



Optimization of cellulase and chitinase enzymes production by plant growth promoting rhizobacteria

Alaa Fathalla Mohammed

Department of Agriculture Botany, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt

*Corresponding author E-mail: alaa.fathalla@yahoo.com



Received: 4 February, 2020; Accepted: 16 February, 2020; Published online: 25 February, 2020

Abstract

The current study aimed to optimize the production of cellulase and chitinase enzymes by plant growth promoting rhizobacteria (PGPR). Bacteria were pre-isolated from soil and identified as; *Pseudomonas fluorescens* NBRC (KW1), *Serratia liquefaciens* ATCC 27592 (EW1), *Bacillus subtilis* SBMP4 (EF1) and *B. megaterium* NBRC 15308 (TF2). The effect of different growth parameters including; pH, temperature, carbon and nitrogen sources, and incubation periods were optimized for production of cellulase and chitinase enzymes by the selected bacterial strains. Three strains mainly, *B. subtilis* SBMP4, *S. liquefaciens* ATCC 27592 and *P. fluorescens* NBRC) recorded positive results for cellulase production. *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1) strains demonstrated significant ability to produce cellulase at 40°C, while *P. fluorescens* NBRC (KW1) strain showed the maximum enzyme production at 30°C. Carboxymethyl cellulose gave the highest cellulase production compared to the other carbon sources. Chitinase enzyme was optimally produced by *B. subtilis* SBMP4 and *S. liquefaciens* ATCC 27592 strains under primary screening. *B. subtilis* SBMP4 had the strongest ability to produce chitinase at 40°C, while *S. liquefaciens* ATCC 27592 at 30°C. The optimum pH observed was at pH 6.0 to get the maximum chitinase production by *S. liquefaciens* ATCC 27592. Potassium nitrate (KNO₃) as an inorganic nitrogen source presented the highest chitinase production by *B. subtilis* SBMP4, whereas yeast extract demonstrated significant chitinase production by *S. liquefaciens* ATCC 27592.

Keywords: *Pseudomonas* sp., *Serratia* sp., *Bacillus* sp., Chitinase, Cellulase

1. Introduction

Enzyme technology is an interdisciplinary field, and enzymes are routinely used in many environmental-friendly industrial sectors. Many microorganisms produce a wide variety of hydrolytic enzymes against different substrate, such as cellulose

and chitin. Cellulose makes up the cell walls of most plants and it is the most abundant biological polymer on the earth. [Zhang and Lynd, \(2004\)](#); [Bai et al., \(2012\)](#) reported that it is the primary product of terrestrial ecosystem photosynthesis. [Jonas and Farah,](#)

(1998) documented that cellulose is a strong fibrous crystalline polysaccharide that resists hydrolysis, and is water insoluble.

According to [Venkata et al., \(2013\)](#); [Vijayaraghavan et al., \(2016\)](#), cellulose consist of thousands of D-glucose units that are linked together with β -1, 4-glycosidic linkage. It is generally degraded by Cellulase, which can hydrolyze the β 1,4 glycosidic linkage to release glucose ([Perez et al., 2002](#); [Abou-Taleb et al., 2009](#)).

Previous studies of [Sang-Mok and Koo, \(2001\)](#); [Kirk et al., \(2002\)](#) pointed that cellulases are inducible enzymes produced by several microorganisms, mainly by bacteria and fungi. Moreover, [Immanuel et al., \(2006\)](#); [Kasana et al., \(2008\)](#) added that cellulases have various potential industrial and biotechnological applications, and hence are in high demand. Several studies over many years were interested in the isolation and characterization of cellulose degrading bacteria more than fungi, because bacteria have elevated growth rate and more resistance to an extreme environment, as compared with fungi ([Lynd et al., 2002](#); [Odeniyi et al., 2009](#); [Rasul et al., 2015](#)). Bacteria belonging to several genera including; *Cellulomonas*, *Cellulovibrio*, *Pseudomonas*, *Bacillus*, *Bacteroides*, *Acetovibrio*, *Streptomyces* and *Micrococcus*, produce different types of cellulase ([Immanuel et al., 2006](#); [Kurniawan et al., 2018](#)).

[Patil et al., \(2000\)](#) demonstrated that chitin is one of the most common biodegradable polymer after cellulose, which exists naturally in the biosphere as a structural polysaccharide of β -1,4-N-acetyl-D-glucosamin. [Zarei et al., \(2012\)](#) added that this component is present in the fungal cell walls and in the exoskeletons of arthropods. Previous study of [Chang et al., \(2007\)](#) reported that chitin and its derivatives have versatile biological activities and agrochemical applications, thus they have high economic values.

Chitinases are receiving an increased attention due to their broad range of applications. [Sahai and Monacha, \(1993\)](#) demonstrated that chitinases are

enzymes that play an important role in biological hydrolysis of chitin. [Hartl et al., \(2012\)](#); [Garcia-Longoria et al., \(2014\)](#); [Cheba et al., \(2016\)](#) reported that these enzymes are produced by several microorganisms including bacteria (i.e. *Bacillus*, *Pseudomonas*, *Aeromonas*, *Vibrio*, *Serratia*, *Enterobacter*), yeasts, actinomycetes, fungi, plants and animals. Many of these chitinase producing microorganisms are recently used as important biocontrol agents against fungal phytopathogens, by degrading the chitin component of the fungal cell wall ([Nguyen et al., 2015](#)), and also control insect pests ([Rathore and Gupta, 2015](#)). In addition, they act as plant growth-promoting, as they promote nutrients absorption and self-defense of the plants ([Sahai and Monacha, 1993](#)). Many chitinolytic bacteria including; *S. marcescens* and *Enterobacter agglomerans* have the potential for the biocontrol of many phytopathogenic fungi ([Downing and Thomson, 2000](#)). Moreover, [Shanmugaiah et al., \(2008\)](#) added that various species of *Bacillus* have the ability to produce chitinase such as; *B. licheniformis*, *B. circulans*, *B. laterosporus*, *B. amyloliquefaciens*, *B. pabuli*, *B. magaterium*, *B. stearothermophilus*, *B. subtilis* and *B. thuringiensis*.

The objective of the current study was to optimize the growth conditions of several bacterial strains (i.e. *P. fluorescens* NBRC, *S. liquefaciens* ATCC 27592 and *B. subtilis* SBMP4), for production of high levels of the cellulase and chitinase enzymes.

2. Material and methods

2.1. Bacterial strains

Four strains of plant growth promoting rhizobacteria (PGPR) were pre-isolated from soil and identified by [Ghanem, \(2017\)](#) as; *P. fluorescens* NBRC (KW1), *S. liquefaciens* ATCC 27592 (EW1), *B. subtilis* SBMP4 (EF1) and *B. megaterium* NBRC 15308 (TF2).

2.2. Screening for cellulase producing bacteria

Determining of the ability to produce cellulase enzymes were carried out by growing the 4 bacterial

strains individually on basal media with following composition: 0.01 % MgSO₄, 0.1 % yeast extract, 0.2 % KH₂PO₄, 0.7 % K₂HPO₄, 0.05 % Sodium citrate, supplemented with 1 % carboxymethyl cellulose (CMC) as carbon source, and then incubating the plates at 30°C for 48 h. After incubation, the plates were flooded by 1 % Congo red and then replaced with 1 mol/ l of NaCl. Positive results were detected by the formation of clear halo zones around the bacterial colonies, according to [Zhou and Li, \(2004\)](#).

2.3. Detection of cellulase activity

The strains that showed clear zones were cultured in basal broth medium supplemented with CMC, at 37 °C for 24 h. After incubation, the cultures were centrifuged for 15 min. at 8000 rpm, and then the supernatant was used as a source of the crude enzyme solution for measurement of the enzyme activity. Cellulase activity was measured through a spectrophotometer (SE6300 UV-VIS) at 540 nm, using the DNSA (3,5-dinitrosalicylic acid) method according to [Lynd *et al.*, \(2002\)](#). Cellulase activity was estimated through detection of the amount of free reducing sugars produced by hydrolysis of the CMC. One unit of enzyme activity was defined as the amount of enzyme that could hydrolyze CMC and release 1 µmol of glucose within 1 min. of the reaction ([Shanmugapriya *et al.*, 2012](#)).

2.4. Optimization of different culture parameters for cellulase production

The selected bacterial strains were grown in CMC broth at various culture conditions including; temperature, pH, substrate concentration, incubation time and carbon sources, to determine the effects of all these factors on cellulase production. The enzyme activity was measured at different pH levels ranging from 5-11, at various growth temperatures ranging from 20°C-45°C, and different incubation periods varying from 1-5 d at 30°C. The effect of different carbon sources on cellulase production was studied by replacing carboxymethyl cellulose in CMC broth

medium with several carbon sources individually such as; xylose, starch, lactose and cellobiose.

2.5. Chitinase production

For the primary screening of chitinase production, the bacterial strains were grown on Colloidal chitin agar prepared in reference to [Wiwat *et al.*, \(1999\)](#), and then plates were incubated at 30°C for 7 d. The formations of clear halo zones around growth of the strains indicate that they can hydrolyze chitin.

2.6. Measurement of chitinase enzyme activity

Strains which showed the ability to hydrolyze chitin were selected, and then chitinase activity was measured according to the method proposed by [Chakraborty *et al.*, \(2012\)](#). Through this method, the positive strains were inoculated and incubated for 5 d in colloidal chitin broth medium. After incubation, the cultures were centrifuged at 12,000 g for 20 min. to obtain culture supernatants. About 1 ml of each culture supernatants was added individually to 1 ml of 1 % (w/v) colloidal chitin prepared in a phosphate buffer pH 6, and then incubated at 50°C for 30 min. After incubation, the enzyme activity was terminated by placing the mixtures in boiling water bath for 3 min. The solutions were centrifuged at 2,600 g for 10 min., and then the amount of reducing sugars produced in the supernatant was determined by Dinitrosalicylic acid (DNSA) according to the method of [Tsujiibo *et al.*, \(1991\)](#); using N-acetyl glucosamine as a reference compound ([Miller, 1959](#)). Finally, the absorbance was measured at 585 nm using a spectrophotometer. One unit of enzyme was defined as the amount of enzyme that released 1 µmol of N-acetyl-D-glucosamine per minute.

2.7. Optimization of different culture parameters for chitinase production

The selected bacterial strains were grown in colloidal chitin broth at different culture conditions such as; temperature, pH, substrate concentration, incubation time and nitrogen sources, to determine the

optimum conditions for chitinase production. The enzyme activity was measured at different pH levels ranging from 5-11, and at various incubation temperatures ranging from 20°C- 45°C, and different incubation periods ranging from 1-7 d at 37°C. The effect of various nitrogen sources on chitinase production was studied by replacing the yeast extract in colloidal chitin broth medium with different nitrogen sources such as; ammonium, urea, KNO₃, NH₄Cl and peptone.

2.8. Statistical analysis

Collected data were statistically analyzed using the appropriate analysis of variance (ANOVA), according to [Steel and Torrie, \(1981\)](#). The experiments were carried out in completely randomized design, using three replicates. Computer program software CoStat version 6.311 was used to analyze the data of the experiments. Least significant difference (LSD) at 5 % level was used separately to evaluate the response of each character.

3. Results and Discussion

3.1. Screening of cellulase producing bacteria

Out of the four tested bacteria only 3 strains namely; *P. fluorescens* NBRC, *S. liquefaciens* ATCC 27592 and *B. subtilis* SBMP4, demonstrated positive results through producing clear halo zones on CMC agar plates after Congo-red staining.

3.2. Effect of different culture conditions on cellulase production

3.2.1. Effect of culture temperature

Evaluating the cellulase enzyme activity at different incubation temperatures revealed that *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1) had the strongest ability to produce cellulase at 40°C (Fig.1). On the other hand, *P. fluorescens* NBRC (KW1) strain expressed maximum enzyme production at 30°C. These results were similar to previous studies of [Jansová et al., \(1993\)](#); [Sethi et](#)

[al., \(2013\)](#) that showed maximum cellulase activity of *B. subtilis* at 40°C.

3.2.2. Effect of pH on cellulase production

The effect of different pH ranges (5.0-11.0) on the cellulase production was studied. Currently, the optimum pH was observed at neutral pH 7.0, giving the maximum cellulase production by the three tested strains; however, the ability of producing this enzyme was decreased significantly below and above pH 7 (Fig. 2), in agreement with the previous results of [Sethi et al., \(2013\)](#).

3.2.3. Effect of different carbon sources

Various carbon sources including; xylose, starch, lactose, and cellobiose were used instead of CMC in the CMC broth medium. Results showed that CMC was the optimum carbon source for highest cellulase production, followed by lactose and celliobiose (Fig. 3).

3.2.4. Effect of incubation periods

Cellulase production by all the three tested strains reached its maximum after incubation for 4 d, below and after this period its production gradually declined (Fig. 4).

3.3. Screening for chitinase producing bacteria

Out of the 4 bacterial strains, only two bacterial strains namely; *B. subtilis* SBMP4 and *S. liquefaciens* ATCC 27592 are selected as chitin degraders, recognized through the formation of clear halo zones around the bacterial colony on the colloidal chitin agar medium.

3.4. Effect of different culture conditions on chitinase production

3.4.1. Effect of incubation temperature on chitinase production

Results obtained presented that *B. subtilis* SBMP4 has the strongest ability to produce chitinase at 40°C

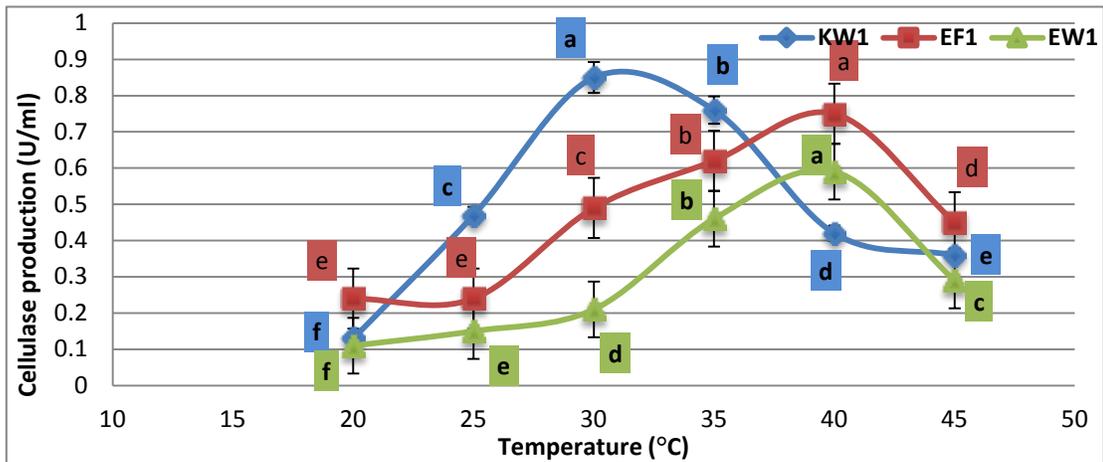


Fig. 1: Effect of different incubation temperatures on cellulase production by *P. fluorescens* NBRC (KW1), *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1). Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

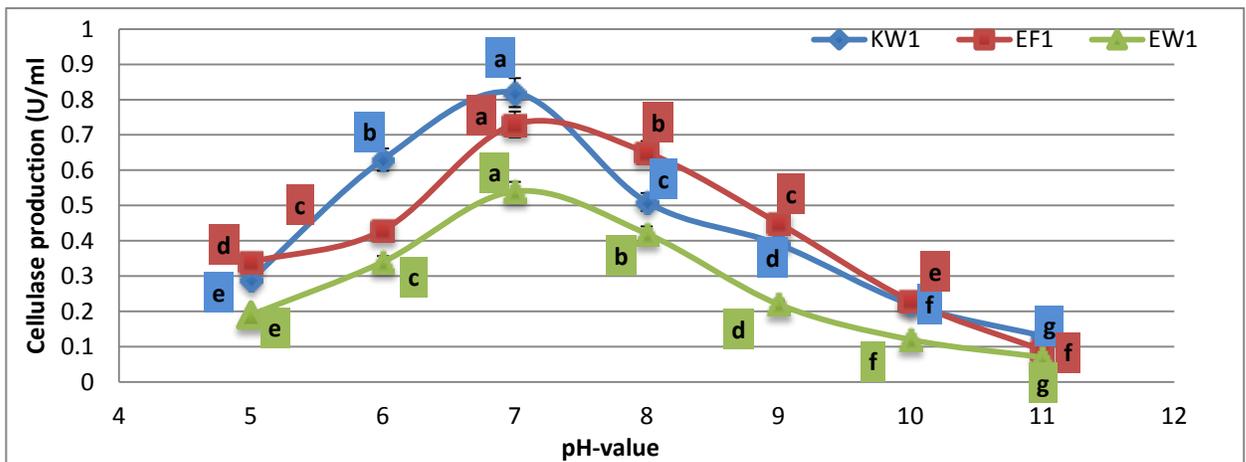


Fig. 2: Effect of the different pH-values on the cellulase production by *P. fluorescens* NBRC (KW1), *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1). Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

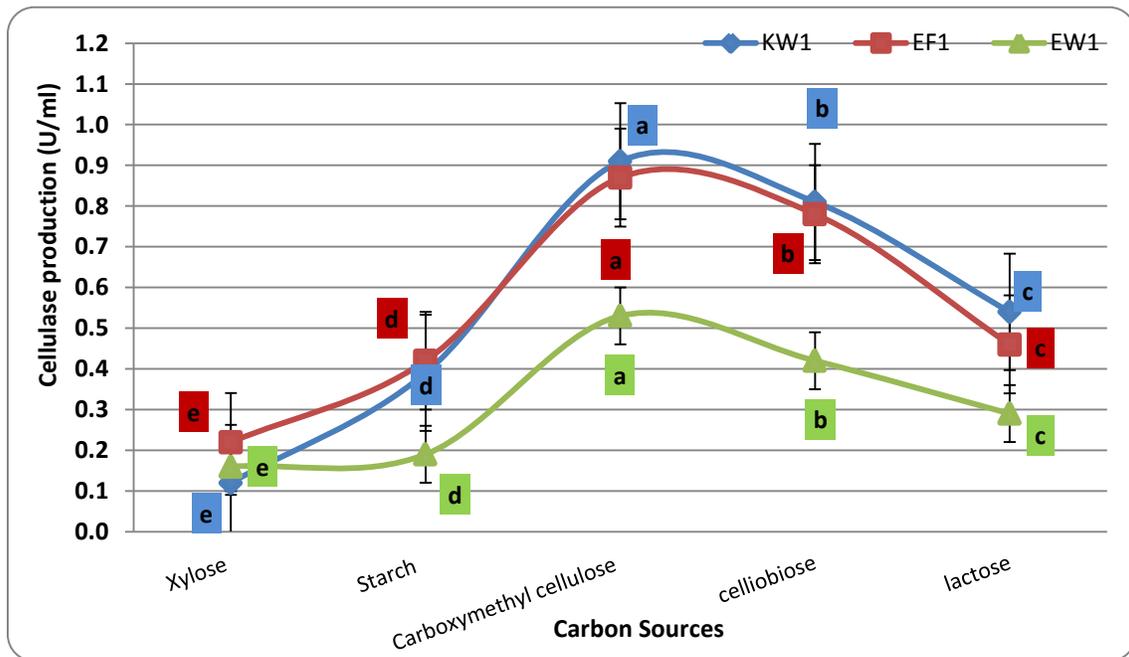


Fig. 3: Effect of different carbon sources on cellulase production by *P. fluorescens* NBRC (KW1), *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1). Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

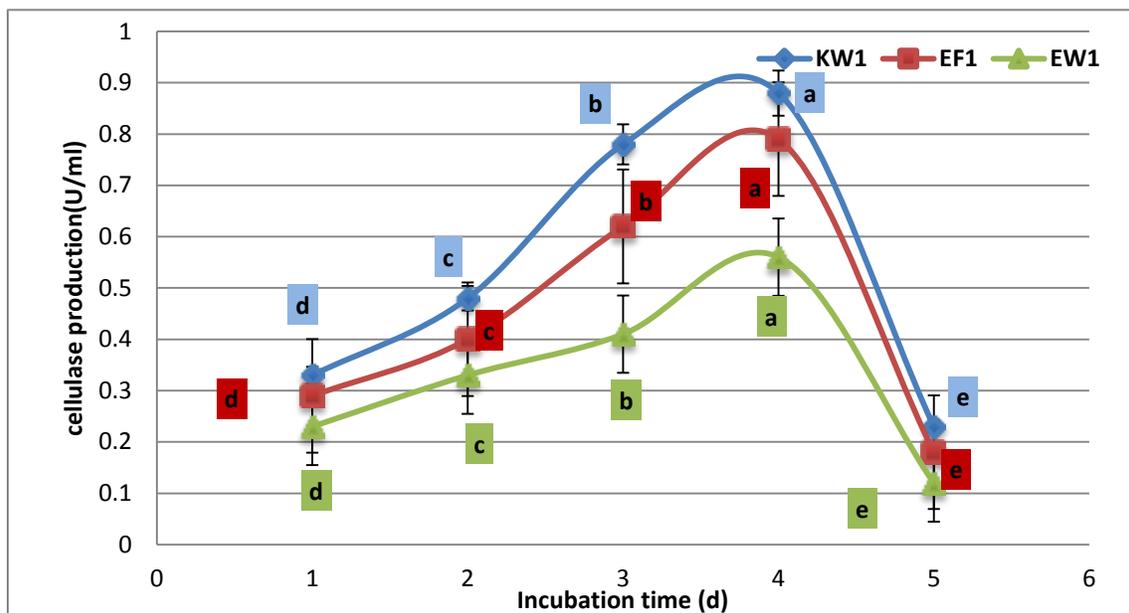


Fig. 4: Effect of the incubation periods on the cellulase production by *P. fluorescens* NBRC (KW1), *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1). Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

followed by 35°C, while *S. liquefaciens* ATCC 27592 optimum temperatures is at 30°C (Fig. 5). Similarly, previous study of [Bhushan and Hoondal, \(1998\)](#) recorded an optimum activity of chitinase enzyme by *Bacillus* sp. at 40-55°C. Current results are closed those of [Frändberg and Schnürer, \(1994\)](#) who reported that the optimum temperature for the activity of chitinase produced by *B. pabuli* was at 40°C. Furthermore, [Shanmugaiah et al., \(2008\)](#) recently demonstrated that the best temperature for chitinase production by *B. laterosporus* was at 35°C. On the other hand, [Lamine et al., \(2012\)](#) reported that the optimum temperature for chitinase production by *S. marcescens* was at 30°C.

3.4.2. Effect of different pH on chitinase production

The effect of different pH on the activities of chitinase was studied. The optimum pH observed is at 6.0 to get the maximum chitinase activity by *S. liquefaciens* ATCC 27592, while the ability of producing this enzyme decreased significantly below and above pH 6.0 (Fig. 6). In addition, the recorded results showed that the initial pH of 7.0 is optimum to get maximum chitinase production by *B. subtilis* SBMP4. However, previous study reported broad range of pH-values of 4.5- 7.5 for chitinase production by *B. cereus* ([Pleban et al., 1997](#)). In another study of [Frändberg and Schnürer, \(1994\)](#), pH of 8.0 was recorded as optimal for chitinase production by *B. pabuli*.

3.4.3. Effect of various nitrogen sources on chitinase production

Among the various nitrogen sources tested, results showed that KNO₃ gave the highest chitinase production by *B. subtilis* SBMP4, while yeast extract expressed significant chitinase production by *S. liquefaciens* ATCC 27592 (Fig. 7). Lowest chitinase production by *B. subtilis* SBMP4 is recorded in presence of NH₄Cl, and *S. liquefaciens* ATCC 27592 (Fig. 7).

3.4.4. Effect of different incubation periods on chitinase production

Chitinase production by *S. liquefaciens* ATCC 27592 reached its maximum level after the 4th day of incubation, after that its production decreased gradually upon incubation for longer periods. On the other hand, maximum level of enzyme production is recorded at the 5th day by *B. subtilis* SBMP4, and then decreased by further incubation (Fig. 8).

Conclusion

This study provides the optimum incubation temperatures for maximum cellulase production by *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1) at 40°C, while *P. fluorescens* NBRC (KW1) is at 30°C, in a basal media of pH 7 containing CMC recorded as the most suitable carbon source. On the other hand, the optimum temperature and pH value for maximum chitinase production by *S. liquefaciens* ATCC 27592 is at 30°C and pH 6, whereas the best nitrogen source recorded is yeast extract. For *B. subtilis* SBMP4, the optimum temperature and pH determined are at 40°C and pH 7, and the best recorded nitrogen source for producing the chitinase enzyme is KNO₃.

Acknowledgement

The author would like to acknowledge the Department of Agricultural Botany, Faculty of Agriculture, Suez Canal University, Ismailia, Egypt, for supporting out the current work.

Conflict of interest

The author declares no conflict of interests exists.

Funding source

This work did not receive any fund.

Ethical Approval

Non-applicable.

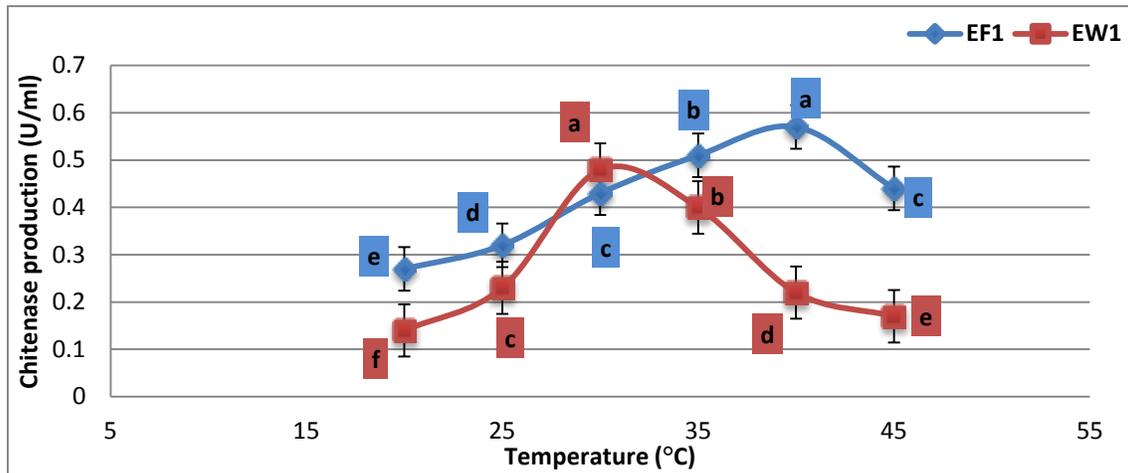


Fig. 5: Effect of different incubation temperatures on chitinase production by *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1), on the colloidal chitin medium. Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

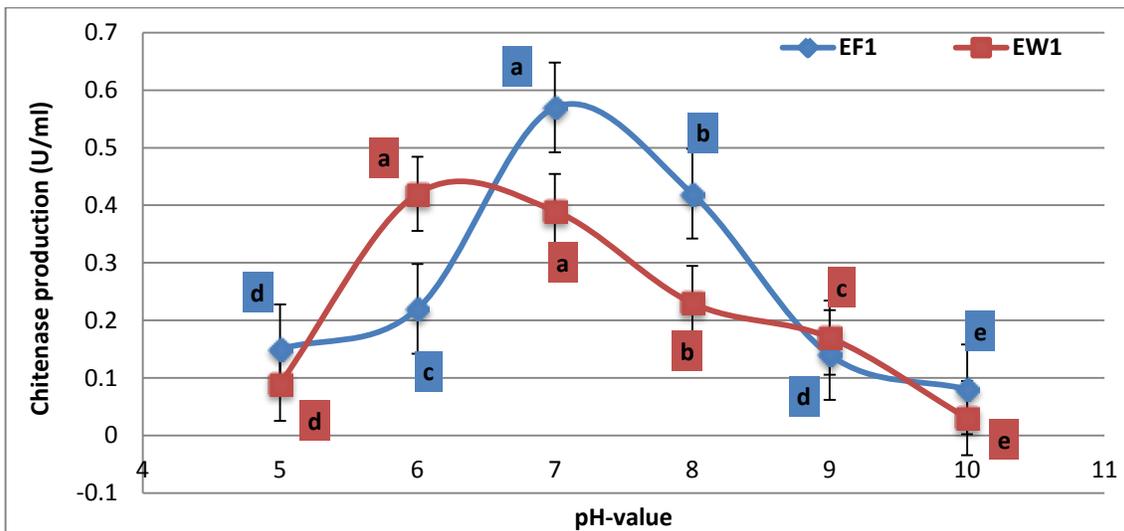


Fig. 6: Effect of different pH-values on chitinase production by *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1), on the colloidal chitin medium. Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

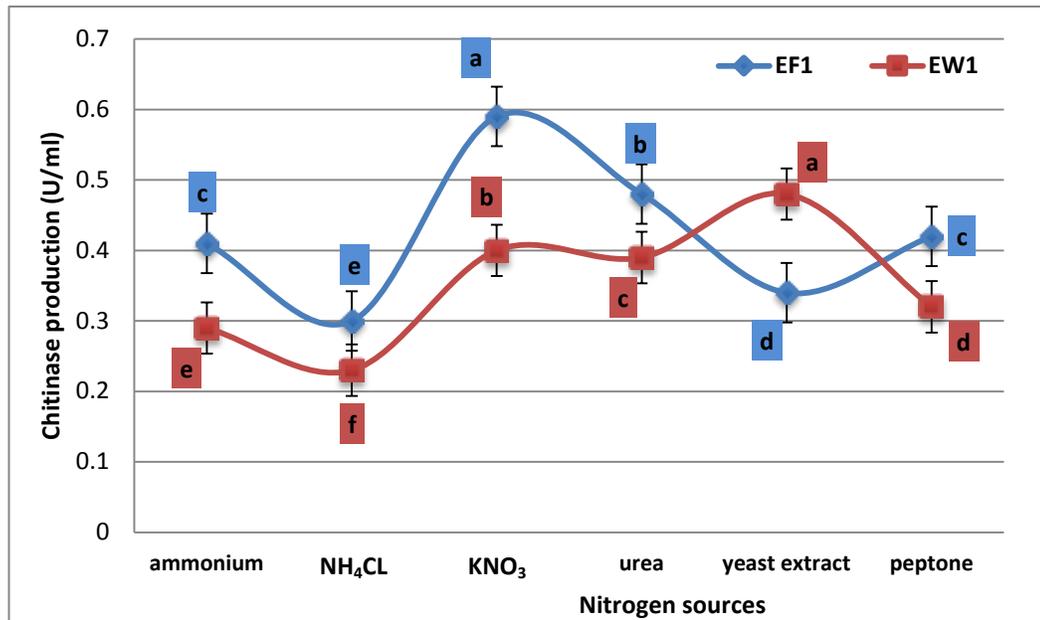


Fig. 7: Effect of several nitrogen sources on chitinase production by *B. subtilis* SBMP4 (EF1) and *S. liquefaciens* ATCC 27592 (EW1), on the colloidal chitin medium. Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

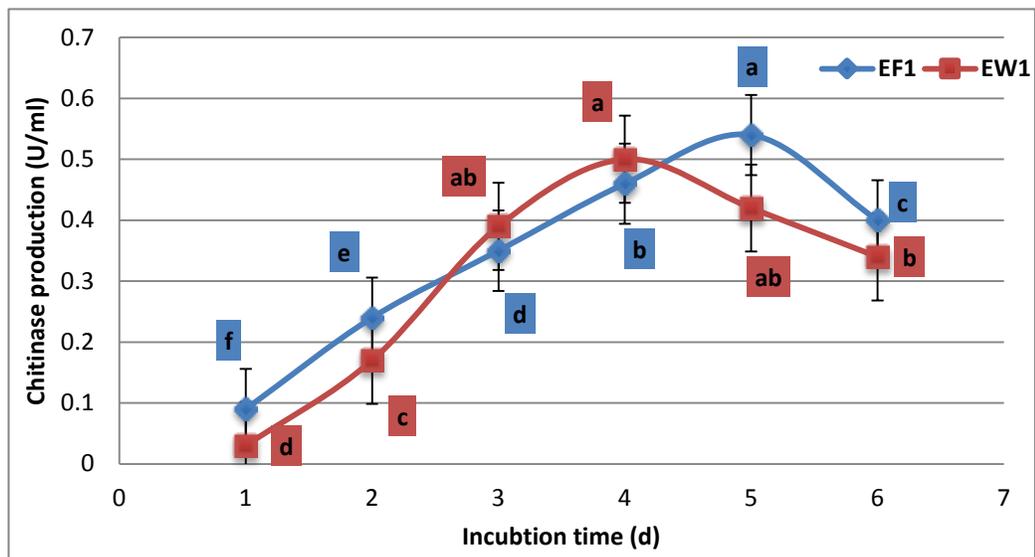


Fig. 8: Effect of different incubation periods on the chitinase production by *B. subtilis* SBMP4 (EF1), and *S. liquefaciens* ATCC 27592 (EW1), on the colloidal chitin medium. Error bars represent standard deviations. Values followed by the same letter do not represent significant difference

4. References

- Abou-Taleb, K.A.; Mashhoor, W.A.; Nasr, S.A.; Sharaf, M.S. and Abdel-Azeem, H.H. (2009).** Nutritional and environmental factors affecting cellulase production by two strains of cellulolytic *Bacilli*. Australian Journal of Basic and Applied Sciences. 3(3): 2429-2436.
- Bai, S.; Kumar, R.M.; Kumar, D.J.; Balashanmugam, P.; Kumaran, M.D. and Kalaiichelvan, P.T. (2012).** Cellulase Production by *Bacillus subtilis* isolated from Cow Dung, Archives of Applied Science Research. 4: 269-279.
- Bhushan, B. and Hoondal, G.S. (1998).** Isolation, purification and properties of a thermostable chitinase from an alkalophilic *Bacillus* sp. BG-11. Biotechnology Letters. 20(2): 157-159.
- Chakraborty, S.; Bhattacharya, S. and Das, A. (2012).** Optimization of process parameters for chitinase production by a marine isolate of *Serratia marcescens*. International Journal of Pharmacy and Biological Sciences. 2(2): 8-20.
- Chang, W.T.; Chen, Y.C. and Jao, C.L. (2007).** Antifungal activity and enhancement of plant growth by *Bacillus cereus* grown on shellfish chitin wastes. Bioresource Technology. 98(6): 1224-1230.
- Cheba, B.A.; Zaghoul, T.I.; EL-Mahdy, A.R. and EL-Massry, M.H. (2016).** Effect of pH and temperature on *Bacillus* sp. R2 chitinase activity and stability. Procedia Technology. 22: 471-477.
- Downing, K.J. and Thomson, J.A. (2000).** Introduction of the *Serratia marcescens* chiA gene into an endophytic *Pseudomonas fluorescens* for the biocontrol of phytopathogenic fungi. Canadian Journal of Microbiology. 46(4): 363-369.
- Frändberg, E. and Schnürer, J. (1994).** Chitinolytic properties of *Bacillus pabuli* K1. Journal of Applied Bacteriology. 76(4): 361-367.
- Garcia-Longoria, L.; Hellgren, O. and Bensch, S. (2014).** Molecular identification of the chitinase genes in *Plasmodium relictum*. Malaria Journal. 13(1): 239.
- Ghanem, O.M. (2017).** Role of arbuscular mycorrhizal fungi, plant growth promoting rhizobacteria and their interactions in improving plant nutrition and soil fertility. Ph.D. Thesis, Faculty of Agriculture, Suez Canal university, Egypt.
- Hartl, L.; Zach, S. and Seidl-Seiboth, V. (2012).** Fungal chitinases: diversity, mechanistic properties and biotechnological potential. Applied Microbiology and Biotechnology. 93(2): 533-543.
- Immanuel, G.; Dhanusha, R.; Prema, P. and Palavesam, A. (2006).** Effect of different growth parameters on endoglucanase enzyme activity by bacteria isolated from coir retting effluents of estuarine environment. International Journal of Environmental Science and Technology. 3(1): 25-34.
- Jansová, E.; Schwarzová, Z. and Chaloupka, J. (1993).** Sporulation and synthesis of extracellular proteinases in *Bacillus subtilis* are more temperature-sensitive than growth. Folia Microbiologica. 38(1): 22-24.
- Jonas, R. and Farah, L.F. (1998).** Production and application of microbial cellulose. Polymer Degradation and Stability. 59(1-3): 101-106.
- Kasana, R.C.; Salwan, R.; Dhar, H.; Dutt, S. and Gulati, A. (2008).** A rapid and easy method for the detection of microbial cellulases on agar plates using Gram's iodine. Current Microbiology. 57(5): 503-507.
- Kirk, O.; Borchert, T.V. and Fuglsang, C.C. (2002).** Industrial enzyme applications. Current Opinion in Biotechnology. 3: 345-351.
- Kurniawan, A.; Prihanto, A.A.; Sari, S.P.; Febriyanti, D.; Sambah, A.B. and Asriani, E. (2018).** Isolation and identification of cellulolytic bacteria from mangrove sediment in Bangka Island. In

IOP Conference Series: Earth and Environmental Science.137(1): 012070

Lamine, B.M.; Lamine, B.M. and Bouziane, A. (2012). Optimization of the chitinase production by *Serratia marcescens* DSM 30121T and biological control of locusts. Journal of Biotechnology and Biomaterials. 2: 133-137.

Lynd, L.R.; Weimer, P.J.; van Zyl, W.H. and Pretorius, I.S. (2002). Microbial Cellulose Utilization: Fundamentals and Biotechnology. Microbiology and Molecular Biology Reviews. 66(3): 506-577.

Miller, G.L. (1959). Use of Dinitrosalicylic acid reagent for determination of reducing sugar. Analytical Chemistry. 31(3): 426-428.

Nguyen, H.Q.; Quyen, D.T.; Nguyen, S.L.T. and Van Hanh, V.U. (2015). An extracellular antifungal chitinase from *Lecanicillium lecanii*: purification, properties, and application in biocontrol against plant pathogenic fungi. Turkish Journal of Biology. 39(1): 6-14.

Odeniyi, O.A.; Onilude, A.A. and Ayodele, M.A. (2009). Production Characteristics and Properties of Cellulase/ Polygalacturonase by a *Bacillus coagulans* Strain from a Fermenting Palm-Fruit Industrial Residue. African Journal of Microbiology Research. 3: 407-417.

Patil, R.S.; Ghormade, V. and Deshpande, M.V. (2000). Chitinolytic enzymes: an exploration. Enzyme and Microbial Technology. 26(7): 473-483.

Pérez, J.; Munoz-Dorado, J.; De la Rubia, T.D.L.R. and Martinez, J. (2002). Biodegradation and biological treatments of cellulose, hemicellulose and lignin: an overview. International Microbiology. 5(2): 53-63.

Pleban, S.; Chernin, L. and Chet, I. (1997). Chitinolytic activity of an endophytic strain of *Bacillus cereus*. Letters in Applied Microbiology. 25(4): 284-288.

Rasul, F.; Afroz, A.; Rashid, U.; Mehmood, S.; Sughra, K. and Zeeshan, N. (2015). Screening and characterization of cellulase producing bacteria from soil and waste (molasses) of sugar industry. International Journal of Biosciences. 6 (3): 230-6.

Rathore, A.S. and Gupta, R.D. (2015). Chitinases from bacteria to human: properties, applications, and future perspectives. Enzyme Research. 1-8.

Sahai, A.S. and Manocha, M.S. (1993). Chitinases of fungi and plants: their involvement in morphogenesis and host—parasite interaction. FEMS Microbiology Reviews. 11(4): 317-338.

Sang-Mok, L. and Koo, Y.M. (2001). Pilot-scale production of cellulase using *Trichoderma mareesei* RutC-30 in fed-batch mode. Journal of Microbiology and Biotechnology. 11(2): 229-233.

Sethi, S.; Datta, A.; Gupta, B.L. and Gupta, S. (2013). Optimization of cellulase production from bacteria isolated from soil. ISRN Biotechnology. 1-7.

Shanmugaiah, V.; Mathivanan, N.; Balasubramanian, N. and Manoharan, P.T. (2008). Optimization of cultural conditions for production of chitinase by *Bacillus laterosporous* MML2270 isolated from rice rhizosphere soil. African Journal of Biotechnology. 7(15): 2562-2568.

Shanmugapriya, K.; Saravana, P.S.; Krishnapriya, M.M.; Mythili, A. and Joseph, S. (2012). Isolation, screening and partial purification of cellulase from cellulase producing bacteria. International Journal of Advanced Biotechnology and Research. 3: 509-514.

Steel, G.D. and Torrie, J.H. (1981). Principles and procedures of statistics. McGraw-Hill. Principles and procedures of statistics, a biometrical approach (2nd Ed.). McGraw Hill International Book Company, USA.

Tsujibo, H.; Yoshida, Y.; Imada, C.; Okami, Y.; Miyamoto, K. and Inamori, Y. (1991). Isolation and characterization of a chitin degrading marine

bacterium belonging to the genus *Alteromonas*.
Nippon Suisan Gakkaishi. 57(11): 2127-2131.

Venkata, N.R.E.; Goli, D.; Rajesh, T. and Asra, P. (2013). Screening and isolation of cellulase producing bacteria from dump yards of vegetable wastes. World Journal of Pharmacy and Pharmaceutical Research. 3(1): 428-435.

Vijayaraghavan, P.; Vincent, S.P. and Dhillon, G.S. (2016). Solid-substrate bioprocessing of cow dung for the production of carboxymethyl cellulase by *Bacillus halodurans* IND18. Waste Management. 48: 513-520.

Wiwat, C.; Siwayaprahm, P. and Bhumiratana, A. (1999). Purification and characterization of chitinase from *Bacillus circulans* No. 4.1. Current Microbiology. 39(3): 134-140.

Zarei, M.; Aminzadeh, S.; Ghoroghi, A.; Motalebi, A.A.; Alikhajeh, J. and Daliri, M. (2012). Chitinase isolated from water and soil bacteria in shrimp farming ponds. Iranian Journal of Fisheries Sciences. 11(4): 911-925.

Zhang, Y.H.P. and Lynd, L.R. (2004). Toward an aggregated understanding of enzymatic hydrolysis of cellulose: non-complexed cellulase systems. Biotechnology and Bioengineering. 88(7): 797-824.

Zhou, X.H. and Li, Z., (2004). CMCase activity assay as a method for cellulose adsorption analysis. Enzyme and Microbial Technology. 35 (5): 455-459.