Commercial Scale Production of Soymilk Based on Soybeans, Soy Flour or Soy Protein Isolates - Critical Parameters

Ignace Debruyne, PhD
ignace.debruyne@gmail.com

Fundamentals of Oilseed and Edible Oil Processing and Refining
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Different roads to a product with broad diversification potential

- Traditional process
- Dairy alternatives
- Formulation based on soy protein ingredients
- Whole soybean processes
- Soybean extraction – modern variations on a traditional process
Traditional Asiatic Soymilk Process:

1. Soaking for 20 h; room temperature
2. Grinding into a slush
3. Cooking for 30 min in pressure cooker
4. Extraction

- Tonyu (soy milk)
- Okara (soy fiber)
Dairy alternatives
World soymilk market (2012)

- China PR 4.2 billion L
  - About 400 million L packed product
- Leading industrial soymilk producers
  - USA 750 ML  Dean Foods: Silk™
  - Europe 650 ML  Alpro; Sojasun; Hain Cel.
  - Korea  Dr. Chung
  - Hong Kong  Vitasoy™
  - SEA 500 ML  Green Spot (Thailand)
Soy Drinks: a success story in Europe and the US, but Asia dominates

LEFT: in L/person/yr
- Top: Alpro (De Standaard, July 14, 2006)
- Bottom: TetraAlwin, 2009
- USA: around 1.7 L/pp/yr

BELOW: in % of dairy market
- Alpro (De Standaard, July 14, 2006)
- USA: around 1.6%
Soymilk = an end product
= Soy Base = a food component

Formulated products
- Dairy-type soymilk
- Soy Dairy blends
- Flavored drinks
- Soy Juice blends
- Fermented products
- Ice cream & Frozen desserts
- Puddings, custards
- Smoothies
- Ice cream

Tofu & derived products
- Pressed, Hard, Soft, Silken
- Smoked, Flavored, ...

Concentrated products
- Soymilk concentrates (ultra filtrated)
- Powders (spray dried)
- Spreads
- Processed tofu

By-product Okara
(from the bean based process)
- Food
- Food ingredient (dried okara)
- Feed (for ruminants)
Soy Processing

- Soy sauce / fermented products
  - Okara
  - Fibre
  - Soymilk
  - Concentrated soymilk
  - Soy yogurt
  - Tofu

- Cleaning, dehulling, soynuts, grinding
- Full fat soy flour

- Hypocotyl

- Hulls
- Fibre/bran

- Cleaning, drying, cracking, dehulling, conditioning, flaking
- Full fat soy flakes
  - Oil extraction
  - Defatted soy flakes

- Crude soybean oil
  - Degumming
  - Neutrallisation
  - Bleaching
  - Deodorisation
  - Refined soybean oil
    - Hydrogenation
    - Inter-esterification

- Soy isolate
  - Soy fibre
  - Margarine, shortening

- Soluble carbohydrate
  - Separation
  - Soy concentrate
    - Extrusion
    - Textured soy concentrate
      - Spun soy fibre
        - Spinning

- Soy molasses
- Soy isoflavones
Soybean ultra-milling and extraction

- Buhler; FSP; ADM; US Soy; Soy·N·Ergy®; etcetera
- Ultra-milling to <10 μm (1000 mesh) or < 30 μm (400 mesh)
- Readily dispersible products, or extra need for high pressure homogenization
- No or limited fibre separation
- Risk for off flavour formation full fat flour sensitive to oxidation
- Risk for gritty mouthfeel
Ultra Fine Soy Flour & Soy Blends

**Applications**

- Bakers/pastry shops: breads, cookies, dough…
- Dairy products substitute: soy beverages, soy yogurt, soy cheeses..
- Prepared meals: Tofu burgers, soups, salad dressings…
- Traditional uses: Soymilk, tofu, soy noodles…

**Technology**

- Patented dry deodorising system
- Ultra fine milling down to 10-35 µm
Comparison between the Buhler micro-milling process and conventional grinding systems (SYMPATEC HELOS measuring process).
Reconstituted soymilk

- ISP Isolated Soy Protein (>90% protein)
- Vegetable oil
- Emulsifier
- Sugar
- Salt
- Flavours; minerals; vitamins
- Water

- Product easily formulated
- Proper emulsifier and protein source yield stable product
- Eliminates the need for soybean extraction
- No by-products

So Good™ soy milk composition:
- Filtered water, soy protein, maltodextrin, grape extract, sunflower oil, acidity regulators (potassium citrate, potassium and diglycerides of fatty acids), stabiliser (carrageenan), salt, zinc gluconate, niacin, vitamin E, riboflavin, vitamin A, thiamin, vitamin D, folic acid, vitamin B12
A selection of commercial ISPs for soy beverages

<table>
<thead>
<tr>
<th>Product</th>
<th>Benefit</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Danisco-Solae ALPHA® 5800</td>
<td>High solubility, Improved mouthfeel and flavor; Intermediate viscosity</td>
<td>Ready-to-drink beverages and culinary applications</td>
</tr>
<tr>
<td>Danisco-Solae ALPHA® 5812</td>
<td>High solubility, Improved mouthfeel and flavor</td>
<td>Ready-to-drink beverages and culinary applications</td>
</tr>
<tr>
<td>Danisco-Solae SUPRO® PLUS 2640 DS</td>
<td>Maximize macronutrient content with lower costs</td>
<td>Healthy, flavored soy beverages and nutritional drinks for the entire family</td>
</tr>
<tr>
<td>Danisco-Solae SUPRO® PLUS 2640 DS IP</td>
<td>Delivers nutrition through identity-preserved soy while providing great taste and proven health benefits</td>
<td>Dry blended powdered soy beverages and nutritional drinks for overall health and wellness</td>
</tr>
<tr>
<td>Danisco-Solae SUPRO® PLUS LF IP</td>
<td>Lactose free, excellent flavor, mouthfeel and dispersibility; also available with protein to calcium ratio as dairy protein</td>
<td>For use in a wide variety of beverage applications Dry blended beverages, ready-to-drink (RTD) neutral or acidic beverages, delivering a wide range of protein levels</td>
</tr>
<tr>
<td>ADM Clarisoy</td>
<td>100 percent soluble and transparent in beverages</td>
<td>Beverage systems with pH levels of less than 4.0</td>
</tr>
<tr>
<td>ADM Nutrisoy PRO-FAM® 974</td>
<td>Highly soluble, highly functional, easily dispersible.</td>
<td>Dairy-free products and milk replacers</td>
</tr>
<tr>
<td>ADM Nutrisoy ARDEX-F-DISP</td>
<td>Readily dispersible, low viscosity, highly soluble, low flavor, low odor.</td>
<td>Processed dairy foods, milk replacer, infant formulas</td>
</tr>
</tbody>
</table>
Instant soymilk powders

Based on

- Isolated soy protein, combined with vegetable oil or fat, emulsifier, other ingredients
- Spray dried soymilk, combined with other ingredients
- Spray dried, enzyme treated soymilk (fibre hydrolysis ⇒ no okara), combined with other ingredients
- Wet milled and (spray) dried [soy + ingredient] blend
BUT WHAT ABOUT SOYBEAN BASED SOY BASE?
Upscaling the Traditional Soymilk Process?

Chain driven bucket system

- One bucket becomes many buckets
- One cooker becomes many cookers
- One separator becomes many separators
Or developing from scratch into a Continuous Process?
Objectives of Soy Base Extraction Technology

- Extract the soluble protein as much as possible
- Achieve the desired flavor, taste and texture
- Inactivate the enzymes; denature ANFs
- Stabilize the product for long shelf-life
- Taste is Number One Consideration
- Nutrition is Increasingly Important
- Pricing is a Significant Factor

But Objective N°1 remains: SUPERIOR TASTING DRINKS & SOYFOODS FOR EVERYONE
Soy Products of the Future

- ‘Traditional’ products can be greatly improved by new technologies: yield; taste; structure
- ‘Western’ style Soy Base is starting material for many products
- Bland soy base will lead to increased acceptance of current as well as future products.
- Completely bland soy base will permit production of the next generation of ‘mainstream’ dairy type products.
Quality Parameters

- Sensory characteristics
- Nutritional properties
- Physico-chemical properties
- Microbiological stability
- Functional characteristics
Sensory Quality

- Smooth: Fine grinding; homogenisation
- Sandy: Fibre particles; poor separation
- Beany: Isoflavone aglycons; saponins; phytic acid; astringency
- Low Beany: Painty, rancid, oil-like; chalkiness
- White: Yellow, clear hylum; soybeans; dehulling; fine emulsion droplets
- Enzyme inactivation: Lipoxygenase; PUFA
- Sweet: Sweet soybeans; added sugars
- Dark cooked: Overcooked; no dehulling; coarse emulsion
# Critical sensory attributes

<table>
<thead>
<tr>
<th>ATTRIBUTES</th>
<th>SCALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color</td>
<td>Light</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Thin</td>
</tr>
<tr>
<td>Balance</td>
<td>Unblended</td>
</tr>
<tr>
<td>Fullness</td>
<td>Thin</td>
</tr>
<tr>
<td>Flavoring Aromatics</td>
<td>None</td>
</tr>
<tr>
<td>Other Aromatics</td>
<td>None</td>
</tr>
<tr>
<td>Vitamin/Fe Aromatics</td>
<td>None</td>
</tr>
<tr>
<td>Sweet</td>
<td>None</td>
</tr>
<tr>
<td>Sour</td>
<td>None</td>
</tr>
<tr>
<td>Mouthfeel</td>
<td>None</td>
</tr>
<tr>
<td>Others</td>
<td>None</td>
</tr>
<tr>
<td>Aftertaste</td>
<td>None</td>
</tr>
</tbody>
</table>
Soybean Supply

- **Quality**
  - Variety
  - Protein Level
  - Moisture Level
  - Age
  - Maturity
  - Harvesting
  - Foreign Material
  - Organic / GMO

- **Storage**
  - At the Farm
  - At the Cleaning and Grading Facility
  - During Shipping
  - At the Soymilk Processor Site
  - Temperature
  - Humidity
  - Air Circulation
  - Load
Does soyfood production require soyfood soybeans?

- IP Soyfood Soybeans are designed for making high quality soyfoods
  - Variety Specific
  - Quality specific
  - System specific

- **SOYFOOD quality:**
  - Protein level high and constant
  - Clean, equal size, equal color
  - No FM, splits, loose hulls
  - Hilum color set
  - System: non-GM; organic
  - Specific minor components set

- Traders guarantee quality and specifications
- Manufacturers must manage the quality control issues associated with IP soybean sourcing
- Downstream processing introduces different flavor quality and consistency challenges
Soy flavour issues

- Effect: beany off-flavour (fishy smell in oil)
- Origin: PUFA in combination with lipoxygenase

$$\text{H}_2\text{O} + \text{O}_2 + \text{PUFA} \rightarrow \text{lipoxigenase (LOX)}$$

$\downarrow$ FA hydroperoxide

$\downarrow$ hydroperoxide lyase

short chain aldehydes

(hexanal; hexenal)

Beany taste
## Compounds causing off-flavours

- **Fishy**: Volatile amines
- **Bitter**: Oxidation products
- **Roasted**: Browning products
- **Cereal**: Furfurals
- **Astringent**: Phenolics
- **Bitter**: Fatty acid dimers, trihydroxy fatty acids
- **Oxidized**: Grassy & beany alcohols
- **Green**: Beany, grassy aldehydes, beany furans
**Lipoxygenase reaction and how to prevent it**

Lipoxygenase can be

- Denatured thermally (low stability)
  or chemically (acid/base)
- Kept inactive by reducing access to substrates

\[
H_2O + O_2 + PUFA + (\text{Lipoxygenase}) = \text{Beany taste}
\]

- **Heat denaturation of protein:** proteins attach to fibre
  - compromised taste (flavour-protein interaction!)
  - reduced yield
  - higher formulation cost & calories loading
- **Native soluble proteins easily dissolve in water**
  - better taste
  - better nutrition
  - better yield
  - lower formulation cost, and less calories
Beany taste formation and how to prevent it

- Heating: thermal denaturation of low stability lipoxygenase; f [T, t, moisture]
- pH control: chemical inactivation with acid/base
- Substrate removal: reduce access to oxygen
- Remove reaction products:
  - Enzymatically (UniCell® Japan Cellfoods: dehydrogenase breakdown of hexanal & hexenal)
  - By fermentation (microbial breakdown; microorganisms having sufficient dehydrogenase activity)
Soy flavour issues: bitter taste

- **Effect:** bitter taste, astringency
- **Origin:**
  - Isoflavones; peptides; phytic acid; free fatty acids
- **Options:**
  - Process control (reduce isoflavone hydrolysis to aglycon form; reduce protein hydrolysis)
  - Debittering (isoflavone / germ removal; soybean leaching)
  - Masking
Soy flavour issues: cooked taste

- Effect: cooking/sterile flavour & mouthfeel

- Objective: improve PDCAAS, reduce TIU

- Options: heating, chemical treatment

  - Options:
    - Process control
    - Masking
Basic processing steps

WHOLE SOYBEANS

Water → Soaking

Water → Rinsing

Water → Grinding

Filtering → OKARA

Heating

SOYMILK
Dehulling: Yes or No?

- **No Dehulling**
  - Saves additional equipment, cost and time
  - Damaged soybean leads to active lipoxygenase and a beany taste
  - Soy base made from dehulled bean may have chalky taste
  - Hulls aid in filtration
  - Hot dehulling insolubilizes protein
  - Hot dehulling gives a moist bean surface sensitive to mould infection
  - Nothing harmful in the hulls

- **Dehulling**
  - HOT or COLD Dehulling?
  - Hot dehulling eliminates/reduces lipoxygenase
  - Better tasting tofu (?)
  - Splits and damaged beans easy to remove
  - Hulls absorb lots of water and clog blanching equipment
  - Wet hulls increase okara mass and moisture
  - May improve emulsion stability
  - Possibility to remove germs (rich in isoflavones)
Cold dehulling
Multicracker Cold Dehulling

- Gap setting: around half the average smallest soybean diameter
- Speed setting adapted to guarantee a minimum level of fines and small pieces
Dehulling

Technology:

- Hot dehulling:
  - indirect preheating
  - hull loosening in fluid bed (popping effect):
    - 90-120 s (short & homogenous)
    - forced SB flow (controlled transfer!)
- Bean impacting (hull loosening)
- Working screws and paddle mixers (hull loosening)
- (Kice) Separators + cleaning of hulls and meats
Hot Dehulling

- clean soybeans
- steam (<=0.5 bar)
- conditioner
- air
- ventilator
- heating
- fluid bed
- impact mill
- working & mixing screw
- buffer silo
- kice
- air in
- air out (cyclones)

Fluid bed treatment

Hull separation & sizing

- hulls
- hull cleaning
- splits
- clean cotyledones

Buhler USA Oil Milling division
Pre-soaking: Yes or No?

- **No Soaking**
  - Less risk for the development of beany taste
  - Dry soybeans more difficult to grind
  - More wear and tear in milling and grinding equipment
  - But dry heat treatment possible

- **Soaking**
  - Improves protein extraction yield
  - Makes the soybeans soft and easy to grind
  - Risk for lipoxygenase and other enzyme activity, unless in absence of oxygen, or at elevated temperature

and ... at what temperature?
Water quality

- For industrial operations, the process water should be soft and clean
- City water, or water pumped from a well, requires proper pre-treatment:
  - Softening
  - Demineralization (if too high in salts)
    - High metal salt content affects taste and yield!
    - Calcium ions will bind to soy protein and form tofu-like curd particles (risk for deposit in the packed product)!
  - (Micro)Filtration to remove all impurities
Hydration ratio with T/t of whole soybean soaking

W.F. Wilkins & L.R. Hackler, Cereal Chem. 46, 1969, 391
In Soybeans: Chemistry, Technology, and Utilization - By KeShun Liu
Published by Springer, 1997
ISBN 0834212994, 9780834212992 / 532 pages
Blanching: Yes or No?

- **No blanching**
  - No loss of insoluble protein, as heat treatment is after separation
  - Cooking could reduce protein solubility and extraction yield
  - More wear and tear in grinding equipment (soy is very abrasive)

- **Blanching**
  - Eliminates lipoxygenase and other enzymes (lipases, phospholipases, proteases, TI, urease)
  - Improves taste by reducing the flavour deterioration in long shelf-life product
  - Loss of soluble components may affect mouthfeel & taste
  - Facilitates grinding, milling and/or homogenisation

Temperature: >80°C
Time: >10-15 min
Hot grinding: Yes or No?

**Hot grinding (>80°C)**
- Eliminates lipoxygenase and other enzymes
- Improves taste
- Faster size reduction and easier grinding

**Cold grinding**
- No protein denaturation, which could reduce solubility and extraction yield
- Higher abrasiveness of soybeans

- Airless grinding
- Colloid milling
- High pressure homogenization
Soy Base: Particle Size Distribution

Capacity dependent:
- Small scale: Filtration
- Intermediate: centrifuges with semi-continuous okara discharge
- High volume: decanters with continuous okara discharge

Courtesy ProSoya
Fibre separation process (1)

With a decanter, centrifuge or by course filtration

Capacity dependent:
- Filtration: small scale
- Centrifuge: large scale; semi-continuous okara discharge
Fibre separation process (2)

High volume
- Decanter: large scale, continuous okara discharge
- Two-phase separation of pasty sediment and liquid

sedicanter
Yield calculation

**Soy Solids Yield**
- Soybeans: 720 kg
- Moisture (M): 11.9%
- Soymilk produced: 10000 kg
- Solids in soymilk (DM; moisture balance): 4.20%

**Soy Protein Yield**
- Protein in soybeans: 39.6%
- Protein in soybeans (on DM): 44.9%
- Protein in soymilk: 2.31%
- Protein in soymilk (on DM): 55.0%

**Yield Calculations**

\[ Y_s = \frac{S \times N \times (1-L/100)}{B \times (1-M/100)} \]

\[ Y_P = Y_s \times \frac{Q}{P} \]

**Results**
- Dehulling loss (%): 0%
- \( Y_S \): 66%
- \( Y_P \): 81%
Deodorization: Yes or No?

- **Deodorization:**
  - Removes volatile off-flavors
  - Removes air
  - Steam injection gives a pasteurization effect

- **No deodorization**
  - Extra processing step
  - Direct UHT already contains deodorization
Factors affecting stability

- Soaking
- Heat treatment severity
- Clarification efficiency
- Particle size/Grinding
- Homogenization
- Addition of stabilizer

- Network contraction
- Viscosity & yield stress
- Emulsion stability
  - Emulsifier
  - Salt
  - pH

- Sedimentation of particles
- Creaming of lipid globules
# Soy base Quality and Extraction Efficiency

<table>
<thead>
<tr>
<th>(% wet basis)</th>
<th>One-Decanter</th>
<th>Two-Decanter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids</td>
<td>8.7</td>
<td>10.9</td>
</tr>
<tr>
<td>Protein</td>
<td>4.0</td>
<td>5.0</td>
</tr>
<tr>
<td>Fat</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>Soluble Sugars</td>
<td>1.4</td>
<td>2.0</td>
</tr>
<tr>
<td>Other</td>
<td>1.3</td>
<td>1.4</td>
</tr>
</tbody>
</table>

The graph shows the relationship between °Brix and % protein for different extraction efficiencies.
Shelf-life

Depends on

- The quality of the raw materials
- The stabilization process (pasteurization, sterilization or UHT)
- Storage and distribution temperature
- Quality of the packaging
- Formulation of the soy drink (effect of salt; stabilizer)
Some typical compositions of formulated soymilk products

<table>
<thead>
<tr>
<th>Region</th>
<th>Protein %</th>
<th>Fat %</th>
<th>Sugars %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>3.6</td>
<td>2.5</td>
<td>3.4</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>2</td>
<td>1.5</td>
<td>~7</td>
</tr>
<tr>
<td>Japan</td>
<td>3.2-3.6</td>
<td>3.1-4.3</td>
<td>2.5-5.2</td>
</tr>
<tr>
<td>Singapore/Malaysia</td>
<td>0.8-2.2</td>
<td>0.6-1.0</td>
<td>~11</td>
</tr>
<tr>
<td>USA/Canada</td>
<td>2.5</td>
<td>1.8</td>
<td>2.5-10</td>
</tr>
</tbody>
</table>
Turnkey plants vs. modular units

**Turnkey plant gives a full integration of**
- Soybean receiving & storage
- Soymilk base production
- Steam supply and use
- Water cooling
- Chillers
- Compressed air
- Effluent treatment plant
- CIP
- Soymilk base storage

**Modular plant**
- Need for and investment in own process technology development and engineering
- Finding process equipment that properly fits together into an integrated process

**From small scale to big plant size**
Tetra Pak
Tetra Alwin™ Soymilk process

Grinding Section
1. Bean grinding
2. Hot water addition
3. Optional sodium bicarbonate unit

Fibre Separation Section
4. Fibre separation
5. Optional okara pump
6. CIP unit for decanter
7. Steam injection
8. Holding tube
9. Deodorisation

Optional 2nd decanter
To okara tank

Deactivation and Cooling Section
10. Cooling
11. Optional pH adjustment

Soya beans

CIP return
CIP pressure
Soya bean milk

Option

Flowchart:
- Soya
- Okara
- Steam
- Hot water
- Cooling water
- Ice water
- Vacuum
- NaHCO₃
- HCl
- CIP solution
Beany Process Setup

Whole Soya Bean
\[ \downarrow \]
Positive Pump \[ \xleftarrow{\text{Water (52 °C)}} \]
\[ \downarrow \]
First Grinder
(Disc Mill)
\[ \downarrow \]
Second Grinder
(Colloid Mill)
\[ \downarrow \]
Holding Tube (150 Sec at 85 °C), slurry temp at 50°C
\[ \downarrow \]
Decanter \[ \rightarrow \] Okara
\[ \downarrow \]
Cooked at 95°C by steam injection and hold for 80secs
\[ \downarrow \]
Cooling by PHE to 25°C
\[ \downarrow \]
Soya base (9°brix, pH - 6.4)
Low Beany Process Setup

Whole Soya Bean
↓
Positive Pump ← Water (90 °C)
↓
First Grinder (Disc Mill)
↓
Second Grinder (Colloid Mill)
↓
Holding Tube (150 Sec at 85 °C), slurry temp 87 °C
↓
Decanter → Okara
↓
Enzyme deactivation unit 120 °C for 80 seconds
↓
Flash Cooling to 80 °C
↓
Cooling by PHE to 25 °C
↓
Soya base (Brix 9, pH – 6.4)
ProSoya:
Soy Base with okara rewash
Benefit of Okara washing

- Higher yield of soy base: +10-12% with one-step washing
- Higher efficiency in extraction process with
  - Optimized cut for Soy Base quality on rewash
  - Loose cut for optimal okara quality on 1st separator
- With proper type of decanter settings, DM of okara can go up from 20-22% to 24-26%
Objective: Optimized Soy Base Yield + Taste

- **Yield**
  - Maximum dissolved dry matter
  - As much protein as possible
  - Trend in favor of higher protein to fat ratio

- **Taste**
  - No beany flavor or other off flavors
  - No astringency, bitterness
  - No chalkiness
  - No cooked flavor
THANK YOU

Ignace Debruyne & Associates Consultancy

ignace.debruyne@gmail.com