Abstract

Viscum album and its endophytic fungal species lectin are reported as antioxidant, antimicrobial, anti-inflammatory and anticancer activity. The present investigation was undertaken to in vitro (by enzymes inhibition) and in vivo antidiabetic activity of endopytic fungi, Alternaria species N-acetyl-galactosamine, 54 kDa protein lectin in alloxan induced diabetic rats. Endophytic fungal lection was orally administered at 400 mg/kg body weight (BW) dose to alloxanized mice (blood glucose>200 mg/dl). Various diabetic parameters were studied and compared with untreated mice. Furthermore, Matrix Assisted Laser desorption Ionization Time Of Flight Mass Spectroscopy (MALDI-TOF-MS) was employed to reveal the characteristics and identification of peptides. The lectin was confirmed by hemagglutination, PAS staining and it is N-acetyl-galactosamine, 64 kDa glycoprotein. The endophytic fungal lectin inhibited the three important diabetic enzymes viz., α-amylase (85.26 ± 1.25%), α-glucosidase (93.41 ± 1.27) and sucrase (81.61 ± 1.05) strongly. The N-acetyl-galactosaminelec tin treated diabetic rats showed significantly increased the body weight (8.50%) compared with the standard drug (9.01%) after 14 days of treatment. The lectin treated rats shown regeneration of pancreatic tissues, ducts and walls, acini, blood vessels, blood capillaries, islet capsules and cells and all these were in accordance with format only and recovery has been observed. The lectin treated diabetic rats also reduced the levels of urea (43.7 ± 5.8), creatinine (0.32 ± 0.01), serum cholesterol (103.54 ± 2.13), triglycerides (124.68 ± 2.49), aspartate transaminase (138) and alanine aminotransferase (57) and this results confirms the health of the animal when compared to standard drug. The study provides evidence that endophytic fungal lectin could exert a protective effect against β-cell damage by its anti-inflammatory effects and aids regeneration might through stimulation of ductal stem cells. However, further experimental studies are still needed for more details on lectin as an adjuvant in the management of diabetes mellitus. The present results revealed that, endophytic fungal lectin possess potent anti-diabetic activity and regenerated the cells or tissues in diabetic rats.

Introduction

Plant endophytic fungi have been recognized as an important and novel resource of natural bioactive products with potential application in agriculture, medicine and food industry [1-3]. In the past two decades, many valuable bioactive compounds with antimicrobial, insecticidal, cytotoxic and anticancer activities have been successfully discovered from the endophytic fungi. These bioactive compounds could be classified as alkaloids, terpenoids, steroids, quinones, lignans, phenols and lactones [4,5].

A nonpeptidal fungal (Pseudomassaria sp.) metabolite acts as an insulin mimetic and unlike insulin, is not destroyed in the digestive tract and may be given orally and resulted in significant lowering of blood glucose levels [6]. Endophytic fungal extracts showed antidiabetic activity [7,8].

Plant lectins are proteins bind to specific carbohydrate groups on the plasma membranes of mammalian cells, inducing variety of biological effects [9]. Many reports are available on plant lectins antidiabetic activity by possessing various mechanisms [10-12].

The present day, the diabetes is almost become a serious public health problem, particularly in developed countries as a major threat to global development [13,14]. This shows the necessities and the importance of more alternate and effective antidiabetic drugs and their systematic studies to manage diabetes.

This investigation was aimed to evaluate endophytic fungal lec tin in in vitro and in vivo on Alloxan induced rats and characterized the lectin. Hyperglycemia, hyperlipidemia and regeneration of histopathological structures were studied in lectin treated Alloxan induced diabetic rats.

Correspondence to: Govindappa M, Natural Product Laboratory, Department of Biotechnology, Shridevi Institute of Engineering & Technology, Sira Road, Tumkur-572 106, Karnataka, India, Tel: +91-7204238327; Fax: +91-8162212628, E-mail: endophyteset@gmail.com

Key words: endophytes, lectin, in vivo antidiabetic, histopathology, serum analysis

Received: December 20, 2014; Accepted: January 10, 2014; Published: January 14, 2015
This is the attempt was made on endophytic lectin antidiabetic activity in in vivo.

Materials and methods

Collection of endophytic fungi, Alternaria species and mass production

The endophytic fungi, Alternaria species was (previously isolated from leaf) collected from stock cultures of Department of Biotechnology, Shridevi Institute of Engineering & Technology, Sira Road, Tumakuru, Karnataka, India and was cultured CzapekDox broth for largescale cultivation, which was incubated at room temperature (26 ± 2°C) for 8 days.

Isolation and purification of lectin from endophytic fungi Alternaria species

Alternaria species lectin was obtained through a sequential purification protocol of Araujo et al. [15] and Rocha et al. [12]. The powdered fungal mycelial mat (10 g) was suspended in 0.15 M NaCl (100 mL). After homogenization in a magnetic stirrer (16h at 4°C), followed by filtration through gauze and centrifuged (4,000 xg, 15 min), the supernatant (crude extract) was taken as starting material. Soluble proteins in crude extract were fractionated with ammonium sulphate and the 30-60% precipitate fraction (30-60 F) was submitted to dialysis (3,500 Da cut-offmembrane, 4°C) against the distilled water (2 h). The 30-60 F was applied (11 mg protein, hemagglutination activity) into a CM-cellulose chromatography column (5.2 cm x 1.6 cm) equilibrated with 10 mM citrate phosphate buffer pH 5.5 at flow rate of 20 mL/h. The unabsorbed proteins were eluted with the buffer solution until the absorbance at 280 nm was lower than 0.05; endophytic fungal lectin was eluted with 0.5 M NaCl. Protein concentration was determined according to Lowry et al. [16] using bovine serum albumin as standard.

Lectin identification tests

Hemagglutination and hemagglutination inhibition assays:
Hemagglutination tests were performed in standard microtitre plates by 2-fold serial dilution method [17]. A 50 ml aliquot of the human erythrocytes (A +ve, B +ve, AB +ve, O +ve) suspension was added and the whole were incubated to inhibit lectin induced hemagglutination. Serial two-fold dilutions D-glucose, maltose, N-acetylgalactosamine were tested for their ability to inhibit lectin induced hemagglutination. Mixtures were incubated for 30 min at room temperature (26 ± 2°C) for 30 min. The reaction was terminated by treating the mixture in a boiling water bath for 5 min. After the addition of 1.0 M of 0.1 M NaOH was added to terminate enzymeactivity. The mixture was centrifuged (3000 g, 15 min) and the glucose content in the supernatant was determined.

Assay of α-amylase inhibitory activity:
The effect of endophytic fungal lectin on α-amylase activity was studied using an enzyme, starch system [20], FRB (1.5%) was mixed by stirred in 25 mL of 4% potato starch in a beaker, 100 mg of α-amylase was added to the starch solution, stirred vigorously, and incubated at 37°C for 60 min. After the incubation period, 0.1 M NaOH was added to terminate enzymeactivity. The mixture was centrifuged (3000 g, 15 min) and the glucose content in the supernatant was determined.

Assay of α-glucosidase inhibitory activity:
α-glucosidase inhibitory activity was assayed according to the method of Honda and Hara [21]. The enzyme solution (10 µL) and varying concentrations of sample emulsion (10.50 µL) were incubated together for 10 min at 37°C and the volume was made up to 210 µL with maleate buffer, pH 6.0. The enzyme reaction was started by adding 200 µL of 2 mM p-nitrophenyl-α-d-glucopyranoside solution and further incubated at 37°C for 30 min. The reaction was terminated by treating the mixture in a boiling water bath for 5 min. After the addition of 1.0 M of 0.1 M diosodium hydrogen phosphate solution, absorption of the liberated p-nitrophenol was read at 400 nm.

Assay of sucrase inhibitory activity:
The effect of the Alternaria species lectin on sucrase activity was assayed according to the method of Honda and Hara [21]. The enzyme solution (10 µL) and varying concentrations of sample emulsion (10.50 µL) were incubated together for 10 min at 37°C and the volume was made up to 200 µL with maleate buffer (pH 6.0). The enzyme reaction was started by adding 100 µL sucrose solution (60 mM). After 30 min, the reaction was terminated by adding 200 µL of 3.5-dinitrosalicylic acid reagent and treating the mixture in a boiling water bath for 5 min. The absorbance of the solution was read at 540 nm. The percent inhibitory activities were calculated using the following formula:

% Inhibition=(AbsControl-AbsSample) x100/Abs Control

Where Abs control is the absorbance of the control reaction(containing all reagents except the test sample), and Abs sample is the absorbance of the test sample. An untreated enzyme solution was used as the control. All experiments were carried out in triplicate.

Glucose diffusion method

Amethod described by Gallagher et al.[22] was used to evaluate the effects of different solvent extracts of endophytic fungal lectin on glucose movement in vitro. This in vitro model used consisted of a dialysis tube (6 cm x 29.31 mm) (Himedia-LA393-5MT-2010) in to
which 6 ml of plant extract and 2 ml of 0.15 M NaCl containing 1.65 mM D-glucose was added. The dialysis tube was sealed at each end and placed in a centrifuge tube containing 45 ml 0.15 M NaCl. The tubes were placed on an orbital shaker water bath and incubated at 37°C for 3 h. The movement of glucose into the external solution was provided. Concentrations of glucose within the dialysis tube were measured and control tests were conducted in the absence of plant extracts. Glucose concentrations were analyzed by enzymatic method using glucose oxidase kit. All tests were carried out in triplicate and the results were presented as means ± SD.

**In vivo experiments**

**Selection of animal species:** Healthy young male albino wistar rats of 8-10 week old, weighing between 150 g to 200 g were selected for **in vivo** antidiabetic studies. Rats were collected from the animal house of Sree Siddaganga College of Pharmacy, Tumkur, Karnataka, India and research was carried out in Pharmacology Department of Sree Siddaganga College of Pharmacy. Rats were housed in animal room at 25 ± 2°C temperatures and maintained with free access to standard food and pure water *ad libitum*. The animal room was regulated by a 12 h light and 12 h dark schedule.

**Toxicity studies (L.D.)**: Based upon the results of **in vitro** antidiabetic activity, the endophytic fungal *Alternaria* species lectin was selected for animal studies. Suspensions of dried, concentrated column fractions were prepared by dissolving in 0.9% v/v cold normal saline solution for treatment. Toxicity studies were carried out endophytic fungal *Alternaria* species lectin in accordance with the modified method Lorke [23]. Maximum dose, up to 1200 mg/kg body weight was treated through oral route of administration. The animals were grouped into 4 groups involving 5 animals in each group. Group-1: lectin- 400 mg/kg body weight, Group-2: lectin fraction- 800 mg/kg body weight, and Group-3: lectin- 1200 mg/kg body weight. The rats were observed for clinical signs and symptoms of toxicity like behavioural changes and mortality within 24 h. All the procedures were performed in accordance with the Institutional Animal Ethics Committee (IAEC). Lethal dose (LD₅₀) was then calculated as the square root of the product of the lowest lethal dose and high non-lethal dose.

**Experimental induction of diabetes**

The animals were fasted for 16-18 h with free access to water prior to the administration of Alloxan. Alloxan monohydrate is cyclic urea analogue having unique properties of producing chronic experimental diabetes by a specific cytotoxic action on β-cells of the islets of Langerhans by a single diabeticogenic dose. Diabetes was induced in nearly 70 rats by intraperitoneal (i.p.) injection of Alloxan monohydrate at a dose of 120 mg/kg body weight, dissolved in 0.9% v/v cold normal saline solution [24]. The rats were then kept for the next 24 h on 5% glucose solution bottles in their cages to prevent hypoglycemia [25]. After an observational period of about 72 h, rats with fasting plasma glucose levels above 300 mg/dl were considered diabetic.

**Experimental protocol:** After an observational period of 72 h, rats with fasting plasma glucose levels above 300 mg/dl were considered diabetic and were assigned into five groups of ten rats in each group.

Animal fasted overnight were randomly divided into 5 groups:

- **Group 1**: NC: Normal control, treated with only normal saline (2.0 ml) orally.
- **Group 2**: DC: Diabetic control
- **Group 3**: STD: Diabetic rats treated with reference drug Glibenclamide, at a dose of 0.5 mg/kg body weight.
- **Group 4**: EAsL: Diabetic rats treated with lectin isolated from *Alternaria* species, at a dose of 400 mg/kg body weight orally.
- **Group 5**: EAtL: Diabetic rats treated with lectin isolated from *Alternaria* species, at a dose of 800 mg/kg body weight orally.

The fasting blood glucose levels were estimated by glucose oxidase-peroxidase reactive strips (Dextrostix, Bayer Diagnostics) with Accu-chek glucometer. Blood samples were collected by cutting the tip of the tail at an interval of 1, 7, and 14 days. The blood results were reported as mg/dl. Blood glucose levels were expressed in mg/dl as mean ± SEM. On day 14, rat’s body weight, serum cholesterol and serum triglycerides were analysed. During the experiment all the rats had free access to standard rat chow and water at all times. Body weight and glycaemic change were calculated according to the formula;

\[
\text{Change in body weight (bw) (\%) =} \frac{\text{Initial body weight} - \text{body weight on 14th day}}{\text{Initial body weight}} \times 100
\]

\[
\% \text{Glycaemic change} = \frac{\text{Glucose concentration 14th day} - \text{Fasting blood glucose on 1st day}}{\text{1st day}} \times 100
\]

The data were statistically analyzed using ANOVA with multiple comparisons versus control group. Values of *p*<0.05 or less were taken as significant.

**Lipid profile**

At the end of 14th day of experiment period, blood was collected in Eppendorf tubes through retro-orbital plexus. Plasma was separated and serum was taken by centrifugation at 4°C using REMI-24 model centrifuge. Lipid profile viz., serum cholesterol and serum triglycerides were measured on automated analyser Olympus AU 400.

**Histopathology**

It is been important to study the determination of affects of endophytic lectin on pancreatic cytoarchitecture. At the end of 14th day, all the animals were sacrificed by lethal chloroform vapor anaesthesia and pancreas was excised and rinsed in ice cold normal saline. A portion of the tissue was fixed in 10% formalin, cut into 5 μm thick sections, and stained using hematoxylin-eosin stain and histopathological observations were made.

**Effect of endophytic lectin on biochemical data**

Normal control, diabetic induced control, lectin treated and standard drug treated rats blood samples were centrifuged at 2,500 g for 15 min at 4°C (REMI, C 24 Cooling Centrifuge, India). Sera were obtained and the levels of the urea, creatinine, aspartate aminotransferase (AST) and alanine aminotransferase (ALT) were measured by enzymatic colorimetric methods in a chemistry autoanalyzer [12].

**Molecular characterization of antidiabetic lectin by MALDI-TOF-MS**

The dried extract was dissolved in 10 μl of 0.1% trifluoroacetic acid (TFA), purified by Zip Tip C18 tips prior to MS analysis. The eluant was mixed with 10 mg ml-1 of 2, 5- dihydroxyxycinnamic acid (DHB) in 50% acetonitrile and 0.1% TFA for spotting onto sample plate anddried for MALDI-TOF-MS analysis. MALDI-TOF-MS analysis wasperformed with the 4700 proteomics analyzer (Applied Biosystems, Framingham, MA, USA) equipped with an ND:YAG laser (355 nm) having a 3–7 ns pulse and a 200 Hz firing rate. MALDI-TOF-MS analyses were obtained in the reflecton positive ion mode. The accelerated voltage
Govindappa M (2015) In vitro and in vivo antidiabetic activity of lectin (N-acetyl-galactosamine, 64 kDa) isolated from endophytic fungi, *Alternaria* species from *Viscum album* on alloxan induced diabetic rats

**Results**

Five different endophytic fungal species were identified from three (stem, leaves and fruit) parts of *Viscum album* [26] from our earlier report. The *Alternaria* species was present in all the three parts used. For the present study, the leaf endophytic fungi *Alternaria* species was selected for present study and it was found to confirmed to contain hemagglutinate protein in agglutinating method, at 25 mM and confirms the lectin is a D-glucose and D-galactosamine specific. We have selected D-galactosaminelectin and in molecular weight determination showed a single band of 64 kDa [26]. The lectin was stained purplish pink with Schiff’s reagent in NATIVE-PAGE in PAS and it confirms as glycoprotein lectin.

The lectin had shown significant inhibition effects on glucose movement into external solution across the dialysis membrane. The lectin showed 41.37 ± 0.59 of glucose diffusion in dialysis membrane and increment movement was 12.54 ± 0.87% (Table 1).

The α-amylase inhibitory activity of lectin was studied using α-amylase star remodel system and inhibitory activity was 85.26 ± 1.25. The lectin significantly inhibited the α-glucosidase and it was 93.41 ± 1.27. The significant enhancement in inhibitory activity of α-glucosidase by lectin. More sucrase inhibition was noticed in lectin (81.61 ± 1.05%) (Figure 1).

**Toxicity studies (LD<sub>sp</sub>)**

The fungal endophyte, *Alternaria* species lectin was used for toxicity studies in rats through oral route administration. No toxicity was observed with fungal lectin in rats upto 1200 mg/kg body weight. We have also studied clinical signs and symptoms of toxicity like behavioral changes in rats and 100% survival rates had seen. The endophytic fungal lectin did not cause deaths of any abnormal behavior changes in rats and 100% survival rates had seen. The endophytic lectin was considered as non-toxic in test concentrations.

**Effect on body weight**

There is a slight increase in body weight in normal control and it may be due to normal growth. The diabetic control rats had reduced the body weight of 5.28%. The diabetic induced rats treated with standard drug Glibenclamide increased in the body weight by 9.01%. The lectin treated rats increased the body weight by 8.50% significantly (Table 2).

**Hypoglycaemic effect of endophytic fungal lectin**

The *Alternaria* species fungal lectin had significant hypoglycaemic effects. The blood glucose level was decreased and observed by 60.76% on 14th day at 400 mg/kg concentration. The blood glucose level reduction was found to be more efficient in lectin treated when compared to standard drug Glibenclamide which showed blood glucose level by 64.04%. The blood glucose on the final day of treatment were 101.33 ± 4.46 mg/dl (normal control), 386.44 ± 10.48 mg/dl (diabetic control), 115.34 ± 0.45 mg/dl (diabetic rats were treated with standard drug Glibenclamide) and 129.62 ± 9.10 mg/dl (lectin treated rats) (Table 3).

**Effect of lectin extract on glucose diffusion from dialysis tube after 3h.**

| Extracts | Glucose diffusion to out of dialysis membrane | Increase of movement (%) |
|----------|---------------------------------------------|--------------------------|
| Lectin   | 41.37 ± 0.59                               | 12.54 ± 0.87             |

*Repeated the experiment thrice, data represents mean ± SD of three replicates
*p<0.01  (please show significant data for lectin effect)

**Table 2. Effect of lectin extract on average body weight of diabetic induced rats.**

| Group | Dose (mg/kg bw) | Day 1  | Day 7  | Day 14 | Change in bw (%) |
|-------|-----------------|--------|--------|--------|------------------|
| Group 1: Normal saline | 98.40 ± 5.01 | 96.14 ± 4.50 | 101.33 ± 4.46 | 2.97 |
| Group 2: 120 mg/kg bw | 323.03 ± 9.01 | 152.14 ± 11.50 | 276.44 ± 10.48 | 19.62 |
| Group 3: 0.5 mg/kg bw | 320.80 ± 10.45 | 199.46 ± 09.52 | 115.34 ± 05.45 | 64.04 |
| Group 4: 400 mg/kg bw | 330.40 ± 7.44 | 215.46 ± 8.41 | 129.62 ± 90.10 | -60.76 |

*Repeated the each experiment thrice, data represents mean ± SD of three replicates

Note: *Group 1: Normal control, Group 2: Diabetic control, Group 3: Diabetic rats treated with standard Glibenclamide and Group 4: Diabetic rats treated with Lectin extract
*p<0.01  (please show significant data for lectin effect)
induced had shown serum cholesterol and serum triglycerides by 153.26 ± 1.45 and 176.64 ± 2.62 respectively. The lectin treated diabetic rats showed reduced levels of serum cholesterol (103.54 ± 2.13) and serum triglycerides (124.68 ± 2.49) whereas standard glibenclamide showed 98.44 ± 1.28 and 110.44 ± 2.02 of serum cholesterol and serum triglycerides (Figure 2).

**Histopathology**

The results of lectin treated rats exhibited well differentiated by cytoarchitecture. In normal control, there was normal distribution of cells of islets, acini, blood capillaries, pancreatic ducts were observed. The normal control also showed acinar cells, islets of Langerhans and blood vessels were good in number, texture and were well organized and connected with connective tissues. Along with RBCs, the 2-3 types of distinguishable islet cells were noticed. No inflammatory pancreatic and blood vessels were seen. Noticed abnormalities were observed in diabetic induced rats and marked inflammatory of blood vessels and ruptured blood capillaries were observed. Pancreatic lobes, acini, islets of Langerhans, exocrine glands, connective tissues and capillaries were depleted and number, cells of islets and pancreatic ducts were decreased. Deformed islets were observed due to diabetes effect and they were formed as amyloid and shrinkage. In endocrine and exocrine, the red blood cells were interdispersed (Figure 3A-3B).

The standard drug, glibenclamide treated diabetes rats had shown regeneration of pancreatic ducts, acinar and connective cells. The interlobular septa, walls of blood vessels, and pancreatic ducts were normal as in normal control. Even distribution of islets and cells of Langerhans, cells of acinar and pancreatic ducts had seen and they were normal (Figure 4A-4B). The endophytic fungi, *Alternaria* species lectin treated diabetes induced rats exhibited significant in preventing damage of pancreatic cells by oxidation stress. The well organized in accordance with their number, texture and dispersion of pancreatic connective tissue and cells, acini, blood vessels and capillaries, pancreatic ducts and their walls, islets capsule had noticed in lectin treated rats. Distinguishable individual of cells of islets and noticed the presence of 2-3 types of islet cells with RBC cells. The architecture of pancreatic histology in lectin treated diabetic induced rats is normal and was similar to normal control (Figure 5A-5F).

Figure 6 clearly depicts that different levels of urea and creatinine known as kidney function markers were significantly increased in sera of alloxan induced diabetic rats. The levels of urea and creatinine significantly decreased after 14 days of treatment. The lectin (40 mg/kg) treated rats had reduced the serum level of urea and creatinine by 15.9% and 0.08% respectively.

The serum AST and ALT were significantly reduced in lectin treated alloxan induced diabetic rats after treatment with 40 mg/kg. The AST and ALT reduced in lectin treated rats by 26% and 5% respectively (Figure 7 and 8).

MALDI-TOF-MS analysis of *Alternaria* species lectin showed the presence of 8 different peptides, of which, 7 peptides had maximum intensities. The peptide fingerprinting of lectin from *Alternaria* species was identified as a ribosome inactivating protein comparable to *Phytolacca americana*. The seven peptides were 2100.09, 1716.86, 1365.72, 1838.95, 893.51, 2329.15, 1179.65, 1765.81 and matched peptides. The protein identified was similar to *Phytolacca americana*.
Govindappa M (2015) *In vitro* and *in vivo* antidiabetic activity of lectin (N-acetyl-galactosamine, 64 kDa) isolated from endophytic fungi, *Alternaria* species from *Viscum album* on alloxan induced diabetic rats

Volume 1(1): 11-19

*Integr Obesity Diabetes*, 2015        doi: 10.15761/IOD.1000104

reported to have antiviral activity, they belong to ribosome inactivating protein family.

**Discussion**

The lectin isolated from endophytic fungi, *Alternaria* species of *Viscum album* and characterized by hemagglutination and it was a 64 kDa from our earlier report [26]. Isolated lectin had shown very potent inhibitor of important diabetic enzymes tested viz., α-glucosidase[27], α-amylase [28] and sucrose [29]. Our reports are confirmatory findings of mentioned references. The glucose diffusion results were confirmation with the findings of Gallagher et al. [22] and Buyukbalci [30], they tried with other different extracts which were potent inhibitors of glucose movement in the same model system and the ability to inhibit glucose diffusion using same *in vitro* method with different plant extracts.

Some antidiabetic plants may exert their action by stimulating the function or number of β-cells and increase the insulin release. In some other plants, the effect is due to decreased blood glucose synthesis due to the decrease in the activity of enzymes. In other plants, the activity is due to slow absorption of carbohydrates and inhibition of glucose transport [31].

The enzyme, α-amylase is responsible in hydrolyzing dietary starch into maltose which then breaks down to glucose prior to absorption. Since α-amylases play an important role in starch assimilation in human beings and animals, the presence of such inhibitors in foodstuffs or plant extracts may be responsible for impaired starch digestion [32]. α-amylase inhibitors may be of value as novel therapeutic agents [33].

The α-glucosidases are crucial in many biological processes includes break down of edible carbohydrates and are also involved in a variety of metabolic disorders such as diabetes [34]. Thus potent and selective glucosidase inhibitors have many interesting potential applications, especially to manage in diabetes [34]. α-glucosidase is one among a number of glucosidases located in the brush-border surface membrane of intestinal cells and is a key enzyme of carbohydrate digestion. α-glucosidase inhibitors block the action of enzyme in the small intestine, which is rate limiting in the conversion of oligosaccharides to monosaccharides necessary for gastrointestinal absorption. Postprandial glucose peaks may be attenuated by delayed the glucose absorption. The main benefits attributed to α-glucosidase inhibitors are, reduction in both postprandial glycemic levels and the total range of postprandial glucose levels [35].

![Figure 5. Microscopic views of the effect of Lectin extract on rat pancreatic tissue, A) Normal acinar cells, B) Recovery of islet cells and blood cells, C) improved connective tissue around pancreatic duct and blood vessel, D) Recovered blood vessel and proper connective tissue E) improvised blood vessel and islets of Langerhans and F) Normal flow of connective tissue in 4 µm section.](image)

![Figure 6. Serum urea (A) and creatinine (B) levels in diabetic rats after treatment of 14 days with endophytic fungal lectin. *p<0.01](image)

![Figure 7. Serum aspartate aminotransferase levels in diabetic rats after treatment of 14 days with endophytic fungal lectin. *p<0.01](image)

![Figure 8. Serum alanine aminotransferase levels in diabetic rats after treatment of 14 days with endophytic fungal lectin. *p<0.01](image)
After treatment with lectin to Alloxan induced rats noticed that had normal body weight, blood glucose level, serum lipid profile and normal pancreatic histological characters after 14 days also. The rats body weight were decreased as diabetes progresses [36]. The lectin treated rats body weight were significantly increased, the results were correlated with the findings of Ahmed et al. [37] and Channabasava et al. [38] (unpublished data).

Saravanan et al. [39] and Quiong et al. [40] have reported that Alloxan induced diabetes mellitus rats had shown hyperglycemia and hyperlipidemia. Marles and Fornsworth [41] and Grower et al. [42] had used plant extracts were responsible for reducing blood glucose level. The endophytic lectin had significant hyperglycemia and antihyperglycemic activity after 14 days of treatment. The similar results have been reported by Harikiran et al. [43] with Bombax melanabicum, Tyagi et al. [44] with Anacyclus pyrethrum, Channabasava et al. [38] with Loranthus micranthus extract (unpublished data). The lectin isolated from Urtica pilulifera seeds had shown similar activity [45]. In hyperlipidemia, serum triglycerides play an important role of development and progression of renal diseases in type I diabetes mellitus [46]. Inactivation and derangements of lipid metabolism are vital determinants and status of the diabetes [47].

In lectin treated diabetic rats had shown significantly decrease in hyperlipidemia parameters by observing elevated serum cholesterol and serum triglycerides. Lectin have shown similar activity was noticed by Liang et al. [48] with Hericium erinaceus.

Alloxan destroys β-cells of islets of pancreas, it elevates the blood glucose level, decrease the protein content, increases the level of cholesterol and triglycerides. In almost all antidiabetic activity, the Alloxan is commonly used and it is similar to diabetes patient [49]. Alloxan producing redox potential and forms superoxide radicals and these increases concentrations of cytosolic calcium destroy the β-cells rapidly [50]. In diabetic induced rats are usually shown decrease in cell numbers in islets, cell damage and cell death [38,51]. The blood vessels were changed into thickened and hyalinized and it causes hypoxia and results into changes in degeneration and necrosis [52] and disorganization of pancreatic architecture and insulin producing cells were depletion leads to structural and functional alterations in Alloxan induced rats [38,53].

The endophytic fungal lectin induced the regeneration of connective tissues, ducts and walls of pancreatic, acini, blood vessels, blood capillaries, islet capsules and cells and organization, number, texture and dispersion were changed in Alloxan induced rats [38,54]. The lectin was also showed β-cells regeneration and blood glucose decrease [38]. The reduction of urea and creatinine was observed in lectin treated diabetic rats. Our results are in agreement with recent reports of Rocha et al. [12] and Omara et al. [55] but they used different plant secondary metabolites.

Significant reduction in AST and ALT in lectin treated rats has an evidence of good health. Our results are in agreement with those of Mansour et al. [56] and Rocha et al. [12] and they reduced these by using different plant metabolites. The levels of serum AST and ALT reduction in diabetic induced rats was due to effect of lectin. The liver problems or diseases are a high problem of health world wide and release of intracellular localized marker enzymes such as AST and ALT into the blood, when cell and mitochondria suggested to injury indicates hepatocytes damage [57]. In MALDI-TOF-MS, the N-acetyl-galactosaminellectin bearing 64 kDa molecular weight lectin was identified and it was similar to ribosomal inactivate protein of Phytolacca americana. The seven peptides were identified in lectin and they were, 2100.09, 1716.86, 1365.72, 1838.95, 893.51, 2329.15, 1179.65, 1765.81 and matched peptides and it was similar to lectin II group and they present in P. americana and possessing ribosomal inactivation and antiviral activity. Now we report here that same lectin is exhibiting strong antidiabetic activity in alloxan induced diabetes rats.

**Conclusion**

All the three diabetic enzymes were inhibited by lectin in *in vitro* and regeneration of histopathological structures in Alloxan induced rats in *in vivo* had showed protective in effect by altering in structural and functional changes in ducts of pancreatic, β-cells, islet, acini. Here, we report first in nationally and internationally that, lectin isolated from endophytic fungi *Aspergillus* species was shown strong antidiabetic activity in both *in vitro* and *in vivo*. The lectin reduced the levels of urea, creatinine, serum cholesterol, triglycerides, aspartate aminotransferase and alanine aminotransferase in diabetes induced rats. In MALDI-TOF-MS, the N-galactosaminelectin bearing 64 kDa molecular weight glycoprotein was identified and it was similar to ribosome inactivate protein of *Phytolacca americana* and which shown strong antidiabetic activity. Further, this endophytic fungal lectin can be used for diabetes treatment.

**Acknowledgements**

We thank Dr. MR Hulinayar, Managing Trustee, Sri Shridevi Charitable Trust (R.), Dr. S. M. Shashidhara, Principal and Sree Siddaganga College of pharmacy, Tumakuru, Karnataka, India and Molecular biophysical unit, IISC, Bangalore, Karnataka India, for encouragement and suggestions during the research. We also thank, Dr Prasad S Koka is a Ramalingaswami Fellow of the Department of Biotechnology, Government of India, New Delhi.

**References**

1. Strobel G, Daisy B, Castillo U, Harper J (2004) Natural products from endophytic microorganisms. *J Nat Prod* 67: 257-268. [Crossref]
2. Gunatilaka AAL (2006) Natural products from plant associated microorganisms: distribution, structural diversity, bioactivity, and implications of their occurrence. *J Nat Prod* 69: 505-526. [Crossref]
3. Verma VC, Kharwar RN, Strobel GA (2009) Chemical and functional diversity of natural products from plant associated endophytic fungi. *Nat Prod Commun* 4: 1511-1532. [Crossref]
4. Rodriguez RJ1, White JF Jr, Arnold AE, Redman RS (2009) Fungal endophytes: diversity and functional roles. *New Phytol* 182: 314-330. [Crossref]
5. Xu L, Zhou L, Zhao J, Jiang W (2008) Recent studies on the antimicrobial compounds produced by plant endophytic fungi. *Natural Product Research and Development* 20: 731-740.
6. Zhang B, Salituro G, Szalkowski D, Li Z, Zhang Y, et al. (1999) Discovery of small molecule insulin mimetic with antidiabetic activity in mice. *Science* 284: 974-981. [Crossref]
7. Prabhavathy D, Nachiyar V (2013) Antimicrobial and antidiabetic activity of an endophytic fungi isolated from *Adathodabeddome*. *Int J Pharm Pharm Sci* 5(3): 780-783.
8. Edward DJ, Srikandac Y, Suhariyo WP, Calyana H, Simanjuntak P (2011) Potential endophytic microbes selection for antidiabetic bioactive compounds production. Asian J. Biochem 46: 465-471. [Crossref]
9. Nowell PC (1966) Phytomassagullatrinum: an inhibitor of mitosis in cultures of normal human leukocytes. Cancer Res 20: 462-466. [Crossref]
10. Li Q, Ye XL, Zeng H, Chen X, Li XG (2012) Study on the extraction technology and hypoglycemic activity of lectin from Trichosanthes kirilowii. Zong Yao Cai 35: 475-479. [Crossref]
11. Hemalatha C, Dhanotharan R, Munusamy S (2011) Effect of Soya bean lectin on streptozotocin induced diabetic rats. Asian J. Exp Biol Sci 2(2): 231-236. [Crossref]
12. Rocha AMD, Fonseca CSMD, Mota DLD, Medeiros PLD, et al. (2013) Lectin from Crataeva tapia bark improves tissue damages and plasma hyperglycemia in Alloxan-induced diabetic mice. Evidence-Based Complementary and Alternative Medicine ID 869305. [Crossref]
13. Vessby B (2000) Dietary fat and insulin action in humans. Br J Nutr 83 Suppl 1: S91-96. [Crossref]
14. Seidell JC (2000) Obesity, insulin resistance and diabetes—a worldwide epidemic. Br J Nutr 83 Suppl 1: S8-S8. [Crossref]
15. Araujo WL, Marcon J, Maccheroni W Jr, Van Elaas JD, Van Vuure JW, et al. (2002) Diversity of endophytic bacterial populations and their interaction with Xyliella fastidiosa in citrus plants. Appl Environ Microbiol 68: 4906-4914. [Crossref]
16. Lowry OH, Rosebrough NJ, Farr AL, Randall RJ (1951) Protein measurement with the Folin phenol reagent. J Biol Chem 193: 265-275. [Crossref]
17. Moreira RA, Oliveira JTA (1983) Lectins from the genus Arthocarpus. Biologia Plantarum 25: 343-348.
18. Dubey G, Bezdor G (1982) A highly sensitive periodical acid-silver stain for 1,2-diol groups of glycoproteins and polysaccharides in polycrylamide gels. Anal Biochem 119: 325-329. [Crossref]
19. Natarajan SS, Xu C, Bae H, Caperna TJ, Garrett WM (2006) Characterization of storage proteins in wild (Glycine soja) and cultivated (Glycine max) soybean seeds using proteomic analysis. J Agric Food Chem 54: 3114-3120. [Crossref]
20. Ou S, Kwok K, Li Y, Fu L (2001) In vitro study of possible role of dietary fiber in lowering postprandial serum glucose. J Agric Food Chem 49: 1026-1029. [Crossref]
21. Honda M, Harv Y (1993) Inhibition of rat small intestinal sucrose and α-glucosidase activities by tea polyphenols. Bioscience Biotechnology Biochemistry 57: 123-124.
22. Gallagher AM, Flatt PR, Duffey D, Adel-WahabYHA (2003) The effects of traditional anti-diabetic plants on in vitro glucose diffusion. NutraResearch 23: 413-424.
23. Lorke D (1983) A new approach to practical acute toxicity testing. Arch Toxicol 54: 275-287. [Crossref]
24. Katsumata K, Katsumata Y, Ozawa T, Katsumata K Jr (1993) Potentiating effects of Archidendron jiringa extracts in Alloxan induced diabetic rats. Horm Metab Res 25: 125-126. [Crossref]
25. Dhannapuri S, Subramanian VR, Rajagopal S, Namasivayam N (2002) Hypolipidemic effect of Cuminum pilulifera in Alloxan-induced diabetic rats. Phytother Res 16: 413-416. [Crossref]
26. Sadananda TS, Govindappa M, Vinay DG, Bhawna B, Pralhad Baishya, et al. (2014) Isolation and characterization of antiviral and ribonuclease inactivating protein from the endophytic fungi Alternaria sp from Viscum album using MALDI-TOF-MS and their antibacterial activity. Drug Invention Today 6: 105-112.
27. Viroonbounyapat P, Karnchanatat A, Sangrivanich P (2012) An α-glucosidase inhibitory activity of three sulfonylurea drugs on the occurrence of Alloxan diabetes in rats. J Agric Food Chem 54: 703-709. [Crossref]
28. Upadhyay SK, Singh PK (2012) Receptors of garlic (Allium sativum) lectins and their role in insecticidal action. Protein J 31: 439-446. [Crossref]
29. Büyükbاقar A1, EI SN (2008) Determination of in vitro antidiabetic effects, antioxidant activities and phenol contents of some herbal teas. Plant Foods Hum Nutr 63: 27-33. [Crossref]
30. Chhetri R, Basnet D, Chiu PF, Kalikotay S, Chhetri G, et al. (2005) Current status of ethnomedicinal plants in the Darjeling, Himalaya. Current Science 89: 268-269.
31. Reddy NVLS, Anarthe SJ, Rachanendra NM (2010) In vitro antioxidant and antidiabetic activity of Asystasia gangetica (Chinese Violet) Linn. (Acanthaceae). International Journal of Research in Pharmaceutical and Biomedical Sciences 1: 72-75.
32. Puls W, Keup U (1973) Influence of an α-amylase inhibitor (BAY d 7791) on blood glucose, serum insulin and NEFA in starch loading tests in rats, dogs and man. Diabetologia 9: 97-101. [Crossref]
33. Robinson KM, Begovic MJ, Rhinehart BL, Heineke EW, Dapec JB, et al. (1991) New potent alpha-glucohydrolase inhibitor MLD 73945 with long duration of action in rats. Diabetes 40: 825-830. [Crossref]
34. Truscheit E, Frommer W, Junge B, Muller L, Schmidt DD, et al. (1981) Chemistry and biochemistry of microbial α-glucosidase inhibitors. Chem Int Ed Engl 20: 744-761.
35. Kamanna VS, Roh DD, Kirschenbaum MA (1998) Hyperlipidemia and kidney disease: concepts derived from histopathology and cell biology of the glomerulus. Histol Histopathol 13: 169-179. [Crossref]
36. Ahmed MFI, Kazim SM, Ghori SS, Mehmajeeb SS, Ahmed SR, et al. (2010) Antidiabetic Activity of Vinca rosea Extracts in Alloxan-Induced Diabetic Rats. Int J Endocrinol 2010: 841090. [Crossref]
Govindappa M (2015) *In vitro* and *in vivo* antidiabetic activity of lectin (N-acetyl-galactosamine, 64 kDa) isolated from endophytic fungi, *Alternaria* species from *Viscum album* on alloxan induced diabetic rats

55. Omara EA, Nada SA, Farrag AR, Sharaf WM, El-Toumy SA (2012) Therapeutic effect of *Acacia nilotica* pods extract on streptozotocin induced diabetic nephropathy in rat. *Phytomedicine* 19: 1059-1067. [Crossref]

56. Mansour HA, Newairy AS, Yousef MI, Sheweita SA (2002) Biochemical study on the effects of some Egyptian herbs in alloxan-induced diabetic rats. *Toxicology* 170: 221-228. [Crossref]

57. Kumar Rajagopal S, Manickam P, Periyasamy V, Namasiyavayam N (2003) Activity of *Cassia auriculata* leaf extract in rats with alcoholic liver injury. *J Nutr Biochem* 14: 452-458. [Crossref]

Copyright: ©2015 Govindappa M. This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.