

**ECONOMIC ANALYSIS OF COTTON TEXTILE FINISHING
PROCESSES
PART 1 – PRETREATMENTS
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Abstract

An economic analysis was conducted on two cotton textile pretreatments designed for the coverage of neps while dyeing cotton yarns and fabrics in textile mills. Pretreatments considered include the use of either chitosan or cellulase enzymes. The benefits examined include reduced dye use and reduced rejection of fabrics, while the costs examined include the cost of the chitosan or enzyme, costs of associated chemicals, additional labor, and variable and fixed overhead costs. The estimated benefits and costs were considered in various scenarios to determine potential cost effectiveness. Results indicated that neither pretreatment is cost effective for textile mills to adopt at this time.

Introduction

Cotton is the most commonly used natural textile fiber in the world, accounting for about 50 percent of total world fiber production (Starbird et al., 1987). Cotton represents about 38 percent of all fibers used in apparel, 18 percent in home furnishings, and about 12 percent of the fibers used in industrial products. The quality of cotton determines whether cotton is used to produce apparel or home furnishings. Cotton with a higher quality is used for clothing, while lower quality cotton is used for household or industrial products.

The Texas economy relies heavily on cotton production. Producers in the Southern High Plains of Texas (SHPT) produced 52 percent of the state's 5,095,000 bales of cotton in 1993 (United States Department of Agriculture, 1995). The SHPT consists of the counties of Andrews, Bailey, Cochran, Crosby, Dawson, Gaines, Glasscock, Hockley, Howard, Lamb, Lubbock, Lynn, Martin, Midland, Terry, and Yoakum. Cotton produced within this region is used by textile mills throughout the world.

Cotton produced in the SHPT has a reputation for having low micronaire which contributes to a high percentage of small knots or fiber entanglements known as neps. Neps appear as white specs on the surface of dyed cotton fabric and are caused by immature fibers which become entangled. The low micronaire is caused primarily by the short growing season, cool night temperatures and early freezes resulting in cotton not maturing properly. The problem of neps is one reason for fabric rejection. Rejection of the fabric at the dyeing stage is expensive because of the cost of the value-added processes from production through processing. Because neps cannot be removed manually from the fiber, processors generally must use one of several treatments to enable the fabric to receive the dye uniformly.

One treatment used for the coverage of neps involves the use of a cationic polymer pretreatment by the pad/dry process (Mehta et al., 1990). This treatment is effective in covering neps when dyeing with direct, reactive and acid dyes. However, because this treatment is based on the pad/dry method, the fabric must be dried after scouring and/or bleaching prior to its application. An alternative to the pad/dry treatment is based on the exhaust method, which eliminates a drying process and is easily incorporated into most fabric preparation sequences already being used (Mehta and Combs, 1990). One treatment which uses the exhaust method involves the use of a derivative of chitin.

Chitosan

Chitin is the second most plentiful, naturally occurring polymer, after cellulose, in the world. Chitin is found in the exoskeletons of arthropods. For commercial uses this product is primarily derived from shrimp and crabs. Chitosan, a derivative of chitin, is prepared by partial deacetylation of the chitin. Chitin and chitosan have a variety of special functions ranging from health and beauty aids to water purification, biomedical applications, agriculture, biotechnology, nutrition, and treatments in the finishing process of textile fibers. Chitosan can also be used in a process which covers neps in cotton fabrics. The chitosan pretreatment is used on yarns before the yarn is woven into fabric. This process takes place within a keir. A keir is a large metal cylinder which is used to dye yarns using the exhaust process.

The fiber containing neps is pretreated with a mixture of chitosan, a non-ionic wetting agent, and sodium sulfate (hereafter referred to as chitosan pretreatment). The chitosan pretreatment requires no additional machinery and increases the dyeing ability of direct and reactive dyes. This treatment is also effective in eliminating differences in color between dyed immature and mature cotton fibers (Rippon, 1984). The binding of the chitosan with the cellulose already present in the cotton fiber increases the fiber's dyeing ability and reduces problems resulting from immature or entangled fibers that will not accept dye, thereby reducing the impact of the quality problem most SHPT producers face.

Chitosan is biodegradable when used and distributed into the environment in a dispersed fashion. Thus, using chitosan treatments in the textile dyeing process represents an environmentally sound practice (Mehta 1996). With the introduction of chitosan pretreatments for cotton yarns and fabrics, the primary problem caused by neppiness can be overcome.

A limitation of the chitosan pretreatment is that it enhances the performance of some dyes better than others. Chitosan treatments, used in conjunction with direct dyes, increase the color strength more than reactive dyes (Mehta, 1996). An additional problem with the chitosan treatment is that it reduces the quality of the wash-fastness and/or color-fastness properties. However, this problem is eliminated with the introduction of a post treatment consisting of fiber-reactive quaternary ammonium compounds (Rippon, 1984). This additional requirement, however, adds to the already numerous stages through which mills must place their yarns without any assurance that their efforts will pay off.

Cellulase Enzymes

Another product used to overcome the problem associated with neps is cellulase enzymes. Cellulase enzymes are used in the scouring, desizing, bleaching, and finishing phases of the textile manufacturing process. The enzymes are used to reduce fabric fuzziness, soften fabric, remove color for special effects, and for the removal of neps (Blanchard and Graves, 1995). The cellulase enzyme causes a chemical reaction with the cellulose on the surface of cotton fibers. The weak, extending fibers (e.g., those fibers which have ends protruding from the fabric providing an appearance of fuzziness) are then detached using mechanical agitation. The fibers must then be cleaned from the fabric. While the chitosan pretreatment can be used on yarns before they are woven into fabric, the enzyme pretreatment must be used on fabrics. Fabrics may be treated with the exhaust process using a dye jig.

The process used by Ankeny (1996) for the use of cellulase enzymes in cotton preparation includes setting the bath at 27 degrees Celsius with the fabric present, and adding a buffer which keeps the pH stable. This mixture is allowed to circulate for five minutes, then the pH is measured and adjusted to between 4.5 and 5 (4.8 is considered optimum) with acetic acid. The temperature is then raised to 58 degrees Celsius, and the pH is again measured and adjusted to 4.8. The cellulase enzyme is added, and the solution is circulated for 30 minutes with high agitation. The liquid is then extracted, the bath is filled with hot water and heated to 83 degrees Celsius followed with 10 minutes of circulation. The bath is drained, and the fabric rinsed with cold water. The final step involves a mechanical treatment such as a tumble dry to remove surface fibers.

The hot water is needed quickly after the chemical reaction between the enzymes and the cotton. The enzymes are neutralized by the hot water before the enzymes can further react with all fibers in the fabric. By neutralizing the enzymes (with either hot water or alkali), fabric strength is maintained. If the enzymes are not neutralized quickly enough, the fibers in the entire fabric will be damaged and will lose strength.

The use of cellulase enzymes to remove neps requires a mechanical treatment. In the above process, the tumble dry component removes all surface fibers which have been damaged by the enzymes. If the fabric is not tumble dried, an alternative mechanical treatment must be used to remove the surface fibers. This can be done in a continuous range with a mechanical arm which rubs against the fabric, removing fibers. To conduct an analysis of this treatment which can be used with the exhaust process, it is assumed that the mechanical action provided by the scouring process within a keir is sufficient to remove the surface fibers when combined with the knitting and weaving of the yarn into fabric.

Specific Problem

Because these pretreatments are unfamiliar to many textile processors, they are reluctant to adopt these practices, thereby not potentially maximizing their profits. Processors should be made aware of the potential economic benefits and costs of these treatments.

The objective of this study was to conduct a benefit/cost analysis of the use of these pretreatments for cotton yarns and fabrics. Issues such as decreased use of dye and decreased rejection of fabrics at the mill are considered.

Methods and Procedures

Estimation of the cost effectiveness of adoption of these pretreatments was accomplished by conducting a benefit/cost analysis for the use of one of these treatments in a representative mill setting. Estimated cost values from the dyeing process of a representative mill are included in Table 1. This representative mill is assumed to be a medium sized textile mill, which uses between 18,000 and 22,000 bales of cotton per year to produce apparel and furniture upholstery. It is assumed that approximately 80 percent of this cotton is used to produce light weight fabrics for apparels and the remainder is used for household and industrial upholsteries.

It is assumed that the representative mill has a rejection rate of 3.5 percent of the fabric. It is further assumed that 10 percent of this rejection is due to the presence of neps. Thus, it is assumed that 0.35 percent of the light weight fabric is rejected due to the presence of neps. If the textile mill were to adopt either of the considered pretreatments, a decrease in the percentage of fabric rejection would be a benefit. It is assumed that textile mills generally will not purchase a lower quality cotton merely because these pretreatments would overcome the problem associated with neps. The purchase of a lower quality cotton would lead to a lower quality finished product.

Cost-effectiveness of the pretreatments considered in this study was determined by whether benefits outweigh costs. The major benefits examined in this study are the reduction in use of dye and the decrease in the amount of fabric rejected due to the presence of neps. The reduction in the amount of dye used is only considered for the chitosan pretreatment because the use of the cellulase enzyme pretreatment does not allow for less dye use. The amount of the reduction in dye used for the chitosan pretreatment will depend on the depth of color preferred, which will affect the amount of dye used.

The cost of adopting either pretreatment can be expressed in the following form:

$$TC = CP + CAC + VOH + FOH + CAL.$$

Where TC is the total cost of the treatment, CP is the cost of the treatment product (i.e., chitosan or cellulase enzymes), CAC is the cost of the additional chemicals (i.e., sodium sulfate, wetting agent, buffer, acetic acid, etc.), VOH is the increase in variable overhead, FOH is the increase in fixed overhead, and CAL is the increase in cost of additional labor. The total benefits (TB) are expressed in the following form:

$$TB = VDD + VDR.$$

Where VDD is the value of the decrease in the amount of dye used (this benefit will only apply to the chitosan pretreatment), and VDR is the value of the decrease in fabric rejection. The economic efficiency of adopting the pretreatments is determined by whether TB is greater than TC, or if net returns ($NR = TB - TC$) are greater than zero.

Results

Chitosan Pretreatment Costs

Table 1 presents the estimated costs of three wet processes from a representative textile mill. This data was supplied from an actual mill setting. To protect the anonymity of the mill, the identification is not disclosed. The first procedure for which data is presented is a bleach formula process. Yarn treated by this process will be used in white fabrics only. These values are expressed in dollars per pound of yarn. The total cost of putting yarn through the bleaching process was found to be \$0.14990 per pound of yarn. This total cost consists of labor, variable overhead (which includes water and electricity),

fixed overhead (representing a percentage of the firm's fixed costs), and chemical costs. Also in Table 1 are the various costs for putting a yarn through a process that involves scouring, not bleaching, and being dyed black. Scouring is a process in which the fabric or yarn is cleansed, using detergents and soaps, and either an abrasion or rubbing treatment. This process is used to remove dirt, grime, soil and other foreign matter or particles. The final process presented in Table 1 is a process in which the yarn is scoured and bleached, then dyed red. The bleach process is less expensive than the other two representative processes because it requires less time to complete the process and there are no dye costs associated with this process. The bleaching process requires approximately 90 minutes to complete, while the dyeing processes requires an additional 40 to 50 minutes.

Table 2 presents the various costs associated with the chitosan pretreatment. Chitosan prices depend on the quantity purchased. Venson, Inc. provided prices for chitosan. If less than 50 pounds is purchased, the price of the chitosan is \$15 per pound. This price decreases to \$10 per pound when the amount purchased is between 50 and 499 pounds. The price is further reduced to \$8.50 per pound and \$8 per pound when the amount purchased is between 500 and 2000 pounds and over 2000 pounds, respectively. Pricing is available at a lower cost per pound when contracting to annually purchase larger quantities over a multi-year period.

The amount of cotton processed in the representative mill is assumed to be 18,000 bales per year (bale weight is 480 pounds). This represents 8,640,000 pounds of cotton lint processed annually. Given that the amount of chitosan used is 0.4 percent on the weight of the cotton, and assuming that the representative mill uses 80 percent of that cotton to produce light weight fabrics, the expected amount of chitosan needed annually is 27,648 pounds (i.e., $18,000 \text{ bales} * 480 \text{ pounds per bale} * 0.8 * 0.004$). Thus, the representative mill qualifies to enter into a contract with the chitosan supplier to receive a lower price. Because these lower prices are not known, the cost effectiveness of the treatment is initially determined using a cost of \$8 per pound for chitosan. However, this cost is later reduced for further analysis.

The chemical costs for the chitosan pretreatment are determined by the amount of chitosan used, the price of chitosan and the prices of associated chemicals. The amount of non-ionic wetting agent used is 0.1 percent on the weight of the yarn, and the amount of sodium sulfate (Glauber salt) used is 10 percent on the weight of the yarn. The price of sodium sulfate is \$0.22 per pound, and the price of the non-ionic wetting agent is \$0.89 per pound.

The time required for the chitosan treatment is assumed to be represented in the fixed overhead costs. Water and electricity used in this process is represented in the variable overhead costs. The bleach process previously presented takes an average of 90 minutes to complete. Because the chitosan treatment takes approximately 30 minutes, it is assumed that one chitosan pretreatment will require one-third of the labor costs, and one-third of the variable and fixed overhead costs specified for the bleach process. Thus, given the data contained in Table 2, the estimated cost of the chitosan pretreatment is approximately \$0.10 per pound of yarn.

Chitosan Pretreatment Benefits

As stated previously, one of the benefits recognized from the use of the chitosan pretreatment is the reduction of the amount of dye used. For direct and reactive dyes, the chitosan treatment can reduce the amount of dye required by ten percent. The reduction in the amount of dye used is based on the K/S value which measures the color value, or strength of the dye (Mehta and Combs, 1990). The average cost of direct dyes is approximately \$7 per pound, and reactive dyes cost an average of \$17 per pound (Mehta 1996). The amount of dye used depends on the desired depth of color. For a moderate shade of any color, the general amount of dye used is approximately 2 percent of the weight of the yarn. Thus, two pounds of dye is used to dye 100 pounds of cotton yarn.

The average amount of dye required to dye one pound of cotton a moderate shade of any color is 0.02 pounds. Assuming the use of a direct dye, the use of the chitosan pretreatment will decrease the required amount of dye by ten percent. Therefore, the amount of dye required to dye one pound of yarn after the chitosan pretreatment is .018 pounds. Assuming the use of a direct dye, the benefit in decreased use of dye resulting from the adoption of the chitosan treatment is 1.4 cents per pound of cotton (i.e. $\$7/\text{lb} * (.02-.018)$).

Another benefit received from adopting the chitosan pretreatment is the decrease in the rejection of fabric due to the problem of neps. The representative mill is assumed to process 6,912,000 pounds of cotton per year

for use in apparels (i.e., 18,000 bales * 480 pounds per bale * 80 percent). It is assumed that the representative mill is producing yarn as a blended product of numerous qualities of raw cotton lint. This yarn is assumed to be homogeneous. Therefore, the mill is assumed to treat all yarn used in apparels with the chitosan process to receive the 10 percent reduction in the 3.5 percent fabric rejection. Thus, with a 3.5 percent fabric rejection, it is assumed that the mill rejects 241,920 pounds of fabric per year. It is further assumed that ten percent of this (24,192 pounds) is rejected due to the presence of neps. The chitosan pretreatment is assumed to be able to prevent the rejection of this 10 percent of the 3.5 percent rejected fabric. The mill is assumed to measure the cost of this rejection in terms of linear yards of fabric. The representative mill receives an average of \$3.25 for each linear yard of finished fabric. They sell their rejected fabric in a secondary market for an average of \$1.25 per linear yard. Therefore, the loss due to rejection is \$2.00 per linear yard of fabric rejected. Assuming a light weight yarn of 5 ounces per square yard of fabric, and a 60 inch fabric width, one linear yard of fabric contains 0.52 pounds of cotton. The 24,192 pounds of rejected fabric represents 46,523 yards of fabric. This fabric has a loss due to the presence of neps of \$2.00 per yard. Therefore, the loss in value of the rejected fabric is \$93,046. Thus, given this value of the use of the chitosan treatment, the value per pound of cotton treated is \$0.0135 per pound of cotton (i.e., \$93,046/6,912,000 pounds of cotton). Therefore, the adoption of the chitosan pretreatment will yield a 1.35 cent benefit per pound of cotton due to the reduction of rejected fabric.

The cost for adopting the chitosan pretreatment is approximately 10 cents per pound of cotton. The combined benefits received from reduced fabric rejection and when using direct dyes are 2.75 cents per pound (i.e., \$0.0140 + \$0.0135), and 4.75 cents per pound (i.e., \$0.0340 + \$0.0135) when using reactive dyes. The net revenues from adoption of the chitosan pretreatment are approximately -\$0.0725 cents per pound of cotton treated when using direct dyes. Thus, the benefits of the chitosan pretreatment do not outweigh the costs of implementing this process in textile mills at this time.

Cellulase Enzyme Pretreatment Costs

The price of the liquid enzyme Cellusoft L[®] ranges between \$3 and \$4 per pound, with the lower price being for shipments of 500 pounds or more of the product (Brian Condon, personal communication, Novo Nordisk, Frankinton, NC, May 23, 1997). The amount of enzyme used is 1 gram per liter of solution. If the process takes place within a 1514 liter capacity keir, this will treat approximately 363 pounds of fiber. The amount of enzyme needed would be approximately 1514 grams, or 3.34 pounds (453.592 grams per pound). Thus, the amount of enzyme needed for the treatment of 1 pound of cotton is 0.0092 pounds (i.e. (3.34 pounds of enzyme) / (363 pounds of fiber)) costing approximately 2.8 to 3.8 cents per pound of fabric.

As mentioned previously, the representative mill processes approximately 6,912,000 pounds of cotton per year for apparel use. To use the enzyme pretreatment, all cotton designated for use in apparels must be treated. Thus, the amount of cellulase enzymes used in a year would be approximately 63,590 pounds of enzyme (i.e., 0.0092 * 6,912,000). This amount is sufficient to receive the discounted price. With the \$3 per pound price, the enzyme cost of treating one pound of cotton would be \$0.0276 (i.e., 0.0092 * \$3).

The treatment process calls for the use of a buffer to stabilize the pH of the solution as the treatment is taking place. A buffer called Tanatex or Buffer-In 5 is often used in the enzyme process developed for stone washing blue jeans. The product is measured on a grams per liter basis and costs approximately \$0.50 per pound (Dean J. Bender, personal communication, Sybron Chemicals, Inc., Birmingham, NJ, May 30, 1997). The amount used in the enzyme pretreatment is approximately 6 grams per liter of solution. As previously stated, the amount of solution used for one treatment within a keir is 1514 liters. Thus, the amount of buffer used for one treatment is 9084 grams (i.e., 1514 liters * 6 grams/liter), or 20.027 pounds of the buffer (i.e., 9084 grams / 453.592 grams per pound). Given that one treatment within the keir contains approximately 363 pounds of fiber, the amount of buffer used per pound of cotton is approximately 0.0552 pounds. Thus, at \$0.50 per pound of product, the cost of buffer per pound of cotton treated is approximately \$0.0276.

Acetic acid is used to bring the pH of the solution to an optimum point of 4.8 during the enzyme treatment. The amount of acetic acid used in the treatment is assumed to be 15 milliliters per 100 liters of solution. This amount will be changed to determine different levels of cost effectiveness in the sensitivity analysis. The cost of the acetic acid is \$0.50 per pound. This leads to a cost of acetic acid per pound of cotton treated of \$0.000014598.

Labor, and variable and fixed overhead costs for the chitosan pretreatments were taken from data provided for the bleach formula. Because the cellulase enzyme treatment requires a scouring process to remove the surface fibers, the treatment costs are taken from the cost values provided by the representative mill for the black color which includes a scouring process. As discussed previously, a scouring process includes either a rubbing or abrasive action which is assumed to be sufficient enough to remove the surface fibers after the chemical reaction between the enzyme and the cotton fibers has taken place. While the scouring process by itself will not remove all surface fibers, the use of the scouring treatment, along with the knitting and weaving processes, will remove a sufficient amount of the fibers. The amount of time required to conduct the enzyme treatment is approximately 10 minutes for the preparation of the solution, 30 minutes of high agitation for the chemical reaction to take place, 10 minutes of hot water to kill the enzyme, and 14 minutes of rinsing in cold water to remove any residual. Therefore the enzyme treatment requires approximately 64 minutes to complete and a typical scouring process takes approximately 40 minutes to complete. Therefore, the values for labor and variable and fixed overhead costs for the enzyme treatment is approximately 142 percent of the costs for the scouring process provided by the representative textile mill. Treatment costs for the cellulase enzyme pretreatments are presented in Table 3. As can be seen in Table 3, the cost per pound of cotton using the cellulase enzyme pretreatment is approximately \$1.08. The cost for this process is high because of the amount of labor, and fixed and variable overhead required.

Cellulase Enzyme Pretreatment Benefits

Unlike the chitosan pretreatments, the use of cellulase enzymes causes a decrease in the K/S value of the treated fabric. Although this decrease is not sufficient to require the use of more dye, the treatment benefit of using less dye with the chitosan pretreatment is not realized when treating the fabric with cellulase enzymes. Thus, the only quantifiable benefit realized from the use of cellulase enzymes is the decreased rejection of fabric due to the presence of neps.

The value of the benefit of decreased rejection received from using the cellulase enzyme pretreatment is the same as that received from the use of the chitosan pretreatment. That is, the benefits received for the decrease in the rejection of fabric is \$0.0135. Therefore, the net revenue for adopting the cellulase enzyme pretreatment is approximately \$-1.07.

Sensitivity Analysis

A sensitivity analysis was conducted on each of the processes considered to determine whether changing certain costs will improve cost effectiveness. Another purpose for the sensitivity analysis was to determine how sensitive the results are to the data used. Certain values could not be determined with 100 percent accuracy. These values were changed to consider various techniques used in different textile mills, different amounts of treatment product used, and different prices for these treatment products. The total costs and benefits received from adoption of a process were also changed to determine what would need to change to cause the pretreatments to become cost effective. Additional changes are made to determine if the treatment would be cost effective in a different time frame.

Chitosan Pretreatment

Many scenarios were considered for each pretreatment. In the sensitivity analysis for the chitosan pretreatments, costs were decreased and benefits were increased to determine whether it would be cost effective for textile mills to adopt this treatment which use different processes or have different costs than those presented by the representative mill.

The original net revenues for the representative textile mill was approximately \$-0.07 per pound of cotton treated. Changing several benefits and costs did not reveal any scenario that would cause the treatment to be cost effective. An extreme scenario which remained not cost effective was when the cost of the entire pretreatment was reduced from approximately 10 cents per pound to 5 cents per pound and the cost of the dye was increased from \$7 per pound (the cost of direct dyes) to \$17 per pound (the cost of reactive dyes). Increasing the cost of the dye increased benefits because less dye is needed after treating the fabric with chitosan. The net revenues from adoption of the chitosan pretreatment in this scenario was approximately \$-0.0255. With negative net revenues for all scenarios considered, it was determined that the chitosan pretreatment would not be cost effective for any textile mill to adopt at this time.

Cellulase Enzyme Pretreatment

Again, several scenarios were considered to determine at what point the cellulase enzyme pretreatment would become cost effective. Benefits were increased and costs were decreased to determine if the pretreatment would be cost effective for other textile mills incurring different costs.

The original net revenues from adoption of the cellulase enzyme pretreatment were approximately \$-1.07. After considering a number of changes in both benefits and costs, the cellulase enzyme pretreatment was not found to be cost effective in any scenario considered. The net revenues were approximately \$-0.55 when labor and overhead costs were decreased by as much as 50 percent and the percentage of rejected fabric due to the presence of neps was increased from the original 10 percent to 15 percent. Ten percent of the overall rejected fabric was rejected due to the presence of neps. If this percentage were to increase, the benefit received from the reduction in the amount of fabric rejected would increase. With negative net revenues for all scenarios considered, it is determined that the cellulase enzyme pretreatment would not be cost effective for textile mills to adopt at this time.

Conclusion

Pretreatments using both chitosan and cellulase enzymes are not cost effective for the representative textile mill within the constraints set forth in this study. The main reason for this is the fact that all cotton destined for use in apparels must be treated. If a cost effective technology existed that would allow mill managers to identify the presence of neps before the fabric has been dyed, the pretreatments in this study could become cost effective. However, because this technology is not available at this time, the pretreatments considered in this study would not be cost effective for textile mills to adopt.

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Table 1. Costs for Various Textile Processes in a Representative Textile Mill (\$/lb of yarn).

Process	Labor	Var OH ¹	Fix OH ²	Dyes	Chem	Total
\$/lb of Cotton Treated						
Bleach	0.032	0.069	0.034	0.000	0.014	0.150
Black ³	0.171	0.367	0.182	0.490	0.165	1.374
Red ⁴	0.157	0.337	0.168	0.100	0.090	0.850

¹ Var OH represents costs of variable inputs such as electricity, water, and others not described elsewhere.

² Fix OH represents costs of fixed inputs as well as time required for the prices.

³ Scoured, not bleached.

⁴ Scoured and bleached before being dyed.

Table 2. Input Costs for the Chitosan Pretreatment.

	Cost (\$/lb)	Amount Used (o.w.y.*)	Cost (\$/lb)
Chitosan	\$8.00	0.4%	\$0.0320
Sodium Sulfate	\$0.22	10%	\$0.0220
Non-ionic Wetting Agent	\$0.89	0.1%	\$0.00089
Labor			\$0.0107
Variable Overhead Costs			\$0.0231
Fixed Overhead Costs			\$0.0113
Total Cost of Process			\$0.0999

* On weight of yarn.

Table 3. Costs per Pound of Cotton Treated for Cellulase Enzyme Pretreatments.

Input	Cost (\$/lb)	Amount Used (lbs.)	Total Cost (\$/lb)
Cellusoft L [®]	3	0.0092	0.0276
Buffer-In 5	0.50	0.0565	0.02825
Acetic Acid	0.50	0.000029195	0.000014598
Labor			0.24282
Var OH			0.521282
Fixed OH			0.259292
TOTAL			1.079259