stunner Bleed
- Stunner No Bleed
- CO2/Ice Slurry Bleed
- CO2/Ice Slurry No Bleed

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Fillet Quality - pH

- Salmon euthanized using humane stunner technology had greater and less fluctuating fillet pH levels (P < 0.05)
- Indicative of less struggle and stress during slaughter
- Generally leads to improved fillet quality
Fillet Quality – Rigor Onset

- Rigor onset significantly slower (5-7 hrs +) for salmon euthanized using humane slaughter technology

- Slower rigor onset generally correlated with improved fillet quality and provides time for pre-rigor processing
Fillet Quality (Depurated vs. Non-Depurated)

- No significant difference in fillet color between non-depurated and 10-day depurated salmon
- No difference in fillet yield
- No difference in percentage fat of fillet measured during proximate analysis
- No difference in fatty acid content
Atlantic Salmon Fillet Yield

The bar chart illustrates the fillet yield (%) for different types of salmon fillets:

- **Skin-On Butterfly Fillet**
  - Non-Depurated: Around 75%
  - Depurated: Slightly higher than Non-Depurated
  - Non-Depurated Mature: Around 60%
  - Depurated Mature: Slightly lower than Non-Depurated Mature

- **Skin-Off / Trimmed Fillet**
  - Non-Depurated: Around 55%
  - Depurated: Slightly higher than Non-Depurated
  - Non-Depurated Mature: Around 45%
  - Depurated Mature: Slightly lower than Non-Depurated Mature

The chart shows that depurated fillets generally have a slightly higher yield compared to non-depurated fillets, with the highest yield observed in non-depurated fillets with a skin-on butterfly fillet configuration.
Other Product Quality Considerations

- Gonadosomatic Index indicates percent body weight makeup of reproductive organs
- Males matured much earlier
- A few females began to mature - 20-21 months of age
- It is critical that early maturation is avoided to maintain color and fillet quality
- Feed contained 30 ppm astaxanthin & 30 ppm canthaxanthin
- Fillet color increased steadily with time
- Males pigmented less
Conclusions

- Humane stunning technology improves fillet attributes
  - Less struggle = lower ATP use and less lactic acid
  - Less fluctuation of flesh pH
  - Slower onset to rigor

- Bleeding did not impact most fillet quality parameters
  - Texture (firmness) was significantly greater for non-bled fish slaughtered using humane stunner
  - Processor (Dr. Brett Kenney) commented that bled fish much cleaner to work with and likely less potential for bacterial accumulation/ spoilage

- Technology commercially available and being used by industry
Fillet color is unaffected after 10 days depuration

Fillet yield, fatty acid concentrations, and fat content unaffected after 10 days depuration

Maturing fish had significantly reduced fillet yield and fat content
Research supported by Tides Canada and the Gordon Betty Moore Foundation.

All experimental protocols were in compliance with Animal Welfare Act (9CFR) and have been approved by the Freshwater Institute Animal Care and Use Committee.

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