Molecular mechanisms adopted by abiotic stress tolerant *Pseudomonas fluorescens* (NBAII-PFDWD) in response to in vitro osmotic stress

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**ABSTRACT:** Water stress in one of the limiting factors which influences the plant growth. Microbes being as a partner are an integral part of the ecosystem which influences the plant growth under stress. In the present study, *Pseudomonas fluorescens* (NBAII- PFDWD) sub- jected to osmotic stress by altering osmotic potential (-10.28 MPa and -26.82 MPa) using Polyethylene Glycol (PEG) 6000 in its growth media revealed expression of proteins which modulates its cell processes. MALDI TOF studies of selected spots from 2D gel analysis of *P. fluorescens* (NBAII- PFDWD) grown under different osmotic stresses revealed that the stress kindled genes which were involved in production of osmoprotectants, genes encoding DNA damage repair and increased the translational accuracy. The studies also showed that *P. fluorescens* possesses unique mechanisms for survival under osmotic stress. The studies indicate the diverse expression of proteins in *P. fluorescens* (NBAII- PFDWD) under different osmotic potentials which helped them to mitigate impact of osmotic stress. The present method unravelled the mechanisms adopted by *P. fluorescens* (NBAII- PFDWD) to thrive under osmotic stress. The bacterium is potential stress tolerant isolate which can be exploited as a plant growth promoting rhizobacteria for agricultural crops grown in stressed soils.

**KEYWORDS:** MALDI- TOF, osmotic potential, osmotic stress, *Pseudomonas fluorescens*, PEG 6000

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**INTRODUCTION**

Bacteria surviving in soil are continuously exposed to number of stresses viz., flooding, high and low temperatures, drought and chemicals. The scientific studies to understand the mechanisms followed by bacteria are interesting and bring forward the survival strategy ratified by them. Bacteria alter their gene expression patterns producing proteins which help them to cope these stresses (Boor, 2006). Stress induced alteration in metabolic pathways including translation is one of the multitude ways to survive under stressful conditions. Protein synthesis is a vital part in cell function as it maintains the fidelity of genetic information (Karas, 2015).

The lipid membrane of Gram negative bacteria maintains stability by balancing its solute content and the osmotic pressure of environment. *Pseudomonas* spp. managed the variation in homeostasis by accumulating compatible solutes by *de novo* synthesis, trehalose, glutamate, manitol, glucosylglycerol, ectoine, and hydroxyectoine; other osmotolerance mechanisms include accumulation of K+ ions, proline, gamma aminobutyrate, -aminobutyrate, alanine, the quaternary amines glycinebetaine, fully N-methylated amino acid derivatives, sucrose, trehalose ( -D-glucopyrano-syl- -D-glucopyranoside) and glucosylglycerol (Kets *et al*., 1996; Freeman *et al*., 2010, 2013). Transcriptional regulation of certain genes like ProU, OmpF, OmpC also occur under osmotic changes (Csonka, 1989). Bacterial sigma factors support bacterial growth and regulate physiological development under stress (Boor, 2006). In addition, membrane transporter and porins facilitate translational stress response under osmotic stress (Wood, 2015). Osmotic potential is used to measure the osmotic property of the bacterial environment.

*Pseudomonas* spp. is ubiquitous and flourishes in diverse habitats. They produce wide variety of stress response system to adapt under environmental changes (Udaonda *et al*., 2012). *Pseudomonas* spp. confers drought resistance by
accumulation of exopolysaccharides and osmolytes which make it notable to use as efficient PGPR in soils (Sandhya et al., 2009).

_Pseudomonas fluorescens_ is widely used as a biological control agent but the mechanism it opts to survive under low moisture conditions is less understood. In the present investigation, our objective was to understand mechanisms executed by _Pseudomonas fluorescens_ (NBAII- PFDWD) to survive under osmotic imbalance. _Pseudomonas fluorescens_ (NBAII- PFDWD) isolated from rhizosphere soil is tolerant to high temperature, salinity, pH and osmotic stress (Ashwitha et al., 2013). In vitro studies were designed to grow the culture in PEG 6000 mediated osmotic stress in media. PEG, is a polymeric co solvent results in osmotic shifts which lead to change in membrane structure by regulating efflux or influx of solvents to maintain balance (Wood, 1999). _Pseudomonas fluorescens_ (NBAII-PFDWD, GenBank HM439956) was selected as an abiotic stress tolerant organism during screening of several isolates. It was found tolerant to 45°C, salinity (1.5M NaCl), pH 9.0 and also moisture stress. The protein profiling of the _P. fluorescens_ (NBAII- PFDWD) grown under stress condition was done using 2D gel electrophoresis and major spots corresponding to stress genes were identified using MALDI-TOF analysis.

**MATERIAL AND METHODS**

**Osmotic stress mediated growth of _Pseudomonas fluorescens_ (NBAII- PFDWD)**

_Pseudomonas fluorescens_ (NBAII- PFDWD GenBank HM439956) was used in the study for investigating the growth under osmotic stress. 50 µl of mid-log-phase culture (12 h) of _P. fluorescens_ (NBAII- PFDWD) was inoculated to 250 ml Erlenmeyer flask containing 100 ml of nutrient broth (g/L): Peptone, 5g; Beef extract, 3g; NaCl, 5g)

| Protein name (Swiss Prot Database) | Log Normalized Values |
|-----------------------------------|-----------------------|
| Spot no. | 0 MPa | -10.28 MPa | -26.82 MPa |

| Spot no. | 0 MPa | -10.28 MPa | -26.82 MPa |
|-----------------------------------|-----------------------|
| 241 | 2-isopropylmalate synthase OS | 5.34 | 5.11 | 4.82 |
| 240 | Probable dual-specificity RNA methyltransferase RlmN OS | 4.95 | 4.64 | 4.46 |
| 477 | 30s ribosomal protein S8 OS | 5.54 | 5.12 | 5.11 |
| 482 | Exodeoxyribonuclease 7 small subunit OS | 5.62 | 5.19 | 5.05 |
| 336 | Bifunctional pantoate ligase/ctydylate kinase OS | 4.18 | 3.94 | 3.78 |
| 391 | Cellular nucleic acid-binding protein homolog OS | 4.84 | 4.34 | 4.36 |
| 392 | Threonine-tRNA ligase OS | 4.72 | 4.48 | 4.40 |
| 496 | Dihydrorotate dehydrogenase (quinone) OS | 5.43 | 5.54 | 5.56 |
| 90 | Ribosome-recycling factor OS | 2.95 | 2.61 | 3.18 |
| 147 | L-ectoine synthase | 4.01 | 4.44 | 4.00 |
| 156 | Arginine deiminase OS | 5.49 | 5.50 | 5.48 |
| 222 | N-acetylmannosamine kinase OS | 4.88 | 4.91 | 4.96 |
| 347 | DNA replication and repair protein RecF OS | 4.56 | 4.53 | 4.46 |
| 354 | Phosphate acyltransferase OS | 5.08 | 4.99 | 4.98 |
| 367 | DNA repair protein RecO OS | 5.14 | 5.01 | 4.95 |
| 429 | Transcription elongation factor GreA OS | 4.36 | 4.72 | 5.01 |
| 426 | Elongation factor Ts OS | 5.16 | 5.17 | 5.23 |
| 486 | Crossover junction endodeoxyribonuclease RuvC OS | 4.87 | 4.92 | 4.93 |
| 184 | Pantothenate synthetase OS | 4.08 | 4.31 | 4.43 |
| 218 | 60 kDa chaperonin OS | 4.20 | 4.40 | 4.43 |
| 206 | DNA mismatch repair protein MutL OS | 4.97 | 4.73 | 4.98 |
| 248 | V-type proton ATPase subunit E OS | 4.50 | 4.13 | 4.32 |
| 263 | Gamma-glutamyl phosphate reductase OS | 4.77 | 4.81 | 4.89 |
| 439 | Ribonuclease HII OS | 4.87 | 4.85 | 4.83 |
| 326 | Transcriptional repressor NrdR OS | 4.75 | 4.84 | 4.94 |
| 355 | Leu operon leader peptide OS | 4.28 | 4.44 | 4.53 |
| 373 | Fructose-1,6-bisphosphatase class 2 OS | 3.96 | 4.23 | 4.37 |
| 396 | Putative ATP-dependent Clp protease proteolytic subunit-like OS | 4.60 | 4.47 | 4.56 |
| 390 | Bifunctional protein GlmU OS | 4.08 | 4.34 | 4.44 |
| 368 | NAD(P)H-quinone oxidoreductase subunit O OS | 4.51 | 4.67 | 4.68 |
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amended with PEG 6000 to attain different osmotic potentials (γ) of 0 MPa, -10.28 MPa and -26.82 MPa concentrations. The pH of the media was adjusted to 7.2 ± 2. The cultures were incubated at 28 ± 2 °C under constant shaking.

**Extraction of bacterial proteins**

The bacterial cells were collected by centrifugation (10,000 g for 10 min) and washed three times with isotonic solution. The proteins were precipitated according to method described by Paul et al. (2006). The protein extracts were frozen until further use.

**2D Gel analysis for stress-related proteins**

The first dimension was carried out at Genei TM Merck Biosciences, Bangalore, India as per standardized protocol. Gel mixture was prepared containing 10.8 M urea, 30% acrylamide, 20 µl of 100 % Triton-X, 130 µl ampholyte pH (3–10), 3 µl TEMED and APS (10%). The 1D was carried out in EttanIPGphor3 (GE Health care). The gel mixture was poured in tube by using (18-gauge needle) syringe up to 15 cm without any air bubble (remaining 1 cm for sample loading space). Once the gel was set the casted gel tube was fixed to the tank with rubber grommet very tightly (sample loading space of tube facing toward the top reservoir). The reservoir top was filled with 1X cathode buffer (400 mM NaOH) and bottom reservoir with 1X anode buffer (100 mM H₃PO₄). The gel was pre-focused by adding 1–3 µl of 2D SLB [9.8 M urea, 2% NP-40 (10% in distilled water), 2% carrier ampholytes 8/10, 25 mM DTT] into sample loading space and power cords were connected to the power supply. Electrophoretic conditions of the rod gels during the IEF (pre-run) were 200 V for 15 min, 300 V for 30 min, and 400 V for 1 h. After IEF (pre-run), 350 µg of sample was loaded and gel was run at 400 V for 16 h. After 16 h, the gels were transferred to a small tray containing 2D equilibration buffer [6 M urea, 75 mM Tris–HCl (pH 8.8), 29.3 % glycerol, 2% SDS, 0.002% bromophenol blue] and left for 30 min.

The second dimension was carried out on 12.5% SDS PAGE. The equilibrated gel was placed on 1% agarose added on the top of the polymerized SDS-gel. Electrophoresis was carried out at 150 V in Genei™ Vertical Maxi Gel system. Protein spots were visualized using Ezee blue gel stainer (Genei™) and the well-resolved spots were numbered. The Mr of individual protein spots was determined by comparison with molecular weight markers. Spot detection was carried out using the software, Progenesis (Nonlinear Dynamics available at www.nonlinear.com). The two-dimensional gels of *P. fluorescens* (NBAII- PFDWD) grown in all three osmotic conditions were compared using this software.

**Protein identification**

Selected proteins were subjected to in-gel proteolytic digestion by excising 1-mm-thick gel and washing for 30 min at room temperature under vigorous shaking with 400 µl of 10 mM ammonium bicarbonate solution containing 50% (v/v) acetonitrile. The gel pieces were dried for 15 min in a vacuum concentrator. The rehydrated gel pieces were incubated in 150 µl reduction solution (10 mM DTT, 100 mM ammonium bicarbonate) for 30 min at 56°C. The reduction solution was then discarded and 100 µl alkylation solution (50 mM iodoacetamide, 100 mM ammonium bicarbonate) was added for 30 min in dark at room temperature. The gel pieces were digested in 5 µl trypsin solution (sequencing grade modified trypsin, Promega, Madison and 10 ng/µl in 5 mM ammonium bicarbonate/5% acetonitrile). The samples were incubated for 5 h at 37°C. The reaction was stopped by adding 1 µl of 1 % trifluoroacetic acid. For better extraction of peptides, the samples were stored overnight at 5 °C.
MALDI-TOF MS Identification of Protein

The analysis was carried out in MALDI-TOF mass spectrometer (Bruker-Daltonics, Germany) at Merck Biosciences, Bangalore, India. The 1 µl of concentrated peptides from the supernatant was mixed with 2 µl of matrix solution [5 mg a-cyano-4-hydroxycinnamic acid in 40 % (v/v) acetone, 50 % (v/v) acetonitrile, 9.9 % (v/v) water, and 0.1 % (w/v) TFA in water]. From this mix, 1 µl was deposited onto the MALDI target. Tryptic peptides were analyzed in positive mode. Background ions from trypsin autolysis and contamination by keratins were removed from mass lists. The proteins were analysed using MASCOT search engine in latest version of the NCBInr database with following relevant search parameters viz., monoisotopic mass accuracy, peptide mass tolerance (0.1 Da), peptide charge state, allowed variable modifications, oxidation of methionine and fixed modification, carbamidomethylation of cysteine. Fragmentation of selected peptides was measured using the PSD mode. The percentage similarity of amino acids, Mr and pl were taken into consideration for identification of the proteins from bacteria of related species/genera.

RESULTS AND DISCUSSION

Capability of P. fluorescens (NBAII-PFDWD) to survive osmotic stress is well addressed in the protein profiling technique. The stress response of P. fluorescens (NBAII-PFDWD) subjected to osmotic stress at different osmotic potential using PEG 6000 revealed wide array of proteins produced by translational modification. Overall more than 300 proteins were expressed in all the three growth conditions. Thirty distinctive spots were selected based on Progenesis software from protein profile gels of all the three growth conditions subjected viz., 0 MPa, -10.28 MPa and -26.82 MPa (Fig. 1) and identified using MALDI-TOF MS. The proteins were abundant under osmotic stress conditions, -10.28 MPa and -26.82 MPa when compared to the normal conditions. Seven spots were detected from protein gel of 0 MPa which were down regulated under osmotic stress (Fig. 1). Eight proteins and 15 proteins which were up regulated under -10.28 MPa and -26.82 MPa were selected for identification respectively. The fold increase of all these proteins are tabulated (Table 1). Comparison of proteins revealed that the expression levels of bifunctional pantoate ligase/cytidylate kinase OS decreased under -10.28 MPa and -26.82 MPa induced osmotic stress. L-ectoine synthase expression was higher under -10.28 MPa induced osmotic stress, however, its expression was almost on par under normal conditions and -26.82 MPa induced stress.

The spot details obtained from Progenesis software clearly distinguishes spots corresponding to transcription elongation factor GreA OS and fructose-1,6-bisphosphatase class 2 OS were up regulated under both cases of osmotic stress. Their expression under normal condition was barely visible in gel. In both osmotic stress conditions, exodeoxyribonuclease 7 small subunit OS was down regulated. Comparison among all the three gels showed that, arginine deaminase OS, DNA replication and repair protein RecF OS, phosphatase acyltransferase OS and DNA repair protein RecO OS showed no significant difference in their expression under normal and osmotic stress conditions (Fig. 2, 3). It was noticed that the 11 proteins selected from both osmotic stress conditions were on par except four identified as transcription elongation factor GreA OS, 60 kDa chaperonin OS, DNA mismatch repair protein MutL OS and Gamma-glutamyl phosphate reductase OS which showed slight increase under -26.82 MPa induced osmotic stress.

In order to survive under moisture stress, Pseudomonas fluorescens (NBAII-PFDWD) produced an array of proteins which helped them mitigate the stress conditions. Most of the proteins shown to over express under moisture condition by P. fluorescens (NBAII-PFDWD) are not reported so far. The current study is novel and has provided an initial platform to explore microbial interaction under stressed ecosystem. Literature studies reveal that all these genes are expressed as stress response in different microorganisms. 2-isopropylmalate synthase was expressed in osmotic stress subjected in Campylobacter jejuni and it belongs to transferases involved in L-leucine and pyruvate metabolism (Cameron et al., 2012). RlmN is associated with catalysis of m2A synthesis with both rRNA nd tRNA. The translation accuracy decreased with inactivation of RlmN in E.coli (Benitez-Paz and Villarroya, 2012). This function reduces the chances of misreading of translational reading frame and further balance bacterial phenotype which could impair under stress conditions. Many genes are expressed for bacterial growth under a stable environment however, its expression varies when the bacteria challenges a distressed milieu. Ribosome profiling provides an insight to its role in expression of bacterial proteins under environmental fluctuations (Starosta et al., 2014). Expression of 30s ribosomal proteins were found to be down regulated in carnocyclin treated Listeria monocytogenes (Liu et al., 2014). DNA repair mechanisms play a pivotal role in altering stressed genes for a normal functioning of a cell. Exodeoxyribonuclease 7 small subunit plays important role in DNA repair by avoiding mutation occurring under environment instability (Lau et al., 2011; Lovett, 2011). DNA binding protein modulate biochemical functions, DNA binding and ferroxidase activity to protect cells from damage due to various stresses when in exponential growth and majorly when they enter stationary phase (Karas et al., 2015). No
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Functional activity was reported for bifunctional pantoate ligase/cytidylate kinase OS under stress conditions. Hence precise regulation of these proteins is important under adverse conditions.

![Fig. 2. A, Spots which are expressed under normal growth conditions (c1) analysed using Progenesis Linear Dynamics Software. Spots 241-392 are shown to be down regulated under conditions c2 (-10.28 MPa) and c3 (-26.82 MPa). B, differentially expressed genes under c2.](image)

Stress involved proteins expression levels switch either by down regulating or up regulating. Eight spots were selected from gel profile of -10.28 MPa induced osmotic stress and fifteen from -26.82 MPa induced osmotic stress, all of which were differentially regulated under stress (Fig. 2, 3). Dihydroorotate dehydrogenase (quinone) OS and arginine deiminase OS were expressed in higher folds under stress and dihydroorotate dehydrogenase (quinone) is involved in pyrimidine biosynthesis however, no function in stress response was observed (Jensen and Larsen, 2003; Kawasaki et al., 2009). Arginine deaminase stimulates the growth of *Pseudomonas* spp. and reverses the adverse effects in acidic environment by serving as energy source (Marquis et al., 1987). Ammonia derived from arginine deaminase breakdown reduced the effect of pH stress in *Staphylococcus epidermidis* (Lindgren et al., 2014). Ribosome-recycling factor OS, L-ectoine synthase, N-acetylmannosamine kinase OS and phosphate acyltransferase OS were over expressed under this stress. Ribosome recycling is closely associated with protein synthesis which is required for bacterial growth. In *E. coli* it was shown that this gene is involve in dissociation of ribosome from mRNA after translation and in turn facilitates next cycle of protein synthesis (Borovinskaya et al., 2007; Li et al., 2012). Increase or decrease in cytoplasmic solutes is primary response to osmotic swing on bacteria. Ectoines belong to an array of compatible solutes produced majorly by halophilic bacteria and are involved in protein stabilization to prevent cell damage under osmotic or temperature stresses (Louis and Galinski, 1997; Kuhlmann et al., 2011). In addition ectoines serve as carbon and nitrogen source or as intracellular reserves (Pastor et al., 2010). Enzymes catalyse metabolic reaction in cell biosynthesis, *N*-acyethylmannosamine kinases catalyse cell biosynthesis and cellular response to DNA damages stimulus. No reports are found with respect to expression of these stress proteins in *P. fluorescens* (NBAII-PFDWD). Acyltransferase utilizes fatty acid to form membrane phospholipids and further helps in membrane expansion. They regulate membrane biogenesis and cell growth. Notable function under stress is not known (Zhang and Rock, 2008). DNA replication is realm of bacterial survival. Osmotic stress induces perturbations in replication cycle. RecF influence the repair mechanism in responsible damage and replication fork stress in *E. coli* and *B. subtilis* (Lenhart et al., 2014; Villarrayo et al., 1998). Bacteria regulate membrane biogenesis of coordinate cell growth by synthesis of fatty acid. RecO are recombinant mediator protein involved in restarting of stalled replication in ssDNA gaps repair and in repairing dsDNA breaks. It is assisted in rapid repair of chromosome breaks in *Deinococcus radiodurans* under radiation and desiccation stress (Lusetti and Cox, 2002; Ryzhikov et al., 2011). Surprisingly, in the present study DNA replication and repair protein RecF OS and DNA repair protein RecO OS were found to be repressed under osmotic stress.

![Fig. 3. Differentially expressed genes as analysed using Progenesis Linear software under c3 (-26.82 MPa).](image)

A slight variation in osmotic potential of media prompted expression of proteins to express at higher folds. Nine proteins were up regulated when only 50% water availability was provided in media. GreA cleaves complexes formed at site of transcriptional arrest and resumes the transcriptional process additionally and they are up regulated in environmen-
The genes which were up regulated were transcription elongation factor GreA OS, elongation factor Ts OS, crossove}

junction endodeoxyribonuclease RuvC OS, crossove}

junction endodeoxyribonuclease RuvC OS, pantetheine synthetase OS, 60 kDa chaperonin OS, Gamma-glutamyl phosphate reductase OS, transcriptional repressor NrdR OS, Leu operon leader peptide OS, fructose-1,6-bisphosphatase class 2 OS, bifunctional protein GlmU OS and NAD(P)H-quinone oxidoreductase subunit O OS. RuV is involved in repair of DNA facing damage due to mutations. They encode endonucleases activities which resolve Holliday structure during recombination (Takahagi et al., 1991). No significant function was reported in stress mechanism however its major function lies in protein biosynthesis. 60 KDa chaperonin or commonly referred E. coli GroEL is generally exhibited under temperature stress and is involved in unfolding the misfolded protein to its natural state (Maguire et al., 2002; Mande and Kumar, 2013). Gamma glutamyl phosphate reductase catalyses metabolic reaction of a major osmoprotectant proline encoded by ProA. Artificial bifunctional enzyme gamma-GK/gamma GPR expression in E.coli increased production of proline and osmotolerance of host (Chen et al., 2006; Liang et al., 2013). It is also associated with production of small amount of glutathione which is linked to proline biosynthesis under oxidative stress (Perez-Arellano et al., 2010). NrdR controls the transcription of genes by binding to promoter region. This regulatory protein controls expression of ribonucleoside reductases which are precursors of DNA synthesis and repair during vegetative growth. These are important for aerobic growth of E. coli (Torrents et al., 2007). Fructose 1, 6-bisphosphatase class 2 OS play central function in glycolysis. Macomber et al. (2011) reported that the cellular over expression of fructose 1,6-bisphosphatase in E. coli reduced inhibitory effects of nickel. GlmU is a precursor for bacterial cell wall synthesis components like lipopolysaccharides and peptidoglycan. Inhibition of GlmU adversely affects cell viability (Larsen et al., 2012). Hence, this has been utilized as target for antibiotic drug discovery (Mochalkin et al., 2007). EF-Ts serves as the guanine nucleotide exchange factor for EF-Tu which is associated in response to nutrient deprivation and protect from stress (Caldas et al., 1998). NADPH-quinone oxidoreductase subunit is induced to protect cell from oxidative stress along with many other detoxifying enzymes (Atia et al., 2014). In E. coli they adapt and overcome a strong imbalance in NADPH redox state (Auriol et al., 2011). Down regulation of three proteins (V-type proton ATPase, Ribosome nuclease II, and Putative ATP-dependent Clp protease proteolytic subunit-like OS) at -26.82 MPa osmotic potential was observed in our study. V-type proton ATPase subunit is a membrane subunit whose major role is not much elucidated. Their function ranges from protein sorting to membrane trafficking. They drive the active transport systems in membrane. These V-type ATPases restrict the influx of external solutes so as to reduce risk of membrane integrity loss (Beyenback and Wiezerek, 2006; Cohen, 2014). Ribosome nuclease II functions as exoribonucleolytic which is important for cell response to stress conditions. In E. coli activity of ribonuclease II was reduced under conditions of slow growth (Song et al., 2016). Similar case was observed in P. fluorescens (NAII-PFWD). RNA polymerases transcribe few genes to up regulate when bacteria reach its stationary phase and when its regular process shut downs (Lau et al., 2011). Clp mediates proteolysis of misfolded proteins subsequent to translation (Schelin et al., 2002). They exhibit adaptive response in B. subtilis against stationary phase phenomena like sporulation (Msadek et al., 1998). DNA repair was active through other set of genes like MutL. MutL belonging to mismatch repair system suppress chromosomal aberration by correcting mismatch bases during replication error occurring under various stress conditions (Harris et al., 1997) and helps in maintaining genetic stability (Oliver et al., 2002). Unlike other methyl directed mismatch proteins, MutL was functional even in stationary phase of E. Coli (Feng et al., 1996). In our studies using P. syringae it was shown that osmotolerance was influenced by synthesis of N-acetylglutamylglutamine amide (NAGGN) that causes reduction of cellular glutamine indicating lower glutamine synthetase activity thereby causing glutamate accumulation (Freeman et al., 2013). In our studies up regulation of Gamma-glutamyl phosphate reductase OS was seen and this protein is involved in synthetises of L-glutamate 5-semialdehyde from L-glutamate. Literature on stress response proteins expressed by a PGPR like P. fluorescens (NAII-PFWD) is very limited. The study has shown that P. fluorescens expressed a wide array of stress response genes which ameliorate its survival in environmental perturbations. The stress response genes identified are complex and P. fluorescens does possess unique pathways to survive under osmotic stress. The culture is being promoted as a useful biological control agent in stressed soils. Application of stress tolerant strains of microorganisms could be considered as a feasible choice in stress prone areas (Meena et al., 2017).

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