



Research Article

Dilute Sulphuric Acid Pretreatment Optimization of Cotton Stalk for Cellulase Production through Box-Bhenken Design

Noor Fatima¹, Muhammad Irfan^{2*}, Hafiz Abdullah Shakir¹, Javed Iqbal Qazi¹

¹Microbial Biotechnology Laboratory, Department of Zoology, University of the Punjab, New Campus Lahore 54590, Pakistan

²Department of Biotechnology, University of Sargodha, Sargodha, Pakistan

Article History

Received: March 10, 2017

Revised: April 17, 2017

Accepted: April 26, 2017

Published: May 16, 2018

Authors' Contributions

NF conducted the experiments. MI conceived the study design. HAS provide technical assistance and JIQ critically evaluated the draft.

Keywords

Cellulase, Cotton stalk, Pretreatment, RSM, *Bacillus subtilis*, Submerged fermentation.

Abstract | In this study, cellulase enzyme production was assessed by pretreating cotton stalk with dilute sulphuric acid which was optimized through response surface methodology. Pretreatment conditions were optimized using three variable with three levels like sulfuric acid concentrations (0.6%, 0.8%, 1% v/v), biomass loading (5%, 10%, 15% w/v), and residence time (4, 6 and 8h). After pretreatment process, cellulase production was achieved by solid substrate which was conducted in 250mL capacity Erlenmeyer flask in which incubation of *Bacillus subtilis* was carried out for 24 h of fermentation period at temperature of 50°C. Results showed that cellulase production was greatly affected by the thermochemical pretreatment as compared to the chemical pretreatment. At the pretreatment condition of 1% H₂SO₄ conc, 6h residence time, 15% substrate concentration maximum CMCase production (0.858 IU/ml/min) was obtained while at pretreatment conditions of 1% H₂SO₄ concentration, 8h residence time, 10% substrate concentration at room temperature followed by routine autoclaving, FPase production up to 0.876 IU/ml/min was recorded. The results of present study were found significant. The cellulase enzyme produced in this process affectively hydrolyzes the pretreated substrate at temperature of 50°C and 53 h of incubation period by releasing reducing sugars of 0.74 mg/ml. This study ensures the effective usage of lignocellulosic biomass at large scale biofuel production.

To cite this article: Fatima, N., Irfan, M., Shakir, H.A. and Qazi, J.I., 2018. Dilute sulphuric acid pretreatment optimization of cotton stalk for cellulase production through Box-Bhenken design. *Punjab Univ. J. Zool.*, **33**(1): 77-85. <http://dx.doi.org/10.17582/pujz/2018.33.1.77.85>

Introduction

Structural complexity and rigidity of lignocellulosic substrate have given rise to the diverse variety of degradative enzyme - the cellulases (Bayer *et al.*, 1998). A great deal of variety of lignolytic microorganisms mainly fungi and bacteria are identified and isolated among them *Trichoderma reesei* and its mutants, white rot fungi an efficient lignin degraders and *Phanerochaete chrysosporium* are most commonly used for cellulose and hemicellulases production (Baldrian and Gabriel, 2003; Falcón *et al.*, 1995; McCarthy, 1987; Zimmermann, 1990; Vicuña, 1988). The bond beta-1, 4-d-glucan in cellulose basically breaks

down by the enzyme cellulases and glucose, cellobiose and cello-oligosaccharides produce as primary product.

Cellulose degradation is achieved by several methods. One of the important methods is the use of cellulase which includes three types of enzyme that degrade cellulose, by a phenomenon of synergism (Iqbal *et al.*, 2010). These three enzymes are endo-glucanases (EG), cellobiohydrolases also called exoglucanases (CBH) and β -glucosidases (BGL). Endo-glucanases and cellobiohydrolases by attacking on the reducing and non-reducing end of the cellulose structure produces the nicks at internal sites, oligosaccharides and new chain ends and cello-oligosaccharides and cellobiose respectively and glucosidases complete the hydrolysis by hydrolyzing the cellobiose and soluble cellodextrins to liberate glucose (Sukumaran *et al.*, 2005).

***Corresponding author:** Muhammad Irfan

m.irfan@uos.edu.pk; irfan.biotechnologist@gmail.com

June 2018 | Volume 33 | Issue 1 | Page 77

Cellulases are produced by microorganisms when grown on cellulosic materials (Lee and Koo, 2001). Global production of cellulase enzymes has great interest in research field. One of the major concerns is low titers of cellulase production. Multifaceted approaches are adopted to improve enzyme production, such as for substrate using inexpensive raw materials, bioengineering the microorganisms, effective bioprocess technologies, *etc.* (Lynd *et al.*, 2002; Sukumaran *et al.*, 2005).

Cellulase secretion is largely effected by the lignocellulosic substrate. Some substrates not required any specific inducers to enhance the synthesis of lignocellulolytic enzyme (Elisashvili *et al.*, 2009). Solid state and submerged fermentation techniques are most commonly used for cellulase production. The SSF is carried out in absence of free water as it is close to the natural environment to produces the high titers of enzyme (Cen and Xia, 1999; Jha *et al.*, 1995).

Various parameters effected the cellulase production like the kind of the substrate, medium pH, nutrient availability, temperature of the fermentation, supply of inducer *etc.* Cellulolytic organisms like fungal species *Trichoderma*, *Penicillium*, *Humicola* and *Aspergillus* (Sukumaran *et al.*, 2005). Due to the capacity of producing the large quantities of extracellular enzyme *Bacillus* sp. is considered one of the important species due to their capacity of producing of large quantities of enzymes (Singh *et al.*, 2004). *Bacillus* *sphaericus* and *Bacillus subtilis* both species are reported to express high cellulose degradation activities (Mawadza *et al.*, 1996; Singh *et al.*, 2004).

Table I: Coded and actual levels of the factors for three factors Box-Behnken design.

Independent variables	Symbols	Coded and actual values		
		-1	0	+1
Acid concentration (%)	X_1	0.6	0.8	1.0
Substrate concentration (%)	X_2	5	10	15
Time (Hours)	X_3	4	6	8

Response surface methodology (RSM) is empirical and statistical analysis widely used for analyzing and modeling the problems by studying the aggregated effect of the several variables, mathematical technique in which several variables influences the response of interest (Kim *et al.*, 2008; Bas and Boyaci, 2007). It is used for optimization of different steps in the multivariable systems. Quantification of input levels and levels of selected response is carried out by using design of experiment. Box-Bhenken and central composite designs are common designs of RSM (Khuri and Cornell, 1987; Montgomery, 2005). The objective of the present study was production of cellulase enzyme from pretreated cotton stalk and its application in saccharification process.

Materials and Methods

Microbial strain

Bacillus subtilis K-18 was taken from repository of Microbial Biotechnology Laboratory and revive on nutrient agar plates and then used in present study.

Pretreatment of cotton stalk

Cotton stalk was collected from field of Shahkot, District Nankana, Punjab, Pakistan. Cotton stalks was washed to remove dust, then sundried for seven days and then oven drying at 70°C for 1 day. The dried cotton stalk was cut into small pieces and turn into powdered form. Pretreatment of powdered cotton stalk was performed as discussed earlier (Arshad *et al.*, 2017).

Fermentation methodology

Cellulase enzyme production was carried out in 25ml of fermentation medium (1% yeast extract and 2% pretreated substrate, pH of 5) in the 250ml capacity of Erlenmeyer flask. This medium was autoclaved and then flasks were inoculated employing 2% (v/v) of inoculum. The culture was incubated at 50°C with shaking 120 rpm for of 24 h. The cultures were filtered by muslim cloth at the end of fermentation period. After filtration, to obtain the clear filtrate as crude source of enzyme, the filtrate obtained by muslim cloth was centrifuged at 10,000 rpm for 10 min at 4°C were carried out. Each fermentation experiments were carried out in triplicate.

Cellulase assay

CMCase and FPase were determined as described in our earlier reports (Irfan *et al.*, 2011). One unit of CMCase or FPase activity defined as the amount of enzyme required to liberate one micromole of glucose from substrate per milliliter per minute under standard assay conditions.

Experimental design

For cellulase production optimization of different pretreatment conditions was carried out by Box-Bhenken design (BBD) with three variables *i.e.*, sulfuric acid concentration (X_1), substrate concentration (X_2) and time (X_3) (Table I). The response was calculated using STATISTICA software.

Results and Discussion

In this study dilute acid pretreatment of cotton stalk was performed with three factors *i.e.* dilute sulphuric acid concentration (X_1), substrate concentration (X_2) and residence time (X_3) with three levels as mentioned in Table I. After pretreatment, the solid residue was washed up to neutrality, dried and further used for the production of cellulase in submerged fermentation by *Bacillus subtilis* at 50°C for 24 h. The experiments were conducted according to Box-Bhenken design of response surface methodology.

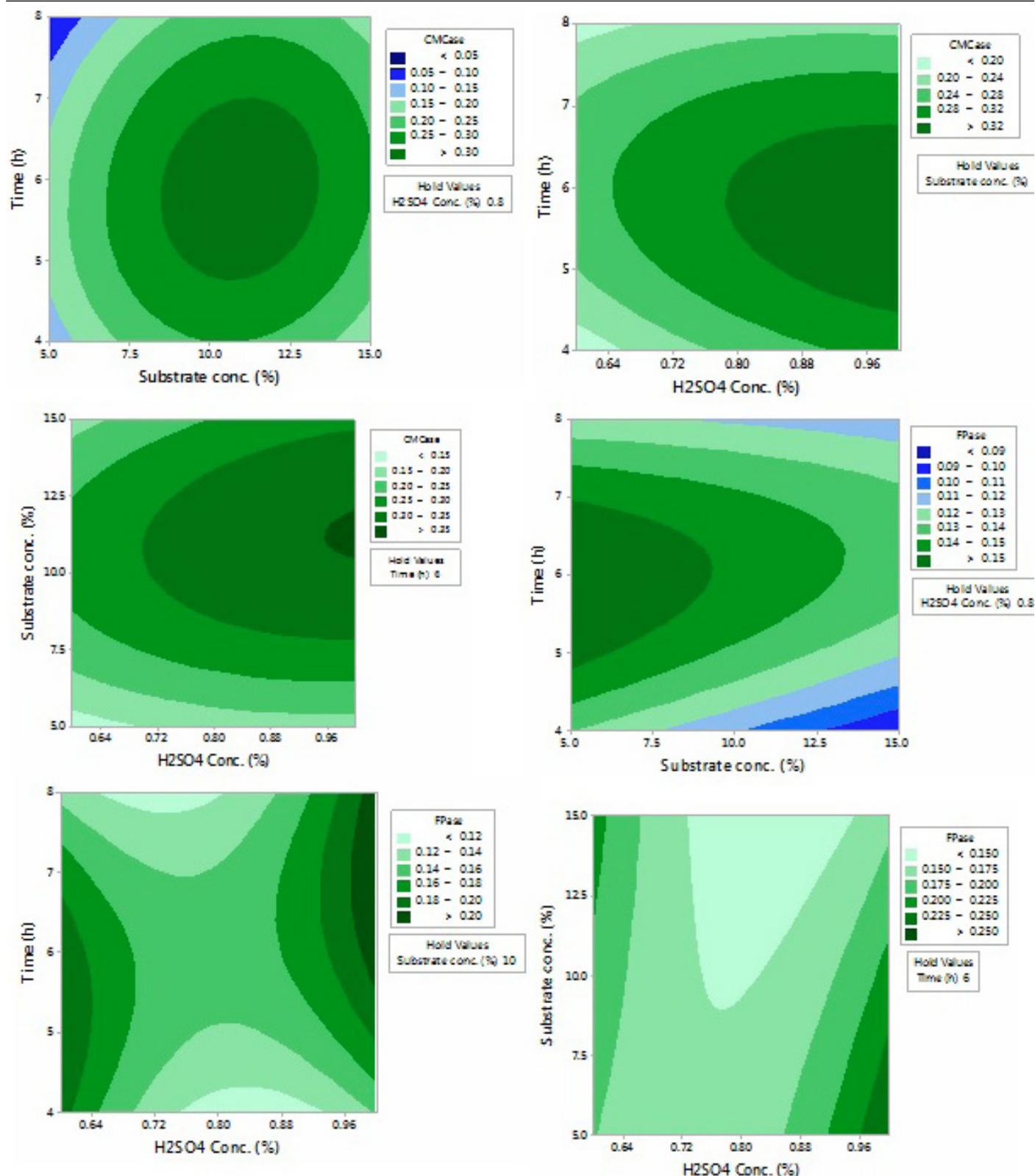


Figure 1: CMCase (IU/ml/min) and FPase (IU/ml/min) production from H₂SO₄ treated cotton stalk.

The calculation of the response was carried out according to polynomial regression equations (Equations 1 to 4). The cellulase enzyme production was found minimum in acid treated cotton stalk while acid followed by steam treated cotton stalk. In case of cellulase production, during fermentation process nature of substrate play a key role in influencing the production of enzyme (Kang *et al.*, 2004). Box-Bhenken design results (Tables III, IV)

revealed that under pretreatment conditions of 15% substrate concentration, 1% H₂SO₄, and time of 6 h. Maximum CMCase activity of 0.885 IU/ml/min was obtained. The highest FPase production (0.876 IU/ml/min) was noted with pretreatment condition of 1% H₂SO₄, 10% substrate concentration and residence time of 10h followed by steaming. Close matching of the observed and predicted values showed the accuracy of model.

Table II: Cellulase production by H₂SO₄ treated cotton stalk using Box-Bhenken design.

Run No.	X ₁	X ₂	X ₃	CMCase activity (IU/ml/min)			FPase activity (IU/ml/min)		
				Observed	Predicted	Residual	Observed	Predicted	Residual
1	0.8	10	6	0.322	0.322	0.000	0.148	0.148	0.000
2	1.0	10	8	0.246	0.226	0.020	0.219	0.211	0.008
3	1.0	15	6	0.303	0.289	0.013	0.129	0.167	-0.037
4	1.0	10	4	0.310	0.291	0.018	0.156	0.141	0.0147
5	1.0	5.0	6	0.124	0.177	-0.052	0.266	0.251	0.0149
6	0.6	15	6	0.231	0.178	0.052	0.195	0.210	-0.014
7	0.8	5.0	4	0.151	0.117	0.034	0.100	0.130	-0.029
8	0.6	10	8	0.162	0.181	-0.018	0.118	0.132	-0.014
9	0.8	15	8	0.137	0.172	-0.034	0.142	0.112	0.029
10	0.6	10	4	0.151	0.172	-0.020	0.180	0.188	-0.008
11	0.6	5.0	6	0.110	0.123	-0.013	0.214	0.176	0.037
12	0.8	5.0	8	0.078	0.046	0.032	0.098	0.121	-0.023
13	0.8	15	4	0.126	0.158	-0.032	0.113	0.089	0.023

Table III: Cellulase production by H₂SO₄ followed by steam treated cotton stalk using Box-Bhenken design.

Run No.	X ₁	X ₂	X ₃	CMCase activity (IU/ml/min)			FPase activity (IU/ml/min)		
				Observed	Predicted	Residual	Observed	Predicted	Residual
1	0.8	10	6	0.800	0.800	0.000	0.695	0.695	0.000
2	1.0	10	8	0.754	0.758	-0.003	0.876	0.751	0.124
3	1.0	15	6	0.885	0.858	0.027	0.341	0.415	-0.074
4	1.0	10	4	0.784	0.775	0.009	0.344	0.314	0.030
5	1.0	5	6	0.744	0.777	-0.032	0.348	0.429	-0.080
6	0.6	15	6	0.762	0.730	0.032	0.789	0.708	0.080
7	0.8	5	4	0.684	0.660	0.023	0.628	0.577	0.050
8	0.6	10	8	0.645	0.654	-0.009	0.657	0.687	-0.030
9	0.8	15	8	0.731	0.754	-0.023	0.738	0.788	-0.050
10	0.6	10	4	0.620	0.616	0.003	0.695	0.820	-0.124
11	0.6	5	6	0.616	0.643	-0.027	0.652	0.578	0.074
12	0.8	5	8	0.587	0.551	0.036	0.660	0.704	-0.043
13	0.8	15	4	0.587	0.624	-0.036	0.654	0.610	0.043

Equations for chemical treated cotton stalk

CMCase activity (IU/ml/min) = $-1.383 + 1.06 X_1 + 0.0740 X_2 + 0.2693 X_3 - 0.453 X_1^2 - 0.00449 X_2^2 - 0.02168 X_3^2 + 0.0145 X_1 X_2 - 0.0466 X_1 X_3 + 0.00210 X_2 X_3$ (Eq. 1)

FPase activity (IU/ml/min) = $0.879 - 2.308 X_1 + 0.0172 X_2 + 0.0327 X_3 + 1.358 X_1^2 - 0.000036 X_2^2 - 0.00846 X_3^2 - 0.0296 X_1 X_2 + 0.0784 X_1 X_3 + 0.00078 X_2 X_3$ (Eq. 2)

Equations for thermochemical treated cotton stalk

CMCase activity (IU/ml/min) = $-0.446 + 0.424 X_1 + 0.0140 X_2 + 0.2754 X_3 + 0.078 X_1^2 - 0.002028 X_2^2 - 0.02543 X_3^2 - 0.0014 X_1 X_2 - 0.0345 X_1 X_3 + 0.00600 X_2 X_3$ (Eq. 3)

FPase activity (IU/ml/min) = $0.94 + 1.47 X_1 + 0.0813 X_2 - 0.388 X_3 - 2.38 X_1^2 - 0.00272 X_2^2 + 0.0107 X_3^2 - 0.0360 X_1 X_2 + 0.356 X_1 X_3 + 0.00130 X_2 X_3$ (Eq. 4)

All the response (CMCase and FPase activity) cal-

culated was statistical analyzed with analysis of variance and results revealed for CMCase production, the proposed model was found significant in both treatments (H₂SO₄ treatment and H₂SO₄ followed steam treatment) while the model was not significant for FPase production. In H₂SO₄ treated cotton stalks the F and P value of the CMCase model was 4.75 and 0.050 while in H₂SO₄ followed by steam treated cotton stalks the values was 7.99 and 0.017, respectively. Coefficient of determination (R² value) of treated (89.54 %) and H₂SO₄ followed by steam treated (93.50%) further confirmed the fitness of the model by accurately showing the predicting response. Furthermore, the model also supported by adjusted R² value of 70.71% (H₂SO₄ treated) and 81.80% (H₂SO₄ followed by steam treated).

These results indicated that pretreatment of substrate is very effective in conversion of raw materials into valuable products with aid of microbes. In previous study, pretreatment of rice straw with 0.5M KOH followed by 0.1N

H₂SO₄ yielded better CMCase activity from *Bacillus* sp. 313SI (Goyal *et al.*, 2014). Ghazanfar *et al.* (2018) reported maximum FPase production from *B. subtilis* K-18 when substrate *Sacharum spontaneum* pretreated with 1% H₂SO₄, substrate concentration of 10% and 4h of residence time followed by autoclaving. Anjum *et al.* (2017) obtained highest yield of cellulase from acacia dust pretreated with 0.8% H₂SO₄, 4 h residence time and 15% substrate concentration. Similarly, peanut shells treated with 0.6% and 0.8% H₂SO₄ yielded maximum CMCase and FPase production by *B. subtilis* K-18 in submerged fermentation,

respectively (Arshad *et al.*, 2017). Eucalyptus leaves treated with 0.8% and 1.0% H₂SO₄ gave maximum titer of CMCase and FPase production using *B. subtilis* K-18 in submerged fermentation, respectively (Iqbal *et al.*, 2017). Arooj *et al.* (2017) stated that banana peduncle produced best cellulase under optimized pretreatment conditions of 0.4N H₂SO₄, substrate concentration of 15% and soaking time of 6h. Another study reported that pretreatment effectively improved cellulase production revealing correlation between physiochemical properties of substrates and enzyme production (Brijwani and Vadlani, 2011).

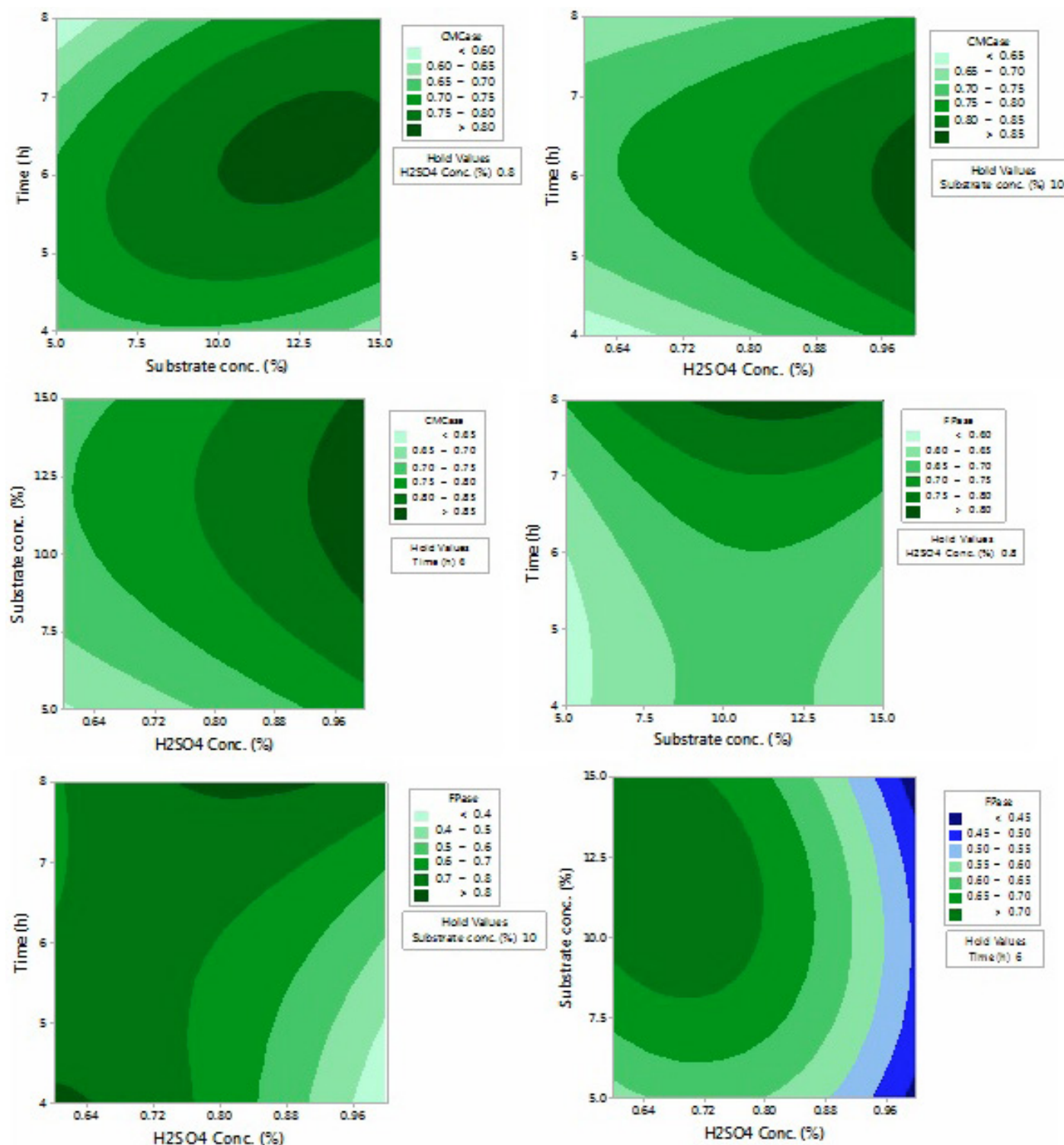


Figure 2: CMCase (IU/ml/min) and FPase (IU/ml/min) production from H₂SO₄ steam treated cotton stalk.

Table IV: ANOVA of chemical (H₂SO₄) and thermochemical treated cotton stalk.

	Sources	DF	Adj SS	Adj MS	F value	P value
Chemical (H₂SO₄) treated						
CMCase (IU/ml/min)	Model	9	0.102398	0.011378	4.75	0.050
	Linear	3	0.029160	0.009720	4.06	0.083
	X ₁	1	0.013474	0.013474	5.63	0.064
	X ₂	1	0.014046	0.014046	5.87	0.060
	X ₃	1	0.001639	0.001636	0.68	0.446
	Square	3	0.069242	0.023081	9.65	0.016
	X ₁ ²	1	0.001210	0.001210	0.51	0.509
	X ₂ ²	1	0.046529	0.046529	19.45	0.007
	X ₃ ²	1	0.027778	0.027778	11.61	0.019
	2 Way interaction	3	0.003997	0.001332	0.56	0.666
	X ₁ *X ₂	1	0.000839	0.000839	0.35	
	X ₁ *X ₃	1	0.001387	0.001387	0.58	
	X ₂ *X ₃	1	0.001770	0.001770	0.74	
	Error	5	0.011964	0.002393		
	Lack of fit	3	0.011964	0.003988		
	Pure error	2	0.000000			
	Total	14	0.114362	0.000000		
FPase (IU/ml/min)	Model	9	0.025788	0.002865	2.12	0.210
	Linear	3	0.001837	0.000612	0.45	0.726
	X ₁	1	0.000500	0.000500	0.37	0.569
	X ₂	1	0.001239	0.001239	0.92	0.382
	X ₃	1	0.000098	0.000098	0.07	0.798
	Square	3	0.016279	0.005426	4.02	0.084
	X ₁ ²	1	0.010892	0.010892	8.08	0.036
	X ₂ ²	1	0.000003	0.000003	0.00	0.964
	X ₃ ²	1	0.004226	0.004226	3.13	0.137
	2 way interaction	3	0.007672	0.002557	1.90	0.248
	X ₁ *X ₂	1	0.003494	0.003494	2.59	0.168
	X ₁ *X ₃	1	0.003936	0.003936	2.92	0.148
	X ₂ *X ₃	1	0.000242	0.000242	0.18	0.689
	Error	5	0.006743	0.001349		
	Lack of fit	3	0.006743	0.002248		
	Pure error	2	0.000000			
	Total	14	0.032531	0.000000		
Thermochemical treated						
CMCase (IU/ml/min)	Model	9	0.109443	0.012160	7.99	0.017
	Linear	3	0.048495	0.016165	10.63	0.013
	X ₁	1	0.034350	0.034350	22.58	0.005
	X ₂	1	0.013931	0.013931	9.16	0.029
	X ₃	1	0.000214	0.000214	0.14	0.723
	Square	3	0.045775	0.015258	10.03	0.015
	X ₁ ²	1	0.000036	0.000036	0.02	0.884
	X ₂ ²	1	0.009490	0.009490	6.24	0.055
	X ₃ ²	1	0.038218	0.038218	25.12	0.004
	2 Way interaction	3	0.015173	0.005058	3.32	0.114
	X ₁ *X ₂	1	0.000008	0.000008	0.01	0.946
	X ₁ *X ₃	1	0.000761	0.000761	0.50	0.511
	X ₂ *X ₃	1	0.014404	0.014404	9.47	0.028
	Error	5	0.007606	0.007606		
	Lack of fit	3	0.007606	0.007606		
	Pure error	2	0.000000	0.000000		
	Total	14	0.117049	0.117049		

	Sources	DF	Adj SS	Adj MS	F value	P value
Thermochemical treated						
FPase (IU/ml/min)	Model	9	0.296322	0.032925	2.50	0.163
	Linear	3	0.151086	0.050362	3.83	0.091
	X ₁	1	0.097806	0.097806	7.43	0.041
	X ₂	1	0.006805	0.006805	0.52	0.504
	X ₃	1	0.046475	0.046475	3.53	0.119
	Square	3	0.058044	0.019348	1.47	0.329
	X ₁ ²	1	0.033334	0.033334	2.53	0.172
	X ₂ ²	1	0.017100	0.017100	1.30	0.306
	X ₃ ²	1	0.006715	0.006715	0.51	0.507
	2 way interaction	3	0.087191	0.029064	2.21	0.205
	X ₁ *X ₂	1	0.005194	0.005194	0.39	0.557
	X ₁ *X ₃	1	0.081325	0.081325	6.18	0.055
	X ₂ *X ₃	1	0.000672	0.000672	0.05	0.830
	Error	5	0.065803	0.013161		
	Lack of fit	3	0.065803	0.021934		
	Pure error	2	0.000000			
Total		14	0.362125	0.000000		

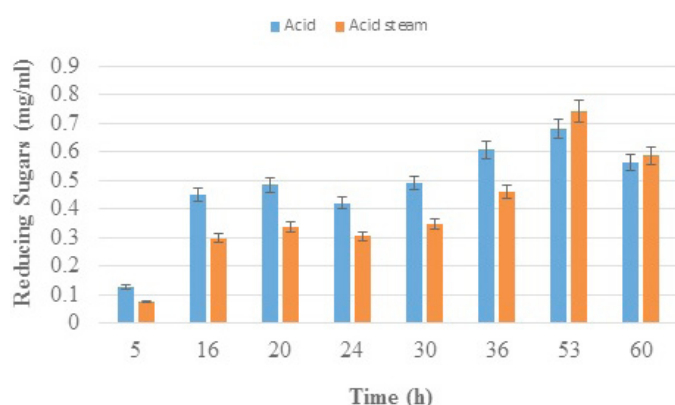


Figure 3: Enzymatic hydrolysis of H₂SO₄ and H₂SO₄ followed by steam treated cotton stalks.

The cellulase enzyme produced from these pretreated substrates was further used for enzymatic hydrolysis of best treated substrate (having maximum total phenolic compounds liberation). The enzymatic hydrolysis was performed at 50°C, pH 5.0 for various time periods to check the optimum time for maximum reducing sugar production. Results (Figure 3) reveals that reducing sugar production was increased with increase in time period, but maximum reducing sugar production was achieved at 53 h of incubation period. Various studies reported different optimum time for saccharification of various substrates like 8h for wheat straw (Asghar *et al.*, 2014), pine needles (Irfan *et al.*, 2017), 72h for rice straw (Kshirsagar *et al.*, 2015) and 105 h for disposable wooden chopsticks (Phummala *et al.*, 2015).

Conclusion

Results of this study concluded that H₂SO₄ pretreatment is efficient for cellulase production by *Bacillus subtilis* in submerged fermentation. The produced cellulase effectively hydrolyzed the pretreated substrate for sugar pro-

duction which could be utilized for fermentation process for the production of different compounds like bioethanol.

Acknowledgement

Authors are thankful to the technical staff of the Microbial Biotechnology Lab of Department of Zoology, University of the Punjab, New Campus, Lahore, Pakistan.

Conflicts of interest

The authors declare no conflicts of interest.

References

- Anjum, A., Irfan, M., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2017. Optimization of sulphuric acid pretreatment of Acacia saw dust through box-bhenken design for cellulase production by *B. subtilis* K-18. *Adv. Life Sci.*, **5**: 19-24.
- Arooj, A., Irfan, M., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2017. Effect of dilute sulphuric acid pretreatment on cellulase production by *Bacillus subtilis* K-18 through response surface methodology. *Proc. Pak. Acad. Sci. B: Life environ. Sci.*, **54**: 11-20.
- Arshad, F., Irfan, M., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2017. Optimization of dilute sulphuric acid pretreatment of peanut shells through Box- Bhenken design for cellulase production by *Bacillus subtilis* K-18. *Punjab Univ. J. Zool.*, **32**: 81-90.
- Asghar, U., Irfan, M., Iram, M., Huma, Z., Nelofer, R., Nadeem, M. and Syed, Q., 2015. Effect of alkaline pretreatment on delignification of wheat straw. *Nat. Prod. Res.*, **29**: 125-131. <https://doi.org/10.1080/14786419.2014.964712>
- Baldrian, T. and Gabriel, J., 2003. Lignocellulose degrada-

- tion by *Pleurotus ostreatus* in the presence of cadmium. *FEMS Microbiol. Lett.*, **220**: 235-240. [https://doi.org/10.1016/S0378-1097\(03\)00102-2](https://doi.org/10.1016/S0378-1097(03)00102-2)
- Bas, D. and Boyaci, I.H., 2007. Modeling and optimization I: Usability of response surface methodology. *J. Fd. Engg.*, **78**: 836-845. <https://doi.org/10.1016/j.jfoodeng.2005.11.024>
- Bayer, E.A., Chanzy, H., Lamed, R. and Shoham, Y., 1998. Cellulose, cellulases and cellulosomes. *Curr. Opin. Struc. Biol.*, **8**: 548-557. [https://doi.org/10.1016/S0959-440X\(98\)80143-7](https://doi.org/10.1016/S0959-440X(98)80143-7)
- Brijwani, K. and Vadlani, P.V., 2011. Cellulolytic enzymes production via solid-state fermentation: Effect of pretreatment methods on physicochemical characteristics of substrate. *Enzyme Res.*, **2011**: 860134. <https://doi.org/10.4061/2011/860134>
- Cen, P. and Xia, L., 1999. Production of cellulase by solid-state fermentation. *Adv. Biochem. Engg. Biotechnol.*, **65**: 69-92. https://doi.org/10.1007/3-540-49194-5_4
- Elisashvili, V., Kachlishvili, E., Tsiklauri, N., Metreveli, E., Khardziani, T. and Agathos, S.N., 2009. Lignocellulose-degrading enzyme production by white-rot Basidiomycetes isolated from the forests of Georgia. *World J. Microbiol. Biotechnol.*, **25**: 331-339. <https://doi.org/10.1007/s11274-008-9897-x>
- Falcón, M.A., Rodríguez, A., Carnicero, A., Regalado, V., Perestelo, F., Milstein, O. and Fuente, G.D., 1995. Isolation of microorganisms with lignin transformation potential from soil of Tenerife Island. *Soil Biol. Biochem.*, **27**: 121-126. [https://doi.org/10.1016/0038-0717\(94\)00174-Y](https://doi.org/10.1016/0038-0717(94)00174-Y)
- Ghazanfar, M., Irfan, M., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2018. Effect of different pretreatment conditions on cellulase production by *Bacillus subtilis* K-18 through Box-Bhenken Design. *Iranian J. Sci. Technol.*, <https://doi.org/10.1007/s40995-017-0463-y>
- Goyal, V., Singh, G., Mittal, A., Yadav, A., Bhuwal, A.K. and Aggarwal, N.K., 2014. Parametric Optimization of cultural conditions for carboxymethyl cellulase production using pretreated rice straw by *Bacillus* sp. 313SI under stationary and shaking conditions. *Biotechnol. Res. Int.*, **2014**: Article ID 651839. <https://doi.org/10.1155/2014/651839>
- Iqbal, S., Irfan, M., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2017. Application of Box-Bhenken design for optimization of different pretreatment conditions for cellulase production. *J. Northeast Agric. Univ.*, **24**: 51-59.
- Iqbal, H.M.N., Asgher, M., Ahmed, I. and Hussain, S., 2010. Media optimization for hyper-production of carboxymethyl cellulase using proximally analyzed agro-industrial residue with *Trichoderma harzianum* under SSF. *Int. J. Agro Vet. med. Sci.*, **4**: 47-55.
- Irfan, M., Gulsher, M., Abbas, S., Syed, Q., Nadeem, M. and Baig, S., 2011. Effect of various pretreatment conditions on enzymatic saccharification. *Songklanakarin J. Sci. Technol.*, **33**: 397-404.
- Irfan, M., Mushtaq, Q., Tabassum, F., Shakir, H.A. and Qazi, J.I., 2017. Carboxymethyl cellulase production optimization from newly isolated thermophilic *Bacillus subtilis* K-18 for saccharification using response surface methodology. *AMB Exp.*, **7**: 29. <https://doi.org/10.1186/s13568-017-0331-3>
- Jha, K., Khare, S.K. and Gandhi, A.P., 1995. Solid-state fermentation of soyhull for the production of cellulase. *Biores. Technol.*, **54**: 321-322. [https://doi.org/10.1016/0960-8524\(95\)00154-9](https://doi.org/10.1016/0960-8524(95)00154-9)
- Kang, S.W., Park, Y.S., Lee, J.S., Hong, S.I. and Kim, S.W., 2004. Production of cellulases and hemicellulases by *Aspergillus niger* KK2 from lignocellulosic biomass. *Biores. Technol.*, **91**: 153-156. [https://doi.org/10.1016/S0960-8524\(03\)00172-X](https://doi.org/10.1016/S0960-8524(03)00172-X)
- Khuri, A.I. and Cornell, J.A., 1987. *Response Surfaces: Design and analysis*. Marcel Dekker, New York.
- Kim, J.K., Oh, B.R., Shin, H.J., Eom, C.Y. and Kim, S.W., 2008. Statistical optimization of enzymatic saccharification and ethanol fermentation using food waste. *Process Biochem.*, **43**: 1308-1312. <https://doi.org/10.1016/j.procbio.2008.07.007>
- Kshirsagar, S.D., Waghmare, P.R., Loni, P.C., Patil, S.A. and Govindwar, S.P., 2015. Dilute acid pretreatment of rice straw, structural characterization and optimization of enzymatic hydrolysis conditions by response surface methodology. *RSC Adv.*, **5**: 46525-46533. <https://doi.org/10.1039/C5RA04430H>
- Lee, S.M. and Koo, Y.M., 2001. Pilot-scale production of cellulose using *Trichoderma reesei* Rut C-30 in fed-batch mode. *J. Microbiol. Biotechnol.*, **11**: 229-233.
- Lynd, L.R., Weimer, P.J. and van Zyl, W.H., 2002. Pretorius IS. Microbial cellulose utilization: fundamentals and biotechnology. *Microbiol. Mol. Biol. Rev.*, **66**: 506. <https://doi.org/10.1128/MMBR.66.3.506-577.2002>
- Mawadza, C., Booger, F.C., Zvauya, R. and Van, H.W., 1996. Verseveld: Influence of environmental factors on endo- β -1,4-glucanase production by *Bacillus* HR 68, isolated from a Zimbabwean hot spring. *Antonie Van Leeuwenhoek*, **69**: 363-369. <https://doi.org/10.1007/BF00399625>
- McCarthy, A.J., 1987. Lignocellulose-degrading actinomycetes. *FEMS Microbiol. Lett.*, **46**: 145-163. <https://doi.org/10.1111/j.1574-6968.1987.tb02456.x>
- Montgomery, D.C., 2005. *Design and analysis of experiments*, 6th ed. John Wiley & Sons Inc., New York.
- Nascimento, R.P., Junior, N.A., Pereira, N., Bon, E.P.S. and Coelho, R.R.R., 2009. Brewer's spent grain and corn steep liquor as substrates for cellulolytic enzymes production by *Streptomyces malaysiensis*. *Lett. appl. Microbiol.*, **48**: 529-535. <https://doi.org/10.1111/j.1472-765X.2009.02575.x>

- Phummala, K., Imai, T., Reungsang, A., Higuchi, T., Sekine, M., Yamamoto, K. and Kanno, A., 2015. Optimization of enzymatic hydrolysis of wood waste by response surface methodology in fermentative hydrogen production. *J. Water environ. Technol.*, **13**: 153-166. <https://doi.org/10.2965/jwet.2015.153>
- Robson, L.M. and Chambliss, G.H., 1989. Cellulases of bacterial origin. *Enzyme Microb. Technol.*, **11**: 626-644. [https://doi.org/10.1016/0141-0229\(89\)90001-X](https://doi.org/10.1016/0141-0229(89)90001-X)
- Singh, J., Batra, N. and Sobti, R.C., 2004. Purification and characterization of alkaline cellulase produced by a novel isolate *Bacillus sphaericus* JS1. *J. Ind. Microbiol. Biotechnol.*, **31**: 51-56. <https://doi.org/10.1007/s10295-004-0114-0>
- Sukumaran, R.K., Singhania, R.R. and Pandey, A., 2005. Microbial cellulases production, applications and challenges. *J. Sci. Ind. Res.*, **64**: 832-844.
- Vicuña, R., 1988. Bacterial degradation of lignin. *Enzyme Microb. Technol.*, **10**: 646-655. [https://doi.org/10.1016/0141-0229\(88\)90055-5](https://doi.org/10.1016/0141-0229(88)90055-5)
- Zimmermann, W., 1990. Degradation of lignin by bacteria. *J. Biotechnol.*, **13**: 119-130. [https://doi.org/10.1016/0168-1656\(90\)90098-V](https://doi.org/10.1016/0168-1656(90)90098-V)