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Neural Network Approach for Optimizing the Bioscouring Performance of Organic Cotton Fabric through Aerodynamic System

C. Vigneswaran[a]*
M. Ananthasubramanian[b]
N. Anbumani[c]

[a]Department of Fashion Technology, [b]Department of Biotechnology
and [c]Department of Textile Technology
PSG College of Technology
Coimbatore, Tamil Nadu, India

(*Corresponding author)

ABSTRACT

The process optimization of bioscouring of 100% organic cotton fabric through enzyme technology with aerodynamic system have been studied with selective specific mixed enzymatic system using four enzymes namely alkaline pectinase, protease, lipase and cellulase. The process variables such as enzyme concentration, temperature and reaction time have optimized to achieve the required water absorbency and pectin removal during bioscouring process by pectinolytic and proteolytic activity on the organic cotton fabrics. These process variables are selected based on the artificial neural network (ANN) and output of experiment was resulted with fabric physic properties such as fabric weight loss, water absorbency, wetting area, whiteness index, yellowness index, and brightness index using MATLAB 7.0 software with minimum error and also studied with and without aerodynamic treatments. The test results have analyzed to predict the optimum process parameters to achieve the required bioscouring fabric properties and removal of pectin degrading rate and compared their results with actual trials. This study will be helpful to the organic cotton processors for the eco-friendly and sustainable textile wet processing using specific mixed enzymatic system in bioscouring processes.

Keywords: Organic cotton, enzyme scouring, pectin, wax removal, air pressure, aerodynamic efficiency.

1 INTRODUCTION

Research on enzyme systems for textile processing and finishing has mainly focused on amylases and cellulases. However, recent biotechnology and genetic engineering advances have opened opportunities for successful applications of other enzyme systems, such as lipases, xylanases, laccases, proteases and pectinases [1, 2]. Today, enzymes can be customized for specific target areas; for example, enzymatic degumming of silk, bioscouring of grey cotton and antifelting and softening of wool. The application of enzymes to organic synthesis is currently attracting more and more attention. The discovery of new microbial enzymes through extensive and persistent screening will open new, simple routes for synthetic processes and, consequently, new ways to solve environmental problems [3, 4]. Advances in biotechnology and enzymology have brought new lines of research and have accelerated the development of enzymatic applications in textile wet processing for now nearly one decade. Amongst the various stages of cotton preparation, textile wet processing is a highly energy, water and chemicals consuming processes [5-7]. Enzymes are known for their specificity, high efficiency and ability to work under mild conditions and provide a promising solution to eco-friendly processing challenges [8, 9]. It is clear that enzyme technology can be used to develop a usable, more environmental friendly, economical competitive scouring process. Several attempts were made to develop an enzymatic cotton scouring process [10-12]. Still this process faces several problems like a long incubation time, high enzyme doses, sometimes non-uniform enzyme action, uneven dyeing behavior, high temperature wax removal and overall slow process speeds [13, 14]. The most important aspect identified was the inability to remove cotton fiber pectin and waxes. The Global Organic Textile standard (GOTs) is emerged as a result of a technical harmonization procedure for organic cotton processing. During last few years GOTs has become the leading organic textile processing standard [15]. Organic agriculture protects the health of people and the planet by reducing the overall exposure to toxic chemicals from synthetic pesticides that can end up in the ground, air, water and food supply, and that are associated with health consequences, from asthma to cancer. Because organic agriculture doesn't use toxic and persistent pesticides, choosing organic products is an easy way to help protect the people. Internationally, Turkey and the United States are the largest organic cotton producers [16].

Apparel and textile companies that are expanding their 100% organic cotton program and developing programs that blend small percentages of organic cotton with their conventional cotton products are driving demand. The need of the organic cotton fabric for textile wet processing is required to process with minimum safe chemicals to health or alternative way to go enzyme technology, because enzymes are substrate specific bio-catalysts; they operate best at ambient pressures, mild temperatures and often at a neutral pH range. Enzymes are gaining an increasingly important role as a tool in various wet textile pre-treatment and finishing processes [17-20]. Biocatalysts have proven to be a flexible and reliable tool in wet textile processing and a promising technology to fulfill the expected future requirements. Enzymatic scouring has been investigated extensively by various institutes and laboratories now for nearly one decade [21-24]. Different enzymes like pectinases such as lyases (EC 4.2.2.2); polygalacturonase endo acting type (EC 3.2.1.15) and polygalacturonase exo acting type (EC 3.2.1.67), proteases (EC 3.4.21-25), cellulases such as endoglucanases (EC 3.3.1.4); cellobiohydrolases (EC 3.2.1.91), xylanases (EC 3.2.1.8), lipases (EC 3.1.1.3) and recently cutinases (EC 3.1.1.74) have been examined to degrade and subsequently remove the natural component present in the outer layer of cotton fibers [25, 26]. These studies incorporated staining tests, scanning electron microscopy (SEM), weight loss analysis, cotton wax residue and nitrogen content analysis. Pectin’s are acidic polysaccharides, which are found in fruits, fibers and vegetables [27, 28]. Pectin being a non-cellulosic material in cotton fibers plays several important roles. It contributes to the firmness and structure of cotton fiber, both as a part of the primary cell wall and as a component of the winding layer [29]. Pectin acts as cementing material for the cellulosic network in the primary wall [30]. Pectin has a complex structure and comprised of α-(1, 4)-linked D-galacturonan backbone, occasionally interrupted by α-(1, 2)-linked α-L-rhamnopyranose residue. In cotton fibers, up to 60% of the galacturonic acid residues of the backbone are methyl esterified [31].

Scouring is related to hydrophilicity and can be achieved by uncovering the pores that are already present in the fibers, by removing waxes and other non-cellulosic materials in the primary wall. Many researchers have recognized the technical feasibility of enzymatic scouring over the last decade. However, continuous enzymatic scouring process has not yet been widely implemented by textile industries. The most important reason identified was the inability to remove cotton fiber waxes during enzymatic scouring [32-35]. Pectinases have proved to be the most effective and suitable for cotton bioscouring. The mechanism of pectinase scouring reportedly assumes that the degradation and elimination of pectins makes the loosened waxes more easily removable with help of mechanical agitation. This allows the cotton to achieve superior hydrophilicity without fiber deterioration. A rational approach is adopted to design a new efficient enzymatic scouring process. Several aspects were considered such as the specificity of enzymes, the complexity of the cotton fiber substrate and mass transfer. Different commercial as well as specially produced pectinases were tested for bioscouring performance. Alkaline pectinases (PL and Bioprep 3000L) work better than acidic pectinases (PGs). The pectin removal efficiency of specially produced PL was comparable to commercial Bioprep 3000L. The most important parameters such as enzyme concentration, pH, temperature, ionic strength, chelators etc. for the bioscouring process have been evaluated [36]. The pectin acts as cement in the primary wall of cotton fibers which is responsible for yellowness of the fiber [37-39]. After enzymatic destabilization of a pectin structure, the different components present in the primary wall layer can be removed easily in subsequent rinsing steps. The aim of this research was to study, the potential of enzyme technology to design an efficient and low-temperature scouring process for 100% organic cotton fabric. Aerodynamic technique has been studied and used for a variety of applications in liquids, dispersions and polymers [40, 41]. It holds a promise in applications in the field of decoloration of textiles. Limited research works have been reported to acceleration of enzyme kinetics through aerodynamic system to improve the reaction of substrate and enzyme binding to high quality and standardization of process parameters [42-44]. In this research work the bioscouring of organic cotton fabric with mixed enzymes have been studied with and without aerodynamic system and their bioscouring performance in terms of fabric physical properties such as fabric weight loss, water absorbency, wetting area, whiteness, yellowness and brightness index of both method of treatment compared and reported. Aerodynamic system of enzyme acceleration has great potential in industrial processes as it offers reduction in cost, time, energy and effluents.

2 MATERIALS AND METHODS

The grey organic cotton yarns of 2/40s Ne for warp and 40s Ne for weft yarns were procured from M/s. Arm strong mills (P) limited, Tirupur, India. The 100% organic cotton fabric was produced which having 64 ends per inch, 60 picks per inch, fabric cover factor of 18.96 and average fabric mass of 120.44 grams per square metre. The sizing of warp yarns of 100% organic cotton was carried out using laboratory model yarn sizing machine using Polyvinyl alcohol starch size (PVA) and the average size add-on the warp yarn was 12.21% and then the sized warp yarns were taken into warp beam preparation for weaving. The average size add-on on the organic cotton fabric was measured with respect to warp and weft yarn mass; it was noticed 8.27%. The aerial density of the organic cotton grey fabric after weaving was found 130.24 grams per square metre.

2.1 ENZYMATIC DESIZING

The PVA sized 100% organic cotton fabrics were treated with 3% concentration of alpha-amylase and process treatments at 60 deg C and 45 min reaction time. The process variables were chosen according to the Box-Behnken method of statistical tool for process optimization [35, 36]. A systematic statistical approach has adopted to obtain optimum weight loss of the sized fabric with different process conditions of alpha amylase enzyme concentration, temperature and treatment time for achieving required level of 8.20% for efficient level of size removal. The enzymatic desizing process was carried out at pH 6-7 level and then the fabrics was thoroughly rinsed with hot water and cold water and dried the fabric at 80 deg C using hot air oven and weigh the fabric using electronic balance with accuracy ±0.01grams.

2.2 ENZYMATIC SCOURING WITH MIXED ENZYMATIC SYSTEM

The bioscouring of organic cotton fabric was carried out by selecting specific mixed enzymes namely (a) alkaline pectinase, (b) protease, (c) lipase, and (d) cellulase. These enzymes were obtained from M/s. RND Biolab limited, Coimbatore, India. The selective alkaline pectinase purified from Pectate Lyase was selected for the degradation of cotton pectin. Various experimental setups and techniques were applied in the enzymatic scouring experiments. All experiments were performed with demineralized water. Scouring experiments where performed in 1 L beaker in which three fabric samples of 10 × 10 cm were treated in an enzyme solution of different concentrations of 2-6%, non-ionic wetting agent of 1-2%, treatment time of 30 min, 45min, 60min and adjusted to pH of 8.5-9.0. The beaker was placed in a temperature controlled water bath at 50°C, 55°C and 60°C which is shown in Figure 1. After the treatment, the fabric samples were rinsed in 500 mL of water at 90°C for 15 minutes, to inactivate the enzymes. Thereafter the samples were rinsed twice for 5 minutes in water at room temperature. Finally, the samples were dried at 80°C using hot air oven and weigh the fabrics using electronic balance with accuracy ±0.01grams.

2.2.1 AERODYNAMIC TREATMENT

The organic cotton fabric was treated with mixed enzymatic system using laboratory model breaker dyeing bath fitted with air pump model U9900 which was supplied by M/s.BOY U®.

(a)

(b)

FIGURE 1. ENZYMATIC TREATMENT IN - (A) LABORATORY MODEL BEAKER BATHAND (B) AIR NOZZLE IN BEAKER

2.2.2 ARTIFICIAL NEURAL NETWORK (ANN)

The software used in this study was backward feed propagation network in MATLAB 7.0. The schematic diagram of typical ANN is shown in Figure *2*. In order to carry out prediction, the network was trained with training patterns namely input and output parameters. Input and output parameters used for training the ANN and their selection criteria are given below.

Input parameters

(i) Enzyme concentration
(ii) Process time
(iii) Process temperature

Output parameters

(i) Fabric weight loss
(ii) Fabric water absorbency
(iii) Fabric wetting area
(iv) Fabric whiteness index
(v) Fabric yellowness index
(vi) Fabric brightness index

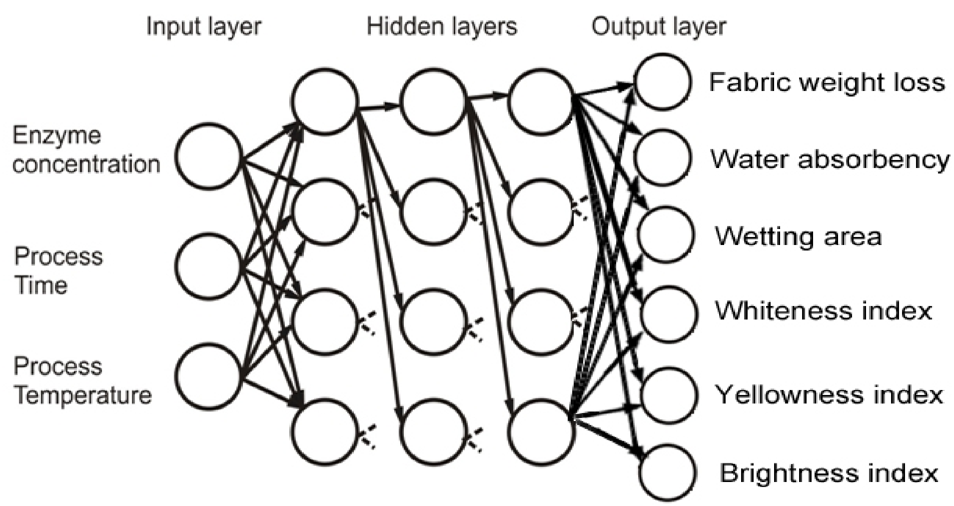


FIGURE 2. SCHEMATIC DIAGRAM OF ANN USED IN BIOSCOURING OF ORGANIC COTTON FABRIC

2.2.3 TRAINING OF NEURAL NETWORK

For training, the organic cotton fabrics were treated with various enzyme concentration, time and temperatures with specific mixed enzyme system. Then the physical characteristics such as fabric weight loss, water absorbency, wetting area, whiteness index, yellowness index and brightness index of the organic cotton fabrics were evaluated with standard testing procedures and their values are trained by using feed backward propagation algorithm. For the error back propagation net, the sigmoid function is essentially for non linear function. Training process of the neural network developed was started with 5000 preliminary cycles to optimize the ANN prediction accuracy. The best structure is one that gives lowest training error and it is found to be minimum error percent. The training of the network was further continued in order to reduce the training error. The average training error of 1% was obtained and terminated at this stage since beyond this reduction in training error was not appreciable.

2.3 TESTING

2.3.1 COLOR SPECTROSCOPY ANALYSIS

The whiteness index, yellowness index, and brightness index value of the bioscoured cotton fabric samples were measured using JAYPAK Color Spectroscopy (Model 4800). The whiteness index was measured with STEPHENSEN 76, observer 10 degree at D65 Illuminant source in the range between 400nm and 700nm. The yellowness index was measured with ASTM D1925, observer 2 degree at C Illuminant source in the range between 400nm and 700nm. The brightness index was measured with TAPPI 452 / ISO 2470, observer 2 degree at C Illuminant source in the range between 400nm and 700nm.

2.3.2 FTIR-FOURIER TRANSFORM INFRARED SPECTROSCOPY

The organic cotton fabric with and without alkaline pectinase enzyme treated fabrics are analyzed using FT-IR Spectrometer – Model: 8400S make: Schimadzu.

2.3.3 Ruthenium Red dye – Pectin determination

The pectin removal of the enzyme treated with alkaline pectinase of organic cotton fabrics were carried out as per procedure [37]. K/S was calculated as in equation (2), known as the Kubelka Munk formula, where R is the reflectance of a sample measured;

$$K/S = (1-R)^2 / 2R \quad \ldots\ldots\ldots\ldots\ldots (1)$$

Since Ruthenium red dyes only pectic and proteinic substances in cotton fibers, the lower the K/S value is, the less of the pectic and proteinic substance is the present in cotton fiber [28].

2.3.4 FABRIC WATER ABSORBENCY

Water absorbency of organic cotton fabric treated with mixed enzymatic system was evaluated according to AATCC test method 79-2000.

2.3.5 WAX CONTENT

The wax content of the grey organic cotton fabric and mixed enzymatic system were carried out as per AATCC test method 97-2009 (revised) by solvent extraction using Soxhlet apparatus.

2.3.6 WEIGHT LOSS

After the enzymatic treatments, the weight losses of the bioscoured organic cotton fabrics were inspected. The amount of weight losses were calculated according to the following formula:

$$\%\text{Weight Loss} = (W_1 - W_2) * 100 / W_1 \quad \ldots\ldots (2)$$

Where
W_1 – the weight of fabric before enzymatic treatment
W_2 – the weight of fabric after enzymatic treatment

3. RESULTS AND DISCUSSION

3.1 PROCESS OPTIMIZATION - SPECIFIC MIXED ENZYMATIC SYSTEM

The process variables such as enzyme concentrations, temperature and reaction time were optimized using MATLAB 7.0 software with neural network experimental design. Table 1 and 2 represent the process variables for training sample of bioscoured organic cotton fabrics of their input values and output results of actual and predicted respectively. The software was executed to get various options / predicted process parameters to achieve required bioscouring performance in terms of scouring weight loss %, water absorbency, wetting area, whiteness index, yellowness index and brightness index. Table 3 and 4 represent the bioscouring of organic cotton fabric with aerodynamic treatment for training sample and output results of actual and predicted respectively.

TABLE 1. ARTIFICIAL NEURAL NETWORK - TRAINING SAMPLES (without aerodynamic)

Sample No.	Input data, Specific Mixed Enzymes							Output data, Trained Samples Fabric Properties (Actual)					
	Enzyme concentrations (%)				Process parameters								
	Pectinase	Protease	Lipase	Cellulase	Time	Temp	pH	Fabric Weight loss (%)	Fabric Water absorbency (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)
S1	4	2	0.4	0.4	30	55	8.5	2.8	3.2	70	26.152	22.142	54.147
S2	4	2	0.6	0.6	30	55	9.5	3.1	2.4	114	26.452	21.831	56.387
S3	4	2	0.8	0.8	30	60	8.5	4.4	1.8	240	27.320	20.392	58.947
S4	6	3	0.4	0.4	30	60	9	4.1	1.4	238	32.520	20.314	57.324
S5	6	3	0.6	0.6	45	55	8.5	4.3	1.2	247	34.378	20.132	58.147
S6	6	3	0.8	0.8	45	60	9	4.4	1.2	251	38.415	17.742	63.436
S7	6	2	0.6	0.8	45	60	8.5	4.7	0.8	330	36.137	19.241	61.524
S8	2	2	0.4	0.4	45	60	9	2.7	6.2	65	27.860	20.690	51.580
S9	2	1	0.6	0.6	30	55	8	2.4	5.8	64	28.600	23.547	52.407
S10	2	3	0.8	0.8	60	60	9	3.8	4.8	67	27.690	22.641	53.452
S11	2	1	0.4	0.4	60	60	8	2.4	5.7	72	27.831	23.640	49.860
S12	0	3	0.6	0.6	60	55	8.5	2.7	7.2	45	24.580	23.654	49.631
S13	0	1	0.4	0.4	60	55	9.5	2.9	8.9	51	23.980	23.972	51.250
S14	6	0	0.8	0.4	45	60	9	3.8	3.1	114	37.860	17.850	52.368
S15	4	1	0.6	0.6	45	60	9	4.5	3.4	120	39.647	19.640	53.240
S16	6	1	0.4	0	30	60	9.5	3.1	4.2	74	32.078	20.068	59.378
S17	4	2	0.1	0	45	60	8.5	2.7	4.4	70	28.520	20.127	58.418
S18	0	2	0.8	0	60	55	9	2.2	8.8	61	22.413	24.371	43.436
S19	8	3	0.8	0.8	60	55	9.5	4.8	1.2	250	52.413	13.140	68.715
S20	8	1	0.2	0	30	60	8.5	2.8	2.5	85	51.452	14.857	51.450
S21	8	3	0	0.4	45	60	9.5	4.1	1.8	264	52.470	14.250	58.670
S22	6	2	0	0.8	60	55	8.5	4.2	1.4	228	47.680	15.857	53.480
S23	2	2	0.6	0.4	60	60	9	3.1	4.8	260	27.650	19.561	52.687
S24	2	3	0.6	0.4	45	55	9	3.4	4.6	268	26.780	20.450	52.681
S25	2	2	0.4	0.8	45	60	8	3.3	4.2	250	27.540	21.580	51.240
S26	4	3	0.6	0.4	30	55	8.5	3.8	2	300	30.681	18.640	54.890
S27	4	3	0.4	0	45	55	8.5	3.6	1.8	310	29.740	19.564	59.570
S28	4	3	0.8	0.4	45	55	8.5	3.5	2	280	30.450	17.698	64.580
S29	8	4	0.8	0.4	30	60	9.5	4.9	1.6	292	52.570	13.800	67.480
S30	0	3	0	0.4	45	60	8	2.8	8.7	48	23.147	22.413	54.138

TABLE 2. ARTIFICIAL NEURAL NETWORK - OUTPUT DATA ANALYSIS (predicted, without aerodynamic)

Sample No.	ANN Output data, Fabric properties						ANN Error %					
	Fabric Weight loss (%)	Fabric Water absorb (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)	Fabric Weight loss (%)	Fabric Water absorb (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)
S1	2.874	3.087	72	28.876	21.927	57.967	-2.657	3.506	-2.857	-10.41	0.967	-7.055
S2	2.989	2.453	119	28.875	21.321	58.035	3.574	-2.246	-4.385	-9.160	2.332	-2.923
S3	4.325	1.837	220	28.876	21.969	57.995	1.695	-2.083	8.333	-5.696	-7.733	1.615
S4	4.090	1.472	218	33.088	19.358	57.986	0.239	-5.150	8.403	-1.747	4.705	-1.156
S5	4.242	1.277	261	34.525	17.173	57.992	1.349	-6.425	-5.668	-0.428	14.697	0.265
S6	4.394	1.249	248	38.309	17.614	58.014	0.127	-4.108	1.195	0.274	0.719	8.545
S7	4.636	0.907	321	35.948	18.752	57.449	1.347	-13.35	2.727	0.520	2.540	6.623
S8	2.856	6.334	57	28.767	22.018	57.035	-5.800	-2.161	12.307	-3.256	-6.421	-10.57
S9	2.497	5.935	61	28.871	21.969	50.622	-4.042	-2.334	4.687	-0.947	6.698	3.404
S10	3.863	4.478	68	27.613	20.760	57.857	-1.671	6.690	-1.492	0.274	8.307	-8.242
S11	2.380	6.011	70	29.115	22.248	48.501	0.829	-5.460	2.777	-4.614	5.886	2.724
S12	2.811	7.844	51	24.595	23.726	47.556	-4.133	-8.949	-13.33	-0.061	-0.307	4.179
S13	2.994	8.284	52	23.967	24.081	51.375	-3.266	6.912	-1.960	0.054	-0.455	-0.244
S14	3.904	2.795	117	38.269	17.423	52.761	-2.747	9.835	-2.631	-1.081	2.388	-0.751
S15	4.419	3.772	121	34.786	20.005	55.319	1.780	-10.92	-0.833	12.259	-1.858	-3.905
S16	3.176	4.009	72	31.654	19.884	55.734	-2.468	4.543	2.702	1.321	0.916	6.136
S17	2.605	4.676	71	28.250	20.356	54.672	3.504	-6.293	-1.428	0.946	-1.139	6.411
S18	2.392	8.196	63	22.399	24.072	46.168	-8.735	6.858	-3.278	0.058	1.223	-5.112
S19	4.888	1.299	248	52.821	15.298	58.034	-1.848	-8.300	0.8	-0.780	-16.42	15.543
S20	2.958	2.297	78	51.297	16.277	53.446	-5.661	8.096	8.235	0.299	-9.561	-3.880
S21	4.162	1.967	248	52.869	13.987	55.547	-1.534	-9.300	6.060	-0.761	1.839	5.321
S22	4.334	1.390	218	47.687	17.588	53.967	-3.195	0.657	4.385	-0.016	-10.92	-0.912
S23	3.009	4.953	261	28.970	20.801	56.661	2.929	-3.202	-0.384	-4.777	-6.342	-7.543
S24	3.405	4.697	270	29.102	20.768	57.901	-0.163	-2.115	-0.746	-8.671	-1.559	-9.908
S25	3.491	4.612	251	23.256	22.293	56.263	-5.812	-9.814	-0.4	15.554	-3.305	-9.803
S26	3.6123	2.034	298	28.878	19.838	58.030	4.939	-1.710	0.666	5.875	-6.429	-5.721
S27	3.437	1.846	304	29.302	19.855	58.031	4.522	-2.565	1.935	1.472	-1.489	2.582
S28	3.654	2.089	283	29.167	17.626	57.948	-4.420	-4.475	-1.071	4.213	0.403	10.26
S29	4.860	1.665	290	51.879	13.788	58.0546	0.802	-4.075	0.684	1.314	0.083	13.96
S30	2.504	8.496	51	22.983	21.973	57.1424	10.543	2.337	-6.25	0.704	1.961	-5.549

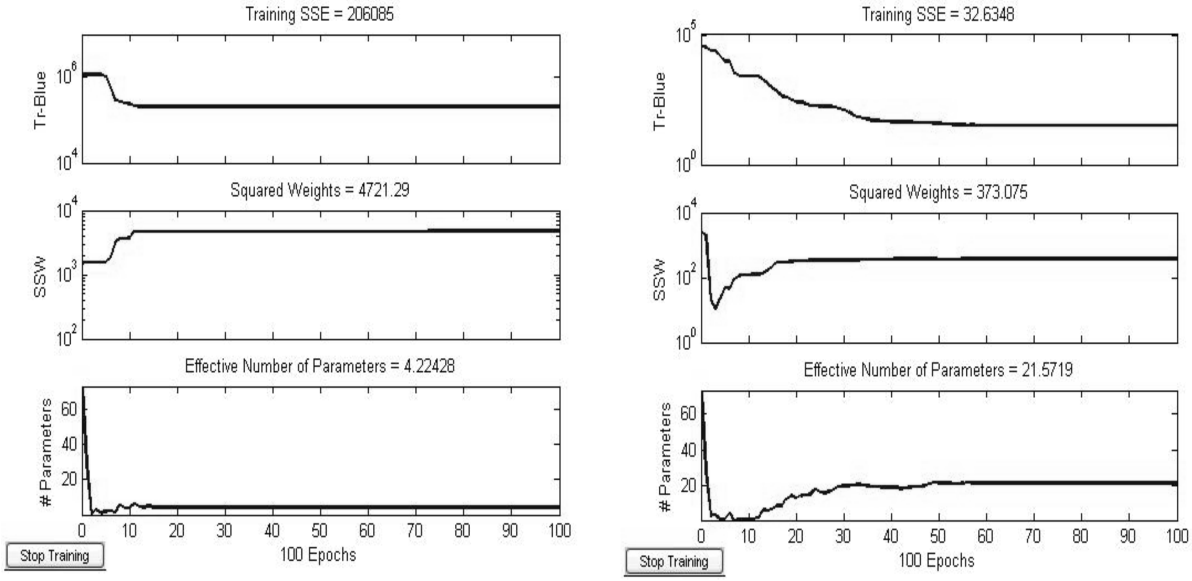
TABLE 3. ARTIFICIAL NEURAL NETWORK - TRAINING SAMPLES
(with aerodynamic)

Sample No.	Input data, Specific Mixed Enzymes							Output data, Trained Samples Fabric Properties (Actual)					
	Enzyme concentrations (%)				Process parameters			Fabric Weight loss (%)	Fabric Water absorbency (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)
	Pectinase	Protease	Lipase	Cellulase	Time	Temp	pH						
S1	4	2	0.4	0.4	30	55	8.5	3.52	2.8	80	30.426	18.532	57.350
S2	4	2	0.6	0.6	30	55	9.5	3.67	2.1	124	31.690	18.254	58.691
S3	4	2	0.8	0.8	30	60	8.5	5.28	1.3	260	32.451	18.392	59.638
S4	6	3	0.4	0.4	30	60	9	4.86	1.2	282	36.561	17.635	59.045
S5	6	3	0.6	0.6	45	55	8.5	5.08	1.1	290	38.358	18.634	60.258
S6	6	3	0.8	0.8	45	60	9	5.24	1.4	278	43.247	15.968	65.639
S7	6	2	0.6	0.8	45	60	8.5	5.67	0.6	362	41.682	17.638	63.561
S8	2	2	0.4	0.4	45	60	9	3.98	5.1	78	32.924	19.524	53.924
S9	2	1	0.6	0.6	30	55	8	3.24	5.4	90	33.625	20.890	53.931
S10	2	3	0.8	0.8	60	60	9	4.86	4.6	98	32.410	18.967	56.278
S11	2	1	0.4	0.4	60	60	8	3.15	5.3	102	31.421	19.269	53.259
S12	0	3	0.6	0.6	60	55	8.5	3.27	6.4	54	28.451	19.928	54.251
S13	0	1	0.4	0.4	60	55	9.5	3.58	7.3	68	28.342	21.368	56.245
S14	6	0	0.8	0.4	45	60	9	4.89	2.9	137	41.632	17.005	54.638
S15	4	1	0.6	0.6	45	60	9	5.21	3.3	142	45.245	18.639	54.068
S16	6	1	0.4	0	30	60	9.5	4.06	3.8	104	35.631	17.526	61.638
S17	4	2	0.1	0	45	60	8.5	3.28	4.2	84	33.683	17.869	60.462
S18	0	2	0.8	0	60	55	9	3.27	7.8	70	28.562	19.425	56.564
S19	8	3	0.8	0.8	60	55	9.5	6.38	0.6	342	58.092	12.314	72.133
S20	8	1	0.2	0	30	60	8.5	3.96	1.7	101	55.631	12.869	54.638
S21	8	3	0	0.4	45	60	9.5	5.26	1.2	314	53.425	13.524	60.254
S22	6	2	0	0.8	60	55	8.5	6.14	0.8	274	52.842	13.974	57.496
S23	2	2	0.6	0.4	60	60	9	4.02	3.8	296	30.691	17.638	54.367
S24	2	3	0.6	0.4	45	55	9	4.24	3.9	302	29.042	18.167	54.025
S25	2	2	0.4	0.8	45	60	8	4.28	3.8	281	30.425	18.214	51.245
S26	4	3	0.6	0.4	30	55	8.5	4.96	1.7	335	31.356	16.931	55.368
S27	4	3	0.4	0	45	55	8.5	4.39	1.5	368	23.652	16.637	61.254
S28	4	3	0.8	0.4	45	55	8.5	4.46	1.3	300	35.691	16.962	65.967
S29	8	4	0.8	0.4	30	60	9.5	6.04	1.2	308	54.681	13.054	70.254
S30	0	3	0	0.4	45	60	8	3.67	7.4	62	26.632	18.421	56.354

TABLE 4. ARTIFICIAL NEURAL NETWORK - OUTPUT DATA ANALYSIS
(predicted, with aerodynamic)

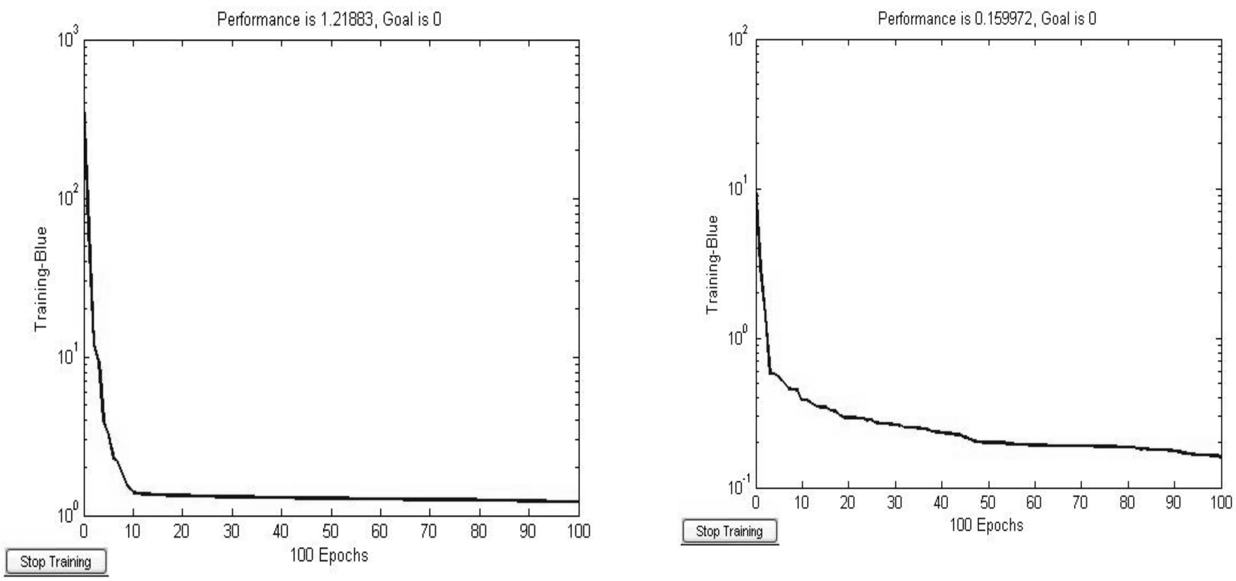
Sample No.	ANN Output data, Fabric properties						ANN Error %					
	Fabric Weight loss (%)	Fabric Water absorb (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)	Fabric Weight loss (%)	Fabric Water absorb (sec)	Fabric Wetting area (mm^2)	Fabric Whiteness Index (WI)	Fabric Yellow Index (YI)	Fabric Bright Index (BI)
S1	3.670	2.92	82.500	30.695	17.563	58.634	-4.261	-0.120	-3.125	-0.884	5.229	-2.239
S2	3.724	2.23	138.23	32.521	18.025	56.364	-1.471	-0.130	-11.48	-2.622	1.255	3.965
S3	4.962	1.45	252.361	33.428	19.634	58.631	6.023	-0.150	2.938	-3.011	-6.753	1.689
S4	5.214	1.35	291.257	34.258	17.690	60.351	-7.284	-0.150	-3.283	6.299	-0.312	-2.21
S5	5.124	1.25	286.340	36.934	18.524	59.634	-0.866	-0.150	1.262	3.712	0.590	1.036
S6	5.586	1.52	284.396	42.635	17.361	64.235	-6.603	-0.120	-2.301	1.415	-8.724	2.139
S7	5.721	0.85	345.128	40.638	18.634	64.351	-0.899	-0.250	4.661	2.505	-5.647	-1.24
S8	4.011	4.70	68.359	33.964	20.341	55.324	-0.779	0.400	12.360	-3.159	-4.185	-2.59
S9	3.264	5.20	88.364	35.558	21.523	52.420	-0.741	0.200	1.818	-5.749	-3.030	2.802
S10	4.869	4.68	92.158	33.640	19.637	55.638	-0.185	-0.080	5.961	-3.795	-3.532	1.137
S11	3.276	5.23	99.254	33.627	20.364	55.634	-4.000	0.070	2.692	-7.021	-5.683	-4.45
S12	3.269	6.75	56.854	29.639	20.632	55.961	0.031	-0.350	-5.285	-4.176	-3.533	-3.15
S13	3.624	7.00	69.361	30.614	21.610	55.964	-1.229	0.300	-2.001	-8.016	-1.133	0.500
S14	4.921	3.20	145.360	44.251	16.964	54.632	-0.634	-0.300	-6.102	-6.291	0.241	0.011
S15	5.264	3.50	155.276	47.632	18.124	55.425	-1.036	-0.200	-9.349	-5.276	2.763	-2.51
S16	4.120	3.45	100.096	36.125	18.637	60.254	-1.478	0.350	3.754	-1.386	-6.339	2.245
S17	3.169	4.01	86.362	34.704	18.963	59.637	3.384	0.190	-2.812	-3.031	-6.122	1.364
S18	3.342	7.25	77.392	30.254	20.530	55.964	-2.202	0.550	-10.56	-5.924	-5.689	1.061
S19	6.425	0.85	346.964	59.312	12.634	69.635	-0.705	-0.250	-1.451	-2.100	-2.599	3.463
S20	4.021	1.38	114.235	56.254	13.085	53.967	-1.540	0.320	-13.10	-1.120	-1.678	1.228
S21	5.316	1.25	317.963	54.962	14.631	58.664	-1.065	-0.050	-1.262	-2.877	-8.185	2.639
S22	6.241	0.95	281.362	54.631	13.692	58.014	-1.645	-0.150	-2.687	-3.386	2.018	-0.90
S23	4.132	3.65	296.851	32.960	18.637	53.691	-2.786	0.150	-0.288	-7.393	-5.664	1.243
S24	4.015	3.85	314.634	30.625	18.631	54.067	5.307	0.050	-4.183	-5.451	-2.554	-0.07
S25	4.286	3.68	286.942	33.964	19.634	52.964	-0.140	0.120	-2.115	-11.632	-7.796	-3.35
S26	4.967	1.95	339.634	33.069	16.963	56.390	-0.141	-0.250	-1.383	-5.463	-0.189	-1.84
S27	4.361	1.62	368.901	24.125	17.032	63.524	0.661	-0.120	-0.245	-2.000	-2.374	-3.70
S28	4.532	1.56	298.634	36.934	17.631	67.019	-1.614	-0.260	0.455	-3.483	-3.944	-1.59
S29	6.072	1.43	324.216	55.637	13.523	68.965	-0.530	-0.230	-5.265	-1.748	-3.593	1.835
S30	3.784	7.32	70.254	27.041	19.631	57.634	-3.106	0.080	-13.31	-1.536	-6.569	-2.27

The software was processed for analyzing the performance and desirability of FDS-Fraction of Design Space of design model of process which are shown in Figure 3 and 4 respectively for optimized test results. The output result of the software to achieve the desired bioscouring of organic cotton fabric on their physical properties such as fabric weight loss, water absorbency, wetting area, whiteness index, yellowness index, and brightness index in the specific enzymatic system, out of which the software opted best process conditions of specific mixed enzymes of sample 19, which was treated with 8% alkaline pectinase, 3%protease, 0.8%lipase and 0.8%cellulase process condition at temperature of 55 deg C and reaction time 60 minutes, pH 8.5 with 1.0% desirability. From the best opted test results, the actual pectin and weight loss of the bioscoured organic cotton fabric was achieved 68.40% and 4.80% respectively with error of 1.218% in case of without aerodynamic treatment. With aerodynamic treatment, the fabric weight loss was observed to be 6.38% and pectin removal to be 76.42%.



(a) **(b)**

FIGURE 3. ANN TRAINING OF MIXED ENZYMATIC SYSTEM IN MAT LAB 7.0 FOR FDS –FRACTION OF DESIGN SPACE LEVEL (A) WITHOUT AERODYNAMIC (B) WITH AERODYNAMIC



(a) **(b)**

FIGURE 4. ANN TRAINING OUTPUT PERFORMANCE OF MIXED ENZYMATIC SYSTEM IN MAT LAB 7.0 (A) WITHOUT AERODYNAMIC (B) WITH AERODYNAMIC

3.2 FABRIC SCOURING WEIGHT LOSS – EFFECT OF ENZYMATIC PROCESS VARIABLES

The effect of enzyme concentration and temperature on weight loss of organic cotton fabric at various time intervals of 30 min, 45 min and 60 min are shown as 3D surface plot in Figure 5. It presents the effect of enzyme concentration and temperature on the weight loss of the alkaline pectinase enzyme treated organic cotton fabrics at various reaction times. With increase in enzyme concentration and temperature there is an increase in fabric weight loss at both lower and higher reaction time intervals. But at higher time duration there is higher rate of pectin and wax hydrolysis with increase in enzyme concentration. An interesting observation noticed during the trials that the organic cotton fabric was noticed higher water absorbency rate at higher enzyme concentration of 6% pectinase, 60 minute time and 60 deg C temperature of maximum weight loss of 3.2% and above.

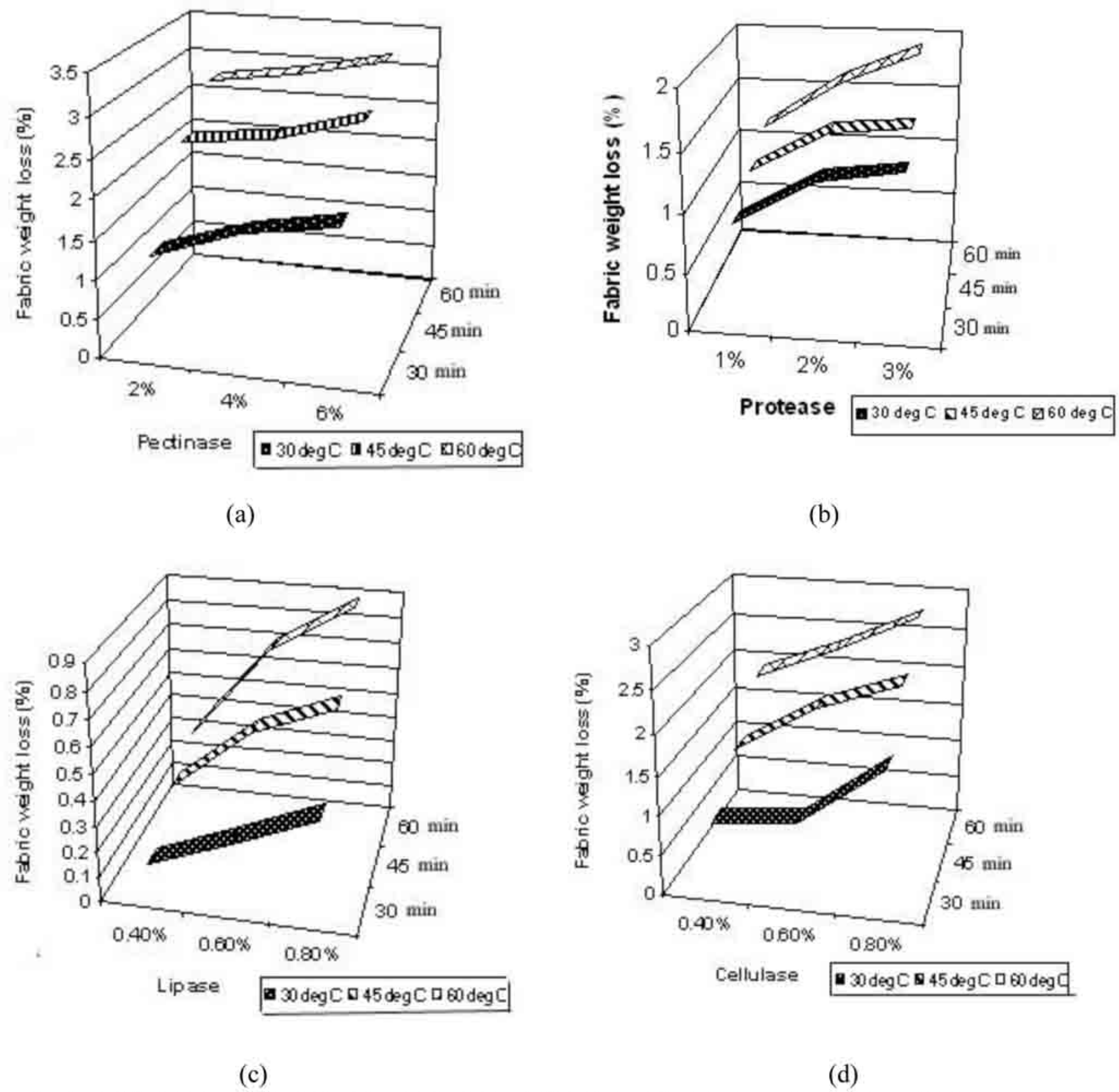


FIGURE 5. THE EFFECT OF (A) PECTINASE, (B) PROTEASE, (C) LIPASE AND (D) CELLULASE ENZYME CONCENTRATION ON WEIGHT LOSS OF COTTON FABRIC

Figure 6 represents the fabric weight loss (%) of organic cotton fabric treated with binary enzyme concentrations, from the test results the pectinase and protease combination; pectinase and lipase combinations shows higher weight loss of fabric. It may be due to removal of pectin and wax removal at higher rate than the individual enzyme treatments.

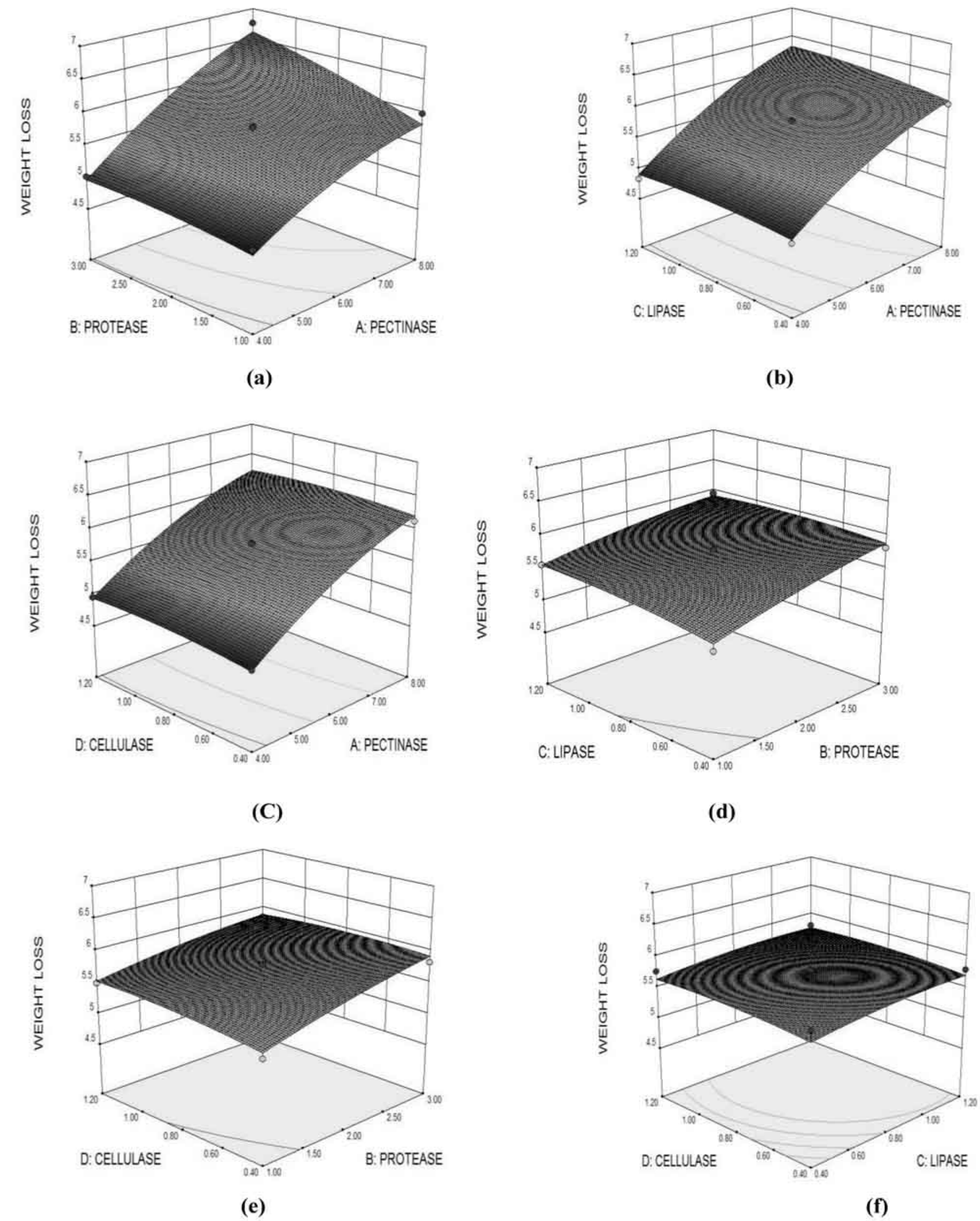


FIGURE 6. THE EFFECT OF (a) PECTINASE AND PROTEASE, (b) PECTINASE AND LIPASE, (c) PECTINASE AND CELLULASE, (d) PROTEASE AND LIPASE, (e) PROTEASE AND CELLULASE AND (f) LIPASE AND CELLULASE ENZYME CONCENTRATION ON WEIGHT LOSS OF ORGANIC COTTON FABRIC

Using the neural network the optimizing mixed enzyme concentrations for achieving required fabric weight loss at 60 deg C and 60 min treatment time, the empirical model was fitted to the response and lack of fit test was carried out and the quadratic equation derived from the design of experimental is given below taking into account the significant interaction effects as given in Table 5. Figure 7 represents the relationship between the actual and predicted weight loss of enzymatic scoured organic cotton fabric.

TABLE 5. ANALYSIS OF VARIANCE

Source	F Value	P-value prob>F
A-PECTINASE	355.97	<0.0001
B-PROTEASE	43.72	<0.0001
C-LIPASE	3.66	0.0799
D-CELLULASE	0.98	0.3409

The model F-value was 30.21 which implied that the model was significant and there was only 0.01% chance that a 'Model F-value' of this large value could occur due to noise. The predicted R^2 value was 0.9381 and is in reasonable agreement with the Adjusted R^2 of 0.9957. Adequate precision which measures the signal to noise ratio was 16.821, which is greater than 4 indicating that the model can be used to navigate the design space. From the Table 5 it is noticed that the enzyme concentration in the degradation of pectin in the scouring process was noticed significant differences at Factual >Fcritical ($F_{2,14}$ values of 355.97>30.21) at 95% confidence level and also noticed significant differences in wax content removal by protease enzyme at Factual>Fcritical ($F_{2,14}$ values of 43.72>30.21).

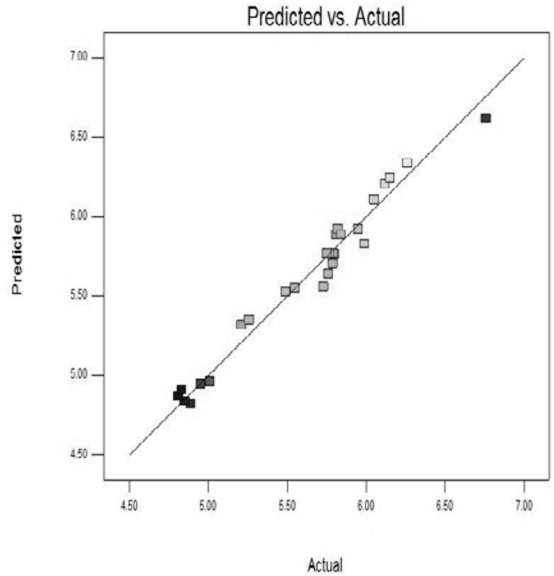
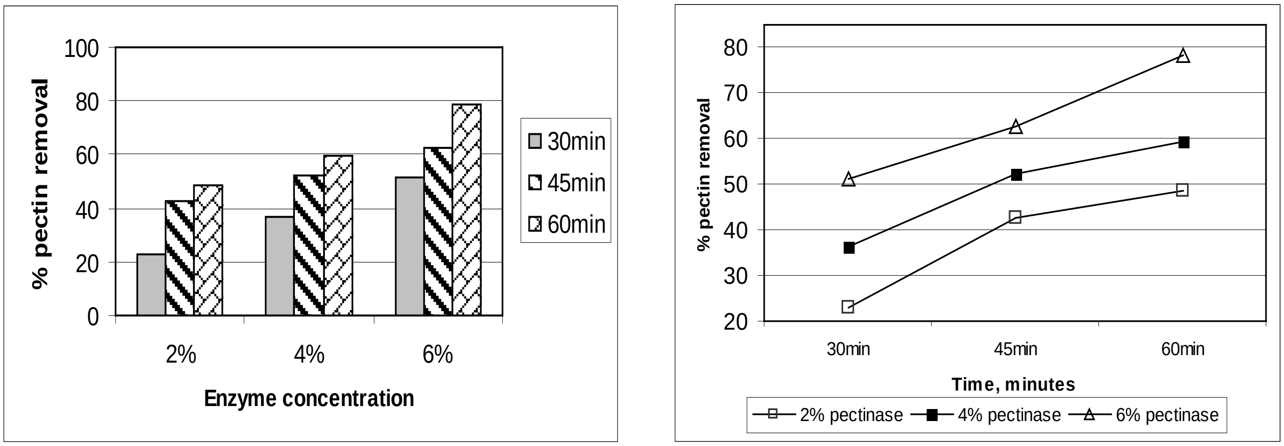


FIGURE 7. RELATIONSHIPS BETWEEN THE ACTUAL AND PREDICTED WEIGHT LOSS OF ENZYMATIC SCOURED ORGANIC COTTON FABRIC

3.3 PECTIN DEGRADATION ANALYSIS

Figure 8 (a) shows that the pectin degradation level of organic cotton fabric treated with various process conditions of time and temperature with 2-6% alkaline enzyme concentration. It was observed that the rate of pectin removal increased with increase in enzyme concentration and higher time and temperature. Figure 8 (b) shows the enzyme kinetics of alkaline pectinase at various concentrations with time interval of 30, 45, 60 minutes of pectin removal rate were noticed at 1.30 and 1.32 times higher in case of 2% to 4% and 4% to 6% pectinase concentration at 60 deg C. It was noticed that the higher pectin removal observed at 60 deg C and 60 min treated pectinase organic cotton fabric was 78.41%, and in addition of efficient wax removal step improves the performance of pectinase in terms of pectin removal and hydrophilicity. The regression equation for evaluating the pectin degradation rate on the organic cotton fabrics is given in Table 6. It may be due to interaction of alkaline pectinase enzyme concentration and temperature at 60 deg C which shows the higher rate of pectin removal by the reaction of enzyme on the organic cotton fiber to break the pectin components.



(a) (b)

FIGURE 8. PECTIN DEGRADATION OF ALKALINE PECTINASE TREATED ORGANIC COTTON FABRIC (a) VARIOUS ENZYME CONCENTRATIONS AT 60 DEG C AND (b) ENZYME KINETICS – INTERACTION OF PECTIN DEGRADATION RATE AT 60 DEG C

TABLE 6. REGRESSION EQUATION OF PECTIN DEGRADATION OF ORGANIC COTTON FABRICS

Enzyme conc.	Regression equation	Correlation coefficient
2%	$Y_1=2.465X_1^2-0.515X_1+33.69$	$R^2=1$
4%	$Y_2=2.691X_2^2-2.315X_2+46.20$	$R^2=1$
6%	$Y_3=2.465X_3^2-0.515X_3+33.69$	$R^2=1$

Note: X-reaction time and Y- pectin removal (%)

3.4 WAX REMOVAL – EFFECT OF PROTEASE AND LIPASE

The wax content of enzyme treated with protease and lipase on organic cotton fabric is shown in Figure 9. It was observed that the wax present in the grey organic cotton fabric was 0.81% and subsequent 3% protease along with lipase treated organic cotton fabric at 0.2%, 0.4%, 0.6% and 0.8% enzyme concentrations at 60 deg temperature and 45 min reaction time noticed 0.62%, 0.52%, 0.37% and 0.30% respectively. It may be due to proteolytic hydrolysis of wax and protein components in the organic cotton fiber.

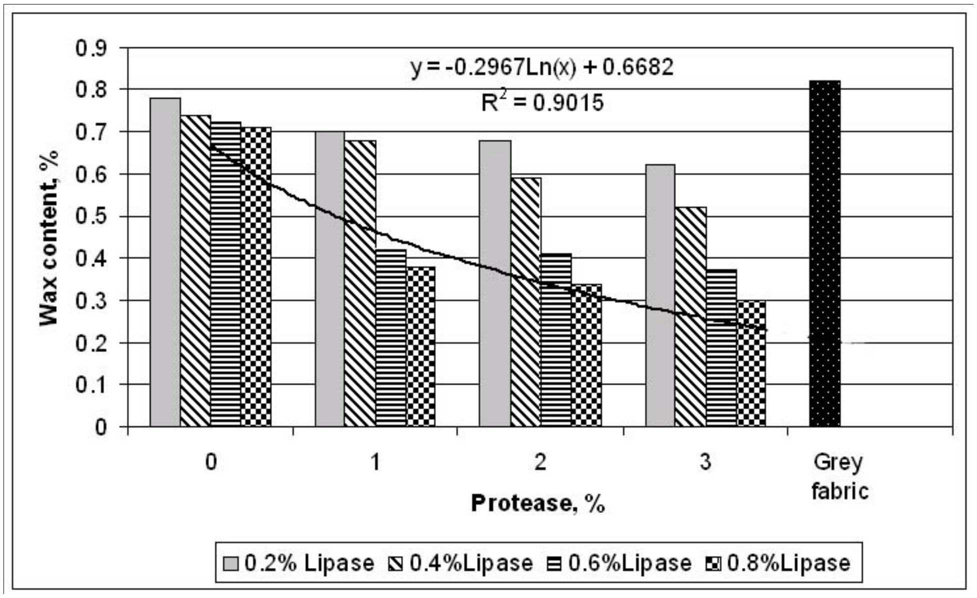


FIGURE 9. WAX CONTENT OF ORGANIC COTTON FABRIC TREATED WITH VARIOUS CONCENTRATIONS OF PROTEASE AND LIPASE AT 60 DEG C AND 45 MIN REACTION TIME

3.5 EFFECT OF AERODYNAMIC TREATMENT

The effect of aerodynamic treatment on the mixed enzymatic system is given in Table 7. The comparison of bioscouring performance with aerodynamic system was noticed overall performance improved at 27.98% higher in fabric weight loss, 0.5 sec reduced time on fabric water absorbency, 20.31% higher fabric wetting area, 12.24% improved whiteness index, reduced 11.28% in yellowness index and 4.11% improved fabric brightness index when compared to without aerodynamic system of mixed enzymatic souring process.

TABLE 7. ARTIFICIAL NEURAL NETWORK - OUTPUT DATA ANALYSIS (PREDICTED) COMPARISON WITH AND WITHOUT AERODYNAMIC SYSTEM

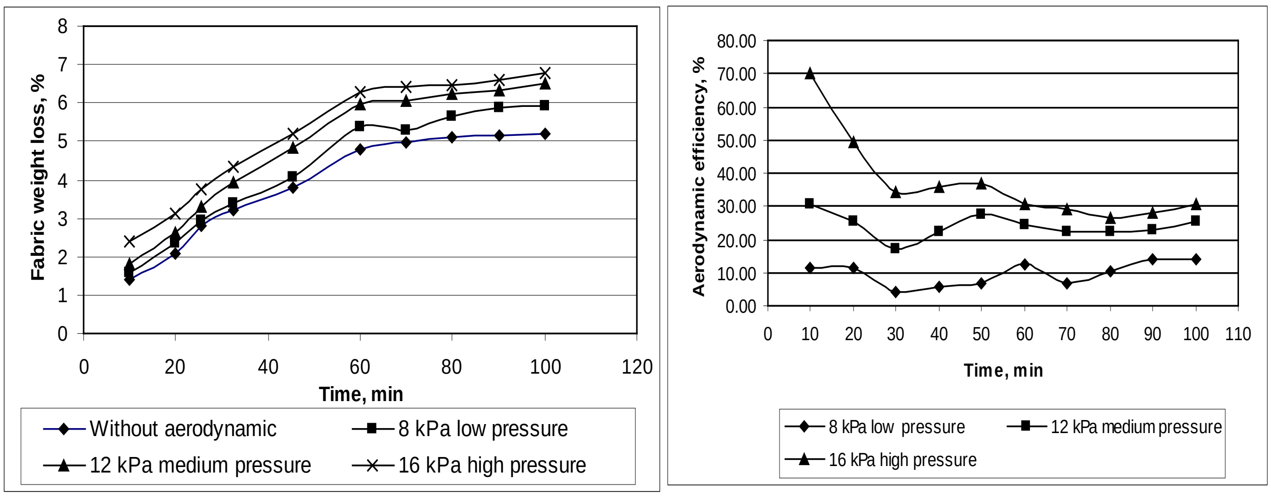
Sample No.	Comparison test results, Fabric properties					
	Fabric Weight loss (%)	Fabric Water absorb (sec)	Fabric Wetting area (%)	Fabric Whiteness Index (%)	Fabric Yellow Index (%)	Fabric Bright Index (%)
S1	-25.714	-0.4	14.286	16.343	-16.304	5.915
S2	-18.387	-0.3	8.772	19.802	-16.385	4.086
S3	-20.000	-0.5	8.333	18.781	-9.808	1.172
S4	-18.537	-0.2	18.487	12.426	-13.188	3.002
S5	-18.140	-0.1	17.409	11.577	-7.441	3.630
S6	-19.091	0.2	10.757	12.578	-9.999	3.473
S7	-20.638	-0.2	9.697	15.344	-8.331	3.311
S8	-47.407	-1.1	20.000	18.177	-5.636	4.544
S9	-35.000	-0.4	40.625	17.570	-11.284	2.908
S10	-27.895	-0.2	46.269	17.046	-16.227	5.287
S11	-31.250	-0.4	41.667	12.899	-18.490	6.817
S12	-21.111	-0.8	20.000	15.749	-15.752	9.309
S13	-23.448	-1.6	33.333	18.190	-10.863	9.746
S14	-28.684	-0.2	20.175	9.963	-4.734	4.335
S15	-15.778	-0.1	18.333	14.120	-5.097	1.555
S16	-30.968	-0.4	40.541	11.076	-12.667	3.806
S17	-21.481	-0.2	20.000	18.103	-11.219	3.499
S18	-48.636	-1	14.754	27.435	-20.295	5.854
S19	-32.917	-0.6	36.800	10.835	-6.286	4.974
S20	-41.429	-0.8	18.824	8.122	-13.381	6.196
S21	-28.293	-0.6	18.939	1.820	-5.095	2.700
S22	-46.190	-0.6	20.175	10.826	-11.875	7.509
S23	-29.677	-1	13.846	10.998	-9.831	3.189
S24	-24.706	-0.7	12.687	8.447	-11.164	2.552
S25	-29.697	-0.4	12.400	10.476	-15.598	0.010
S26	-30.526	-0.3	11.667	2.200	-9.168	0.871
S27	-21.944	-0.3	18.710	-20.471	-14.961	2.827
S28	-27.429	-0.7	7.143	17.212	-4.159	2.148
S29	-23.265	-0.4	5.479	4.016	-5.406	4.111
S30	-31.071	-1.3	29.167	15.056	-17.811	4.093

3.5.1 AERODYNAMIC EFFICIENCY

The efficiency of the aerodynamic treatment was calculated by the extent of fabric weight loss over a period of time with and without aerodynamic mixed enzyme treatment in bioscouring process.

$$\text{Aerodynamic efficiency \%} = \frac{\text{Fabric weight loss with aerodynamic} - \text{Fabric weight loss without aerodynamic}}{\text{Time}} \quad (5)$$

Figure 10 (a) represents the effect of aerodynamic treatment on bioscouring of organic cotton fabric with mixed enzymes treatment for sample no.19 treated at 55 deg C and 60min. Figure 10 (b) represents the aerodynamic efficiency of bioscouring process at various time periods. It was noticed that at the beginning of 10 min, aerodynamic efficiency increases 11.43%, 30.71% and 70.02% at 8 kPa, 12 kPa and 16 kPa air pressure levels respectively when compared to without aerodynamic treatments and subsequent process treatment during interval of 20 min and 30 min it show slightly decreases, it may be due to stabilization of aerodynamic pressure along with enzyme reaction. Further it was noticed aerodynamic efficiency increased at 50min, 60min and 70min treatment time, which may be due to better removal of pectin and wax on the organic cotton fabric and also which it turn expose more surface area for enzyme action. Table 8 represents the regression correlation of bioscoured organic cotton fabric at various process conditions. Overall performance of aerodynamic system in terms of efficiency % on organic cotton fabric was noticed improved 9.72%, 24.08% and 37.20% treated at 8 kPa, 12 kPa and 16 kPa air pressure levels respectively.



(a) **(b)**

FIGURE 10. EFFECT OF AERODYNAMIC ON (a) FABRIC WEIGHT LOSS (%) DURING S19 SAMPLE TEMP 55DEG C AND (b) AERODYNAMIC EFFICIENCY IN BIOSCOURING PROCESS

TABLE 8. REGRESSION EQUATION OF WEIGHT LOSS % OF BIOSCOURED ORGANIC COTTON FABRICS

Treatment Condition	Regression Equation	Correlation Coefficient
Without aerodynamic	y = 0.0427x + 1.5742	$R^2 = 0.9034$
Low pressure (8 kPa)	y = 0.0495x + 1.5978	$R^2 = 0.9319$
Medium pressure (12 kPa)	y = 0.0527x + 1.9502	$R^2 = 0.9115$
High pressure (16 kPa)	y = 0.0494x + 2.5013	$R^2 = 0.909$

Note: X-reaction time, min and y-fabric weight loss, %

3.6 FTIR SPECTROSCOPIC ANALYSIS

The FTIR spectra of the desized organic cotton fabric and 2%, 4%, 6% pectinase enzyme treated cotton fabrics are given in Table 9. It mainly highlights changes in the non-cellulosic impurities by characterizing the carboxyl acids and esters that are present in pectin and waxes. It can be clearly understood that the presence of cellulose group peaks around 1000-1200cm^{-1} and integrity of the pectin and wax compounds in the organic cotton fabric at 1736cm^{-1} and 1617cm^{-1} respectively. The hydrolysis of the pectin during alkaline pectinase enzymatic treatment (D) at 6% concentration and 45min reaction time of the organic cotton fabric showed the removal of pectin and wax groups in the specimen at 3315 cm^{-1} which was responsible for –OH group stretching, the CH stretching at 2917

$cm^{-1,}$ the asymmetrical COO- stretching at 1617 cm^{-1}, and CH wagging at 1316 cm^{-1}. The absorbance intensity of the characteristics peaks at around 1736 cm^{-1} varied in the following order: desized fabric > 2% pectinase > 4% pectinase > 6% pectinase fabrics. The test results, the transmittance (%) of the pectinase enzyme treated organic cotton fabrics are noticed lower level when compared to desized fabric which was due to the degradation of pectin, waxes and non-cellulosic compounds while pectinolytic degradation. The residual non-cellulosic components were analyzed after enzyme treatment using FTIR reports by differentiating the transmittance (%) wave length. From the test results, the peaks at 1058cm^{-1}, 1112cm^{-1} and 2362cm^{-1} groups are responsible for C-C stretch from phenyl ring, $-CH_2$ symmetric stretching and C-H stretching in the alkaline pectinase treated organic cotton fabrics.

TABLE 9. FTIR TEST RESULTS OF ORGANIC COTTON FABRICS AND THEIR TRANSMITTANCE VALUES

Wave length cm-1	Desized fabric	Without Aerodynamic system		With Aerodynamic system	
		Mixed enzymes	Difference, %	Mixed enzymes	Difference, %
559	45.8	49	6.987	49.4	7.860
617	45.2	47.6	5.310	47.9	5.973
667	45.8	46.1	0.655	46.3	1.091
898	53.4	57.1	6.929	57.8	8.239
1058	34.8	38.2	9.770	38.2	9.770
1112	35.3	37.4	5.949	37.6	6.515
1165	37.5	38.3	2.133	38.7	3.200
1371	25.1	27.7	10.359	27.9	11.155
1431	44.8	46.3	3.348	46.8	4.464
1617	52.2	58.4	11.877	60.1	15.134
1736	54.3	64.1	18.048	64.8	19.337
2362	46.8	48.6	3.846	48.9	4.487
2917	36.3	40.6	11.846	41.5	14.325
3415	22.7	23.4	3.084	23.7	4.405

3.7 FABRIC PROPERTIES

3.7.1 WATER ABSORBENCY

Figure 11 represents the effect of Pectinase, protease, lipase and cellulase enzyme combination on water absorbency characteristics of the organic cotton fabrics. It is observed that the water absorbency of fabric was noticed in the range of 2-10 sec. The better water absorbency was noticed at 8% of pectinase, 3% of protease, 0.8% of lipase and 0.8 of cellulase. The lower the water absorbency time better scouring can be done.

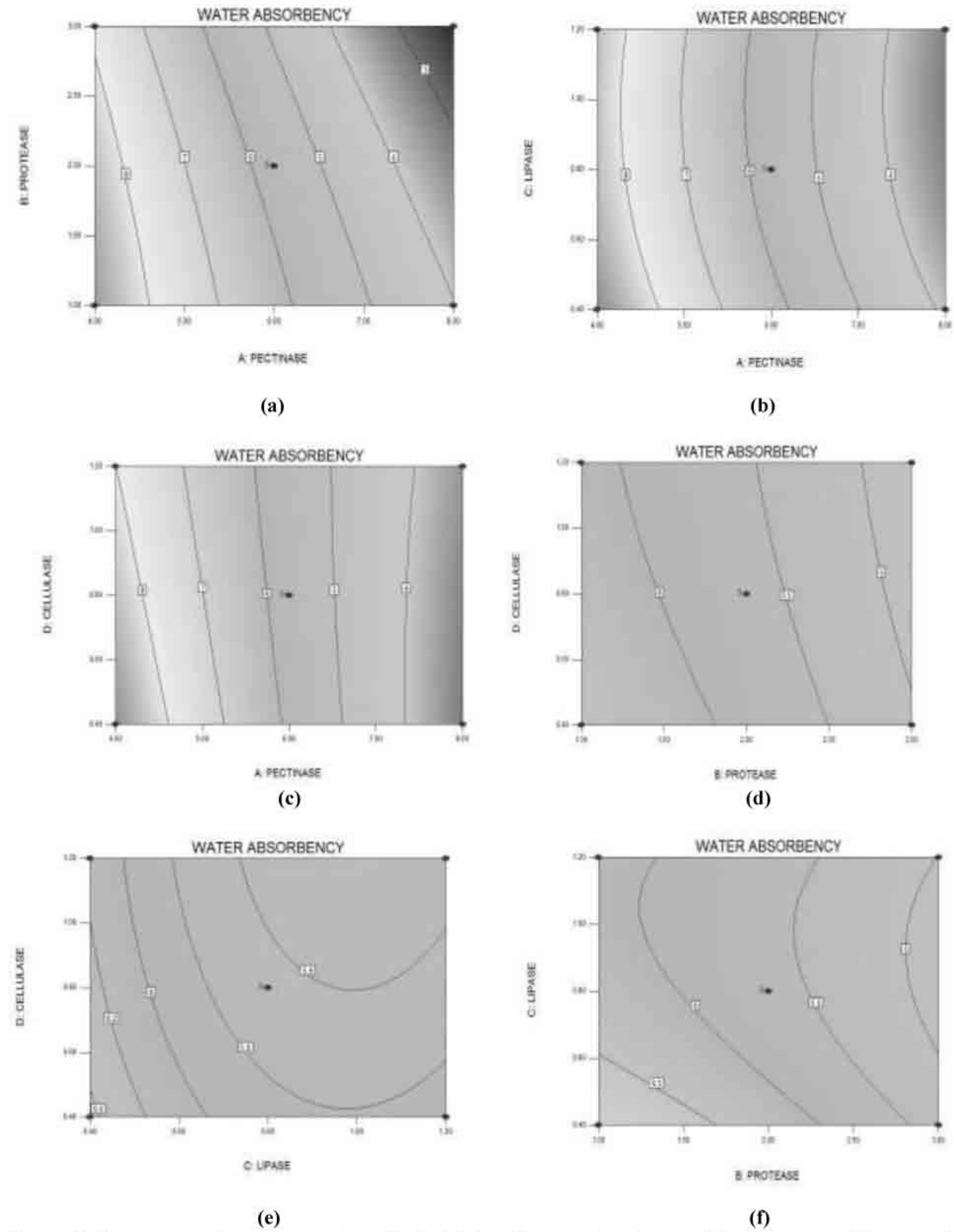


Figure 11 Contour graphs represents the effect of (a) pectinase and protease, (b) pectinase and lipase and (c) pectinase and cellulase enzyme, (d) protease and cellulase, (e) protease and lipase and (f) cellulase and lipase enzyme concentration on fabric water absorbency

From Table 10, the water absorbency (sec) of bioscoured organic cotton fabric was noticed better in sample no.7 which was treated with 6%pectinase, 2%protease, 0.6%lipase and 0.8%celluase at 45min reaction time, 60 deg C, and pH 8.5. It may be due to higher removal of wax/oil component in the organic cotton up to 84.2% and presence of cellulase enzyme which improves partial surface hydrophilic nature in the organic cotton fabric. The highest time in sec for water absorbency of the organic cotton fabric was noticed in sample no.18 which was treated in absence of pectinase and protease enzymes. These enzymes are playing important role in the fabric water absorbency by removal of pectin and wax components. By adding the cellulase enzyme in the bioscouring process was observed improved water absorbency, it may be due partial hydrolysis of cellulose molecules on the cotton surface.

TABLE 10. ANALYSIS OF VARIANCE -WATER ABSORBENCY

Source	F Value	P-value prob>F
A-PECTINASE	251.59	<0.0001
B-PROTEASE	57.28	0.0012
C-LIPASE	36.21	0.1005
D-CELLULASE	41.03	0.3293

The model F-value was 30.21 which implied that the model was significant and there was only 0.01% chance that a 'Model F-value' of this large value could occur due to noise. The predicted R^2 value was 0.9381 and is in reasonable agreement with the Adjusted R^2 of 0.9957. Adequate precision which measures the signal to noise ratio was 16.821, which is greater than 5 indicating that the model can be used to navigate the design space. From the Table 10 it is noticed that the enzyme concentration in the water absorbency in the scouring process was noticed significant differences at $F_{actual} > F_{critical}$ ($F_{2,14}$ values of 251.59>30.21) at 95% confidence level with respect to pectinase enzyme. There is found significant difference in protease and lipase enzyme treatment on water absorbency at $F_{actual} > F_{critical}$ ($F_{2,14}$ values of 57.28 > 30.21 and 36.21 > 30.21 respect to protease and lipase enzyme treatment). It may be due to the enzyme reaction time on the degradation of wax and oil compounds depends mainly the selected range of times to achieve required weight loss of the cotton fabric to achieve better water absorbency.

3.7.2 FABRIC WHITENESS INDEX

From Table 1, the highest whiteness index of bioscoured organic cotton fabric with mixed enzymatic system was observed 52.57% at 8% pectinase, 4%protease, 0.8% lipase and 0.4% cellulase enzyme at 30 min reaction time, 60 deg C and pH 9.0 (Sample no.29). It may be due to better integration and higher concentration of pectinase for removal of pectin up to 78.42% and wax/oil component removal up to 92.4% on the organic cotton bioscoured fabrics which has higher water absorbency and lower yellowness in nature when compared to sample no.18. The mixed enzymes such as pectinase, protease and lipase plays a important role for removal of pectin and wax/oil components and also cellulase enzyme supports the exo and endo partial surface reaction of the organic cotton fabrics.

3.7.3 FABRIC YELLOWNESS INDEX

From Table 1, the lowest yellowness index of the bioscoured organic cotton fabric with specific enzymatic system was 13.14% at 8%pectinase, 3%protease, 0.8%lipase and 0.8%cellulase of sample no.19 treated at 60 min reaction time, 55 deg C and pH 9.5. It may be due to higher removal of pectin and wax component in the organic cotton fabric in the enzymatic system which has whiteness index of 52.413. It is noticed that highest whiteness index of organic cotton fabric show lower yellowness index in all the treated fabrics. For sample no.18 which has highest yellowness index of 24.371% due to absence of pectinase and cellulase enzymes, 2%protease and 0.8%lipase. From the test results, the pectinase plays important role in removal of pectin for lowering the yellowness index on fabric and cellulase plays the better mixed enzyme reaction on the organic cotton fabric during bioscouring.

3.7.4 FABRIC BRIGHTNESS INDEX

From Table 1, the highest fabric brightness in bioscoured organic cotton fabric was found in the sample no.19 which was treated with 8%pectinase, 3%protease, 0.8%lipase and 0.8% cellulase at 60 minute time, 55 deg C, and pH 8.5. It may be due to higher whiteness of 52.413 and lower yellowness index of 13.14 and fabric treated higher pectinase and cellulase concentrations. It was also noticed that higher concentration of cellulase enzyme treated fabric observed higher brightness index due to surface smoothness of the organic cotton fabric. The lowest brightness index of organic cotton fabric was noticed in sample no.18, it was treated in absence of pectinase and cellulase, 2%protease and 0.8% lipase enzyme conditions. It was noticed that pectinase and cellulase enzymes plays important role in brightness index of the bioscoured organic cotton fabrics.

3.7.5 MULTIVARIATE ANOVA

The bioscouring performance of organic cotton fabric was analysed with and without aerodynamic treatment using mixed enzymes and their statistical results are given in Table 11. From the ANOVA test results that it was noticed significant differences between with and without aerodynamic treatments on the fabric properties of fabric weight loss, water absorbency, wetting area, whiteness index, yellowness index and brightness index at $F(2,29)>Fcri$, and also $Pvalue>0.05$ test in case of mixed enzymatic system.

TABLE 11. MULTIVARIATE ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Scouring weight loss, %	13.642	1	13.642	317.80	3.62E-17	4.182
Fabric water absorbency, sec	4.056	1	4.056	53.12737	5E-08	4.182
Fabric wetting area, mm2	12269.4	1	12269.4	78.58746	9.43E-10	4.182965
Fabric whiteness Index	214.6853	1	214.6853	81.27522	6.56E-10	4.182965
Fabric yellowness Index	80.81954	1	80.81954	116.5433	1.13E-11	4.182965
Fabric brightness Index	77.7081	1	77.7081	117.6292	1.01E-11	4.182965

3.7.6 COLOR COORDINATES

Table 12 shows color coordinates and color differences of organic cotton treated with mixed enzymatic system compared with and without aerodynamic system for Sample 19. The color values were evaluated in CIELAB color space, with three axes, namely as L*, a* and b*. The L* is the color coordinates which represents the lightness of the samples and can be measured independently of color hue. The a* stands for the horizontal red-green color axis. The C* represents brightness or dullness of the samples. Any increase in the C* of samples could be concluded as more brightness of the fiber. According to the results, the L* and C* values increase for the samples treated with mixed enzymatic scouring with aerodynamic system; the a* and b* values decrease for the samples it contributes to a decrease in yellowness and redness nature of fabric when compared to without aerodynamic system. A decrease in C* value contributes to a increase in brightness of the samples, which is an important factor in textile products. Difference in color coordinates and ΔE of the samples has noticed significant differences $F_{(2,29)}$ 36.43 > 4.18 Fcrit hence

Factual > Fcrit at 95% confidence level of statistical test.

TABLE 12. COLOR CO-ORDINATES OF FABRICS AFTER TREATMENT WITH AERODYNAMIC SYSTEM

Samples		L*	a*	b*	c*	H*	DL*	Da*	Db*	Dc*	Δ E
Without aerodynamic	Standard	68.753	24.481	-5.643	23.123	347.025	-	-	-	-	-
with aerodynamic	8kPa	68.924	22.425	-5.115	23.801	347.156	0.171	-2.056	0.528	0.678	2.129
	12kPa	72.057	21.481	-4.512	24.95	348.142	3.304	-3.000	1.131	1.827	4.603
	16kPa	73.037	18.993	-3.439	25.302	349.741	4.284	-5.488	2.204	2.179	7.302

4. CONCLUSIONS AND PROSPECTIVE RESEARCH

The bioscouring performance of 100% organic cotton fabric using mixed enzymatic system was studied with and without aerodynamic treatment at various process variables using artificial neural network. From the research study the following conclusions were derived:

- The alkaline pectinase enzymes are better active and catalyze the degradation of pectin at temperature range of 55-60 deg C and time of 45min to achieve required level of 75-80% pectin degradation. The pH of the process bath is also a major influence for better reaction of enzyme to catalyze the hydrolysis of pectin groups.
- The higher enzyme concentration at 6% level and higher temperature of 60 deg C took lesser time to achieve required pectin hydrolysis. Process variables are optimized using MATLAB 7.0 and it will pave the way to predict the enzyme kinetics at various concentrations, temperature and reaction time to achieve required degradation of pectin with minimum error %.
- The output result of the software to achieve the desired bioscouring of organic cotton fabric on their physical properties such as fabric weight loss, water absorbency, wetting area, whiteness index, yellowness index, and brightness index in the specific enzymatic system, out of which the software opted best process conditions at 8% alkaline pectinase, 3%protease, 0.8%lipase and 0.8%cellulase process condition at temperature of 55 deg C and reaction time 60 minutes at pH 8.5 with 1.0% desirability.
- From the best opted test results, the actual pectin and weight loss of the bioscoured organic cotton fabric was achieved 68.40% and 4.80% respectively with error of 1.218% in case of without aerodynamic treatment. With aerodynamic treatment, the fabric weight loss was observed 6.38% and pectin removal up to 76.42%.
- The overall aerodynamic efficiency was achieved 9.72%, 24.08% and 37.20% treated at 8 kPa, 12 kPa and 16 kPa air pressure levels respectively on organic cotton fabric through mixed enzymatic system when compared to without aerodynamic.

5. INDUSTRIAL IMPORTANCE

This study provides industrial bio-scouring technologies and an insight into the properties of mixed enzymatic systems and the predictability of their scouring performance while deciding the recipe and process parameters.

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