



# Pushing Forward: Opportunities to Drive Progress in Aquaculture Feed in Iowa

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# Presentation Outline

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- Introduction
- DDGS composition
- DDGS in aquaculture feeds
- Soy in aquaculture feeds
- Aquaculture feed processing considerations
- Conclusions

# Introduction

# Introduction

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- Global aquaculture
  - Fastest growing animal food-producing sector
  - 2009: 52 million tonnes
  - Annual growth rate over 6.9% (1970-2006)
- 2006
  - > 77% of world fish used for human consumption
  - 33% used for fish meal and fish oil manufacture

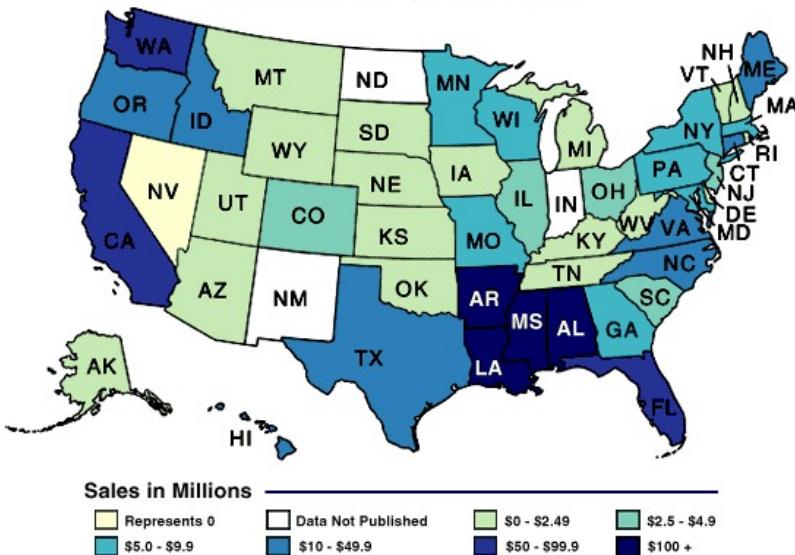
# U.S. Aquaculture

## • U.S. Aquaculture

### Aquaculture Sales: 2005

U.S. Total Sales - \$1.09 Billion

Source: 2005 Census of Aquaculture, USDA-NASS



### U.S. Fish numbers:

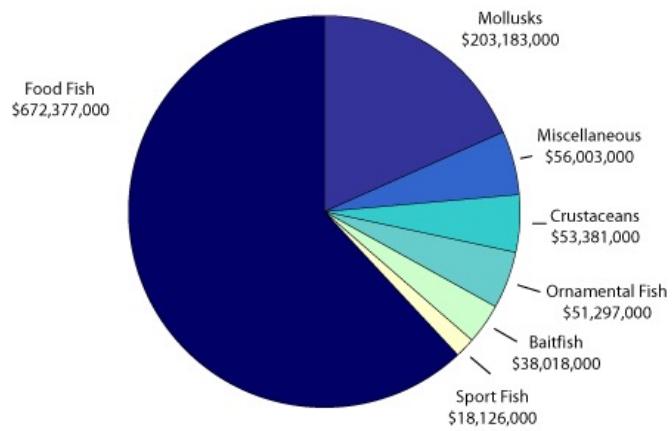
- Channel catfish – 396,554,000
- Rainbow trout – 56,355,000
- Tilapia – 13,272,000

### TOP 10 STATES Value of Aquaculture Products Sold: 2005 U.S. Total - \$1.09 Billion

Mississippi	\$249.7 million
Arkansas	\$110.5 million
Alabama	\$102.8 million
Louisiana	\$101.3 million
Washington	\$93.2 million
California	\$69.6 million
Florida	\$57.4 million
Virginia	\$40.9 million
Idaho	\$37.7 million
Texas	\$35.4 million

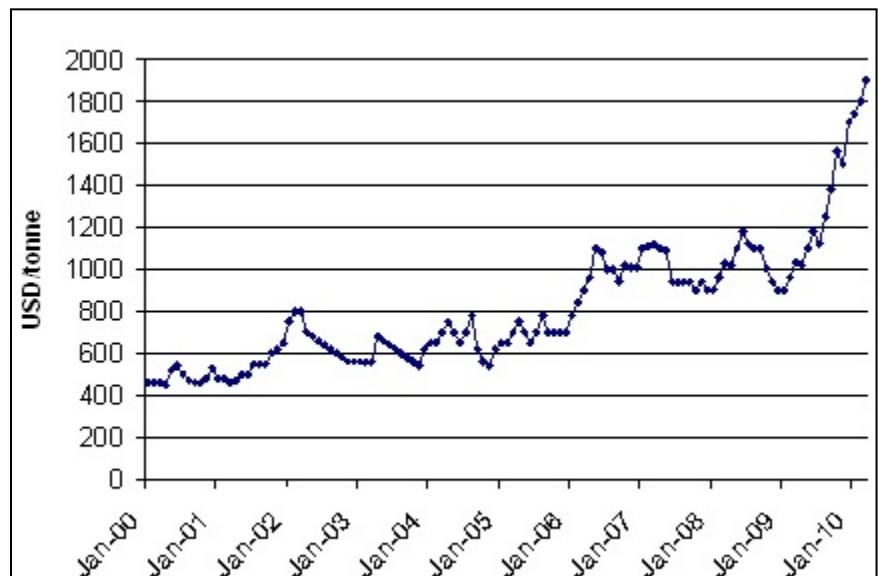
Source: 2005 Census of Aquaculture, USDA-NASS

### Value of Aquaculture Products Sold by Type: 2005 U.S. Total - \$1,092,386,000



# Introduction

- Feed costs
  - 40%-70% of operating costs
  - Fish meal is an important ingredient
    - Supplies fish with essential proteins, amino acids, and fatty acids
- Fish meal prices
  - > 1000 \$/tonne during last four years
  - ~ 2000 \$/tonne in 2010
- Why?
  - Demand for fish meal
  - Overfishing of wildlife stocks
- Solution
  - Use of alternative protein ingredients
  - Lower cost
  - Greater availability
  - Many to choose from



Fish meal price over time

# Introduction

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- Animal products:
  - Fish meal
  - Fish processing byproducts
  - Fish processing waste silage
  - Blood meal (BM)
  - Feather meal (FEM)
  - Meat and bone meal (MBM)
  - Poultry by-product meal (PBM)

# Introduction

- Plant-based products:
  - Alfalfa meal
  - Black beans (*Phaseolus vulgaris L.*)
  - Chickpeas (*Cicer arietinum L.*)
  - Corn distillers grains (DDGS)
  - Corn gluten meal (CGM)
  - Corn gluten feed (CGF)
  - Cottonseed meal (CSM)
  - Lentils (*Lens culinaris*)
  - Lupin seed meal (LSM)
  - Navy beans (*Phaseolus vulgaris L.*)
  - Peas (*Pisum sativum L.*)
  - Pinto beans (*Phaseolus vulgaris L.*)
  - Rapeseed (RSM)/ Canola meal
  - Soybean meal (SBM)
  - Soybean protein concentrate (SPC)
  - Soybean protein isolate (SPI)
  - Other ingredients

# Introduction

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- Challenges with many alternative ingredients
  - Unwanted nutrients – anti-nutritional factors
    - Trypsin inhibitors, protease inhibitors, lectins, gossypol
  - Nutrient variability
  - Poor nutrient balances
    - Amino acid profiles
    - Fatty acid profiles
  - Cost-intensive processing
  - **Cost**
  - **Availability**
  - **Effectiveness in fish performance**

# Introduction

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- Soy
  - Global availability
  - Protein-rich ingredient
  - Bridge the gap between wild fish resources and global demand
  - Competitive price
- Challenges
  - Lower protein content than fishmeal
  - Antinutritional factors (ANFs) reduce digestibility
  - Lack of some essential amino acids

# Introduction

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- DDGS may be an effective protein source for aquaculture feeds
  - Low cost
  - High availability
  - Effective feed ingredient

# Introduction

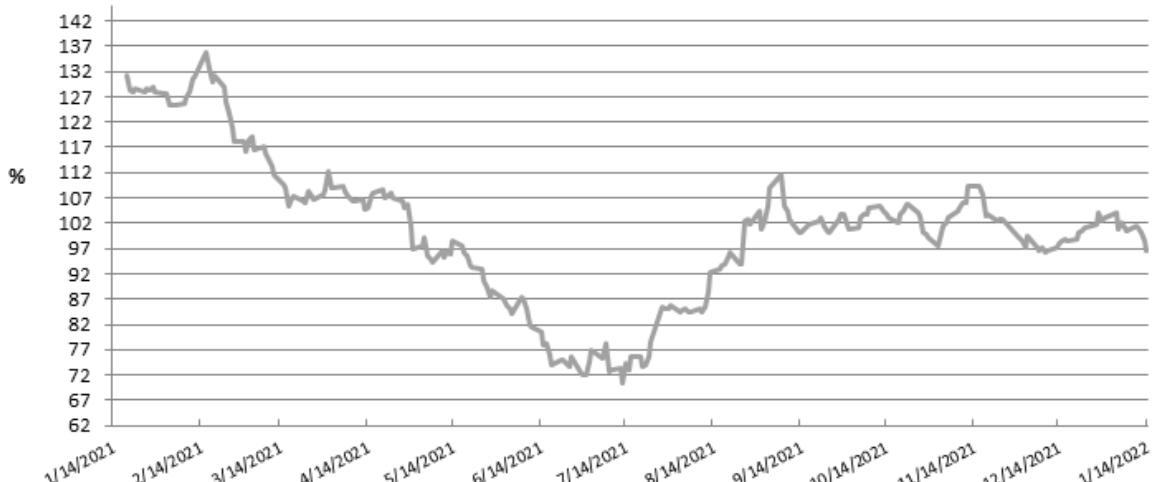
- DDGS
  - Global availability (US = primary origin)
    - Has exceeded SBM in production
  - Moderate protein (~ 30%) and oil (~ 5-10%) levels
  - Competitive price (1/2 price of SBM)
  - No antinutritional factors
- Challenges
  - Lower protein content than SBM
  - Lack of essential amino acids
  - Corn is primary source (others much lower supply)
  - Variability
  - Industry changes and opportunities

## US DDGS Export Prices (Current-month Platts Assessment)



DDG Value Relative to:	1/13	1/6
Corn	1.01%	96.00%
Soybean Meal	49.56%	49.24%
Cost Per Unit of Protein:		
DDG	\$7.78	\$7.67
Soybean Meal	\$8.92	\$8.85

### S&P Global Platts' CIF DDGS realtive value to CIF corn\*



\* Measures Platts' DDGS CIF assessment as a % of its Corn CIF NOLA corn assessment (current-month)

# DDGS Composition

# DDGS / Fishmeal

## Chemical composition of corn-based DDGS

Property	Range of Values (%) <sup>a</sup>	Menhaden Fishmeal (%) <sup>a</sup>
Dry matter	87.9 – 90.6	90
Protein	29.4 – 32.6	65
Fat	9.6 – 12.8	10
Ash	4.2 – 6.6	19
<u>Carbohydrate</u>	5.4-10.6	
Crude fiber		
Total dietary fiber	24.2-39.8	
Neutral detergent fiber	25.0-51.3	
Acid detergent fiber	8.0-21.0	
Starch	4.7-5.9	
Nitrogen free extract	33.8-54.0	

<sup>a</sup> Source: various commercial products

# DDGS / Fishmeal

Amino acid profile ranges for corn-based DDGS

Amino acid	Range of Values (%) <sup>a</sup>	Menhaden Fishmeal (%) <sup>a</sup>
Arginine	1.19 – 1.47	3.7
Cystine	0.4-0.8	0.6
Histidine	0.79 – 0.88	1.7
Isoleucine	1.08 – 1.24	2.6
Leucine	3.28 – 3.76	4.5
Lysine	0.85 – 1.08	5.0
Methionine	0.59 – 0.73	1.8
Phenylalanine	1.45 – 1.67	2.5
Threonine	1.04 – 1.19	2.4
Tryptophan	0.20 – 0.26	5.2
Tyrosine	1.14 – 1.35	1.9
Valine	1.43 – 1.67	3.1
Alanine	1.8	
Aspartic acid	1.8	
Glutamic acid	4.6	
Glycine	1.0	
Hydroxyproline	0.2	
Proline	2.6	
Serine	1.4	

<sup>a</sup> Source: various commercial products

# DDGS / Fishmeal

## Vitamin composition of corn-based DDGS

Vitamin	Range of Values (mg/kg) <sup>a,b</sup>	Menhaden Fishmeal (mg/kg) <sup>c</sup>
Biotin	0.77 – 1.04	0.1
Choline	2548 – 2551	3112
Folacin	0.73 – 0.90	0.1
Niacin	72.0 – 88.5	55
Pantothenic acid	13.83 – 13.9	8.6
Pyridoxine	4.60 – 5.00	4.7
Riboflavin	8.30 – 8.39	4.8
Thiamin	2.8 – 5.9	0.6
Vitamin E	39.1 – 40.7	
Vitamin A	1363 (IU/kg)	
Vitamin D	600 (IU/kg)	

<sup>a</sup> Source: Hertrampf and Piedad-Pascual (2006)

<sup>b</sup> Source: NRC (1993)

<sup>c</sup> Source: various commercial products

# DDGS / Fishmeal

## Mineral composition of corn-based DDGS

Mineral	Range of Values (%) <sup>a, b</sup>	Menhaden Fishmeal (%) <sup>c</sup>
Calcium	0-0.5	3.8
Phosphorus	0.4-1.0	2.6
Potassium	0.4-1.3	1.1
Magnesium	0.1-0.4	1.9
Sulfur	0.3-1.1	
Sodium	0-0.52	0.7
Chlorine	0.1-0.4	
Zinc	38.0-312.1 mg/kg	98.9 mg/kg
Manganese	9.0-49.5 mg/kg	48.6 mg/kg
Copper	3.0-52.8 mg/kg	3.3 mg/kg
Iron	68.0-295.0 mg/kg	904 mg/kg
Selenium	0.35 mg/kg	1.9 mg/kg

<sup>a</sup> Source: Rosentrater and Muthukumarappan (2006)

<sup>b</sup> Source: NRC (1993)

<sup>c</sup> Source: various commercial products

# DDGS in Aquaculture Feeds

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Some Published Research

# Potential Use of DDGS

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- Three important questions:
  - 1) Will fish eat feed with DDGS?
  - 2) What kind of growth performance will result?
  - 3) What is net cost of production?

Need complete, balanced feeds  
Not just 100% pelleted DDGS

# DDGS in Aquaculture Feeds

Most aquaculture research has used DDGS from beverage distilleries

Species	DDGS (%)	Citation
Tilapia	19 – 29 (distillery)	Tudor et al., 1996
	30 (distillery)	Coyle et al., 2004
	0 – 49 (distillery)	Wu et al., 1996
	0 – 82.23 (distillery)	Wu et al., 1997
	100 (distillery solubles)	Kohler and Pagan-Font, 1978
	100% (distillery)	Tidwell et al., 2000
Catfish	35 (distillery)	Webster et al., 1992
	0 – 30 (distillery)	Webster et al., 1993
	0 – 70 (distillery)	Webster et al., 1991

Species	DDGS (%)	Citation
Rainbow Trout	3.3 – 6.6 (thin stillage - wheat)	Thiessen et al., 2003
Prawns	40 (distillery)	Tidwell et al., 1993
	40 (distillery)	Tidwell et al., 1998
	100 (distillery)	Coyle et al., 2003
	100 (distillery)	Coyle et al., 2004



Nile tilapia



Channel catfish



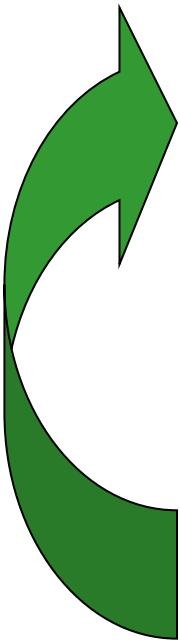
Rainbow Trout



Prawns

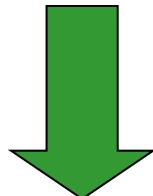
# DDGS in Aquaculture Feeds

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## 1) Processing research

- How much DDGS can be used?
- Need a cohesive, stable, floating feed



## 2) Feeding trials

- How much DDGS can fish eat?
- What level will result in optimal growth?

# DDGS in Aquaculture Feeds

- Nile tilapia

Composition (%, dry matter basis) of experimental diets

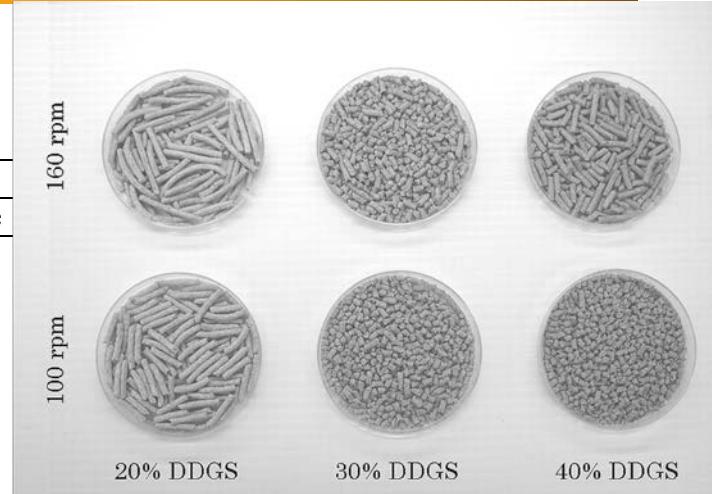
Ingredient	Diets			Reference
	1	2	3	
DDGS	20	30	40	0
Soybean meal	33	29	25	
Corn flour <sup>b</sup>	35	29	23	
Menhaden fishmeal	5	5	5	
Cod liver oil	2	2	2	
Soybean oil	2	2	2	
Vitamin mix <sup>c</sup>	1	1	1	
Mineral mix <sup>d</sup>	2	2	2	

Proximate Composition (% db)

Crude Protein	28.5	30.0	30.4	36.7
Crude Lipid	8.12	8.79	10.5	5.90
Crude Fiber	3.72	3.65	4.45	3.21
Ash	7.59	7.28	7.30	8.52

Weight gain (WG), food conversion ratio (FCR), protein efficiency ratio (PER), and apparent digestibility (APD) for 42 d

DDGS (%)	WG (%)	FCR	PER
20	66.5 (20.5) a	2.88 (0.79) a	1.31 (0.32)
30	48.6 (15.8) b	3.83 (1.08) b	0.99 (0.27)
40	49.7 (10.2) b	3.58 (0.87) b	1.04 (0.23)
Reference	73.8 (16.3) a	2.53 (0.50) a	1.16 (0.21)



From: Shaeffer et al., 2010a

# DDGS in Aquaculture Feeds

- Nile tilapia

Composition (%, dry matter basis) of experimental diets

Ingredient	Diets					Reference
	1	2	3	4	5	
DDGS	17.5	20.0	22.5	25.0	27.5	0
Soybean meal	59.0	57.7	56.5	55.2	54.0	52.7
Corn	10.7	9.5	8.2	7.0	5.7	24.5
Menhaden fishmeal	5.0	5.0	5.0	5.0	5.0	15.0
Whey	5.0	5.0	5.0	5.0	5.0	5.0
Soybean oil	2.0	2.0	2.0	2.0	2.0	2.0
Vitamin mix	0.6	0.6	0.6	0.6	0.6	0.6
Ascorbic acid	0.2	0.2	0.2	0.2	0.2	0.2
<u>Proximate Composition (%, dry matter basis)</u>						
Crude protein	40.1	39.9	39.9	37.8	38.0	39.8
Crude lipid	4.87	5.48	5.77	5.15	5.57	3.36
Crude fiber	9.7	11.6	11.0	12.9	13.2	12.9
Ash	7.50	6.60	6.45	6.45	6.50	6.55



Weight gain (WG), food conversion ratio (FCR), protein efficiency ratio (PER), and apparent digestibility (APD) for 50 d

DDGS (%)	WG (%)	FCR	PER
17.5	80.8 (5.8) a	2.68 (0.11) ab	0.93 (0.04) ab
20	91.2 (12.5) a	3.18 (<0.01) b	0.79 (<0.01) b
22.5	74.4 (5.0) a	3.21 (0.13) b	0.78 (0.03) b
25	75.4 (12.5) a	2.99 (0.16) b	0.89 (0.05) b
27.5	82.2 (2.9) a	4.99 (0.28) c	0.53 (0.03) c
0, Reference	128.2 (6.6) b	2.39 (0.27) a	1.09 (0.10) a



From: Shaeffer et al., 2010b

# DDGS in Aquaculture Feeds

- Yellow perch

Composition (%, dry matter basis) of experimental diets

Ingredient	Diets					
	1	2	3	4	5	6
DDGS	0	10	20	30	40	50
SM	31.5	26	20.5	15	9.5	4
Celufil	17	13.6	10.2	6.8	3.4	0
Menhaden fish meal	24	24	24	24	24	24
CMC	5	5	5	5	5	5
Menhaden oil	6	6	6	6	6	6
Soybean oil	5.5	4.4	3.3	2.2	1.1	0
Vitamin mix	3	3	3	3	3	3
Mineral mix	8	8	8	8	8	8
<u>Proximate Composition (%)</u>						
Crude protein	29.5	29.6	30.4	30.4	30.2	30.3
Crude lipid	16.0	16.6	16.4	16.4	16.7	18.1

Weight gain (WG), food conversion ratio (FCR), protein efficiency ratio (PER), and apparent digestibility (APD) for 126 d

DDGS (%)	WG (%)	FCR	PER	APD (%)
0	170 (6) bc	3.28 (0.06) a	31.1 (0.4) a	49.4 (2.8) a
10	167 (5) cd	3.37 (0.10) a	30.0 (0.9) a	47.6 (2.2) a
20	181 (11) ac	3.25 (0.23) a	33.3 (3.0) a	51.3 (5.1) a
30	196 (16) ab	2.94 (0.15) a	34.7 (1.8) a	46.2 (2.7) a
40	198 (7) a	2.85 (0.14) a	36.0 (1.8) a	55.5 (4.0) a
50	140 (2) d	3.16 (0.17) a	30.7 (1.3) a	69.6 (3.7) b



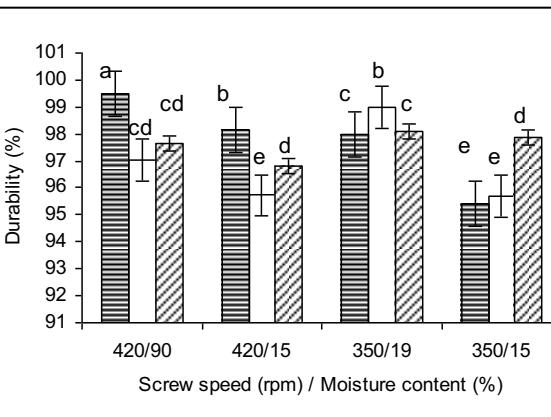
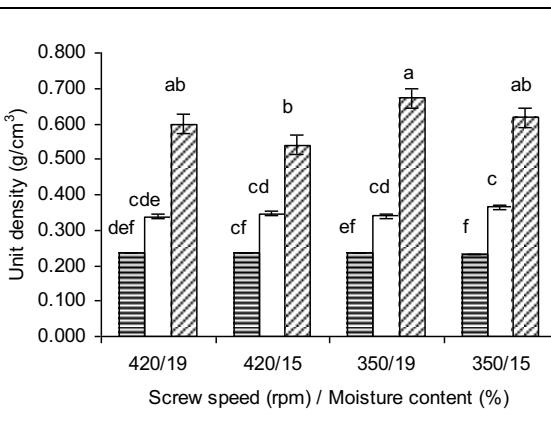
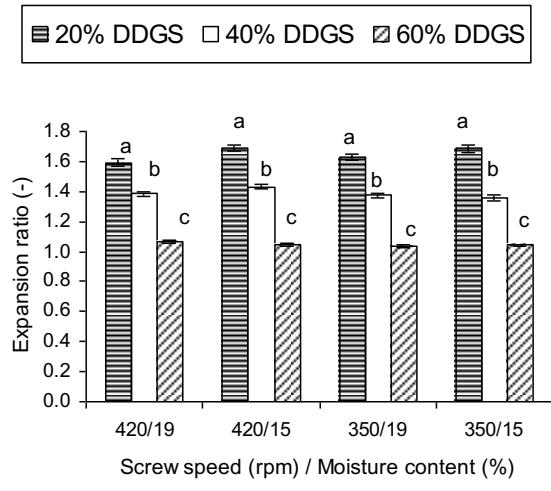
From: Shaeffer et al., 2010c

# Extrusion Processing Nile tilapia

- Commercial scale extrusion
  - Wenger TX-52 twin-screw extruder
    - 52-mm diameter screws
    - 25.5:1 barrel length-to-diameter
    - 3.175 mm die openings
  - Conditions used
    - DDGS levels: 20, 40, 60%
    - Same ingredients as feeding studies
      - Isocaloric target: 360 kcal/100 gram
      - Protein target: 29 to 30%
    - Moisture contents: 15, 19% (wb)
    - Screw speeds: 350, 420 rpm



# Extrusion Processing Nile tilapia



Expansion ratio: 1.05 to 1.8

- Increasing the level of DDGS had a significant effect – expansion decreased as DDGS increased
- Moisture content and screw speed had no significant effects
- All extrudates floated > 24 h

Unit density: 0.2 to 0.7

- Lowest unit density for 20% DDGS level
- Higher moisture content and lower screw speed resulted in significantly lower unit densities

Pellet durability: all > 95%

- Changing the level of DDGS and moisture content had significant effects
- Screw speed had no significant effect

Possible to produce floating feeds up to 60% DDGS

# Optimal Extrusion Processing

## Nile tilapia

Feed #1 (based on our own feeding trials)		% in Feed
Ingredients		
Dry DDGS		20
Soybean meal, solvent extracted		44.2
Corn flour		25
Fishmeal, menhaden		8
Vitamin Mix		0.6
Mineral Mix		0.2
Oil Soybean		2
Total		100



Feed #2 (based on US Grains study)		% in Feed
Ingredients		
Dry DDGS		15
Soybean meal, solvent extracted		58
Corn flour		21
Mono Calcium Phosphate		2.4
Vitamin Mix		0.5
Mineral Mix		0.25
Oil Soybean		2.85
Total		100



Processing Data	Ranges
Die size (mm)	3.175
Probator feed rate (kg/h)	15
Conditioning cylinder pressure (PSI)	25 - 45
Conditioning cylinder steam (kg/min)	0.22
Temperature entering extruder ( C )	96 - 98
Extruder shaft speed (RPM)	360 - 475
Extruder water addition (kg/h)	0.07 - 0.12
Extruder motor load (%)	15 - 20
Temperature head 2 zone 1	44 - 49
Temperature head 3	26 - 49
Temperature head 4 zone 2	35 - 41
Temperature head 5 zone 3	25 - 46
Temperature head 6 zone 4	25 - 60
Temperature head 7 zone 5	71 - 80
Temperature head 8	73 - 82
Temperature head 9 zone 6	73 - 90

Vy, L. H., 2006. Feeding trial of DDGS for tilapia fish.  
U.S. Grains Council, South East Asia.

All extrudates were of high quality

- PDI > 88%
- Floated > 24 h

# Soy in Aquaculture Feeds

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Some Published Research

# Soybean Meal

Table 2: Ingredient components (% db) and nutrient compositions (% db) of the feed blends.\*

Ingredients	Dry weight of ingredients (% db)					
	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6
Soybean meal	31.5	26	20.5	15	9.5	4
DDGS	0	10	20	30	40	50
Fish meal (menhaden)	24	24	24	24	24	24
Vitamin mix	3	3	3	3	3	3
Mineral mix	8	8	8	8	8	8
Soybean oil	5.5	4.4	3.3	2.2	1.1	0
Celufil	17	13.6	10.2	6.8	3.4	0
CMC	5	5	5	5	5	5
Menhaden oil	6	6	6	6	6	6
Total	100.0	100.0	100.0	100.0	100.0	100.0
Feed blend composition (% db)						
Total moisture (% wb)	19.5	18.7	18.2	18.4	19.1	18.6
Total dry matter (% wb)	80.5	81.3	81.8	81.6	80.9	81.4
Crude protein (% db)	29.5	29.6	30.4	30.4	30.2	30.3
Crude fat (% db)	16.0	16.6	16.4	16.4	16.7	18.1



# Soybean Meal

Table 4. Food conversion ratio (FCR), protein efficiency ratio (PER), viscerosomatic indices (VSI), hepatosomatic indices (HSI), Fulton-type condition factor (K), and apparent protein digestibility (APD) for yellow perch fed diets containing various levels of distillers dried grains with solubles (DDGS) and soybean meal (SBM) for 126-d. Values (treatment means  $\pm$  SE) not significantly different ( $P \geq 0.05$ ) have the same letter for a given dependent variable.

DDGS (%) / SBM (%)	FCR	PER	VSI (%)	HSI (%)	K	APD (%)
0/31.5	3.28 (0.06) z	31.1 (0.4) z	10.2 (0.1) z	1.5 (0.1) z	1.14 (0.01) y	49.4 (2.8) y
10/26	3.37 (0.10) z	30.0 (0.9) z	10.6 (0.3) z	1.7 (0.1) yz	1.13 (0.02) y	47.6 (2.2) y
20/20.5	3.25 (0.23) z	33.3 (3.0) z	9.9 (0.5) z	1.7 (0.1) yz	1.16 (0.02) y	51.3 (5.1) y
30/15	2.94 (0.15) z	34.7 (1.8) z	10.5 (0.3) z	2.0 (0.03) yz	1.15 (0.02) y	46.2 (2.7) y
40/9.5	2.85 (0.14) z	36.0 (1.8) z	10.6 (0.2) z	2.6 (0.3) x	1.14 (0.004) y	55.5 (4.0) y
50/4	3.16 (0.17) z	30.7 (1.3) z	9.9 (0.2) z	2.1 (0.1) y	1.07 (0.02) z	69.6 (3.7) z

# FERMENTED SOYBEAN MEAL (FSBM)

Table 5. Composition (g/100g, db) and proximate composition analysis of experimental diets containing various levels of fermented soybean meal (FSBM).

Ingredients	Diets (FM/FSBM)				
	100/0	75/25	50/50	25/75	0/100
Herring Meal <sup>a</sup>	42.96	32.22	21.48	10.74	0.00
FSBM <sup>b</sup>	0.00	11.36	22.73	34.09	45.45
Celufil <sup>c</sup>	10.60	9.90	9.10	8.40	7.60
Lasi Trout Mix (min/vit) <sup>d</sup>	3.11	3.11	3.11	3.11	3.11
Vitamin C (Stay-C) <sup>e</sup>	0.53	0.53	0.53	0.53	0.53
Wheat flour (whole) <sup>f</sup>	15.96	15.96	15.96	15.96	15.96
Corn gluten meal <sup>g</sup>	27.41	27.41	27.41	27.41	27.41
Menhaden oil <sup>h</sup>	5.90	6.60	7.40	8.10	8.90
Total	100	100	100	100	100
<u>Proximate Composition (%)</u>					
Crude Protein	56.34	49.23	48.23	46.65	44.47
Crude Lipid	12.69	10.86	9.75	9.93	9.60
Crude Fiber	8.80	6.84	6.30	6.77	9.62
Gross Energy (GE) <sup>i</sup>	4.38	3.80	3.64	3.57	3.41

Table 6. Mean weight gain (WG), food conversion ratio (FCR), protein efficiency ratio (PER), viscerosomatic index (VSI), hepatosomatic index (HSI), Fulton-type condition factor (K), muscle ratio (MR) of experimental diets containing varying levels of fermented soybean meal (FSBM). Values are treatment means ( $\pm$  SE) for experimental diets. Values not significantly different ( $P > 0.05$ ) have the same letter within a given column.

FM/FSBM (%)	WG (%)	FCR	PER	VSI (%)	HSI (%)	K	MR (%)
100/0	141.1 z (7.2)	1.9 z (0.08)	1.01 z (0.05)	9.48 z (0.29)	1.66 z (0.27)	1.27 z (0.02)	41.3 z (0.4)
75/25	119.0 y (3.4)	2.1 yz (0.04)	1.12 z (0.02)	9.03 xz (0.08)	1.26 z (0.07)	1.23 z (0.03)	41.8 z (0.3)
50/50	110.9 xy (3.8)	2.2 xyz (0.06)	1.11 z (0.03)	8.8 xy (0.20)	1.29 z (0.12)	1.22 z (0.03)	403 z (0.7)
25/75	97.5 x (1.3)	2.3 wxyz (0.03)	1.05 z (0.01)	9.73 wz (0.41)	1.34 z (0.06)	1.09 z (0.12)	38.8 z (0.8)
0/100	73.0 (5.4) w	2.8 w (0.16)	0.92 z (0.06)	9.8 wz (0.23)	1.17 z (0.09)	1.11 z (0.11)	39.6 z (1.0)

# FERMENTED SOYBEAN MEAL (FSBM) & SOY PROTEIN CONCENTRATE (SPC)

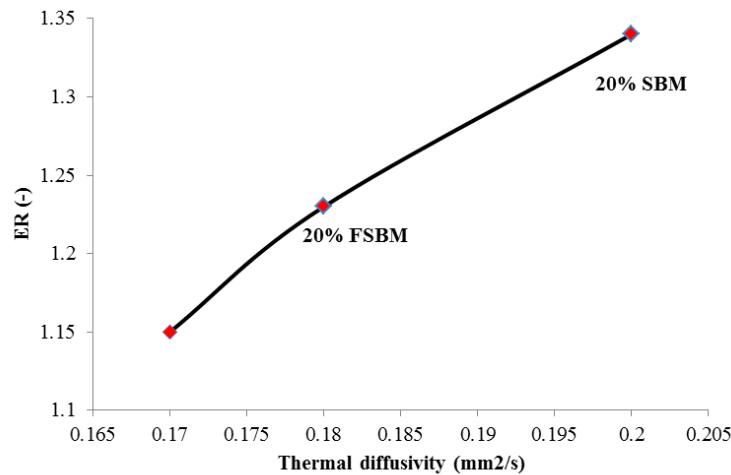
Table 7: Ingredient components (% db) and nutrient compositions (% db) of the feed blends.

Ingredients	Dry weight of ingredients (% db)		
	Control	Diet 1	Diet 2
HP DDG <sup>a</sup>	30.99	31.43	31.43
PepSoyGen <sup>b</sup>	0.00	21.15	0.00
Solae SPC <sup>c</sup>	0.00	0.00	21.15
Fish meal <sup>d</sup>	20.39	0.00	0.00
Corn gluten meal <sup>e</sup>	14.97	15.18	15.18
Whole wheat flour <sup>f</sup>	22.96	19.24	19.24
CMC <sup>g</sup>	6.71	3.40	3.40
Vitamin premix <sup>h</sup>	0.56	0.57	0.57
Mineral mix <sup>i</sup>	0.11	0.11	0.11
Oils	—	—	—
Supplements <sup>j</sup> (total from below)	3.36	8.92	8.92
Stay-C	0.06	0.06	0.06
Choline	0.23	0.23	0.23
Phytase	0.04	0.04	0.04
DVAqua	0.14	0.14	0.14
Arginine	0.00	0.57	0.57
Lysine	0.00	1.70	1.70
Isoleucine	0.00	0.00	0.00
Histidine	0.00	0.00	0.00
Glycine	0.57	0.57	0.57
Methionine	0.00	0.57	0.57
Taurine	0.00	0.00	0.00
Sodium chloride	1.13	1.13	1.13
Potassium chloride	0.91	0.91	0.91
Mgnesium oxide	0.06	0.06	0.06
Calcium phosphate	0.23	2.95	2.95
Total	100.00	100.00	100.00
Feed blend composition (% db)			
Protein	37.18	40.6	43.27
Fat	7.52	7.83	7.82
Crude Fiber	0.24	0.24	0.24
Ash	2.73	4.53	4.53

Table 8: Treatment effects on extrudate physical properties.

	Treatment		
	Control	Diet 1	Diet 2
MC (%db)	4.41 <sup>b</sup> (0.85)	5.46 <sup>a</sup> (0.45)	5.02 <sup>ab</sup> (0.23)
a <sub>w</sub> (-)	0.17 <sup>b</sup> (0.01)	0.25 <sup>a</sup> (0.01)	0.25 <sup>a</sup> (0.01)
k (W/m°C)	0.05 <sup>a</sup> (0.01)	0.05 <sup>a</sup> (0.01)	0.05 <sup>a</sup> (0.01)
R (m°C/W)	19.87 <sup>b</sup> (0.72)	19.87 <sup>b</sup> (0.95)	21.13 <sup>a</sup> (0.94)
α (mm <sup>2</sup> /s)	0.17 <sup>b</sup> (0.01)	0.18 <sup>b</sup> (0.01)	0.2 <sup>a</sup> (0.01)
ER (-)	1.15 <sup>c</sup> (0.07)	1.23 <sup>b</sup> (0.08)	1.34 <sup>a</sup> (0.09)
UD (kg/m <sup>3</sup> )	662.46 <sup>a</sup> (78.17)	601.43 <sup>b</sup> (67.02)	504.02 <sup>c</sup> (68.87)
BD (kg/m <sup>3</sup> )	514.88 <sup>a</sup> (1.07)	478.78 <sup>a</sup> (5.12)	417.5 <sup>b</sup> (60.31)
WAI (-)	3.09 <sup>b</sup> (0.03)	2.93 <sup>b</sup> (0.13)	3.63 <sup>a</sup> (0.66)
WSI (%)	8.29 <sup>b</sup> (0.55)	10.04 <sup>a</sup> (0.79)	8.72 <sup>b</sup> (0.78)
PDI (%)	99.53 <sup>a</sup> (0.08)	99.23 <sup>ab</sup> (0.02)	99.13 <sup>b</sup> (0.43)
L* (-)	26.84 <sup>c</sup> (0.20)	28.7 <sup>b</sup> (0.53)	31.31 <sup>a</sup> (2.20)
a* (-)	6.84 <sup>c</sup> (0.03)	8.68 <sup>b</sup> (0.10)	9.19 <sup>a</sup> (0.10)
b* (-)	11.84 <sup>c</sup> (0.09)	13.5 <sup>b</sup> (0.15)	15.54 <sup>a</sup> (1.30)

# FERMENTED SOYBEAN MEAL (FSBM) & SOY PROTEIN CONCENTRATE (SPC)



Relation between extrudate thermal diffusivity and expansion ratio



Extruded diets containing 21% SPC



Extruded diets containing 21% FSBM

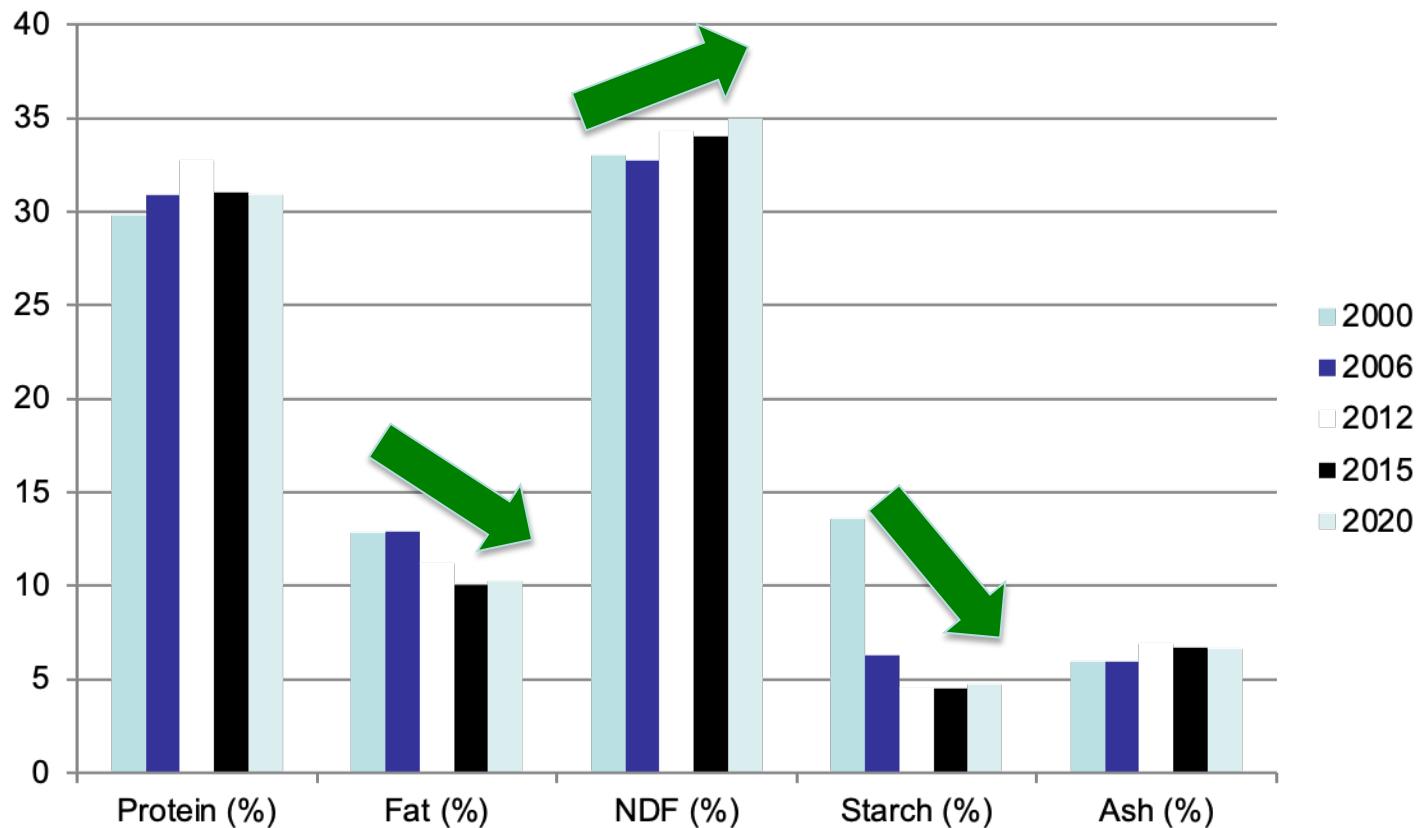
Table 9: Mean weight gain (WG), food conversion ratio (FCR), protein efficiency ratio (PER), viscerosomatic index (VSI), hepatosomatic index (HSI), Fulton-type condition factor (K), muscle ratio (MR) of experimental diets containing varying levels of feed grade soy protein concentrate (SPC). Values are treatment means ( $\pm$  SE) for experimental diets. Values not significantly different ( $P > 0.05$ ) have the same letter within a given column.

Diet	WG (%)	FCR	PER	VSI (%)	HSI (%)	K	MR (%)
Control	$63.7 \pm 6.1$ z	$3.40 \pm 0.27$ z	$0.81 \pm 0.07$ z	$8.5 \pm 0.43$ z	$1.54 \pm 0.08$ z	$1.14 \pm 0.07$ z	$28.3 \pm 1.30$ z
Diet 1	$17.3 \pm 2.8$ y	$10.5 \pm 1.44$ y	$0.34 \pm 0.60$ y	$10.7 \pm 0.48$ z	$2.00 \pm 0.15$ z	$1.02 \pm 0.02$ z	$28.4 \pm 1.18$ z
Diet 2	$80.0 \pm 4.1$ z	$2.71 \pm 0.10$ z	$0.97 \pm 0.04$ z	$10.0 \pm 0.21$ z	$1.71 \pm 0.10$ z	$1.20 \pm 0.02$ z	$30.8 \pm 1.30$ z

# Process Evolutions

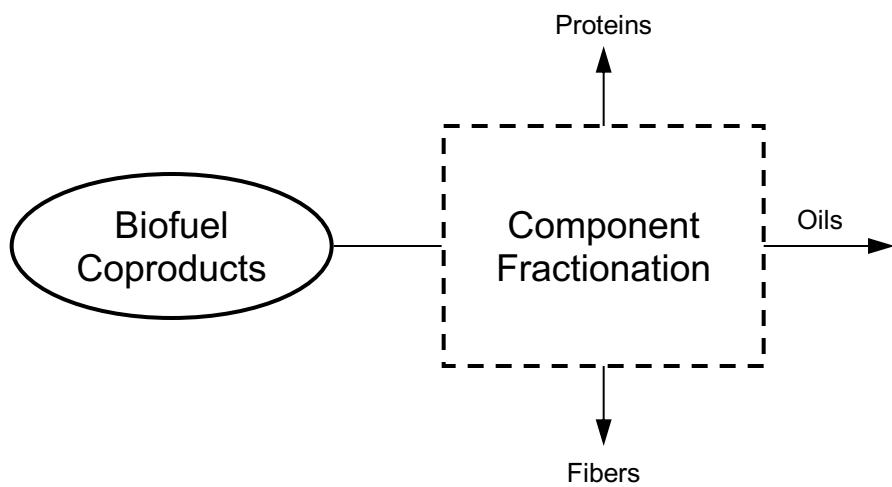
New Opportunities

# COMPOSITIONS

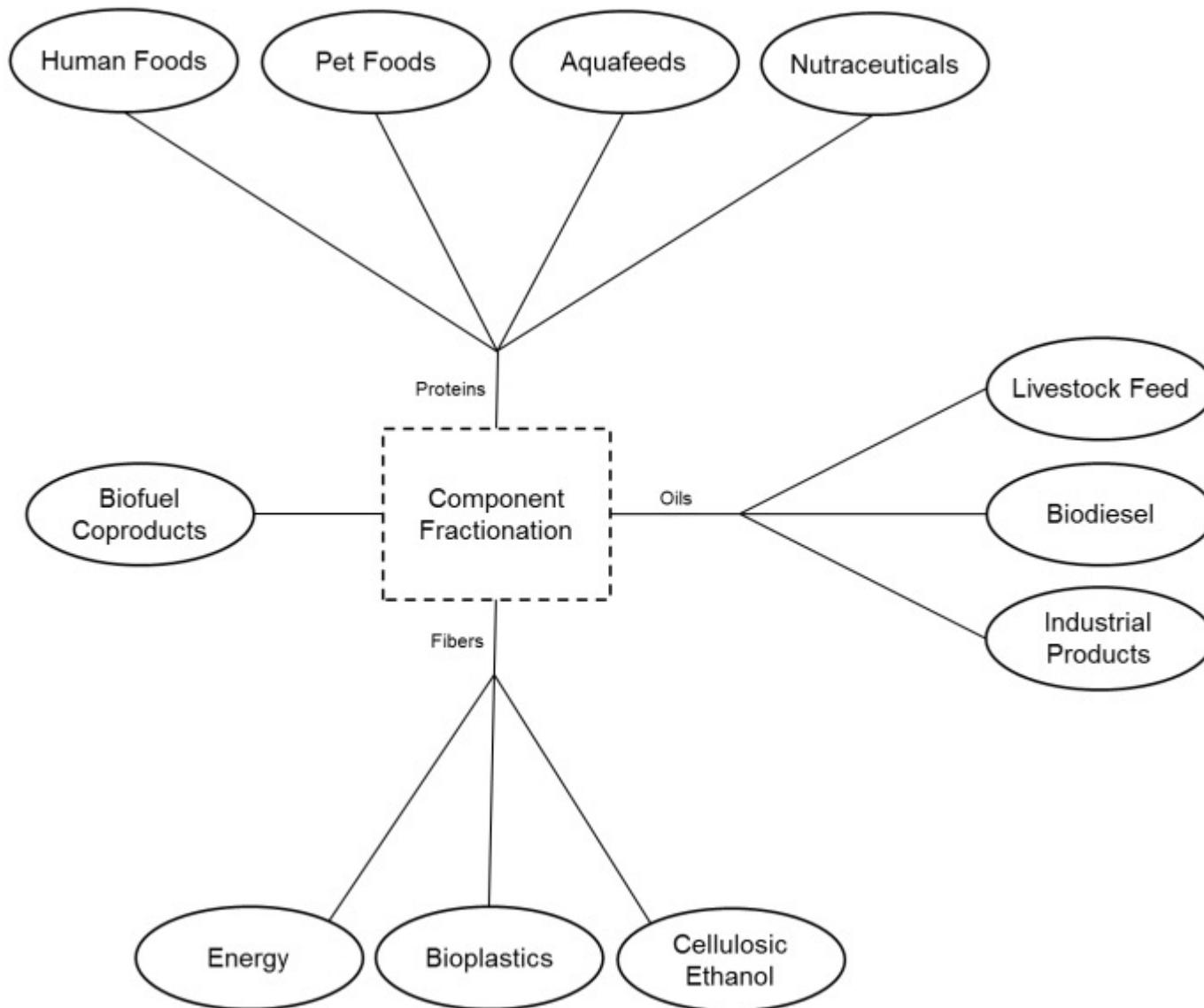


Source: <http://www.dairyone.com>

# FRACTIONATION



# FRACTIONATION

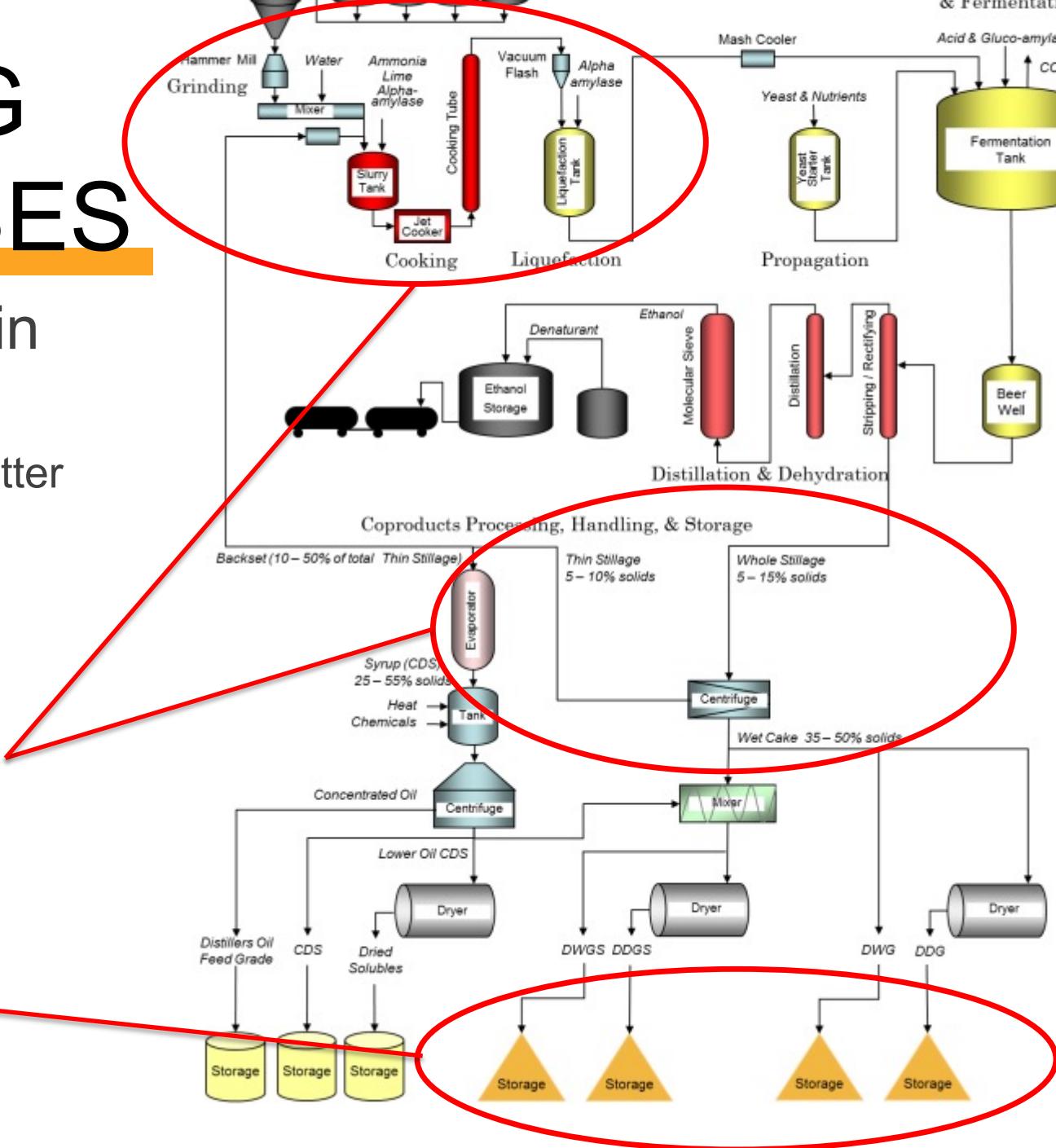


# EVOLVING PROCESSES

- Fiber & protein separation
  - Upstream is better

Current focus  
High potential

Potentially effective



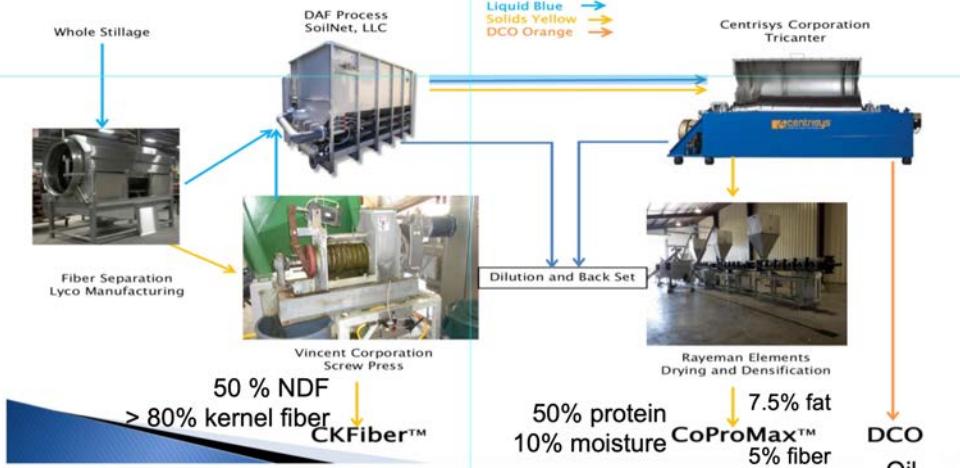
# EVOLVING PROCESSES

- Fiber & protein separation
  - Several technologies
    - CoProMax
    - D3Max
    - FQPT
    - FST
    - Marquis
    - Valicor/Trucent
    - CPT
- 
- Post-fermentation
- Pre-fermentation

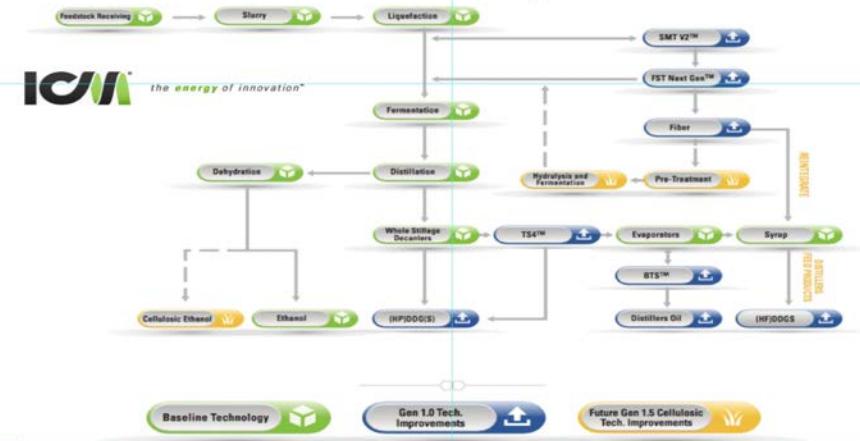
Which is best approach?  
Which is most cost effective technology?

Protein levels (CP): ~38 to > 50%  
Fat levels (CF): 5-7%

# Protein/Fiber Separation

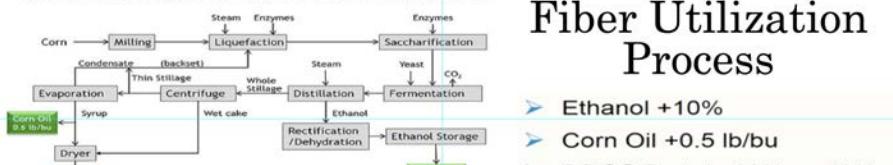


# Protein/Fiber Separation



## Evolutions / revolutions are accelerating

The primary process steps in a corn dry mill are shown in the figure below



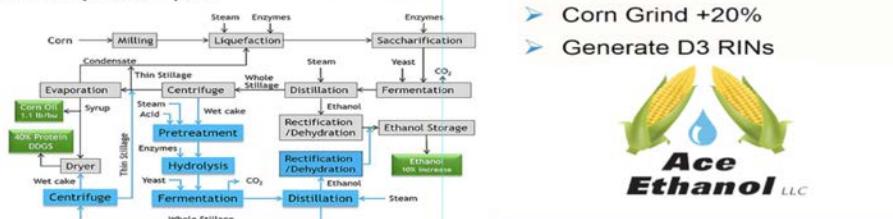
IOWA STATE UNIVERSITY

## Fiber Utilization Process

- Ethanol +10%
- Corn Oil +0.5 lb/bu
- DDGS Protein 30% → 40%
- DDGS Volume -20%
- Dryer Energy -20%
- Corn Grind +20%
- Generate D3 RINS



The figure below shows how the D3MAX process (shown in blue) "bolts-on" to the dry mill ethanol plant.



## MSC™ PRODUCTS

### • Still Pro 50™ Protein

- 3-4lb/Bu
- 50+% Protein
- Corn Gluten Meal + Brewer's Yeast
- Various Successful Feed Trials



### • DDGS

- 28% Protein
- 7% Fat



### • OIL

- Yield Over 1.0lb/bu





VS.



Dried Distillers Grain Products					
Industry Name	Common Analysis (As Fed)			Current AAFCO Definition	General Description
	%Protein	%Fat	% Crude Fiber		
DDGS	23-36	3-9	<14	27.6, 27.8	Distillers grains with condensed distillers solubles with a portion of oil removed. Can be in dry or wet form (dry form common analysis displayed).
Full Fat DDGS	21-34	8-12	<14	27.6, 27.8	Distillers grains with condensed distillers solubles. No oil has been removed. Can be in dry or wet form (dry form common analysis displayed).
Deoiled DDGS	26-36	<3	<14	27.9	Solvent extracted DDGS.
DDGS with Bran	23-36	3-16	<14	27.6, 27.8, 48.2	DDGS mixed with bran separated by plant prior to fermentation. Can be in dry or wet form (dry form common analysis displayed).
DDGS Mechanically Separated	24-48	3-8	<14	27.5, 27.4	Post distillation residual whole stillage resulting from the mechanical separation of fiber and protein. Contains condensed distillers solubles.
DDG	24-35	4-8	<14	27.5	Distillers grain. May have a portion of oil removed. Does not contain condensed distillers solubles.
HiPro DDG	36-48	4-6	<12	27.5	Distillers grain. Portion of fiber and oil removed which concentrates protein. Does not contain condensed distillers solubles.
Other Distillers Products					
Industry Name	Common Analysis (As Fed)			Current AAFCO Definition	General Description
	%Protein	%Fat	% Crude Fiber		
Syrup (CDS)	5-25	3-23	0-4	27.7	Condensed thin stillage.
Distillers Yeast	40-55	0-8	0-6	96.5	Inactive <i>Saccharomyces cerevisiae</i> yeast removed from the process stream after fermentation either before or after distillation.
Industry Name	%Total Fatty Acids	%Unsaponifiable Matter	%Insoluble Impurities		
	>85	<2.5	<1	33.10	Oil removed by centrifugation from the condensed distillers solubles stream or by solvent extraction of DDGS.
High Fiber Distillers Products					
Industry Name	Common Analysis (As Fed)			Current AAFCO Definition	General Description
	%Protein	%Fat	% Crude Fiber		
Bran/Fiber with Syrup	18-28	4-9	15-20	48.2, 27.7	Bran separated by plant prior to fermentation mixed with condensed distillers solubles. Can be in dry or wet form (dry form common analysis displayed).
Fermented Fiber Mechanically Separated	<24	2-7	10-20	27.5, 27.4	Post distillation mechanical separation of the whole stillage resulting in a concentration of fiber. Does not contain distillers solubles unless listed.
Fermented Protein Products					
Industry Name	Common Analysis (As Fed)			Current AAFCO Definition	General Description
	%Protein	%Fat	% Crude Fiber		
Fermented Protein	48+	3-8	<8	27.5	Portions of fiber and oil removed by concentrating residual grain and yeast proteins by methods commonly used in distilling industry. Contains concentrated spent yeast products. Does not contain condensed distillers solubles unless listed.
Fermented Protein Mechanically Separated	48+	1-5	<8	27.5	Post distillation separation of protein from the whole stillage, utilizing only mechanical separation. Will contain spent yeast products, no non-mechanical methods utilized post distillation. Does not contain distillers solubles unless listed.
This table is meant for informational purposes only and does not convey any regulatory or specification requirements. The information listed is not all inclusive and is current as of date displayed in title and will be updated as industry innovation continues. The Distillers Grain Technology Council does not endorse any specific product or brands of feed products.					
2/11/2021					

# Aquaculture Feed

## Processing Considerations

# DDGS Aquaculture Feeds

- High protein / high fiber feeds



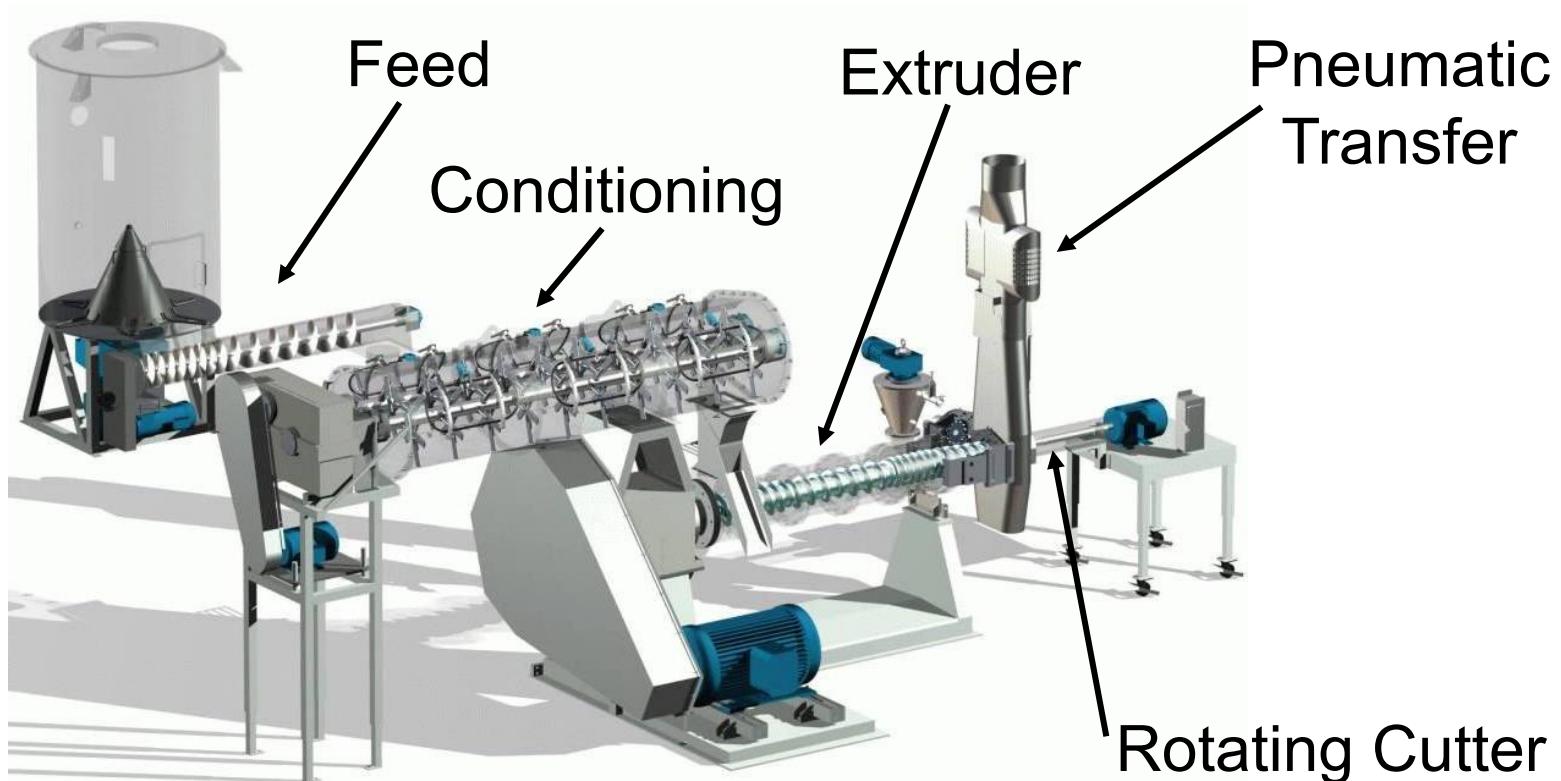
Pellet mill processed

vs.



Extrusion processed

# Extrusion Processing



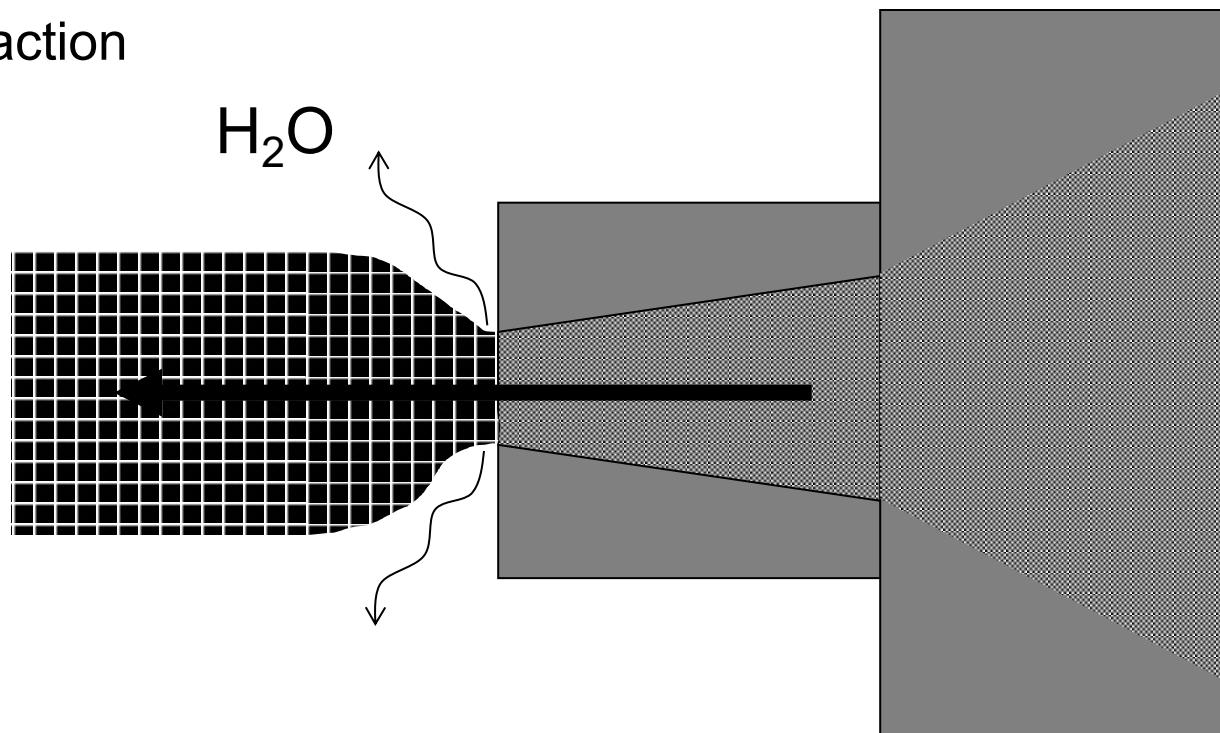
MAP2:01 01





# Extrusion Processing

- Advantages to extrusion
  - Mixing / kneading
  - Frictional heating
  - Steam / water addition
  - Various screw configurations
  - Puffing, not compaction



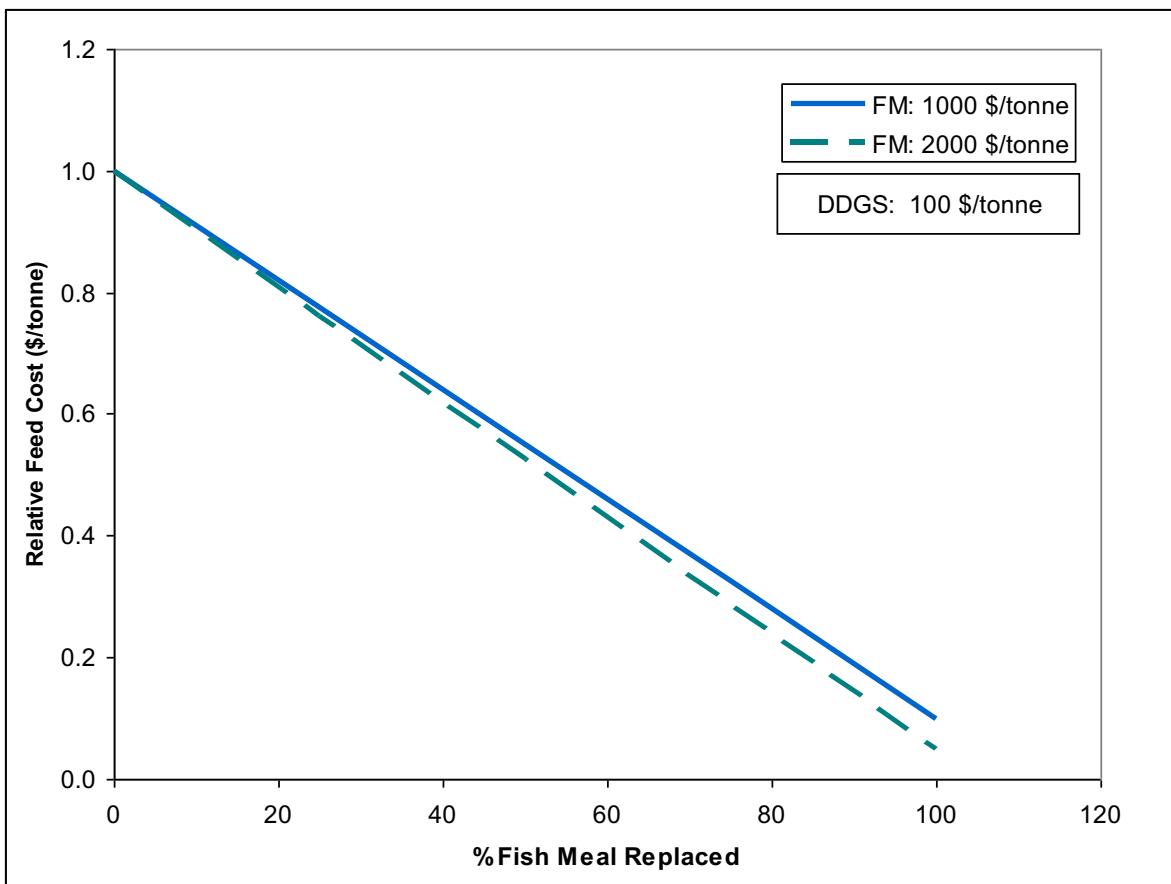
# Extrusion Processing

- Challenges
  - High fiber, high protein, low starch (glue)
    - Limited expansion, floatability, & cohesion
  - Final product characteristics impacted by
    - Processing conditions used
      - Temperature, screw speed, screw configuration, die opening, moisture/steam addition
    - Raw ingredients used
      - Particle size, composition, moisture content
- Want feed products that
  - Float, water stable, durable
- What is an optimum DDGS-based feed???
- How do you achieve this???

# Conclusions

All species can utilize up to 20% with no problems

- DDGS
  - 1/10 to 1/20 the price of fish meal



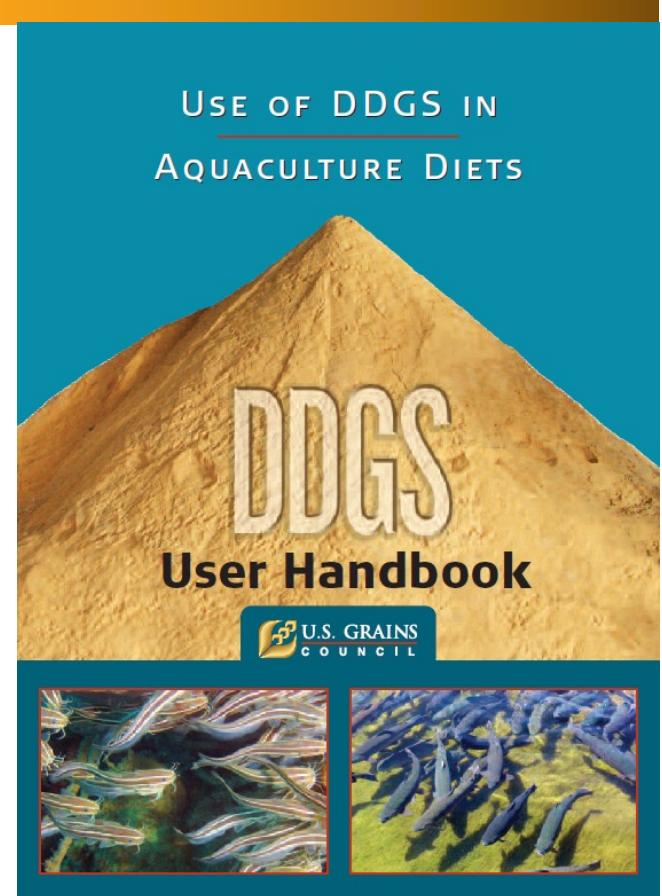
# Conclusions

**Table 2: Current, Revised Recommendations  
for Maximum Dietary Inclusion Rates of DDGS for Various Species of Fish.**

Species	% DDGS	Comments
Catfish	Up to 30%	
Trout	Up to 15%	Without synthetic lysine and methionine supplementation
Trout	Up to 22.5%	With synthetic lysine and methionine supplementation
Salmon	Up to 10%	
Freshwater Prawns	Up to 40%	Can replace some or all of the fish meal in the diet
Shrimp	Up to 10%	No studies are available but based upon research results with freshwater prawns, a minimum of 10% DDGS in shrimp should be acceptable.
Tilapia	Up to 35%	Without synthetic lysine and supplementation in high protein diets (40% crude protein)
Tilapia	Up to 82%	With synthetic lysine and tryptophan supplementation in low protein diets (28% crude protein)

<http://www.grains.org/ddgs-information/217-ddgs-user-handbook>

**All species can utilize up to 20% with no problems**



# Iowa Ingredients for Aquaculture Feeds

- Thank you
  - Questions?
  - Comments?
- Kurt Rosentrater

Iowa State University  
Distillers Grains Technology Council  
[karosent@iastate.edu](mailto:karosent@iastate.edu)



A large pile of fish, mostly dark-colored with some lighter ones interspersed, is contained within a circular metal tray. The fish are piled high, filling most of the frame.

Thank You

[karosent@iastate.edu](mailto:karosent@iastate.edu)





# For More Information on DDGS in Aquaculture Feeds

- Cheng, Z. J. and R. W. Hardy. 2004. Nutritional value of diets containing distiller's dried grain with solubles for rainbow trout, *Oncorhynchus mykiss*. *Journal of Applied Aquaculture* 15(3/4): 101-113.
- Hung, L. K. 2007. Feeding trial of DDGS for common carp. U.S. Grains Council South East Asia. Activity No. M06GX64322. [www.grains.org](http://www.grains.org).
- Lim, C., J. C. Garcia, M. Yildirim-Aksoy, P. H. Klesius, C. A. Shoemaker, and J. J. Evans. 2007. *Journal of the World Aquaculture Society* 38(2): 231-237.
- Schaeffer, T., M. L. Brown, and K. A. Rosentrater. 2010a. Performance characteristics of Nile tilapia (*Oreochromis niloticus*) fed diets containing graded levels of fuel-based distillers dried grains with solubles. *Journal of Aquaculture Feed Science and Nutrition* (accepted, in press).
- Schaeffer, T. M. L. Brown, and K. A. Rosentrater. 2010b. Utilization of diets containing graded levels of ethanol production co-products by Nile tilapia. *Journal of Animal Physiology and Animal Nutrition* (accepted, in press).
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- Vy, L. H. 2006. Feeding trial of DDGS for tilapia fish. U.S. Grains Council South East Asia. Activity No. M05GX54318. [www.grains.org](http://www.grains.org).

# For More Information on DDGS Extrusion

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- Rosentrater, K. A., K. Muthukumarappan, and S. Kannadhason. 2009. Effects of ingredients and extrusion parameters on aquafeeds containing DDGS and potato starch. *Journal of Aquaculture Feed Science and Nutrition* 1(1): 22-38.
- Rosentrater, K. A., K. Muthukumarappan, and S. Kannadhason. 2009. Effects of ingredients and extrusion parameters on aquafeeds containing DDGS and corn starch. *Journal of Aquaculture Feed Science and Nutrition* (accepted, in press).
- Kannadhason, S., K. Muthukumarappan, and K. A. Rosentrater. 2008. Effect of starch sources and protein content on extruded aquaculture feed containing DDGS. *Food and Bioprocess Technology* (accepted, in press).
- Kannadhason, S., K. A. Rosentrater, and K. Muthukumarappan. 2008. Twin screw extrusion of DDGS-based aquaculture feeds. *Journal of the World Aquaculture Society* (accepted, in press).

# For More Information on DDGS Extrusion

- Chevanan, N., K. A. Rosentrater, and K. Muthukumarappan. 2008. Effect of DDGS, moisture content, and screw speed on the physical properties of extrudates in single screw extrusion. *Cereal Chemistry* 85(2): 132-139.
- Chevanan, N., K. Muthukumarappan, and K. A. Rosentrater. 2008. Extrusion studies of aquaculture feed using distillers dried grains with solubles and whey. *Food and Bioprocess Technology* 2: 177-185.
- Chevanan, N., K. A. Rosentrater, and K. Muthukumarappan. 2008. Effects of processing conditions on single screw extrusion of feed ingredients containing DDGS. *Food and Bioprocess Technology* (accepted, in press).
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- Chevanan, N., K. A. Rosentrater, and K. Muthukumarappan. 2007. Twin screw extrusion processing of feed blends containing distillers dried grains with solubles. *Cereal Chemistry* 84(5): 428-436.

# DDGS in Aquaculture Feeds

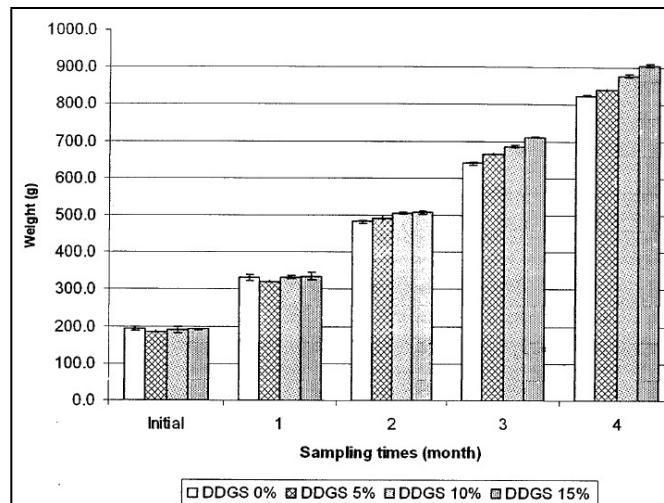
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Review of Published Research

# DDGS in Aquaculture Feeds

- U.S. Grains Council (Vy, 2006)
  - Red tilapia: Vietnam, 120 days
    - DDGS levels: 0, 5, 10, 15% of total diet

	DDGS 0%	DDGS 5%	DDGS 10%	DDGS 15%
Soybean Meal 47	58.54	56.58	56.37	57.85
Corn Yellow	23.56	28.15	27.13	20.72
Rice Bran 10	11.41	3.75	0.00	0.00
Fish Oil	2.89	2.88	2.87	2.87
Mono Cal. Phos (21)	2.49	2.53	2.51	2.46
Vitamin Mix	0.50	0.50	0.50	0.50
Mineral Mix	0.25	0.25	0.25	0.25
Choline Chloride (60%)	0.20	0.20	0.20	0.20
Antimold	0.10	0.10	0.10	0.10
Antioxidant	0.03	0.03	0.03	0.03
Stay C 35	0.03	0.03	0.03	0.03
DDGS (Distillers Grain Solubles)	0.00	5.00	10.00	15.00
<i>Calculated Nutrient</i>				
CRUDE PROT (%)	29.87	29.68	30.32	31.77
FAT(%)	6.87	6.37	6.23	6.45
FIBRE (%)	4.38	3.99	3.96	4.26
Calcium (%)	0.54	0.54	0.54	0.54
Av. Phosphorus Fish (%)	0.49	0.50	0.50	0.48
Total Phosphorus (%)	1.15	1.07	1.04	1.07
LYSINE (%)	1.75	1.71	1.72	1.79
METHIONINE (%)	0.42	0.43	0.44	0.47
MET. + CYS. (%)	0.90	0.91	0.95	1.00
TRYPTOPHAN (%)	0.38	0.38	0.38	0.40
THREONINE (%)	1.15	1.15	1.18	1.25
Magnesium (%)	0.27	0.24	0.23	0.24
Dig. Energy Fish(Carp) (kcal/kg)	2465	2442	2484	2588
Dig. Protein Fish (%)	25.95	25.70	26.15	27.24
DE/DP Fish	95	95	95	95
Starch (%)	20.28	22.26	20.73	15.83
wn:3 total (%)	0.90	0.90	0.90	0.90
wn:6 total (%)	0.52	0.45	0.55	0.80
Vitamin C (ppm)	105	105	105	105



Descriptions	DDGS 0%	DDGS 5%	DDGS 10%	DDGS 15%
No. of fish	400	400	400	400
Ave initial weight (g)	193.5	184.4	190.0	192.5
Total Initial weight (kg/cage)	77.6	73.6	76.0	77.2
Number tilapia at harvest	376	381	389	389
Ave weight at harvest (g)	824.2 <sup>a</sup>	839.3 <sup>b</sup>	879.4 <sup>c</sup>	907.4 <sup>d</sup>
Total biomass at harvest (kg)	309.8	319.7	342.3	353.2
Ave weight gain (g)	630.7 <sup>a</sup>	654.9 <sup>b</sup>	689.4 <sup>c</sup>	714.9 <sup>d</sup>
Total feed consumed (kg)	575.8	575.8	575.8	575.8
Feed Conversion Ratio	2.48 <sup>a</sup>	2.34 <sup>b</sup>	2.16 <sup>c</sup>	2.09 <sup>d</sup>
Mortality rate (%)	5.9 <sup>a</sup>	4.8 <sup>b</sup>	2.7 <sup>c</sup>	2.8 <sup>c</sup>
Survival rate (%)	94.1	95.2	97.3	97.2

# DDGS in Aquaculture Feeds

- U.S. Grains Council (2007)
  - Hybrid tilapia (*O. aurea X O. nilotica*): Taiwan, 90 days
    - DDGS levels: 0, 10, 20, 30, 40% of total diet

Ingredient	Dietary DDGS Level				
	0	10	20	30	40
Fish meal	10.00	8.00	6.00	4.00	2.00
DDGS	0.00	10.00	20.00	30.00	40.00
Roasted SBM	42.00	41.50	41.00	40.50	40.00
Wheat	45.50	37.89	30.30	22.69	15.10
Vitamin mix	1.00	1.00	1.00	1.00	1.00
Mineral mix	1.00	1.00	1.00	1.00	1.00
Lysine	0.00	0.10	0.19	0.30	0.39
Methionine	0.00	0.01	0.01	0.01	0.01
Cr2O3	0.50	0.50	0.50	0.50	0.50
Total	100.00	100.00	100.00	100.00	100.00
CP	28.14	28.11	28.08	28.05	28.02
CF	12.00	12.72	13.45	14.17	14.89
ASH	5.37	5.20	5.04	4.88	4.72
Energy (Kcal)	4118.37	4114.38	4111.15	4107.16	4103.93

Dietary DDGS Level	Initial WT (g)	Final WT (g)	WT Gain (g)	FCR
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
0	1.35 ± 0.32	7.92 ± 2.52	6.57 ± 2.24 <sup>a</sup>	1.23 ± 0.12 <sup>a</sup>
10	1.33 ± 0.33	8.13 ± 2.68	6.80 ± 2.37 <sup>a</sup>	1.14 ± 0.12 <sup>a</sup>
20	1.17 ± 0.32	6.11 ± 1.62	4.94 ± 1.30 <sup>ab</sup>	1.23 ± 0.04 <sup>a</sup>
30	1.13 ± 0.35	4.29 ± 1.73	3.16 ± 1.39 <sup>b</sup>	1.62 ± 0.15 <sup>b</sup>
40	1.11 ± 0.36	3.94 ± 2.16	2.83 ± 1.80 <sup>b</sup>	1.81 ± 0.38 <sup>b</sup>

Tilapia	Dietary DDGS Level				
	0	10	20	30	40
Cost (NT/Kg feed)	16.32	15.43	14.53	13.64	12.74
FCR	1.23	1.14	1.23	1.62	1.81
Cost (NT/Kg fish)	20.07	17.59	17.87	22.10	23.05

# DDGS in Aquaculture Feeds

- Lim et al. (2007)
  - Nile tilapia (*Oreochromis niloticus*): U.S., 70 days
    - DDGS levels: 0, 10, 20, 40% of total diet

	Experimental diets (%) <sup>a</sup>				
	1	2	3	4	5
Menhaden fish meal	8	8	8	8	8
Soybean meal	54	40	35	24.5	24.5
Corn meal	30	26.7	23.3	16.6	16.6
Wheat middlings	5	5	5	5	5
Distiller's dried grains with solubles	—	10	20	40	40
Corn oil	3.6	2.8	2	0.5	0.5
Carboxymethyl cellulose	3	3	3	3	3
Dicalcium phosphate	1	1	1	1	1
Vitamin premix <sup>b</sup>	0.5	0.5	0.5	0.5	0.5
Mineral premix <sup>c</sup>	0.5	0.5	0.5	0.5	0.5
Lysine HCl	—	—	—	—	0.4
Celufil	3.4	2.5	1.7	0.4	—
Analyzed β-glucan (g/kg diet)	<3.0	<3.0	<3.0	3.4	3.6
Proximate composition (%)					
Moisture	90.55	90.8	91.3	90.96	91.36
Protein	30.87	31.58	32.2	33.14	33.73
Lipid	5.46	5.56	5.45	5.48	5.35
Ash	6.84	5.87	6.85	6.8	6.94

Diets	Weight gain (g)	Feed intake (dry matter basis, g)	FER <sup>2</sup>	PER <sup>3</sup>	Survival (%)
1	48.0 <sup>ab</sup>	73.23 <sup>b</sup>	0.66 <sup>a</sup>	1.93 <sup>a</sup>	97.5
2	51.1 <sup>a</sup>	81.40 <sup>a</sup>	0.63 <sup>ab</sup>	1.82 <sup>ab</sup>	93.3
3	48.9 <sup>ab</sup>	75.18 <sup>ab</sup>	0.65 <sup>ab</sup>	1.85 <sup>ab</sup>	93.2
4	41.1 <sup>c</sup>	71.50 <sup>b</sup>	0.58 <sup>b</sup>	1.59 <sup>c</sup>	98.2
5	44.7 <sup>bc</sup>	71.83 <sup>b</sup>	0.62 <sup>ab</sup>	1.70 <sup>bc</sup>	96.7
Pooled SEM	1.2	2.02	0.02	0.06	1.8

<sup>1</sup> Values are means of four replicates per treatment. Means in the same column with different superscripts are significantly different at  $P < 0.05$ .

<sup>2</sup> FER = weight gain (g)/dry feed fed (g).

<sup>3</sup> PER = wet weight gain (g)/crude protein fed (g).

# DDGS in Aquaculture Feeds

- U.S. Grains Council (2007)
  - Milkfish (*Chanos chanos*): Taiwan, 90 days
    - DDGS levels: 0, 10, 20, 30, 40% of total diet

Ingredient	Dietary DDGS Level				
	0	10	20	30	40
Fish meal	10.00	8.00	6.00	5.00	3.00
DDGS	0.00	10.00	20.00	30.00	40.00
Roasted SBM	17.00	12.00	7.00	3.00	0.00
Defatted SBM	25.00	28.00	30.00	30.00	30.00
Wheat	45.00	38.90	33.78	28.68	23.58
Oil	1.00	1.00	1.00	1.00	1.00
Vitamin mix <sup>1</sup>	1.00	1.00	1.00	1.00	1.00
Mineral mix <sup>2</sup>	1.00	1.00	1.00	1.00	1.00
Lysine	0.00	0.10	0.20	0.30	0.40
Methionine	0.00	0.00	0.02	0.02	0.02
Total	100.00	100.00	100.00	100.00	100.00
CP	28.03	27.96	28.07	28.00	28.03
CF	5.98	5.98	5.98	5.98	6.17
ASH	5.21	5.01	4.84	4.64	4.45
	3872.1	3848.2			
Energy (Kcal)	6	3	3823.22	3798.89	3784.30

Dietary DDGS Level	Initial WT (g)	Final WT (g)	WT Gain (g)	FCR
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
0	17.63 ± 0.46	89.20 ± 13.42	71.57 ± 13.34	2.64 ± 0.49
10	17.62 ± 0.06	95.50 ± 1.55	77.88 ± 1.50	2.29 ± 0.06
20	17.89 ± 0.53	93.23 ± 2.92	75.34 ± 2.42	2.36 ± 0.11
30	17.83 ± 0.29	100.38 ± 7.31	82.55 ± 7.57	2.23 ± 0.07
40	17.66 ± 0.30	91.31 ± 1.99	73.65 ± 1.81	2.39 ± 0.03

Milkfish	Dietary DDGS Level				
	0	10	20	30	40
Cost (NT/Kg feed)	15.79	14.72	13.65	12.84	11.83
FCR	2.64	2.29	2.36	2.23	2.39
Cost (NT/Kg fish)	41.67	33.70	32.22	28.63	28.28

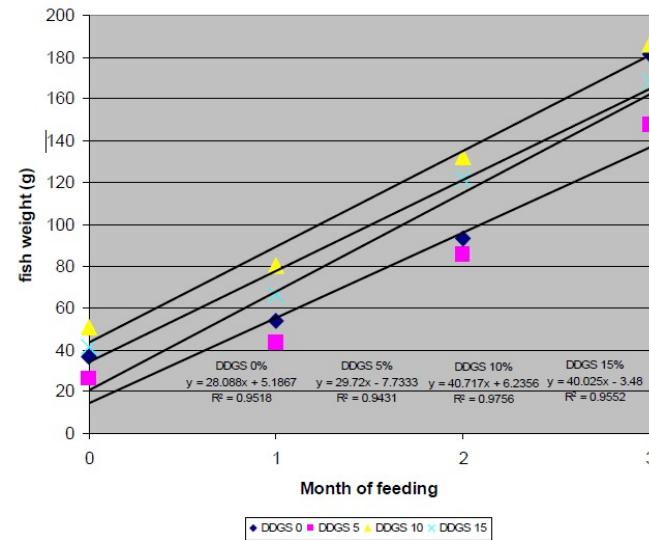
# DDGS in Aquaculture Feeds

- U.S. Grains Council (Hung, 2007)
  - Common carp (*Cyprinus carpio*): Vietnam, 90 days
    - DDGS levels: 0, 5, 10, 15% of total diet

Ingredient	DDGS 0%	DDGS 5%	DDGS 10%	DDGS 15%
SBM (%)	44.50	46.42	41.71	40.12
Cassava (%)	20.00	20.00	20.00	20.00
Rice bran (%)	15.00	15.00	13.40	10.00
Fish meal (%)	5.00	5.00	5.00	5.00
Meat & bone meal (%)	5.00	2.12	5.00	5.00
Wheat pollard (%)	4.60	1.10	-	-
DDGS (%)	-	5.00	10.0	15.00
Fish oil (%)	2.90	2.89	2.89	2.88
Corn Gluten meal (%)	1.00	-	-	-
MCP (%)	1.00	1.47	1.00	1.00
Vit. and Min. mix for Fish (%)	0.50	0.50	0.50	0.50
Lecithin (%)	0.50	0.50	0.50	0.50
Total	100.000	100.000	100.000	100.000

## Calculated Nutrient

Digest. Energy (Mcal/kg)	2.90	2.87	2.90	2.92
Protein (%)	29.1	28.7	29.0	29.1
Fat (%)	8.0	8.0	8.4	8.3
Crude fiber (%)	4.9	5.0	4.9	4.9
Ash (%)	8.1	8.0	8.2	8.0
Phosphorus, Total (%)	1.18	1.17	1.17	1.15
Lysine (%)	1.67	1.67	1.64	1.62
Methionine (%)	0.43	0.43	0.44	0.45
Met. + Cyst. (%)	0.87	0.87	0.89	0.92
ω 3 fatty acids (%)	1.0	1.0	1.0	1.0
ω 6 fatty acids (%)	0.7	0.9	1.1	1.2



Descriptions	DDGS 0%	DDGS 5%	DDGS 10%	DDGS 15%
No. of fish /cage	1200	1200	1200	1200
Ave initial weight (g)	36.9	26.2	50.7	41.6
Weight at 2 months (g)	54.0	43.3	80.2	66.6
Weight at 3 month (g)	93.1	85.6	132.1	121.6
Weight at 4 month (g)	181.5	147.8	186.0	168.6
Number Fish died /cage	8.2	6.6	7.4	8.2
Survival rate (%)	99.3	99.5	99.4	99.3

# DDGS in Aquaculture Feeds

- Cheng and Hardy (2004)
  - Rainbow trout (*Oncorhynchus mykiss*): U.S., 42 days
    - DDGS levels: 0, 7.5, 15.0, 22.5% of total diet
    - DDGS levels: 0, 7.5, 15.0, 22.5% of total diet (with lysine and methionine supplements)

Ingredients <sup>1</sup>	Diets						
	1	2	3	4	5	6	7
Herring meal	30.0	22.5	15.0	7.5	22.5	15.0	7.5
Distiller's dried grain with solubles	0.0	7.5	15.0	22.5	7.5	15.0	22.5
Fish oil, herring	17.6	17.7	17.8	17.9	17.7	17.8	18.1
Whole wheat	18.1	12.7	7.3	1.9	13.15	7.91	2.51
Soybean meal, 48%	15.0	15.0	15.0	15.0	15.0	15.0	15.0
Corn gluten meal (white)	16.9	22.2	27.5	32.8	21.2	25.8	30.36
L-lysine-HCl, 98.5%, feed grade	0.0	0.0	0.0	0.0	0.41	0.82	1.23
DL-methionine	0.0	0.0	0.0	0.0	0.14	0.27	0.40
Vitamin C (Stay-C)	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Choline chloride	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Trace mineral premix <sup>2</sup>	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Vitamin premix <sup>3</sup>	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Chemical analyses (%), as is basis, n = two samples)							
Moisture	6.0	5.8	5.8	6.3	6.2	6.4	6.9
Crude protein	43.4	43.7	43.8	43.7	43.9	44.2	43.5
Crude fat	19.4	19.9	18.9	17.1	19.3	18.5	18.8
Ash	8.6	6.8	6.2	4.9	6.9	5.7	4.7
Phosphorus	0.9	0.8	0.7	0.6	0.8	0.7	0.6

Items	Diets			
	1	2	3	4
Initial weight (g)	49.9±0.5a	49.9±0.8a	49.9±0.2a	49.9±0.3a
Final weight (g)	98.8±1.8a	93.8±2.8ab	96.4±0.9ab	92.8±1.3b
Weight gain (g)	48.9±1.9a	43.9±2.4ab	46.5±0.6ab	42.9±1.3b
Feed conversion ratio (g diet/g gain)	1.21±0.04a	1.35±0.06b	1.25±0.02a	1.34±0.02b

Items			
	5	6	7
Initial weight (g)	49.8±0.6a	49.8±0.7a	49.8±0.5a
Final weight (g)	101.1±2.6a	104.1±3.9a	96.2±2.1ab
Weight gain (g)	51.3±2.0a	54.3±4.6a	46.4±1.7ab
Feed conversion ratio (g diet/g gain)	1.20±0.05a	1.11±0.09a	1.29±0.04ab