

# **A Small Step Towards A More Sustainable, Responsible & Profitable Textile Industry**

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**Olney Address**

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# Acknowledgement

- **Undergraduate Students**

- Emanuel, L.R.; George, B.; Kelly, E.; McBride, O.; Hidalgo, H.; Tan, Y.C.; Temme, L.; Zhang, S.M.

- **Graduate Students**

- Cai, S.B.; Chang, Y.; Chen, L.H.; Chen, L.Y.; Dong, Z.; Hassan, F.; Huang, Y.L.; Huda, S.; Jiang, Q.R.; Karst, D.; Li, W.; Liu, L.Y.; Ma, Z.Z.; Mi, X.; Mu, B.N.; Pang, G.W.; Qiao, X.; Reddy, N.; Ruan, X.H.; Shao, Y.Y.; Shi, Z.; Thillainayagam, V.; Wang, L.; Wizi, J.; Xu, H.L.; Xu, S.X.; Xu, W.J.; Yang, J.; Yang, M.P.; Yang, R.; Zhao, Y.; Zhao, Y.Z.; Zhu, X.Y.; Zou, Y.

- **Collaborators**

- Chen, J.G.; Chen, Z.Z.; Cui, L.; Dong, Z.; Han, S.Y.; Hou, X.L.; Huang, D.; Li, S.Q.; Liu, P.C.; Ma, B.M.; Reddy, N.; Shen, L.; Wang, B.J.; Wang, L.M.; Xu, H.L.; Xu, L.

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# Challenges

- **Annual fiber consumption: >120 M tons**
  - Doubled in 20 years
- **Environmental impacts**
  - Fiber and chemical productions
  - Slashing
  - Wet Processing
  - Waste and spent textiles
- **Sustainability**
  - Reduce, Replace, Reuse and Recycle

# Our Efforts

- **Fibers**
  - **Non-traditional biobased fibers**
- **Sizes**
  - **Plant/animal proteins to replace PVA**
- **Coloration**
  - **Natural dyes from agricultural wastes**
  - **Plant oil-aqueous dyeing systems**
- **Complete recycling of dyes/salts and waste/used textiles**
  - **Spent dyebath/rinse water**
  - **Waste and used textiles**

# Biofibers

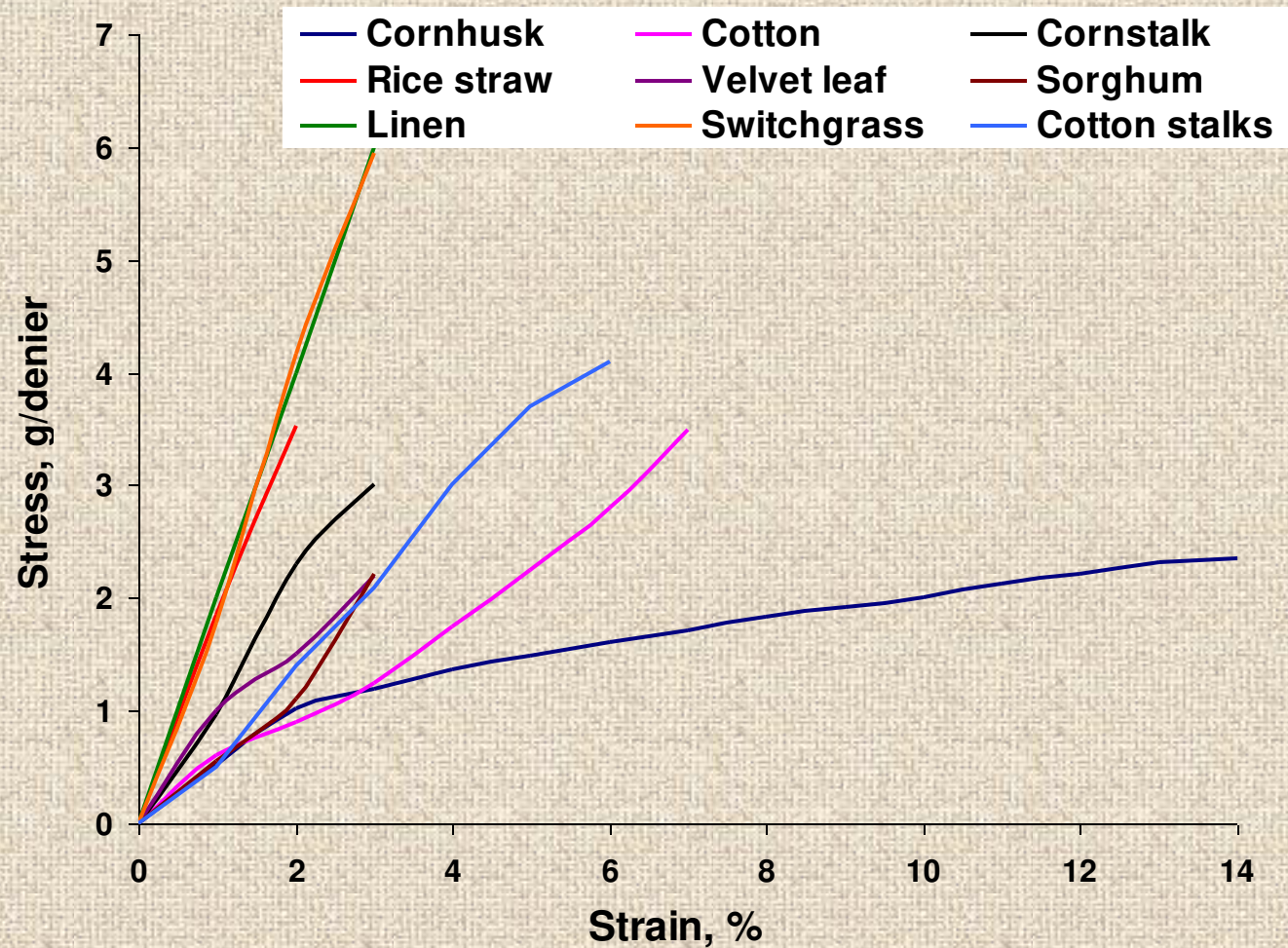
- **Non-traditional natural and regenerated fibers**
- **Challenges**
  - **Property and cost**
- **Our efforts**
  - **Lignocellulosics**
    - **Crop stovers**
  - **Proteins**
    - **Distillers grains**
    - **Oil seed meals**
    - **Feathers**
    - **Low quality/waste hair fibers**

## **Worldwide Availability of Raw Materials and Non-traditional Lignocellulosics**

Raw Material	Availability, Million Tons	
	Source	Fibers
<b>Rice straw</b>	<b>580</b>	<b>116</b>
<b>Wheat straw</b>	<b>570</b>	<b>114</b>
<b>Cornstalk</b>	<b>320</b>	<b>64</b>
<b>Cornhusk</b>	<b>64</b>	<b>13</b>
<b>Soybean straw</b>	<b>214</b>	<b>43</b>
<b>Sorghum</b>	<b>59</b>	<b>12</b>
<b>Pineapple leaf</b>	<b>233</b>	<b>23</b>
<b>Sugarcane rind</b>	<b>29</b>	<b>3</b>
<b>Total</b>	<b>2069</b>	<b>388</b>

\*The potential fiber availability has been calculated based on 20% yield of fibers (10% for pineapple leaf fibers and sugarcane rind fibers)

## Stress-Strain Properties of Some Non-traditional Natural Cellulose fibers compared with cotton and linen



# Examples of Lignocellulosic Textiles



CREDITS (TOP TO BOTTOM): GERRY ALLEN; HANDOUT/REUTERS/CORBIS; Y. YANG



## << AGRI-COUTURE

More than half of the 67 million tons of textile But with rocketing oil prices, agricultural bypr scientists reported last week at the American C Textile scientist Yiqi Yang of the University that are "long and fine enough for textiles but Narendra Reddy extracted finger-length fiber: Adding cotton, they spun a yarn and wove it in textile fiber could be produced from half of Brian George, a textile engineer at Philadel such fibers makes them hard to work with ur seems economically viable if the fibers "can

Yang says rice-straw fibers are stronger than those from cornhusks, which he managed to make a sweater out of a few years ago. His next project is to get spinnable fibers from chicken feathers, whose honeycomb structure, he says, could potentially make for textiles lighter and warmer than wool.

June 7 | Number 4 | 2005

# Green Chemistry

Cutting-edge research for a greener sustainable future

www.rsc.org/greenchem Volume 7 | Number 4 | April 2005 | Pages 169-240

ISSN 1463-9262

Reddy and Yang  
Natural cellulose fibres from cornhusks

Alford et al.  
Immobilized gadolinium tritrate as a recyclable catalyst

Docherty and Kulp  
Toxicity and antimicrobial activity of ionic liquids

Wang et al.  
Recovery of amino acids using biphasic systems

RSC | Advancing the Chemical Sciences

1463-9262(2005)7:4;1-C

1692005 143018

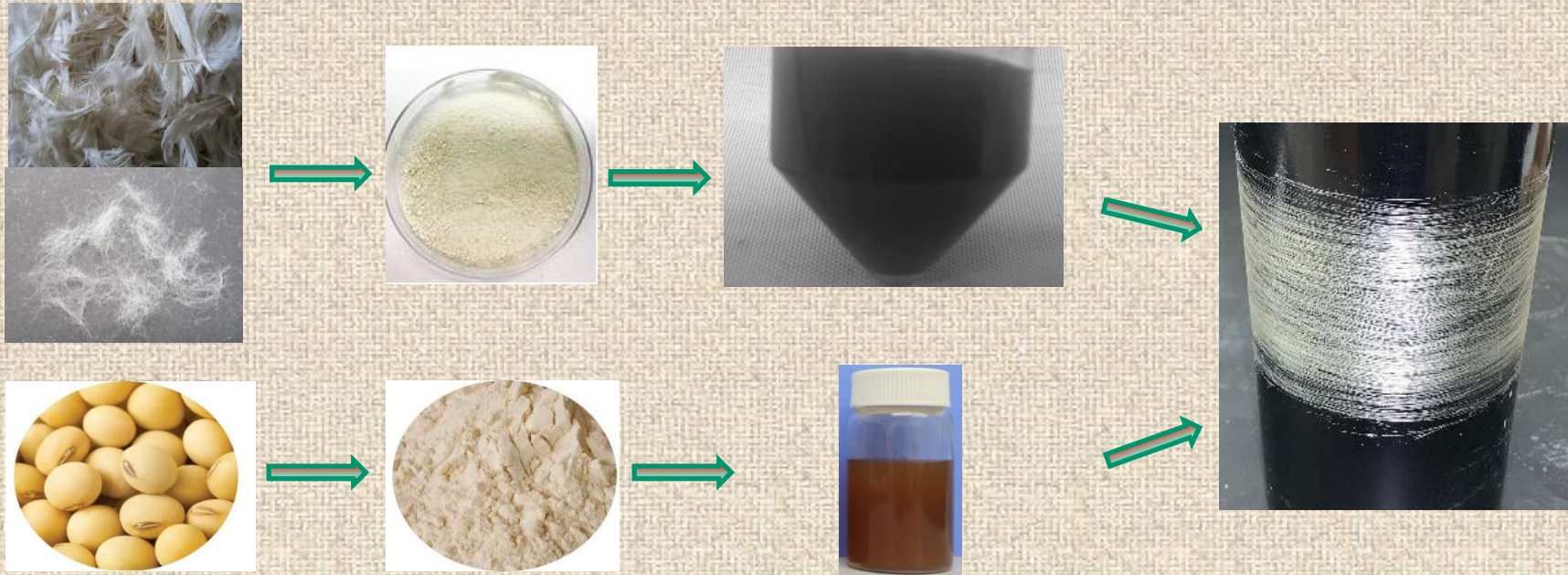
# Worldwide Availability of Raw Materials and Potential Protein Fibers/Chemicals

<b>Raw Material</b>	<b>World Production (Million tons)</b>	<b>Protein Content</b>	<b>Potential Protein for Biofibers/Chemicals (Million Tons)</b>
Soybeans	206.5	44%	9.1*
Wheat	632.6	13%	8.2*
Corn	724.6	9%	6.5*
Milk	622.3	3%	1.9*
Peanut	30.2	27%	0.8*
Feather	8	~100%	8.0**
Total	2224		34
<i>Wool</i>	<2		
<i>Silk</i>	<0.5		

\* Assumed 10% availability of proteins for biofiber/chemical production

\*\* Assumed 100% availability for biofiber/chemical production

# Fabrication of Regenerated Protein Fibers



## Properties of Plant Protein Fibers Compared to Wool

<b>Fiber</b>	<b>Breaking Tenacity g/den</b>	<b>Breaking Elongation %</b>	<b>Modulus g/den</b>	<b>Moisture Regain %</b>
<b>Wheat Gluten</b>	<b>1.1 ± 0.07</b>	<b>23 ± 2.7</b>	<b>34 ± 2.2</b>	<b>18</b>
<b>Wheat Gliadin</b>	<b>1.2 ± 0.9</b>	<b>25 ± 3.2</b>	<b>29 ± 2.8</b>	<b>15</b>
<b>Soyprotein</b>	<b>1.0 ± 0.12</b>	<b>8.5 ± 1.1</b>	<b>42 ± 1.4</b>	<b>15</b>
<b>Zein</b>	<b>1.1 ± 0.02</b>	<b>30.0 ± 2.9</b>	<b>-</b>	<b>-</b>
<b>Wool</b>	<b>1.2 -1.8</b>	<b>30-40</b>	<b>30- 45</b>	<b>16</b>

# Comparison of feather keratin fibers and wool

Fiber source	Dry Properties			Wet Properties		
	Stress (MPa)	Strain	Toughness (J cm <sup>-3</sup> )	Stress (MPa)	Strain	Toughness (J cm <sup>-3</sup> )
<b>Keratin fibers</b>	110-145	8-12%	17-19	60-90	22-28%	22-28
<b>Crosslinked keratin fibers</b>	195-215	16-22%	27-32	120-140	27-35%	29-35
<b>Wool</b>	150-190	30-40%	28-38	120-160	42-50%	33-40

# Size

- **PVA for high-speed weaving**
  - COD
- **Challenges**
  - High speed weaving efficiency
- **Our efforts**
  - Plant and feather proteins

# Industrial Weaving Results Using Sizes from Soy Protein Isolates



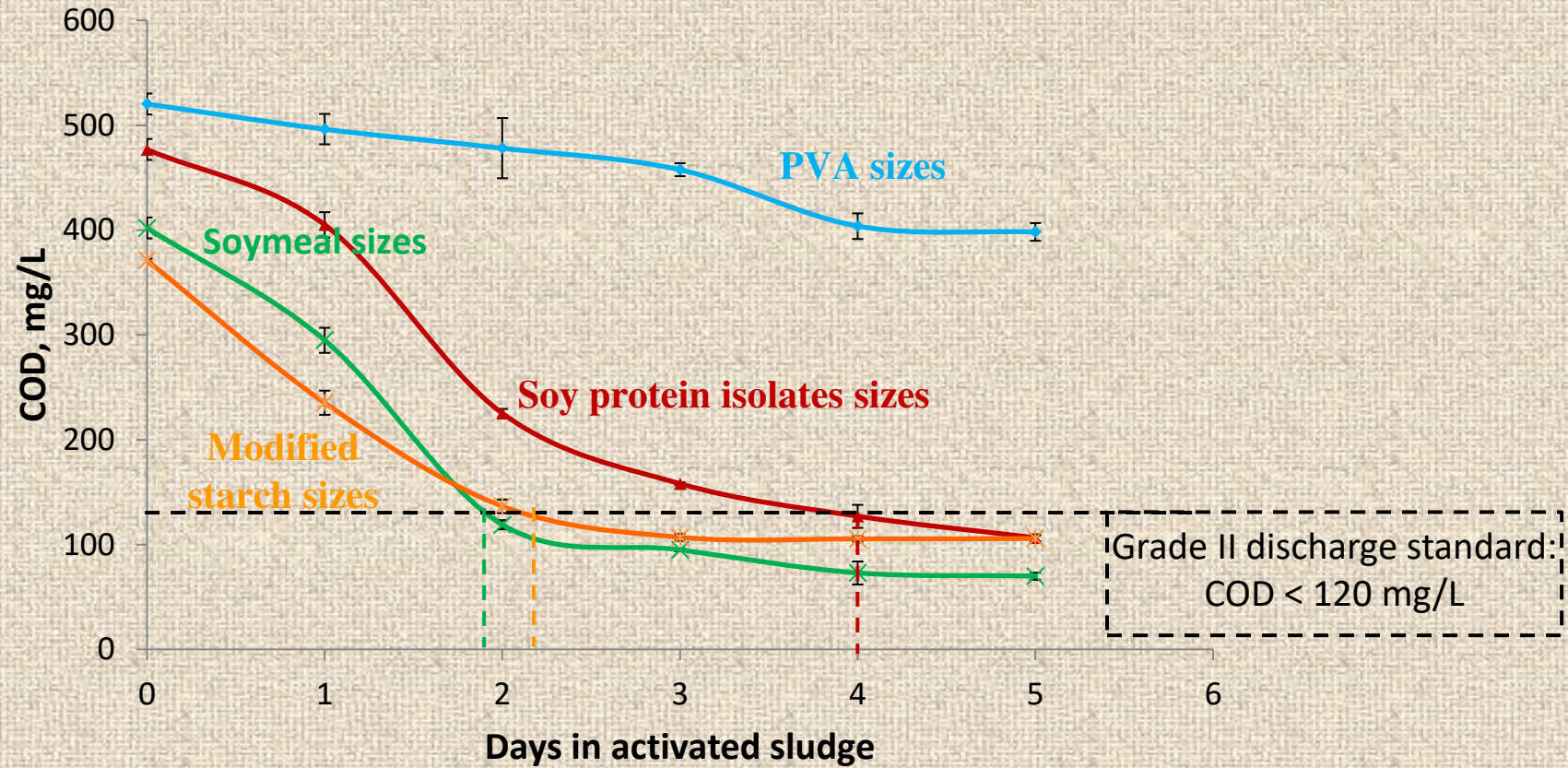
Yarn	Sizes	Add-on, %	Relative weaving efficiency, %
Cotton	Soy protein isolate sizes	16	100
	PVA sizes	21	87
	Modified starch sizes	21	61
30/70 Poly/cotton	Soy protein isolate sizes	11	100
	PVA sizes	17	97
	Modified starch sizes	14	90
Polyester (plant A)	Soy protein isolate sizes	11	97
	PVA sizes	17	100
Polyester (plant B)	Soy protein isolate sizes	10	100
	PVA sizes	7	100

# Desizing Performance

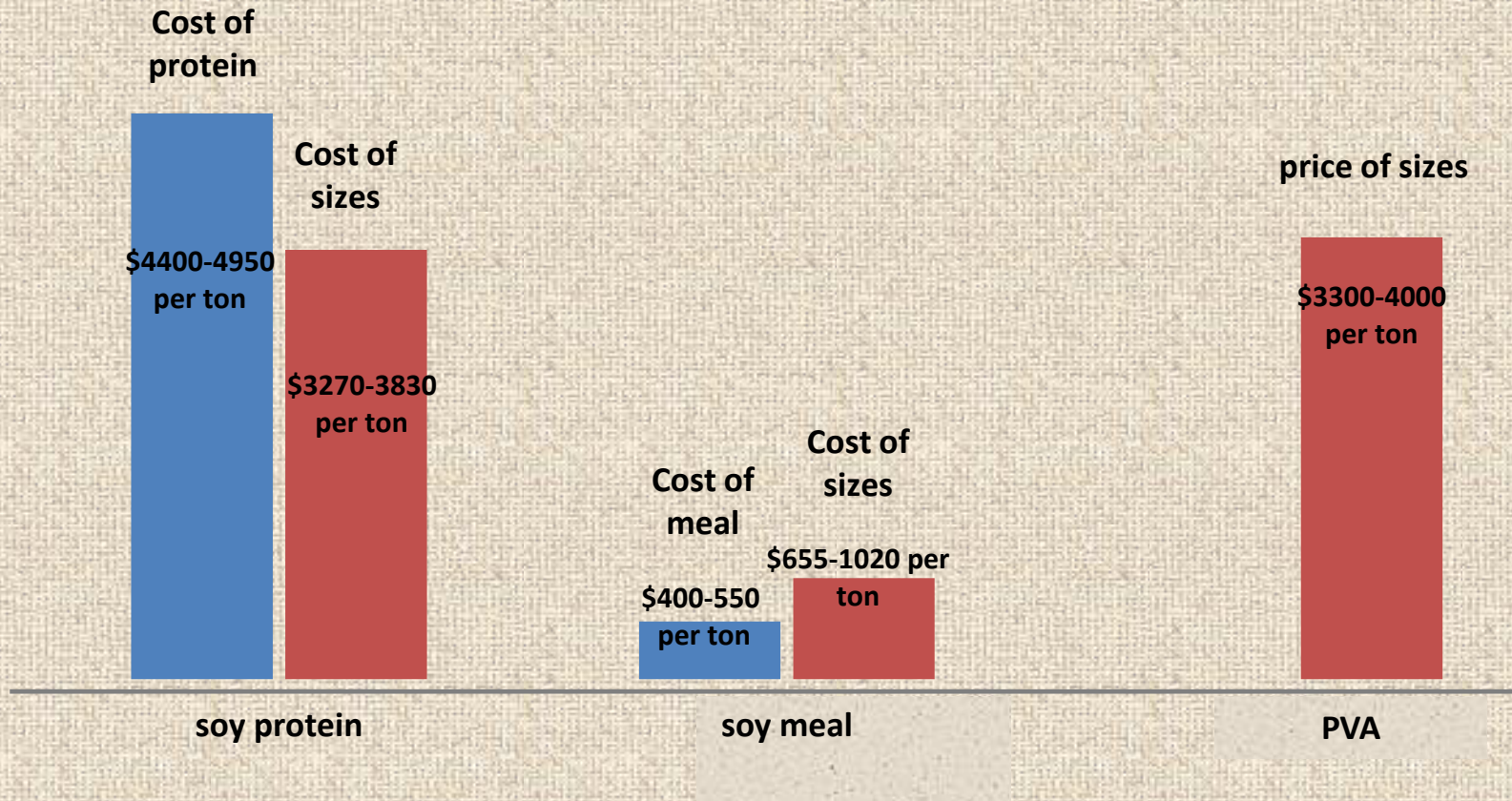
Fabric	Desizing efficiency, %			
	Soy protein isolates	Soymeal	PVA	Modified starch
Cotton	95.0 ± 2.1	92.1 ± 1.0	100	62.4 ± 4.3
30/70 Poly/cotton	100	98.3 ± 0.5	98.2 ± 1.6	65.0 ± 4.9
Polyester	100	100	94.5±2.6	-

\*Three rinses at 90 °C, liquor/fabric = 5/1

# Biodegradation-COD



# Cost Comparison: Soy protein, Soymeal vs PVA



# Traditional Coloration

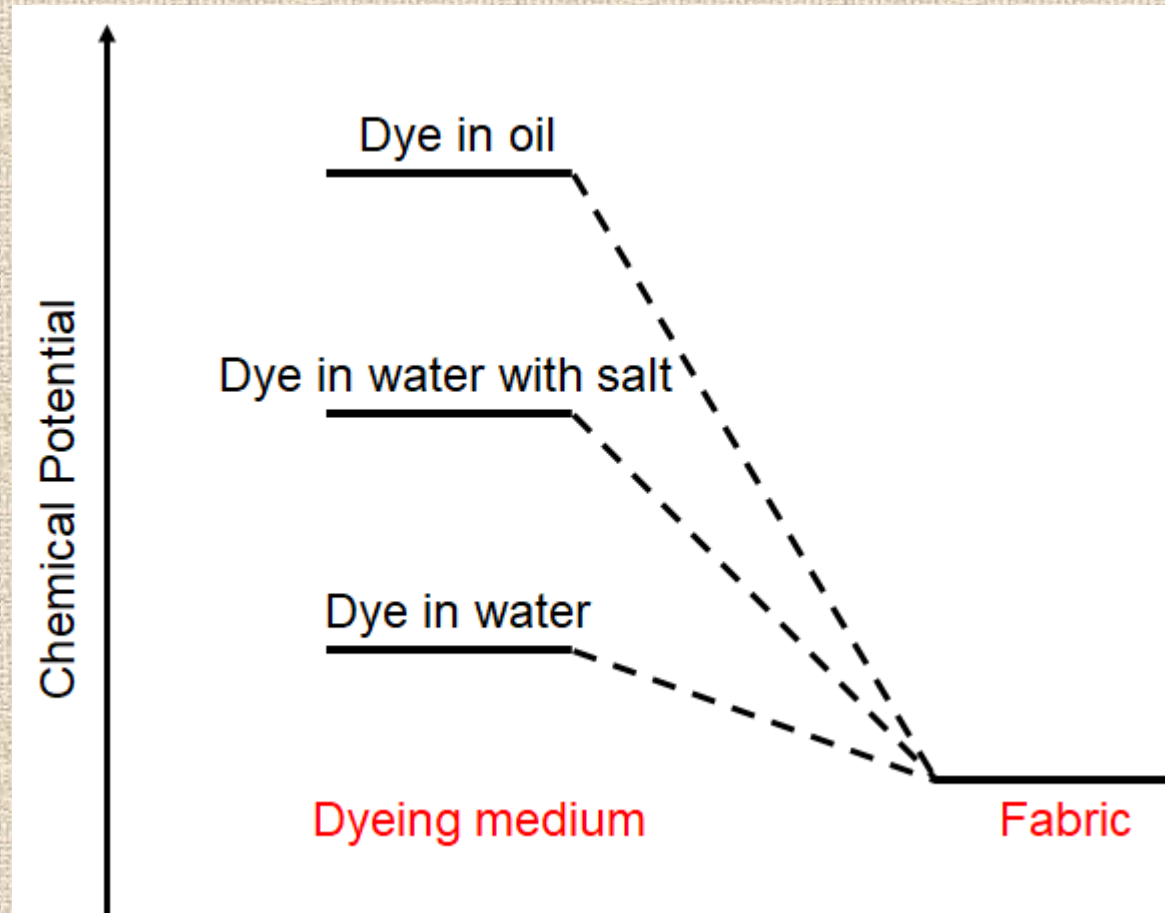
- **Salt and dye in the spent batch dyebath**
  - **Mainly reactives**
- **Challenges**
  - **Environmental problems**
- **Our efforts**
  - **Dual liquid system**
    - **Water: fiber inner phase**
    - **Oil: outer phase**

# Our Approach

- **Using plant oil/water dyeing system**
  - High dye fixation
  - No salt
- **Excellent levelness**
  - Controlled dye sorption rate
- **Reuseable dyebath**
- **Low costs**
  - No need for 100% recycling of solvent
  - No need for equipment modification
- **Environmental responsibility**
  - Plant oils are safe to use
  - Plant oils are easily degradable by activated sludge currently used

# Principles

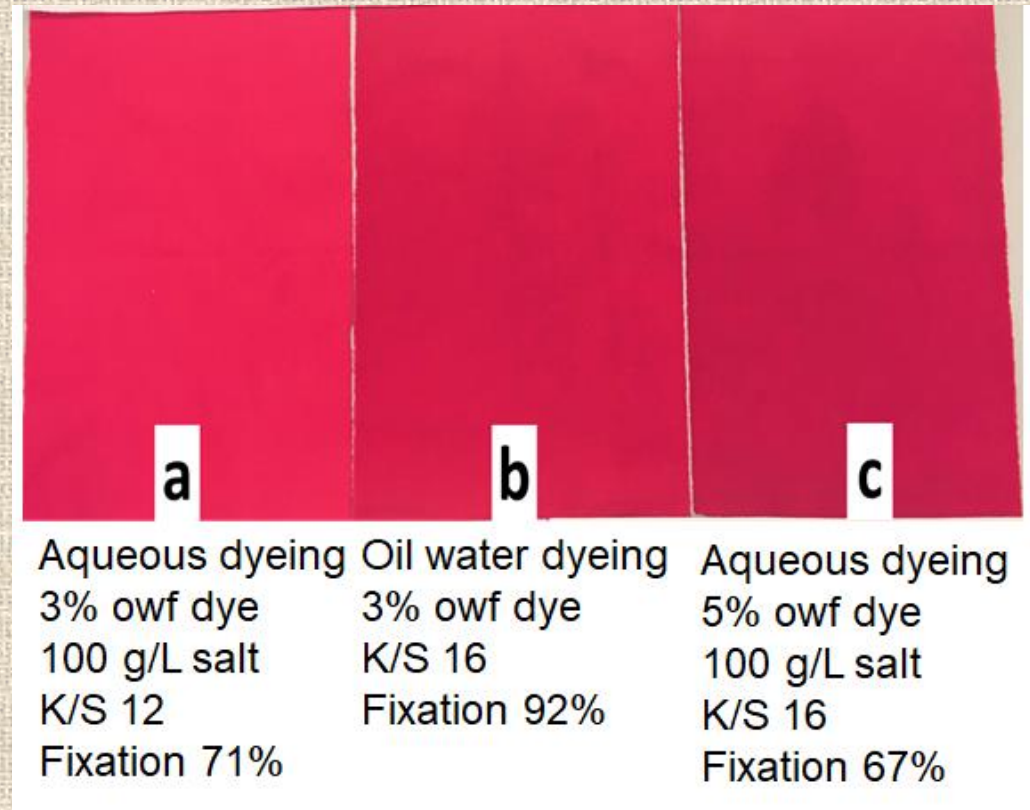
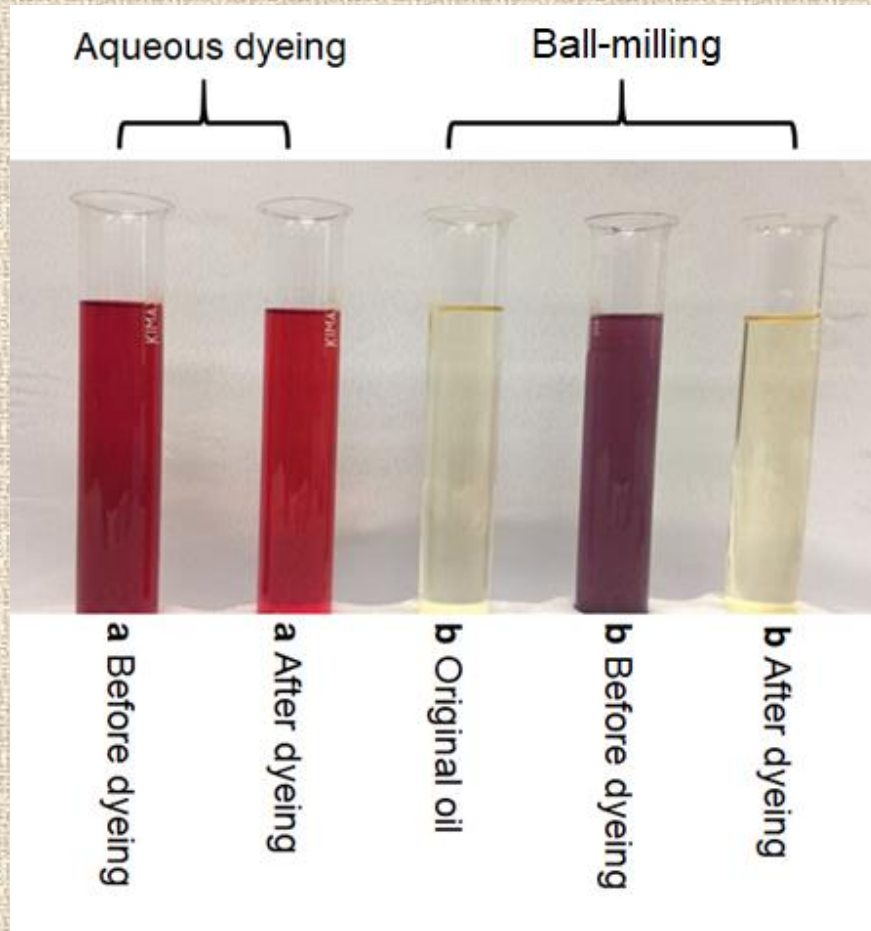
- Increased chemical potential of dye in external phase, thus increased affinity of dyes to fabric



# Potential Problems and Solutions

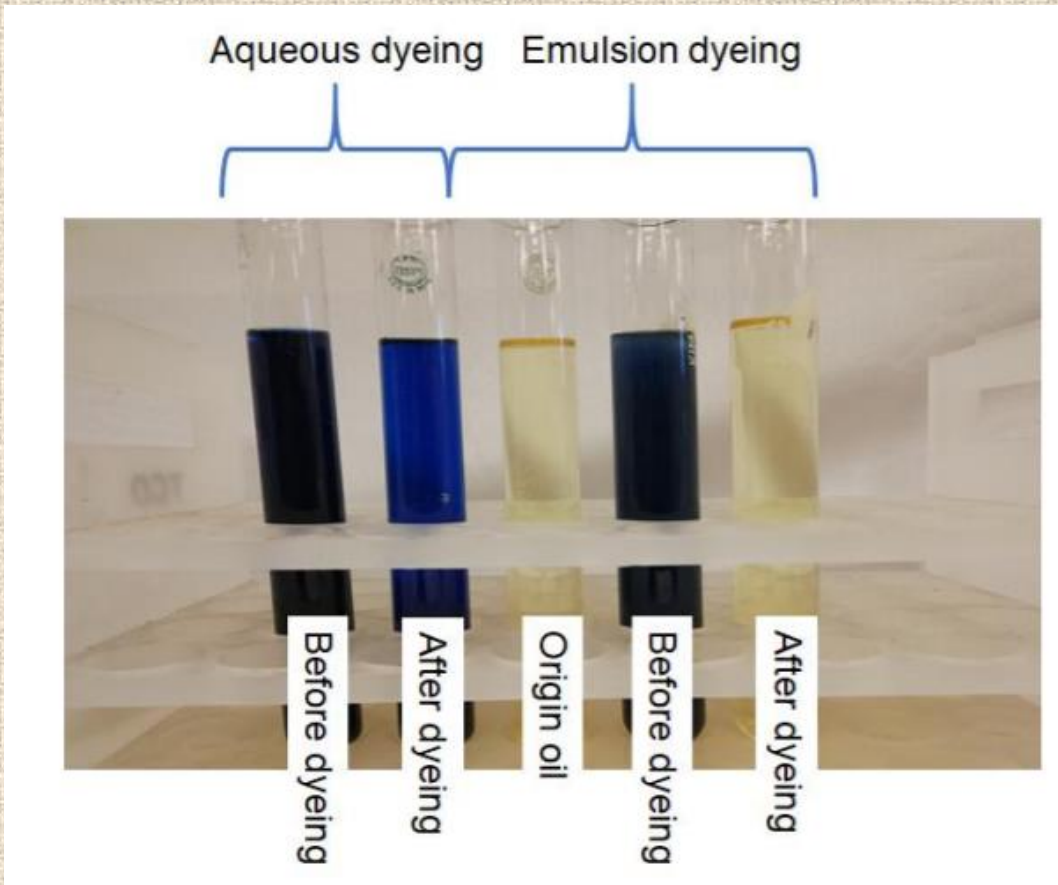
- **Fast dye sorption rate**
  - **Problem**
    - Uneven dyeing
  - **Solution**
    - Controlled dye sorption rate
    - Controlled dye migration and diffusion
- **Strong oil sorption on/in fibers**
  - **Problem**
    - Complete removal of oil from fabrics
  - **Solution**
    - Fill capillaries with water to prevent oil entrance

# High Dye Uptake and Fixation-Ball milling



3% (owf) of Reactive Red 120, ratio of oil to fabric: 20:1.  
100% owf water content. Cottonseed oil

# High Dye Uptake and Fixation-Emulsion



**2% (owf) of Reactive Blue 19, Ratio of oil to fabric: 20:1. 100% owf water content Cottonseed oil**

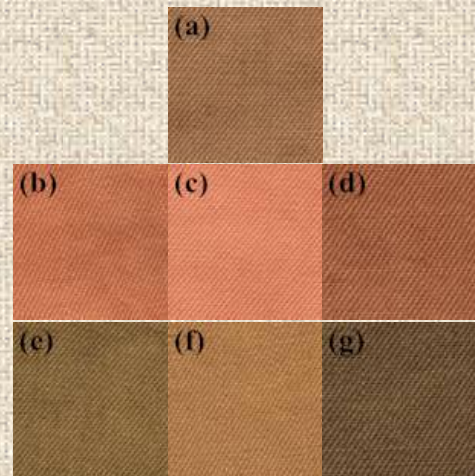
# Coloration with Natural Dyes

- **Challenges**
  - **Cost**
  - **New environmental concerns**
- **Our efforts**
  - **Natural dyes from agricultural wastes**
    - **Hulls and peels of grains and fruits**
      - **Sorghum Hulls**
      - **Orange Peels**
      - **Chlorophyllin**
      - **Granatum**
      - **Banana Peels**

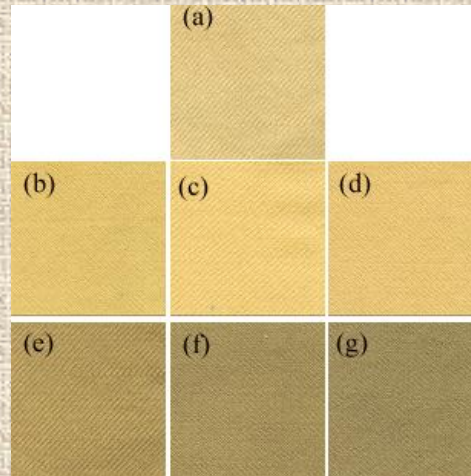
# **Advantages of Natural Dyes from Wastes**

- **Low cost comparing to planting just for dyes**
- **No additional environmental problems**
- **Large availability**
- **Unique properties**
  - **Antibacterial**
  - **UV blocking**
  - **Fluorescent**

# Some Examples



**Sorghum Hulls**



**Orange Peels**



**Chlorophyllin**

# Dye Removal from Spent Dyebath

- **Challenges**
  - **Costs**
  - **New environmental issues**
- **Our efforts**
  - **High sorption capacity**
  - **High regeneration capability**
    - **Ionic interaction with minimal van der Waals attractions**
  - **Environmental responsibility**
    - **Non-toxic in production and regeneration**

# Efficient Dye Removal and Sorbent Regeneration

- **Dyestuff sorption capacity**
  - 7g/g hydrolyzed Reactive Blue 19
- **Sorbent regeneration**
  - Concentration factor: 19 with 99% dye desorption efficiency.
- **Easy salt and dye reuse**
  - 8% reduction in dye sorption with 5 g/L NaCl
  - 12% reduction in dye sorption with 10 g/L NaCl

# Recycling of Dyes and Fibers from Apparels and Carpets

- **Challenge**
  - **Dye removal from textiles without damages**
  - **Costs**
- **Our efforts**
  - **Systems for complete dye removal and fiber separation**
    - **Elimination of dye affinity to textiles**
    - **Dissolution of dye and fiber polymers**
    - **Selective sorption/desorption and precipitation for dye and fiber separation and purification**

# Credit to the Journals

**This presentation is based on our following publications**

**ACS Sustainable Chemistry & Engineering. 5(6) 4589-4597(2017); 7(16) 13698-13707 (2019).**

**Acta Biomaterialia. 6(10) 4042-4051 (2010).**

**Biomacromolecules, 8(2) 638-643 (2007).**

**Bioresource Technology. 100(14) 3563-3569 (2009); 277. 157-170 (2019).**

**Chemical Engineering Journal. 427. 131570 (2022).**

**Environmental Science & Technology. 47(9) 4505-4511 (2013); 49(4) 2391-2397 (2015).**

**Food Hydrocolloids. 90. 443-451(2019).**

**Green Chemistry, 7(4) 190 – 195 (2005); 22(5) 1726-1734 (2020).**

**Industrial & Engineering Chemistry Research. 51(25) 8341-8347 (2012).**

**Journal of Applied Polymer Science, 59(3) 433-441(1996).**

**Journal of Cleaner Production. 52. 410-419 (2013); 139. 267-276 (2016); 236. 117566 (2019).**

**Journal of Materials Chemistry A. Materials for Energy and Sustainability. 6(22). 10320-10330(2018).**

**Trends in Biotechnology, 23(1) 22-27 (2005); 29(10) 490-498 (2011).**