



Optimizing Laccase Production from *Delonix regia* Pods by *Aspergillus carbonarius* F5 Using Response Surface Methodology and its Dye Decolorization Potential

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Introduction: Laccase is a multi-copper enzyme that directs oxidation of compounds by reducing oxygen to water molecules. It has been identified as a significant enzyme which possesses diverse interest in industrial sector due to its ability to degrade toxicants from dye-utilizing related industries.

Aim: The current research focuses on the optimization of laccase from *Aspergillus carbonarius* F5 on *Delonix regia* pods, for application in dye degradation.

Methodology: Potential laccase producing fungi were screened and characterized using 18S rRNA. Laccase production was further conducted on untreated and acid pretreated *Delonix regia* pods. Plackett-Burman design and Central Composite Design (CCD) of the Response Surface Methodology (RSM) was used to screen for various nutritional and environmental factors to improve the yield of the enzyme and then applied for dye decolorization studies.

Results: The fungal strain with the highest laccase activity was identified as *Aspergillus carbonarius* F5. The acid pretreated *Delonix regia* pods showed considerably high enzyme activity

when compared with untreated. Moreover, variation of notable nutritional and environmental factors were detected to improve laccase yield. The effect of input parameters such as incubation period, pH, temperature and $MgSO_4$ were documented as the major factors influencing high laccase yield using Plackett-Burman design. Results obtained from the modelling of experiment using CCD-RSM shows that maximum laccase production of 8.04 U/ml was recorded at temperature 36°C, pH 6, $MgSO_4 \cdot 7H_2O$ at 0.2 (g/L), and 7 days which reveals a 8.28 –fold increase. The outcome of the investigation performed on dye decolorization suggests an 87.6 % and 62.6 % degradation on congo red and malachite green dyes respectively.

Conclusion: *Delonix regia* pods could be an added substrate, suitable for optimization of laccase by *Aspergillus carbonarius* F5 and the enzyme was capable of decolorizing industrial dyes.

Keywords: *Laccase; delonix regia pods; optimization; response surface methodology; Aspergillus carbonarius F5; dye decolorization.*

1. INTRODUCTION

Laccases (oxygen oxidoreductases; EC 1.10.3.2) are the blue multicopper protein family that brings about oxidation of phenolic and non-phenolic compounds through generation of water from molecular oxygen reduction [1]. Laccases are ubiquitously distributed in wide range of biotic sources including plants [Rice, *Oryza sativa* [2]], bacteria [*Weissella viridescens* LB37, *Bacillus* sp. MSK-01] [3, 4], fungi [*Aspergillus* sp. Omeje, *Schizophyllum commune* Han 881] [5, 6], and insects [*Drosophila melanogaster*] [7]. However, they are predominantly found in fungi (*Trametes versicolor* and *Trichoderma Harzianum*) [8]. Fungal laccase have attracted considerable attention over the years due to their ability to weaken all plant cell wall components through their enzymatic systems [9].

Laccases have been widely applied in food processing industry, pulp and paper industry, pharmaceutical sector, delignification of lignocellulosic waste and biodegradation in textile industry [10, 11]. Dyes are majorly used as colorants in food, pharmaceutical and textile industries. However, disposal of effluent from textile industries pose a great threat to marine life and the environment at large. This is linked to the presence of undesirable and harmful compounds. Moreover, several strategies have been introduced to overcome such environmental menace through the use of laccase induced detoxification. Laccases have been found worthy in the degradation of phenolic compound present in dyes [5] and this biological detoxification is sustainable both ecologically and economically. Interestingly, different strains of microorganisms have been documented to produce of laccase at different capacities. Thus, exploring new laccase producing strain is vital. The dye decolourization potential of laccase

have been previously studied especially from *Streptomyces ipomoeae* CECT 3341 [12], *Aspergillus* sp. [13] and *Peroneutypa scoparia* [14]. However, the production of laccase from *Aspergillus carbonarius* is scarcely reported.

In recent times, the use of saw dust, rice husk and olive mill waste, most especially for laccase production have been reported due to its low-cost and abundance [15-17]. However, the production of laccase from *Aspergillus carbonarius* using *Delonix regia* pods as substrate, have not been investigated. *Delonix regia* pods (flamboyant pods) is an abundant underuse biomass, growing on a flowering plant belonging to the pea family. The pods are oblong, woody, flat and approximately 55 cm. It is green and turns brown when matured [18]. The pods have been reported for use as bioabsorbent [19] and bioenergy [20]. The lignin composition of *Delonix regia* pods makes it an excellent biomass for the production of industrially important enzyme such as laccase.

It is well proven that numerous microorganisms differ in their cultural conditions and nutritional requirement for enzyme production. Therefore, it is critical to study the effect of growth parameters (pH, temperature, carbon, nitrogen, and mineral sources) on the organism of interest. Nambisan, [21] carried out an optimization studies for laccase production using one factor at a time (OFAT). This techniques has been proven to be efficient in assessing the effect of each parameter (variable) on laccase production when tested independently. However, it cannot assess the interactive effects of the parameters on laccase production. Statistical optimization studies by design of experiment using RSM is an ideal modelling approach. It has been reported to portend the potential to improve production of enzymes. In addition, it identifies significant

factors such as pH, temperature, incubation period, that could increase the performance of the organism. Thereafter, the combined interactive effect among the significant factors is directed towards enhancement of the enzyme production.

Therefore, this study intends to optimize the best process parameters, suitable for maximum laccase production by a locally isolated *Aspergillus carbonarius* F5 grown on *Delonix regia* pods, using Central Composite Design (CCD) of Response Surface Methodology (RSM) as well as to investigate the dye decolorization potential of its crude laccase.

2. MATERIALS AND METHODS

2.1 Sample Collection and Fungi Isolation

Soil samples were obtained from five different locations (1 km apart) within the University of Ilorin, Kwara State, Nigeria. The samples were collected in sterile polythene bags for analysis. Appropriate dilution were carried out and inoculated on to potato dextrose agar (PDA) plate, followed by incubation at 30 °C for 5 days. Pure cultures were obtained and stored at 4°C.

2.2 Screening for Laccase Producing Fungi

2.2.1 Plate screening method

The fungi isolates were screened on PDA medium supplemented with 0.02 % guaiacol and incubated for 5 days at 30 °C. Culture plate showing dark brown coloration was selected and further tested for dye decolorization.

2.2.2 Dye decolorization method

The ability to decolorize dye in potato dextrose broth (PDB) supplemented with 1 mg/ml malachite green dye and 0.1 % congo red dye was tested. Ten millimeter (10 ml) of the broth was inoculated with 2 agar plugs of mycelia using 5 mm cork borer and incubated for 5 days at 30 °C. Tube containing PDB and dye without the fungi was regarded as the control. A discoloration of the dye indicated the presence of lignolytic enzyme [22].

2.3 Identification of Fungal Isolate

The laccase positive fungus was identified based on macroscopic and microscopic examination

according to the method described by Senanayake [23]. For molecular identification, DNA extraction was performed using the methods described by Girma [24]. To amplify the internal transcribed spacer (ITS) region of the rRNA gene, the forward primer (ITS4-TCCTCCGCTTATTGATATG) and (ITS5-GGAAGTAAAAGTCGTAACAAGG) reverse primer was used as described by White [25]. The polymerase chain reaction (PCR) cocktail mixture comprised of 2.5 µl of 10x PCR buffer, 1 µl of 25 mM MgCl₂, 1 µl of DMSO, 2 µl of 2.5 mM dNTPs, 0.1 µl of 5 u/l Taq DNA polymerase, and 3 µl of 10 ng/l DNA. The total reaction volume was increased to 250 µl with 13.4 µl of nuclease-free water. The PCR was executed using a Veriti thermal cycler (Applied biosystems) for 36 cycles of denaturation at 94 °C for 30 s after an initial denaturation at 94°C for 5 min. Annealing took place at 54°C for 30 seconds, followed by elongation at 72°C for 7 min and holding at 10°C. The PCR products were purified and the amplified fragments were visualized in a safe view-stained 1.5 % agarose electrophoresis gel. Consequently, the purified PCR products were sequenced using an automated sequencer (ABI genetic analyzer 3500, Applied Biosystems, USA). With the aid of the NCBI-BLAST-n search, the sequence were compared to those of other *Aspergillus* species available in the GenBank. Multiple-sequence alignments of parallel sequences was done using Seqtrace software (version 0.90). The evolutionary distances (Phylogenetic tree) were computed by neighbor joining method with bootstrap values of 1000 replica runs using MEGA 6.06.

2.4 Substrate Collection and Processing

Matured *Delonix regia* pods were collected within the campus of the University of Ilorin, Kwara State, Nigeria. They were sun dried, crushed and milled to 1-2 mm particle size. Acid catalyzed pretreatment of the substrate was carried out using dilute sulphuric acid at 1.5% v/v at 15 % w/v substrate loading for 15 min. The pretreated substrate was filtered and subjected to repeated washing with distilled water. The residue was air dried at room temperature for further use.

2.5 Time Course for Laccase Production

Laccase production was carried out in a basal medium described by Jaber [26] with slight modification, containing :Yeast extract, 2 g; Peptone, 2 g; CuSO₄, 2.0mM; MnSO₄, 1 mg; MgSO₄.7H₂O, 0.2 g; FeSO₄.7H₂O 1 mg; KH₂PO₄,

1 g; ZnSO₄ 0.1 g; NaH₂PO₄, 0.5 g; and CaCl₂ 0.2 g in 1L distilled water at pH 5.0. Two agar plugs (5 mm diameter) from a 5 day old fungi culture was inoculated into 250 ml Erlenmeyer flask containing 50 ml of the basal medium, 2 g each of pretreated and untreated *Delonix regia* pod. All flasks were incubated on a shaking incubator (150 rpm) at 30 °C for 7 days. Samples were withdrawn at 24 h interval and centrifuged (centrifuge 80-2 Maxmill medical) at 5,000 rpm for 15 min at 4°C. The supernatant was obtained and used as crude enzyme for laccase assay.

2.6 Laccase Assay

Laccase activity was carried out in a reaction mixture containing 3 ml of 100 mM acetate buffer pH 5.0, 1 ml of 10 mM guaiacol and 1 ml crude enzyme. Enzyme blank containing 3 ml acetate buffer, 1 ml guaiacol and 1 ml sterile distilled water was also maintained. The intense brown colour observed after 10 min incubation at 30 °C was due to oxidation of guaiacol by the laccase enzyme. Hence, confirming the laccase activity. The absorbance was read at 470 nm on spectrophotometer (VIS spectrophotometer S32A). One unit of laccase activity (U/ml) was defined as the amount of enzyme catalyzing the 1 μmol of the substrate per min per ml under the specified assay condition. Enzyme activity was calculated as seen in equation 1:

$$\text{Laccase activity (U/ml)} = \frac{\Delta \text{ in absorbance/min} \times 4 \times V_t \times DF}{\epsilon \times V_S}$$

Where; V_t = Final volume of reaction mixture (ml)
 V_S = Sample volume (ml)
 ε = Extinction coefficient of guaiacol (0.6740μ/M/cm)
 4 = Derived from unit of definition
 DF = Dilution factor Equation 1

2.7 Selection of Significant Parameters by Plackett Burman (PB)

Based on literature search, 12 variables were selected as potential factors affecting laccase production. The parameters evaluated include 7 medium components: MgSO₄.7H₂O, peptone, yeast extract, CaCl₂, CuSO₄, NaHPO₄, substrate type and 5 physiochemical parameters including: pH, incubation period, inoculum size, temperature, and substrate concentration. A set of 40 experiment [duplicates at two stages high (+) and low (-1)] were designed using the PB design of the MINITAB 17 (Minitab LLC., Pennsylvania, USA) Table 1. Plackett- Burman Design is based on the first-order polynomial model shown in equation 2

$$y = \beta_0 + \epsilon \beta_i X_i$$

Where y is the response (laccase production U/ml),

β₀ is the model intercept
 β_i is the linear coefficient and
 X_i is the level of the independent factor (i = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 and 12) Equation 2

Table 1. Independent factors and levels for Plackett-Burman design

Factors	Symbol code	Low level	High Level
		-1	1
Temperature	A	30	40
MgSO ₄ .7H ₂ O(g/l)	B	0.02	0.2
Inoculum size (mm)	C	3	5
CaCl ₂ (g/L)	D	0.02	0.2
Substrate concentration (%)	E	3	5
CUSO ₄ (mM)	F	2	4
pH	G	4	6
NaHPO ₄ (g/l)	H	0.05	0.5
Incubation time (h)	I	24	120
Yeast extract (g/l)	J	1.0	2.0
Substrate type	K	Treated	Untreated
Peptone (g/l)	L	1.0	2.0

Table 2. Independent factors and levels for central composite design (CCD)

Independent Variable	Symbol code	Actual values of codes				
		+α	+1	0	-1	-α
Temperature	A	45	40	35	30	25
pH	B	7	6	5	4	3
MgSO ₄ .7H ₂ O	C	0.29	0.2	0.11	0.02	-0.07
Incubation time (h)	D	168	120	72	24	-24

2.8 Optimization of Laccase Production using Response Surface Methodology (RSM)

The selected most significant independent variables including temperature (A), pH (B), MgSO₄.7H₂O (C) and Incubation period (D) were further optimized using central composite design. These variables were evaluated at five coded levels -α, -1, 0, +1 and +α. Table 2 shows the ranges of variables studied with the coded and actual levels. A total of 50 experimental runs were created in duplicate, with 32 cube points, 2 center points, and 16 axial points. To determine the significance of the constructed model, the data obtained from laccase production were subjected to analysis of variance (ANOVA). In equation 3, the responses were fitted using the response surface regression approach with the second order polynomial equation

$$Y = \beta_0 + \beta_1 A + \beta_2 B + \beta_3 C + \beta_4 D + \beta_{11} A^2 + \beta_{22} B^2 + \beta_{33} C^2 + \beta_{44} D^2 + \beta_{12} AB + \beta_{13} BD + \beta_{14} BC + \beta_{15} AD + \beta_{23} AC + \beta_{24} CD$$

(Equation 3)

2.9 Investigation of Crude Enzyme for Dye Decolorization

The dye degradation potential of the fungi was tested using two dyes: malachite green and congo red dye. Crude laccase was produced at optimized condition obtained from the CCD-RSM, with activity at 8.04 U/ml. The ability to degrade malachite green dye (1 mg/ml) and congo red dye (0.1 %) was further investigated. The absorbance of malachite green dye and congo red dye was measured at 610 nm and 560 nm respectively. Ten millimeters (10 ml) of the different dyes were dispensed in sterile tubes and sterilized at 121° C for 15 min. After autoclaving, 1 ml crude laccase was added and incubated at 30 °C for 5 days at 100 rpm. The change in color was examined by measuring the absorbance at 24 h interval. [27]. Percentage decolorization was calculated using equation 4

$$\% \text{ Decolorization} = \frac{\text{Initial absorbance} - \text{Observed absorbance}}{\text{Initial absorbance}} \times 100$$

(Equation 4)

2.10 Statistical Analysis

The data analysis was carried out by general linear model and regression analysis using MINITAB 17 software. Values reported are means of (n=3), ± SD.

3. RESULTS AND DISCUSSION

3.1 Laccase Screening

Laccase is a highly active enzyme that is capable of oxidizing a wide variety of substrate. The result obtained from the preliminary screening indicated that laccase positive fungi developed a dark brown coloration at the reverse side of the PDA-guaiacol plate. In this study, guaiacol was used as substrate because it allows rapid detection of results through colour change, gives reliable results and it's less expensive. Laccase of *Lentinula edodes* expressed from *Pichia pastoris* exhibited a very high catalytic activity when assayed with 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS). However, its performance does not match the activity on green applications [28]. However, guaicol showed better association with decolorization of dyes in comparison to ABTS and 2,6-dimethoxyphenol [28]. Complete decolorization of the malachite green and congo red dyes was observed when the fungus was further screened on broth medium containing the dyes. Decolorization of malachite green dye by *Trichoderma virens* at an absorption rate of 81.82 mg/g was reported [29]. The cultivation of *Aspergillus niger* in 500 g/L dyes resulted in a 100 % decolorization of different textile dyes [30]. *Aspergillus flavus* showed capacity for acid blue and acid violet dyes decolorization at 96 and 97 %, respectively [31]. Likewise, a 97 % decolorization of congo red dye by *Aspergillus niger* was observed after 6 days cultivation [32].

3.2 Molecular Analysis and Phylogeny

The *Aspergillus carbonarius* F5 gene sequence was homologous to *Aspergillus carbonarius* M1013136 and *Aspergillus ibericus* A-1618 as suggested by phylogenetic tree constructed through the neighbor joining method. *A. ibericus* showed a 99 % similarity with *Aspergillus carbonarius* (Figure 1). *Aspergillus carbonarius* have been previously implicated in production of invertase and β -D-fructosyltransferase [33], biodegradation of polyethylene [34] and hydrocarbons [35]. Species of *Aspergillus* are versatile and majority of them have been documented to play a significant role in lignocellulosic degradation through secretion of extracellular enzymes. However, to the best of our literature search, there are little or no report on laccase production by *Aspergillus carbonarius*.

3.3 Fermentation and Optimization

3.3.1 Pre- optimization

During this study, pretreated and untreated *Delonix regia* pods were used for laccase production in order to compare the enzyme yields. The hemicellulose, cellulose and lignin content of *Delonix regia* pods was reported at 24.13%, 13.9%, 23.36 %, respectively [36] . The maximum laccase activity for both treated and untreated substrate were recorded at 0.97 U/ml and 0.75 U/ml respectively at 120 h. This shows that the treated substrate gave rise to relatively high laccase yield as compared to the untreated substrate (Figure 2). This was due to the liberation of sugars from hemicellulose and cellulose fraction of the substrate during acid pretreatment, making it easily accessible by the fungi. Interestingly, the fungus was able to degrade the untreated substrate to produce substantial amount of laccase. Also, a decrease in laccase activity for both substrates was observed at 144 to 168 h. A maximum yield in laccase activity from *Aspergillus* sp. HB_RZ4 was attained on the 8th day [10].

3.3.2 Significant factors selection for F5 laccase production by PB design

The effects of medium components and physicochemical factors on laccase production by *Aspergillus carbonarius* F5 grown on treated and untreated *Delonix regia* pods were determined using PB design (Table 3). The

parameters were selected based on available information reported in literature [37, 38]. It has been reported that the presence of diverse parameters such as carbon and nitrogen sources, inoculum size, metal salts and substrate concentration plays crucial role in laccase production. Also, during this study the application of yeast extract and peptone were used in combination at different ratio as a source of nitrogen (Table 3). Maximum laccase yield was observed with run order 8. An enzyme yield of 3.14 U/ml was obtained from the treated substrate, while the untreated substrate gave rise to an enzyme yield of 3.04 U/ml (run order 5) with a combination of all the factors. Incubation period, pH, temperature and $MgSO_4 \cdot 7H_2O$ have substantial effect on laccase yield as seen in (Table 4). According to Bakkiyaraj [37], the combination of nitrogen sources enhances laccase production. However, there were no significance difference with the use of peptone and yeast extract [39] . In a similar experiment using the PB design, yeast extract and copper sulfate were significant factors affecting laccase production [38]. However, pH, temperature and $CuSO_4$ were found to contribute significantly to laccase production [40]. The statistical significance model terms were studied using ANOVA. Fischer's test was used to assess the significance of the model which was compared to the corresponding p value. The ANOVA with $p < 0.05$ indicate significant model terms. Incubation period, pH, temperature and $MgSO_4 \cdot 7H_2O$ exert positive effect on laccase yield. However, yeast extract, peptone, $CaCl_2$, $CuSO_4$, $NaHPO_4$, inoculum size, substrate concentration and substrate type exhibited negative effects on laccase yield. The coefficient of determination R^2 , adjusted R^2 and predicted R^2 were 0.9085, 0.8987 and 0.8755 respectively showing correlation among the observed and predicted values. The first order linear model, as shown in equation 5, predicted the effect of the independent variables on laccase production.

$$\begin{aligned} \text{Laccase (U/mL)} = & + 2.373 - 0.0884 A - 1.877 B - 0.0781C + \\ & 1.741 D - 0.0340 E + 0.1223 F + 0.2762 G + \\ & 0.500 H + 0.00956 I + 0.074 J + 0.0121 K + \\ & 0.014 L \end{aligned}$$

Equation 5

The four significant factors were selected for further improvement via RSM

Table 3. Plackett-Burman design matrix for screening of independent variables and the enzyme yield obtained

Run order	MgSO ₄ . 7H ₂ O (g/l)	Inoculum size (mm)	Substrate loading (%)	CUSO ₄ (Mm)	pH	NaHPO ₄ (g/l)	Incubation time (h)	Yeast extract (g/l)	Temperature (°C)	CaCl ₂ (g/l)	Peptone (g/l)	Substrate type	Enzyme Yield (U/ml)
1	0.2	5	5	4	4	0.05	24	1	30	0.02	1	Untreated	0.96±0.007
2	0.2	3	5	4	4	0.5	120	1	40	0.02	1	Treated	1.04±0.007
3	0.2	3	3	4	6	0.5	120	1	30	0.2	2	Treated	2.98±0.140
4	0.2	5	3	4	6	0.05	120	2	40	0.02	1	Treated	1.64±0.070
5	0.02	3	3	4	4	0.5	120	2	30	0.2	1	Untreated	3.04±0.021
6	0.2	3	3	2	6	0.05	120	1	40	0.02	2	Untreated	1.35±0.040
7	0.2	5	3	2	6	0.5	24	2	40	0.2	1	Untreated	0.98±0.070
8	0.02	5	5	2	6	0.5	120	2	30	0.02	1	Treated	3.14±0.014
9	0.02	3	5	2	6	0.5	24	1	40	0.2	1	Treated	0.88±0.007
10	0.02	5	3	2	4	0.05	120	1	40	0.2	1	Untreated	1.02±0.007
11	0.02	5	5	4	6	0.5	24	1	40	0.02	2	Untreated	1.03±0.014
12	0.2	3	5	2	4	0.05	24	2	40	0.2	2	Treated	0.88±0.007
13	0.2	5	5	2	4	0.5	24	2	30	0.02	2	Treated	0.16±0.007
14	0.02	5	5	4	4	0.05	120	2	40	0.2	2	Treated	1.06±0.007
15	0.02	3	3	2	6	0.05	120	2	30	0.02	2	Untreated	2.40±0.007
16	0.2	3	3	4	6	0.05	24	2	30	0.2	1	Untreated	1.37±0.007
17	0.02	5	5	4	6	0.05	24	1	30	0.2	2	Untreated	2.33±0.007
18	0.02	3	3	4	4	0.5	24	1	40	0.02	2	Untreated	0.94±0.000
19	0.2	5	5	2	4	0.5	120	1	30	0.2	2	Untreated	2.20±0.021
20	0.02	3	3	2	4	0.05	24	1	30	0.02	1	Treated	1.08±0.007

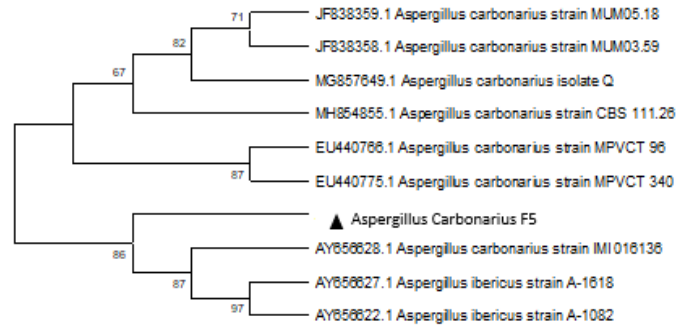


Fig. 1. Phylogenetic relationship based on homology index for *Aspergillus carbonarius* F5

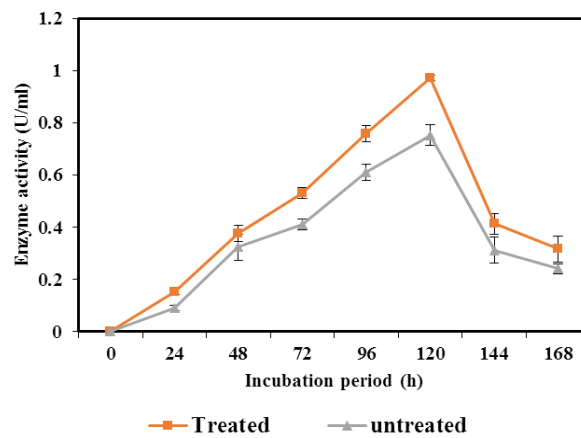


Fig. 2. Laccase production by *Aspergillus carbonarius* F5 grown on treated and untreated *Delonix regia* pods. Values are means of (n=3), ± SD. Error bars smaller than the symbol are not visible

Table 4. Analysis of variance for process optimization using Plackett-Burman design

Source	Degree of freedom	Sum of squares	Mean squares	F- value	P- value
Model	12	22.8689	1.9057	11.68	0.000
Linear	12	22.8689	1.90574	11.68	0.000
Temperature (°C)	1	7.8075	7.80749	47.86	0.000*
MgSO ₄ .7H ₂ O(g/l)	1	1.1411	1.14109	6.99	0.013*
Inoculum size (mm)	1	0.2440	0.24398	1.50	0.232
CaCl ₂ (g/l)	1	0.9816	0.98157	6.02	0.051
Substrate concentration (%)	1	0.0464	0.04638	0.28	0.598
CUSO ₄ (mM)	1	0.5978	0.59780	3.66	0.066
pH	1	3.0504	3.05035	18.70	0.000*
NaHPO ₄	1	0.5072	0.50715	3.11	0.089
Incubation period	1	8.4309	8.43091	51.68	0.000*
Yeast extract	1	0.0543	0.05432	0.33	0.569
Substrate type	1	0.0058	0.00581	0.04	0.852
Peptone	1	0.0020	0.00202	0.01	0.912
Error	27	4.4050	0.16315		
Pure error	20	0.0074	0.00037		
Total	39	27.2739			

F= fischer function; *(p<0.05) = probability; R²=0.9085; R² adjusted=0.8987; R² predicted 0.8755

3.3.3 Optimization of F5 laccase using CCD-RSM design

Optimization of the significant factors affecting laccase production was necessary because the preliminary optimization could not provide information on the interactive effect of the factors responsible for laccase yield. It is important to note that the interaction of the factors are responsible for regulating fungal metabolism. Therefore, optimization of the significant factors using CCD-RSM was carried out to improve laccase production by *Aspsrgillus carbonarius* F5. A set of 4 factors (based on preliminary screening) and 50 runs was experimented. The results revealed variations in laccase yield due to the four independent factors maintained for the fermentation. Optimum laccase activity (5.05 U/ml) was obtained in run order 22 at 120 h of incubation while the lowest yield (0.71 U/ml) was obtained in run order 18 at 72 h (Table 5). Laccase yield was increased by 5.20-folds after optimization. Likewise, increase in laccase yield from 6.0U/ml to 7.9U/ml by *Penicillium chrysogenum* using central composite rotatable design was reported [41]. All the selected variables were statistically significant at 95% confidence level showing interactive effects among the variables (Table 6). Also, second order polynomial equation (regression equation) was generated to determine the main effects, interactive effects and quadratic effects of the significant parameters (pH, temperature, incubation period and MgSO₄) on laccase production Eq 6 using the Minitab software,.

$$\begin{aligned} \text{Laccase U/mL} = & 16.76 - 0.124 A - 5.07 B \\ & + 6.57 C - 0.0979 D \\ & + 0.00003A^2 + 0.536B^2 \\ & + 8.6 C^2 + 0.000199 D^2 \\ & + 0.0045 AB - 0.00109 BD \\ & + 0.04 BC + 0.002497AD \\ & - 0.303 AC + 0.0470 CD \end{aligned}$$

Equation 6

The model generated was fitted into the regression equation. The final statistical significance of the significant factors were performed using the analysis of variance (ANOVA) (Table 6). The significance of the model was assessed using the probability “p” and Fichers “F” test. The adjusted R² and Co-efficient of determination R² predicted the statistical accuracy of the model. The p values < 0.05 indicated the significance of the model terms. From the table A, B, C, D, A², C², BC and CD were the significant model terms. The correlation coefficient (R²) shows the coherency of the predicted and experimental values. From this study, the R² at 0.9269 indicated perfect correlation between the predicted and experimental values. The R² value 0.9269 indicates that the model could explain up to 92.69% of the variability of the response and 7.31% could not be explained by the model. The predicted R² (0.8976) is in reasonable agreement with the adjusted R² (0.9086).

The laccase yield obtained via optimization on *Delonix regia* pods in the current study, is comparable to similar optimization studies (Table 7).

Table 5. The RSM-CCD for significant factors affecting laccase production

Run order	MgSO ₄ .7H ₂ O (g/l)	Temperature (°C)	pH	Incubation period (h)	Enzyme (U/ml)
1	0.2	30	4	120	2.56 ± 0.007
2	0.11	35	5	-24	0.78 ± 0.007
3	0.2	30	6	24	1.74 ± 0.007
4	0.2	40	6	24	1.47 ± 0.140
5	0.2	40	4	120	4.14 ± 0.037
6	0.02	40	6	24	1.70 ± 0.000
7	0.11	35	5	168	4.65 ± 0.007
8	-0.07	35	5	72	1.06 ± 0.000
9	0.11	35	5	72	1.20 ± 0.070
10	0.11	35	3	72	1.58 ± 0.000
11	0.29	35	5	72	1.57 ± 0.007
12	0.02	40	4	120	4.04 ± 0.000
13	0.02	40	4	24	1.34 ± 0.007
14	0.2	40	4	24	0.90 ± 0.000
15	0.2	40	6	120	4.60 ± 0.000
16	0.2	30	6	120	2.78 ± 0.000
17	0.2	30	4	24	1.68 ± 0.000

Run order	MgSO ₄ .7H ₂ O (g/l)	Temperature (°C)	pH	Incubation period (h)	Enzyme (U/ml)
18	0.11	45	5	72	0.71 ± 0.000
19	0.02	30	4	120	2.38 ± 0.007
20	0.02	30	6	24	2.00 ± 0.007
21	0.11	35	7	72	4.78 ± 0.007
22	0.02	30	6	120	5.05 ± 0.140
23	0.02	40	6	120	4.09 ± 0.000
24	0.02	30	4	24	1.32 ± 0.000
25	0.11	25	5	72	1.41 ± 0.037

Table 6. Analysis of variance of response surface quadratic model for laccase production

Source	Degree of freedom	Sum of squares	Mean squares	F- value	P- value
Model	14	75.1075	5.3648	17.80	0.000
Linear	4	45.4001	11.3500	37.67	0.000
A- pH	1	6.5512	6.5512	21.4	0.000*
B- Temperature	1	2.6456	2.6456	8.78	0.005*
C- Incubation period	1	35.3960	35.3960	117.47	0.000*
D- MgSO ₄ .7H ₂ O	1	0.8073	0.8073	2.68	0.011*
Square	4	16.1987	4.0497	13.44	0.000
A ²	1	6.4843	6.4843	21.52	0.000*
B ²	1	0.0000	0.0000	0.00	0.995
C ²	1	4.7636	4.7636	18.81	0.000*
D ²	1	0.1092	0.1092	0.36	0.551
2- way interaction	6	13.5087	2.2514	7.47	0.000
AB	1	0.0162	0.0162	0.05	0.818
AC	1	0.0873	0.0873	0.29	0.594
AD	1	0.0004	0.0004	0.00	0.970
BC	1	11.4924	11.4924	38.14	0.000*
BD	1	0.5949	0.5949	1.97	0.169
CD	1	1.3175	1.3175	4.37	0.044*
Error	35	10.5463	0.3013		
Pure error	25	1.2521	0.0501		
Total	49	86.6537			

R²= 0.9269; adjusted R²= 0.9086; predicted R²0.8976 p< 0.05

Table 7. Comparison of optimal laccase production on different carbon sources

Organism	Carbon source	Fermentation type	Optimization method	Laccase yield (U/ml)	Fold increase	References
<i>Aspergillus flavus</i> PUF5	Ribbed gourd Peel	Submerged	CCD- RSM	15.96	4.60	[42]
<i>Penicillium chrysogenum</i>	Sucrose	Submerged	CCRD- RSM	7.9	1.32	[41]
<i>Pleurotus ostreatus</i>	Glucose	Submerged	CCD- RSM	2.70	3.13	[43]
<i>Aspergillus</i> sp. HB_RZ4	Glucose	Submerged	CCD- RSM	9.03	1.24	[44]
<i>Pycnoporus sanguineus</i> & <i>Beauveria brongniartii</i>	Glucose	Submerged	CCD- RSM	2.08	2.50	[45]
<i>Aspergillus carbonarius</i> F5	<i>Delonix regia</i> pods	Submerged	CCD- RSM	5.05	5.20	Present study

3.3.4 Analysis of variable interactions

The interactive 3D plot was determined to illustrate the interaction between the factors and to determine optimum concentration of specific factor for high laccase yield. The 3D plots shows the interactions between two varying factors while keeping the third factor at midpoint. Value for $p > 0.05$ for AB, AC, AD and BD shows insignificant interactions. From the plot, the highest laccase yield at 7.5 U/ml will occur when incubation period increased to 150 h (linear relation with laccase yield) and temperature of around 36 °C. Laccase activity was found to increase with longer incubation period. Temperature around 36 °C increased laccase yield, further increase in temperature led to drastic decrease in laccase yield (Fig 3a). The incubation period increased with increase in laccase yield, and maximum yield of 6.0 U/ml was obtained when incubation period is maximum and MgSO₄ is around 0.2 g/l (Fig 3b). Lower concentration of MgSO₄ (0.2 g/l) induced the laccase synthesis. Higher concentration of MgSO₄ has toxic effect on the fungal growth, hence lower laccase activity was observed. Mesophilic temperature was sufficient for the fungi growth. Higher temperature was unfavorable and thus negatively affected laccase yield. Since longer incubation period was

required, additional study was carried out to confirm the optimum predictions observed in the model. Laccase activity under optimized condition (0.2 g/L MgSO₄, temperature 36 °C and incubation period at 168 h) yielded 8.04 U/ml, compared to the predicted at 7.5 U/ml.

3.4 Dye Decolorization by Crude Laccase

The crude laccase was evaluated for its ability to decolorize malachite green dye and congo red dye. An increase in percentage decolorization was observed with longer incubation periods (120 h). Also, decolorization at 87.6% congo red was obtained, while 62.6 % decolorization was obtained for malachite green (Figure 4). This in agreement with Wakil [27], where highest decolorization (65.84 %) of malachite green and methyl red (87.50 %) by purified laccase was achieved after 96 h. The decolorization of methyl orange with crude laccase from *Halopiger aswanensis* strain ABC_IITR was reported to be 55.2 % at 12 h [46]. The decolorization of Azo dyes (RB220 and RB5) with crude laccase, achieved on the 6th and 10th day, respectively was above 90 %. [47]. However, Leo [48] reported the decolorization of malachite green dye within the 1 h and congo red dye within 6 h at 68.61 % and 48.5 % , respectively.

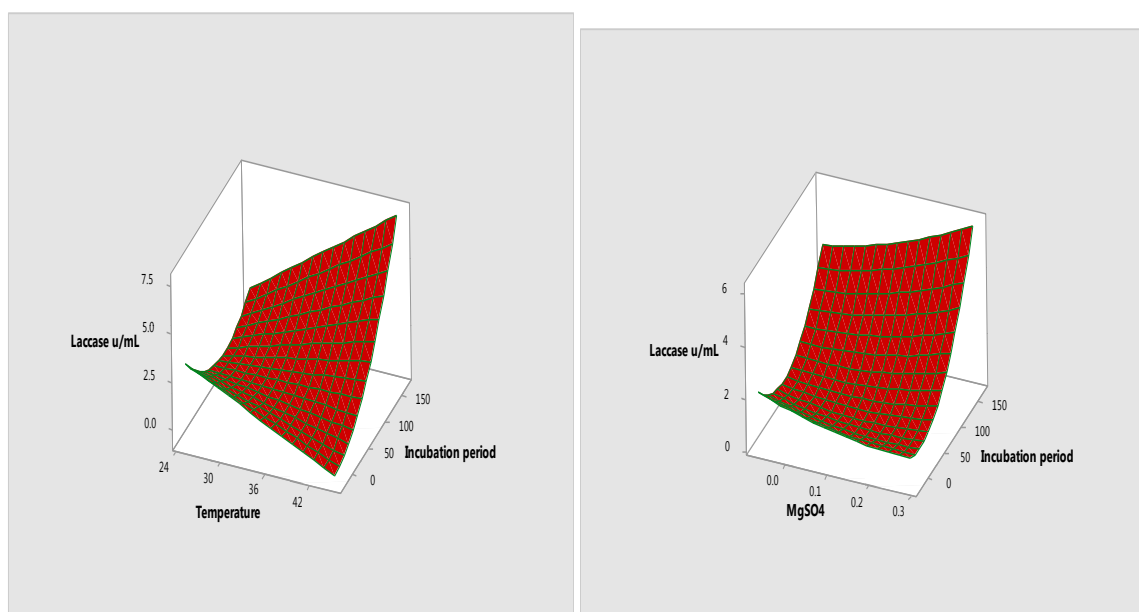


Fig. 3. a-b: The 3-D response surface plots depicting interactions between independent variables. a: temperature-incubation period and b: MgSO₄-incubation period, affecting laccase yield (U/ml) by *Aspergillus carbonarius* F5

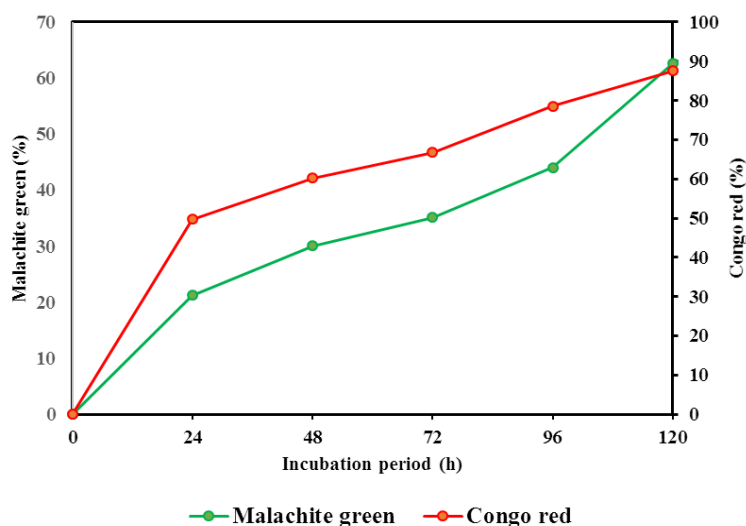


Fig. 4. Decolorization of synthetic dyes by crude laccase obtained from *Aspergillus carbonarius* F5. Values are means of (n=3), \pm SD. Error bars smaller than the symbol are not visible

4. CONCLUSION

In the current study, *Delonix regia* pods was established as a more cheaper, sustainable, effective and biodegradable ecofriendly substrate for laccase production when subjected to microbial biodegradation action by *Aspergillus carbonarius* F5 under SmF. The outcome documented from the statistical analysis using the PDB indicate temperature, pH, incubation period and $MgSO_4$ all have significant effect ($p < 0.05$) on laccase production while a 8.28-fold increase in laccase yield and model accuracy was accomplished with CCD-RSM. Significant interactions were evident between incubation period- $MgSO_4$ and temperature-incubation period. Dye decolorization by the laccase was effective with higher percentage decolorization. Therefore, the study clearly demonstrates the potential of *Delonix regia* pods as carbon substrate for statistical-based optimization of laccase by F5 with subsequent usage in dye decolorization. . Future studies will focus on purification of the enzyme for appropriate kinetic studies and characterization

CONFLICT OF INTEREST

Authors have declared no conflicting interest.

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