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Application of Taguchi method for optimizing the process parameters for the removal of Chromium(VI) using Sugarcane bagasse.

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Abstract

The aim of the present investigation is to remove hexavalent chromium from artificial effluent by biosorption using sugarcane bagasse and to analyze the result by Taguchi method. L_9 orthogonal array was applied as an experimental design to analyse the results and to determine optimum conditions for chromium (VI) removal from aqueous solution. Various operating parameters were selected to study the biosorption for the removal of chromium(VI) from the effluent. The operating parameters such as initial metal ion concentration, pH, dosage of bisorbent and temperature were studied and the significance of the variables was analysed using Taguchi method. Taguchi method is suitable for the experimental design and for the optimization of process variables for the Chromium(VI) removal.

Keywords: Biosorption, taguchi design, Chromium(VI) and optimization.

1. INTRODUCTION

Due to increase in various industrial and mining activities around the globe has led to various deterioration of the ecosystem and therefore poses dangers to human health and environment[1]. Heavy metals are coming out invariably as a toxic pollutants reached into water bodies due to various anthropogenic activities. There are many physical and chemical processes involved for removing metal ions from solution such as precipitation, ultra-filtration, chemical, solvent extraction, and membrane separation[2]. The major disadvantage of these processes is their high operational cost and difficult maintenance. However, biosorption, a surface phenomenon, has one of the predominant and promise in removing heavy metal ions from solution of waste water. It has been observed that commercial activated carbon has been proven as an efficient adsorbents but its cost is prohibitive[3]. Several biosorbents such as rice husk, spent grain, peat, sawdust, and green algae have been researched for the adsorption of metal ions in aqueous solution. They combine the advantages of being readily available in large quantities, cheap and are environmentally friendly[4]. In this study, sugarcane bagasse was treated and tested for its potential to remove hexavalent chromium from synthetic wastewater under laboratory conditions. The objective of this research is to investigate the biosorption of Cr^{6+} by sugarcane bagasse from aqueous solution using Taguchi method and to find out the optimum values of all the parameters.

2. MATERIALS AND METHODS

2.1. Biosorbent and biosorbate

Sugarcane bagasse was collected from a sugar-mill located at ghatkesar in Hyderabad (India). The collected bagasse was dried under sun light for a week and bagasse was separated manually. Bagasse was boiled first with distilled water for 30 min to remove soluble sugars present in it. The material so obtained was dried at 100 - 120°C in hot air oven for 24 hr, and then the material was grinded and sieved through the sieves of BSS 150 to 200 (0.075 to 0.104 mm).

2.2. Preparation of aqueous solution

A stock solution of Cr(VI) 500 mg/L was obtained by dissolving 1.4144 gm of potassium dichromate ($K_2Cr_2O_7$) in 1 L of deionized water and the solution was used for further experimental solution preparation. The pH values were adjusted with 0.1 M HNO_3 or 0.1 M NaOH. Analytical grade reagents were used throughout this study.

Figure 2.1 Biosorption of Chromium(IV)

2.3. Batch Experiments

A series of experiments were carried out in 250 ml stoppered glass Erlenmeyers flasks with 100 ml chromium(VI) solution to investigate the operational parameters such as the effect of initial metal in concentration, pH, dosage of biosorbent and temperature for removal of Chromium(VI). Erlenmeyers flasks were placed at a shaker (SUKUN) with a shaking of 150 rpm for 2 hr. After biosorption, all the samples were centrifuged with a centrifuge (Thermo) at 10,000 g for 5 min to separate the solid phase from the liquid phase, and then analysis of the residual concentration of Chromium(VI) by UV spectrophotometer (Spectronic 21, Milton Roy Co.) To investigate the effect of initial metal in concentration(100-300ppm) at different temperature (20 to 50°C) for different weight of biosorbent (varying from 1.0g to 2.0g) for removal of Cr(VI). The effects of the medium pH on biosorption effieicny of the biosorbent was studied from 2, 5 & 8, which was adjusted by adding a few drops of diluted aqueous solutions of 0.1M HCl or 0.1M NaOH. All experiments were conducted in duplicates and two controls were performed.

Percentage removal of metal ions can also be computed using the following equation

$$\%\ of\ Cr = \frac{C_o - C_e}{C_e} \times 100 \qquad (1)$$

Where

C_e = Equilibrium concentration (ppm) of Chromium(VI).
C_o = Initial concentration(ppm) of Chromium(VI).

Table 2.1 Experimental design parameters

Symbol	Factors	Unit	Levels		
			1	2	3
A	Initial Metal Ion Concentration	PPM	100	200	300
B	pH		2	5	8
C	Dosage	gm	1	1.5	2
D	Temperature	°C	20	35	50

2.4 Taguchi's methodology of experimental design

In this work, a Taguchi's L_9 orthogonal array has been selected for the experimental trial run as it is the basis for the analysis of Taguchi method. Taguchi orthogonal arrays provide that all controlled variables are equally considered in experiments. The minimum number of trial run must be more than or equal to the total degrees of freedom. Each row of orthogonal array represents different combination of level parameters. Number of process parameters and their levels were used to select the array. For this experiment, four process parameters such as metal ion concentration, pH, biosorbent dose and temperature with three levels were chosen (Table-2.1). Experiments were conducted as per the combinations shown in the Table-2.2. For each interaction, a batch of three samples were made and the percent removal of chromium(VI) after biosorption was calculated by equation (1). The collected data was analyzed for mean response and Signal to Noise ratio (S/N) with higher characteristics. Analysis of variance, ANOVA was applied to data to determine the importance of each factor on removal of hexavalent chromium.

Table 2.2 Experimental data and sample statistics for Sugarcane bagasse

Expt No	Main Factors				% of Removal Cr(VI)			Mean	S/N Ratio
	A	B	C	D	1	2	3		
1	100	2	1.0	20	79.20	77.95	79.58	78.91	37.9419
2	100	5	1.5	35	83.49	80.28	79.00	80.92	38.1246
3	100	8	2.0	50	79.33	79.61	79.50	79.48	38.0051
4	200	2	1.0	20	79.96	78.28	80.24	79.50	38.0054
5	200	5	1.5	35	81.68	81.89	78.77	80.78	38.1422
6	200	8	2.0	50	79.84	76.04	80.62	78.84	37.9261
7	300	2	1.0	20	81.21	78.20	79.01	79.47	38.0012
8	300	5	1.5	35	78.15	75.50	82.61	78.76	37.9077
9	300	8	2.0	50	79.97	82.56	78.46	79.33	37.9774

2.5 Signal to noise ratio(S/N)

The control figures that may help decreased variety and improved quality could be immediately identified by taking a look at the sum variety display as a reaction. Analysis in this content has tended to which components may be influencing the normal reaction. Orthogonal show has made a change of the replication information to an alternate price which is a measure of the variety present. The Taguchi method generally covers two parts, the S/N ratio and the analysis of variance (ANOVA) table, where the S/N ratio determines the level setting of the factors affecting quality variations. The S/N ratio depicts the quality stability, which means higher S/N ratio lesser loss.
The S/N ratio equation for three characteristics of quality (mapping) is listed below, where the number of test runs is depicted as n, and the value of one test is shown as y_i:

Nominal-the-best type I, the quality characteristic variance and the average bias should be concurrently indicated.

$$\frac{S}{N} = -10\log_{10}\frac{\sum_{i=1}^{n}(y_i - m)^2}{n} = 10\log_{10}[(\bar{y} - m)^2 + S_n^2] \quad (2)$$

The median of experimental results for each test is defined as m; the number of runs of each experimental group is denoted as n; the standard deviation is represented as S_n.

$$S_n = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y})^2}{n}} \quad (3)$$

The mean of the experimental results of each experimental group is depicted as y.

Nominal-the-best type II is used in cases with one or more adjustable factors, where the mean can be adjusted to the target value without introducing bias, considers only the quality characteristic variance, and is actually applied to cases where the target value is equal to zero.

$$\frac{S}{N} = -10\log_{10}\frac{\sum_{i=1}^{n}(y_i-\bar{y})^2}{n} = -10\log(S_n^2) \qquad (4)$$

Nominal-the-best type III is employed in cases with one or more adjustable factors, where only the quality characteristic variance is considered, and the mean can be adjusted to the target value without incurring bias.

$$\frac{S}{N} = -10\log_{10}\frac{s^2}{\bar{y}^2} \qquad (5)$$

Smaller-the-better:

$$\frac{S}{N} = -10\log_{10}\frac{\sum_{i=1}^{n}(y_i)^2}{n} \qquad (6)$$

Larger-the-better:

$$\frac{S}{N} = -10\log_{10}\frac{(1/y_i)^2}{\bar{y}^2} \qquad (7)$$

After S/N ratios are calculated, S/N ratio curves can be plotted according to the level of each controllable factor in order to represent which level combination has the optimal effect. As the results of the Taguchi method, as indicated in Eq. (7), the larger of S/N is considered optimal in this study. Therefore, an L_9 comparison list could acquire optimal parameters through ANOVA (Minitab 18.0) simulation and then utilize the best parameters in the biosorption to demonstrate the removal of heavy metals. Experimental parameters of the L_9 comparison list include initial metal in concentration, pH, dosage of biosorbent and temperature. The data obtained from the experiments could next be analyzed for further test of contaminants elimination.

3. Results and discussion

3.1 Main effect plot

Main effect plot for the percentage removal of chromium(VI) using sugarcane bagasse is shown in the Figure 3.1 & 3.2. The plot is used to visualize the relationship between the variables and output response. The effect of initial metal ion concentration on percentage removal is shown by the factor 'A'. The percentage Cr(VI) removal of the increase with increase in metal ion concentration. The removal % has a steady decrease trend as the concentration of metal ion increases. At low concentrations, there will be unoccupied active sites on the adsorbent surface. From Figure 3.1 that initially, the removal percentage was around 79.77 due to the presence of abundant free pores but as the concentration increased the pores became blocked and the removal % decreased. The highest removal % was 79.77 % at 100 ppm and approaches constant till the concentration reaches 300 ppm.

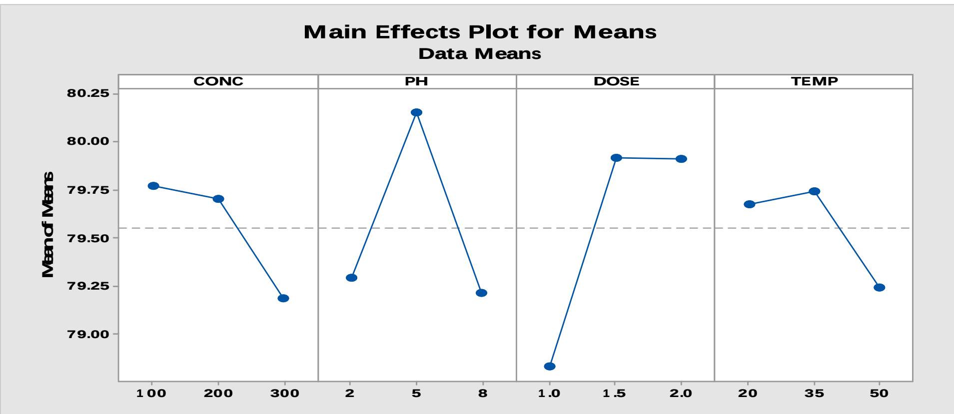

Figure 3.1 Main Effect Plot for Means for removal of Chromium(VI)

The initial solution pH is an important impact factor for the biosorption process. Because the hydrogen ion and hydroxyl ion are adsorbed quite easily, therefore the biosorption of other ions can be affected by the pH of the solution. It was necessary to discuss the effect of pH on the adsorption of Chromium(VI) Fig. 3.1 indicated that the increase in the solution pH was helpful for the biosorption of Chromium(VI) onto sugarcane bagasse. As initial solution pH increased from 2 to 5, the percentage of removal of Cr^{6+} values increased from 79.29 to 80.15. This is due to the cationic reaction with OH^-. Acidic condition produces more H^+ ions in the system. The surface of the adsorbent gathers positive charges by absorbing H^+ ions, which prevent the adsorption of Cr^{6+} ions onto adsorbent surface due to electrostatic repulsion and the competition between H+ ions and Chromium(VI) for the adsorption sites. As the solution pH increased, the number of negatively charged surface sites on the adsorbent decreased, which may result in the decrease in adsorption of cationic molecules due to the electrostatic attraction. However, the biosorption of Cr^{6+} had slight decrease change when pH was within the range of 5 – 8, which indicated that the electrostatic mechanism was not the only mechanism for biosorption in present system. Percentage of removal of Chromium was also affected by the chemical reaction between the biosorbent and Cr^{6+} molecules. By experiments, the pH of aqueous effluent was near 6.0 and it was not adjusted in other experiments.

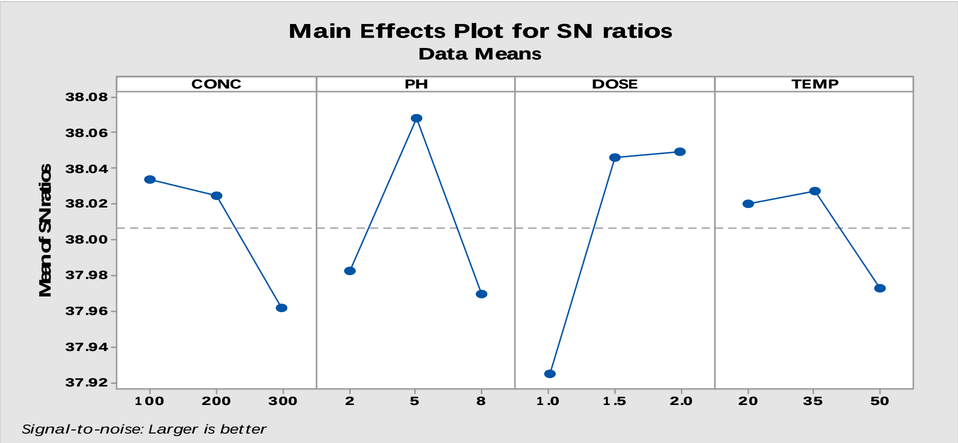

Figure 3.2 Main Effect Plot for S/N Ratios for removal of Chromium(VI)

The biosorbent dosage varied from 1.0 – 2.0 gm shown in figure 3.1. It is evident that there was a steady increase in the removal % of chromium as the amount of biosorbent dosage increased. This is due to the fact that with the increase in dosage the number of free pores and surface area increased greatly and thus biosorption increased resulting in higher removal efficiency. However, the removal % remained almost constant from 300 ppm around 79.91%. This is probably due to the conglomeration of biosorbent particles which results in no further increase in surface area of the sugarcane bagasse. Thus the removal % becomes almost constant.

With rise in temperature, there has been a continuous decrease in the removal % of the Chromium. Increase in temperature results in random motion of fluid particles. The intermolecular distance increases and there is a constant rapid motion of the molecules. Due to this, as the temperature rises the molecules start to vibrate rapidly and their probability of getting absorbed into the pore reduces. From the Figure 3.1 it is evident that at low temperature of 20°C the molecular motion was very low and the removal % was 79.68 % but at higher temperatures around 50°C, dropped to 79.24 %.

Different levels (1, 2 & 3) of the parameter (A, B, C & D) and their mean percentage of removal of chromium was shown in the Table 3.1 & 3.2. It is observed form the table, level '3' shows highest metal removal of 79.79 % for the initial metal concentration followed by level '2' shows highest metal removal of 80.15 %, 79.92 % and 79.75 % for pH, dosage of biosorbent and temperature of the reaction respectively.

Table 3.1 Taguchi's analysis of % of metal removal

Response Table for Signal to Noise Ratios Larger is better					Response Table for Means Larger is better				
Level	Conc	pH	Dose	Temp	Level	Conc	pH	Dose	Temp
1	38.03	37.98	37.93	38.02	1	79.77	79.29	78.84	79.68
2	38.02	38.07	38.05	38.03	2	79.71	80.15	79.92	79.75
3	37.96	37.97	38.05	37.97	3	79.79	79.22	79.91	79.24
Delta	0.07	0.10	0.12	0.05	Delta	0.59	0.94	1.08	0.50
Rank	3	2	1	4	Rank	3	2	1	4

3.2 Implementation of ANOVA

Table 3.2 shows the process parameters (factors) that were chosen for the % of metal ion removal from aqueous solution by sugarcane bagasse. Four levels were specified for each parameter. Table 3.2 shows the ANOVA for % of metal ion removal.

Table 3.2 Analysis of Variance for SN ratios

Source	DF	Seq SS	Variance	F-Ratio	Pure Sum	Pure Sum
Conc	2	0.006	0.003	0.000	0.006	10.853
pH	2	0.018	0.009	0.000	0.018	31.644
Dose	2	0.025	0.012	0.000	0.025	44.268
Temp	2	0.004	0.002	0.000	0.004	8.291
Residual Error	0	0.000	0.000	0.000	0.006	0.000
Total	8	0.058				100.000

Analysis of variance (ANOVA) was performed to check whether the process parameters were statistically significant or not. The F-test is a tool to check which process parameters have a significant effect on removal of Chromium(VI). The P value less than 0.05 shows that the parameter is significant. ANOVA table for removal of Chromium(VI) is shown in the Table 3.2. It is observed form the table the most influential factor was dosage of biosorbent (sugarcane bagasse) and pH because the P value is less than 0.05 with the corresponding sum of the square is higher compared to other variable in the Table 3.2. Then the less significant variables are metal ion concentration and temperature.

These results have proved the success of Taguchi method in the prediction of the optimum parameters for higher % of Cr(VI) ion removal. Examination of the calculated contribution for all control factors also shows a very high influence of factor C followed by B, A and D on the % of Cr(VI) ion removal shown in Fig. 3.3. The optimum test conditions were estimated from the significant factors are tabulated in Table 3.2. Thus, based on the level of % of contribution only C (44.268 %) and B (31.644 %) were most predominant while the factors followed by A (10.853 %) and D (8.291%) were lease importance was shown in Fig. 3.3.

Table 3.2 Estimated individual factors effect on % of removal of Cr (VI)

Symbol	Factors	Optimum Level
A	Initial Metal Ion Concentration	100 ppm
B	pH	5.0
C	Dosage	3.0 gm
D	Temperature	35°C

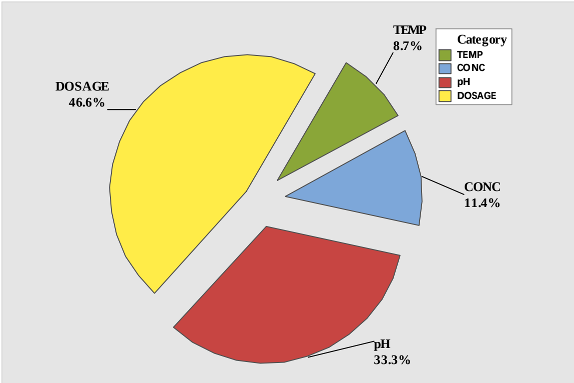

Figure 3.3 Plot for contribution of each parameters.

4. Conclusion

In this study, sugarcane bagasse was tested and evaluated as a cheapest and easily available biosorbent for removal of hexavalant chromium from its aqueous solution by batch biosorption. The Taguchi method was applied to investigate the effects of pH initial metal in concentration, pH, dosage of bisorbent and temperature were studied on percentage removal of chromium(VI). The level of importance of the factors considered was determined using ANOVA. Based on the ANOVA method, it was found that all the four factors initial metal in concentration, pH, dosage of bisorbent and temperature have profound influence on the percentage removal of hexavalant chromium from its aqueous solution. The dosage of biosorbent is the major factor that affects the percentage (%) removal of chromium (VI) with its % contribution of 44.268% and is relatively followed by pH of aqueous solution 31.644% and initial metal in concentration 10.853% . An optimum parameter combination for the maximum percentage removal of hexavalant chromium was obtained by using the analysis of signal-to-noise (S/N) ratio. The optimum test condition at which the maximum percentage removal of hexavalant chromium was obtained has been determined to be A3, B2, C2 & D2 levels. The experimental results confirmed the validity of the used Taguchi method for optimizing the parameters in biosorption operations.

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References

[1]. C. H. Yen, K. F. Chen, Y. T. Sheu, C. C. Lin, J. J. Horng, Pollution Source Investigation and Water Quality Management in the Carp Lake Watershed, Taiwan, Clean – Soil Air Water 2012, 40 (1), 24–33.
[2]. M. Baborowski, V. Simeonov, J. W. Einax, Assessment of Water Quality in the Elbe River at Flood Water Conditions Based on Cluster Analysis, Principle Components Analysis, and Source Apportionment, Clean – Soil Air Water 2012, 40 (4), 373–380.
[3]. X. Fan, B. Cui, K. Zhang, Z. Zhang, H. Shao, Water Quality Management Based on Division of Dry and Wet Seasons in Pearl River Delta, China, Clean – Soil Air Water 2012, 40 (4), 381–393.
[4]. M. T. Sikder, Y. Kihara, M. Yasuda, Yustiawati Y. Mihara, S. Tanaka, D. Odgerel, et al., River Water Pollution in Developed and Developing Countries: Judge and Assessment of Physicochemical Characteristics and Selected Dissolved Metal Concentration, Clean – Soil Air Water 2013, 41 (1), 60–68.
[5]. M. Yıldırım, B. Topkaya, Assessing Environmental Impacts of Wastewater Treatment Alternatives for Small-Scale Communities, Clean – Soil Air Water 2012, 40 (2), 171–178.
[6]. N. G. Turan, E. B. Gümüs¸el, Utilizing Natural Liner Materials for Heavy Metal Removal in Simulated Landfill Conditions, Clean – Soil Air Water 2013, 41 (4), 403–410.
[7]. C. Noubactep, Metallic Iron for Water Treatment: A Critical Review, Clean – Soil Air Water 2013, 41 (7), 702–710.
[8]. M. Sathishkumar, A. R. Binupriya, D. Kavitha, S.E. Yun, Bioresour. Technol. 2007, 98, 866–873.

[9]. M. Sathishkumar, K. Vijayaraghavan, A. R. Binupriya, A. M. Stephan, J. G. Chai, S. E. Yun, J Colloid Interface Sci. 2008, 320, 1, 22–29.
[10]. M. Sathishkumar, A. R. Binupriya, D. Kavitha, R. Selvakumar, R. Jayabalan, J. G. Choi, S. E. Yun, Chem. Eng. J. 2009, 147, 265–271.
[11]. Batch and continuous (fixed-bed column) biosorption of crystal violet by Artocarpus heterophyllus (jackfruit) leaf powder.Colloids and Surfaces B: Biointerfaces. 2012;92:262–270.
[12]. Osu Charles I, Odoemelam SA. Studies on adsorbent dosage, particle sizes and pH constraints on biosorption of Pb(II) and Cd(II) ions from aqueous solution using modified and unmodified Crasstrotrea gasar (Bivalve) biomass. International Archive of Applied Sciences and Technology. 2010;1:62-68.
[13]. Fraley S, Oom M, Terrien B, Date JZ. Design of Experiments via Taguchi Methods: Orthogonal Arrays: The Michigan Chemical Process Dynamic and Controls Open Text Book. USA. 2006. 678-698.
[14]. Parks J. On stochastic optimization: Taguchi methods demystified, its limitations and fallacy clarified. Probabilistic Engineering Mechanics. 2006;16(1):87-101.
[15]. R.-L. Tseng, P.-H. Wu, F.-C. Wu, and R.-S. Juang, “Half-life and half-capacity concentration approach for the adsorption of 2,4-dichlorophenol and methyl blue from water on activated carbons,” Journal of the Taiwan Institute of Chemical Engineers, vol. 42, no. 2, pp. 312–319, 2011.
[16]. M. Dogan, H. Abak, and M. Alkan, “Adsorption of methylene blue onto hazelnut shell: kinetics, mechanism and activation parameters,” Journal of Hazardous Materials, vol. 164, no. 1, pp. 172–181, 2009.
[17]. Tian X, Li C, Yang H, Ye Z, Xu H: Spent mushroom: a new low-cost adsorbent for removal of congo red from aqueous solutions. Desalin Water Treat 2011,27:319–326.
[18]. El Qada EN, Allen SJ, Walker GM: Adsorption of basic dyes from aqueous solution onto activated carbons. Chem Eng J 2008, 135:174–184.
[19]. Crini G: Non-conventional low-cost adsorbents for dye removal: a review. Bioresource Technology 2006, 97:1061–1085.
[20]. Allen S, Mckay G, Porter J: Adsorption isotherm models for basic dye adsorption by peat in single and binary component systems. J Colloid Interf Sci 2004, 280:322–333.