

## Full Length Research Paper

# Glycosidases Activities and Protein Content Variations during Fruit Development and Ripening in three Texture Contrasted Tomato Cultivars

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Excessive softening is the main factor limiting fruit shelf life and storage. It is generally acceptable now that softening of fruit which occurs during the ripening is due to synergistic actions of several enzymes on cell wall polysaccharides. As a subject for this study, we have assayed some glycosidase activities using 3 tomato cultivars (*Lycopersicon esculentum*) contrasted for their texture phenotypes; the cherry tomato line Cervil (*Solanum lycopersicum* var. *cerasiforme*), a common taste tomato line Levovil (*S. lycopersicum* Mill) and ViIB a modern line, large, firmer and with good storage capability. Four glycosidase activities namely  $\alpha$ -galactosidase,  $\beta$ -galactosidase,  $\beta$ -mannosidase and  $\beta$ -glucosidase were extracted from tomatoes cell wall of the three species. Cell wall protein from fruits was extracted and compared among the three cultivars at the following stages; 14 days after anthesis (14DPA) fruit; 21 days after anthesis (21DPA), turning (breaker), red and over ripe. Glycolytic activities were compared among these cultivars at the precited developmental stages, where gross variations were noticed from stage to stage and also from species to species in accordance with the fruit firmness status. Interestingly, ViIB cultivar, the firmer among the other two, though possessed the highest total protein content, exhibited the lowest enzymatic activities. Taken together, these results may therefore allow us to conclude that studies of glycolytic activities in a single tomato cultivar cannot be generalized to all species. Thus, the correlation between tomato softness and the glycosidase activities may affirm direct involvement of these enzymes on fruit development and softening)

**Keywords:** Tomato cultivars; texture; glycosidases; cell wall protein; development stage.

## INTRODUCTION

Fruit ripening is genetically programmed and involves physiological, biochemical, and structural changes, such as cell wall hydrolysis, pigment degradation and synthesis, carbohydrate metabolism, and generation of secondary metabolism compounds which influence fruit appearance, texture, flavour, and aroma (Mworira et al. 2011) and (Prasanna et al. 2007). The softening of fruits that occurs after harvest is a major factor that contributes to the losses of good percentage of all fresh produce grown world-wide. Many efforts to suppress expression of cell wall-degrading enzymes have not provided the

insight needed to genetically engineer fruits whose softening can be adequately controlled (Meli et al. 2010) and (Giovannoni et al. 1989). Studying the biochemical mechanisms involved in this loss is a global effort to modify plants genetically so that they produce fruit that resist the softening process. It was believed that polygalacturonase (PG) and pectin methylestrase (PME) are principally responsible for fruit ripening (Giovannoni et al. 1989) and (Brummell and Harpster 2001). However, several subsequent studies demonstrated that inhibition of neither PG nor PME could interfere with fruit ripening (Tieman and Handa 1994; Tieman et al. 1992). Since wall rigidity and intercellular cohesion in fruit tissue have also been partially attributed to cross-linkages that contain arabinose and galactose (Wong 2008). The

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modification of cross-linking polymers could contribute to the loss of wall structure and fruit firmness that occurs during ripening. If this were so, softening could be at least partly attributable to the action of enzymes that cleave bonds between sugars other than galacturonic acid (Giovannoni et al. 1989; Ahmed and Labavitch 1980). Now, it is well acknowledged that glycosidases play fundamental role in loosening cell wall structure in fruit development and ripening in tomato (Wallner and Walker 1975; Brummell and Harpster 2001), berries (Hilz et al. 2006), coffee beans (Marraccini et al. 2005), mango (Ali et al. 1995), pappaya (Manenoi and Paul 2007) and several other fruits (Prasanna et al. 2007).

The tomato (*Solanum lycopersicum*) is a major vegetable crop that has achieved tremendous popularity over the last century, with thousands of cultivars having been selected with varying fruit types, and for optimum growth in differing growing conditions. The domestication of the tomato *Solanum lycopersicum* and associated selective pressures eventually led to the large-fruited varieties cultivated today. Cultivated tomatoes vary in colour intensity, shape, quality and size from toberberries, about 5 mm in diameter, through cherry tomatoes, about the same 1–2 centimeters (0.4–0.8 in) size as the wild tomato to up to beefsteak tomatoes 10 centimeters (4 in) or more in diameter (Bai and Lindhout 2007; Barrett et al. 1998).

Glycosidases have been related to tomato development and ripening in several reports. Studies on glycosidases at varying ripening stages have also been done (Gross and Wallner 1979; Smith and Gross 2000; Wallner and Walker 1975). Currently commercialized tomato cultivars are of vast texture variations, however, no information is yet available on relating the texture of these cultivars with endogenous glycolytic hydrolases at different stages of development and ripening. In this investigation we have used three texture contrasted tomato cultivars; the cherry tomato line Cervil (*Solanum lycopersicum* var. *cerasiforme*), a common taste tomato line Levovil (*S. lycopersicum* Mill) and ViIB a modern line, large, firmer and with good storage capacity, with the objective to determine any possible correlation between fruit texture and glycosidase activities in order to pave way for further understanding the mechanism underlying the softening process which restrict the longer shelf life of fresh fruits.

## MATERIALS AND METHODS

### Tomato Growth Conditions

Six plants per cultivar of Cervil, Levovil and ViIB were grown in pots in a greenhouse under standard conditions. Tomatoes were collected at varying 6 stages of development and ripening; 14 days post-anthesis (14DPA), 21 days post-anthesis (21 DPA), turning (breaker), red and over ripe. To harvest the first two stages, flowers were tagged at anthesis. For the latter three stages, fruits were

harvested based on fruit color.

## Protein extraction methods

### Total protein extraction

Five hundred mg of pericarp powder material was directly extracted in 1.2 ml of Laemmli sample buffer (Laemmli 1970) during 15 min at room temperature. After 15 min centrifugation at 5500g the protein content of the supernatant was assayed using the Biorad protein assay kit with bovine serum albumin (BSA) as a standard according to the manufacturer prescriptions.

### Soluble cell wall proteins extraction

The method was adapted from (Chivasa et al. 2002). Unless otherwise stated all steps were carried out at 4°C. Red ripe tomato pericarps were cut with a cleaned razor into small pieces and immediately immersed in ice-cold 20mM K<sub>2</sub>HPO<sub>4</sub> pH 6.0 buffer, dried on filter paper before weighing. They were then rinsed twice with degassed ice-cold 3mL/g 10 mM MES buffer, pH 5.5 and immersed in flasks containing the same solution. Rinsing buffer was discarded and tissue pieces were vacuum infiltrated at 60kPa for 30 seconds for removal of gas trapped in veins. Ice-cold degassed 100mM KCl, 10 mM MES, pH 5.5 buffer plus 5µL of protease inhibitor cocktail (Sigma) was added on the basis of 5 mL per gram of plant material then soaked pericarp segments were subjected to 60kPa vacuum for 3 minutes with gentle intermittent shaking. Vacuum was released; pericarp pieces were allowed to stand in the infiltration buffer for 3 minutes. Infiltration buffer was then removed and excess buffer was blotted away from tomato segments. Pericarp pieces were then transferred into 15mL Falcon tube internally lined with mesh into a U-shape and previously holed at their bottom part. The whole unit was inserted into a 50 mL clean Falcon tube and centrifuged for 10 min at 1000 rpm. Infiltration juice collected at the bottom of the 50 mL Falcon tube from various vacuum infiltration experiments was collected, concentrated with Marosep centrifugal device (15 mL capacity/10kDa membrane cutoff) followed by desalting by washing using three volume of 50 mM Na-Acetate buffer, pH 6 with 1µL/mL protease inhibitor cocktail. Protein was quantified using Bio-Rad protein estimation kit and preserved at -80°C till further use.

### Calculation of fruit water Content

Equal amount of fresh pericarp of Cervil, Levovil and ViIB was washed with distilled water and placed in open previously weighed container, the container was then placed in an oven at 70° C and the pericarp was dried to a constant weight. The container, plus dry tissue, was weighed and recorded. The pericarp dry weight was determined by subtraction of the empty container from container with the dried tissues.

### Protein Estimation

Protein content was quantified with Bio-Rad Bradford assay protein using BSA as a standard.

### Wall protein Purity assessment

This was carried out by following the intracellular marker glucose-6 phosphate as reported (Li et al. 1989) Briefly, the reduction of NADP<sup>+</sup> by Glucose-6 phosphate dehydrogenase (G6P-D, EC 1.1.1.49) was monitored spectrophotometrically at 340 nm in a 1 ml reaction mixture containing 25 µM Tricine, pH 8, 25 µM glucose-6-phosphate, 0.1M MgCl<sub>2</sub>, 25 µM NADP, and the enzyme.

**Table 1:** Wall protein purity confirmation with detection of intracellular glucose-6 phosphate Dehydrogenase

Extract	Activity (nM/min/g)	% activity
Whole Cell	770	100
Vacuum infiltrate (soluble wall protein)	0.76	0.1%

**Table 2:** Summary for wall protein from the three tomato cultivars Cervil, Levovil and ViIB

Gentype	FM* g	Juice (mL)	Protein µg/mL	Total protein mg	Protein µg/g FM
Cervil	360	16	84	1350	4
Levovil	360	26	23	612	2
ViIB	360	20	52	1040	3

\* FM: Fresh Material

### Protein electrophoresis

Cell wall proteins were separated by SDS-Page according to Laemmli (Laemmli 1970). 40 µg protein samples were loaded on 13% acrylamide SDS-PAGE gels. Gels were stained with coomassie colloidal as per Scheler et al's procedures (Christian Scheler 1998). Briefly, proteins were first fixed for 1 h in 50% ethanol, 2% phosphoric acid. Gels were then washed 1 h in 2% phosphoric acid. Gels were submitted to a sensitization step for 20 min in 17% ethanol, 15% ammonium sulfate, and 2% phosphoric acid, and 0.1% Coomassie colloidal was then added to this buffer. After 3 days of staining, gels were washed for 10 min in deionized water, 10 min in 20% ethanol, and finally, 10 min in deionized water.

### Estimation of glycosidase activities

β-mannosidase, β- and α-galactosidase and β-glucosidase were determined according to Li method (Li and Li 1970). One unit of enzyme was expressed as µmole of p-nitrophenol liberated per ml per min under the assay conditions using a molar extinction coefficient of  $1.77 \times 10^4$  for p-nitrophenol (Li 1967).

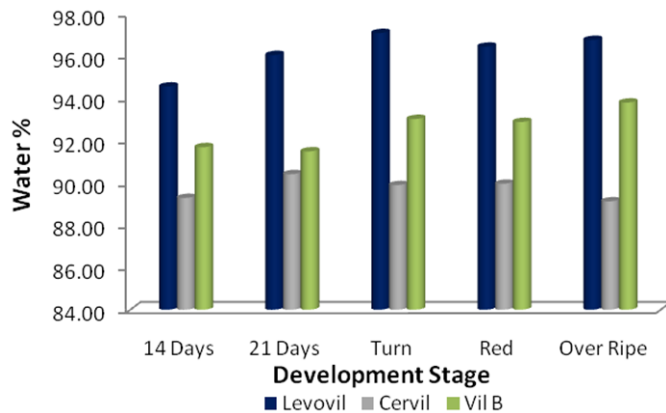
## RESULTS AND DISCUSSION

Plant cell wall has been long known to be a common residence for many glycosidases and acid hydrolases (Pierrot and Wielink 1977; Asamizu et al. 1981; Murray and Bandurski 1975). However, since glycosidases are also documented to be localized in other cellular compartments like mitochondria, protein bodies, plastid etc (Thornton 2005; Sekhar and DeMason 1990; Nikus et al. 2001), it was urging to start our work with isolation of glycosidases from cell wall. A mild isolation strategy that meant for purifying soluble wall proteins (henceforth denoted S-CWP) with maintaining cytoplasmic

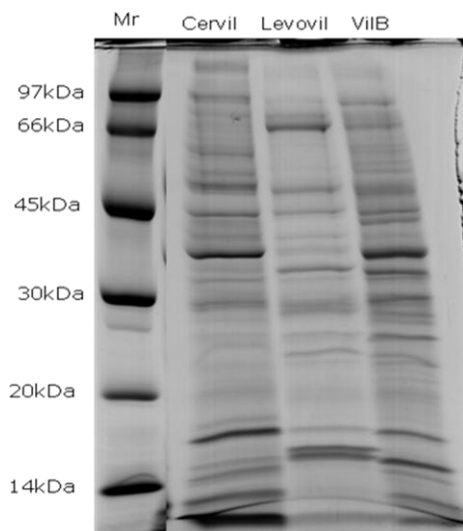
compartment intact was employed. To validate cell wall protein purity, we assayed extract for any possible activity for the intracellular marker Glucose-6 phosphate dehydrogenase (G6P-D). The obtained result for purity confirmation is shown in Table 1, as it clear from these results, the obtained wall protein purity was of acceptable limit as only 0.1% of total cellular G6P-D activity was detected in the extract. Almost the same intracellular contamination limit was obtained in the wall protein extracted for other cultivars. The wall protein extract obtained from Cervil, Levovil and ViIB varied in volume and protein quantity in which Cervil was the richest in protein content followed by ViIB and finally Levovil. The highest juice volume was obtained for Levovil which is justifiable on the high softness characterizes this cultivar as compare to Cervil and ViIB (Table 2). To gain an idea about total water content in the three varieties, we calculated the water accumulation percentage at the varying development stages (Figure 1); maximum water accumulation was detected in breaker stage for both Levovil and ViIB. Cervil had least water accumulation as compared to the formers.

Electrophoretic patterns analysis for the three cultivar's wall protein extract exhibited, unexpectedly, bands variation patterns. Cervil and ViIB electrophoretic pattern shared some degree of resemblances. However, Levovil pattern was very different as compared to Cervil and ViIB pattern. Since Cervil and Levovil are relatively soft as compared to ViIB, which is very firm with higher storage capacity, we expected ViIB to exhibit a different electrophoretic protein profile as compared to Cervil and Levovil, but that was not the case as shown in Figure 2.

To corelate between texture and glycosidase activities we intensionally chosen to study activities of α-

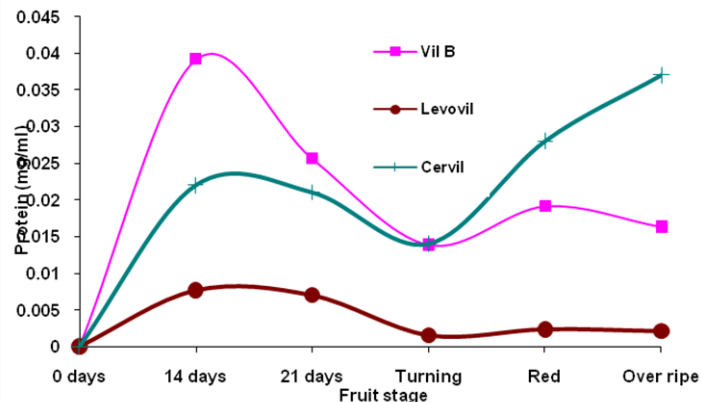


**Figure 1:** Percentgae of total cellular water content in the three cultivars. Calculation for each genotype was done in three independent experiments. Details on experimnetal conditions are given in materials and methods section.



**Figure 2:** Polyacrylamide gel electrophoresis of cell wall protein from Cervil, Levovil and VilB tomato cultivars: 40  $\mu$ g protein samples were loaded on 13% acrylamide SDS-PAGE gels. Gels were stained with coomassie colloidal (see experimental body). Protein markers used were: Phosphorilase (97 kDa), BSA (66 kDa), Egg albumin (45 kDa), Carbonic anhydrase (30 kDa), trypsin inhibitor (20kDa) and  $\alpha$ -lactalbumin (14 kDa).

galactosidase,  $\beta$ -galactosidase,  $\beta$ -mannosidase and  $\beta$ -glucosidase, for the following reasons; their known localization in cell wall, direct involvement in ripening mechanism and easy detection. Plants were grown and fruits were collected at 5 varying stages of development; 14days post-anthesis (14DPA), 21 days post-anthesis



**Figure 3:** Protein Concentration (dry matter) at varying development stages. Each point represent a mean of three independent experimnets.

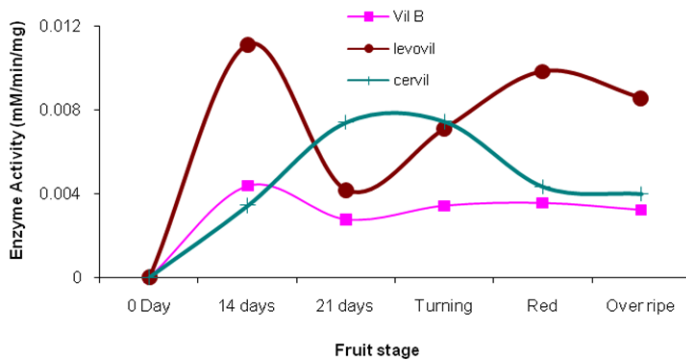
(21 DPA), at turning (when fruit just starts getting red), red (fully red fruit) and over ripe (when fruit becomes very soft). All of these enzymes were detected in both total fruit protein and cell extract, however with some variations. Strong activities were exhibited by  $\beta$ - and  $\alpha$ -galactosidase whereas  $\beta$ -mannosidase and  $\beta$ -glucosidase were, comparatively, of weak activities.

### Total Protein Content

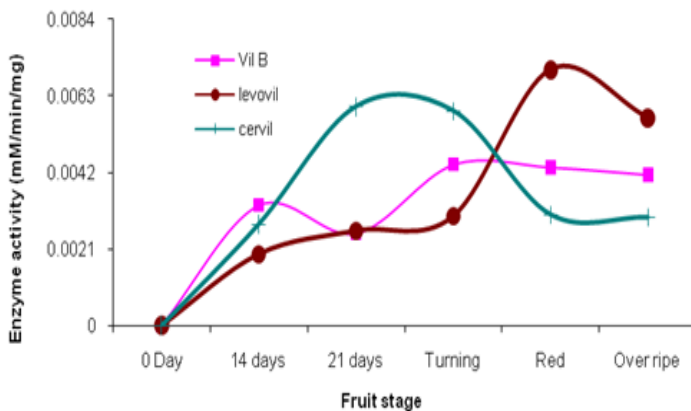
In the current study, we freshly collected fruits and immediately processed them for total whole cell protein content as shown in the experimental body. Evaluation of protein content at each development stage is exhibited in figure 3. Protein content (dry matter) at each developmental stage exhibited interesting results in which the three cultivars accumulated maximum protein content at 14DPA (stage of cell expansion) (Mapelli et al. 1978). The highest protein content was noticed for VilB followed by Cervil and finally Levovil. Protein content, in all cultivars, sharply declined following cell expansion stage to reach minimum level at the onset of fruit ripening (turning). Another elevation was observed as the fruit progressed towards over ripe stage.

### $\beta$ -glucosidase Activity

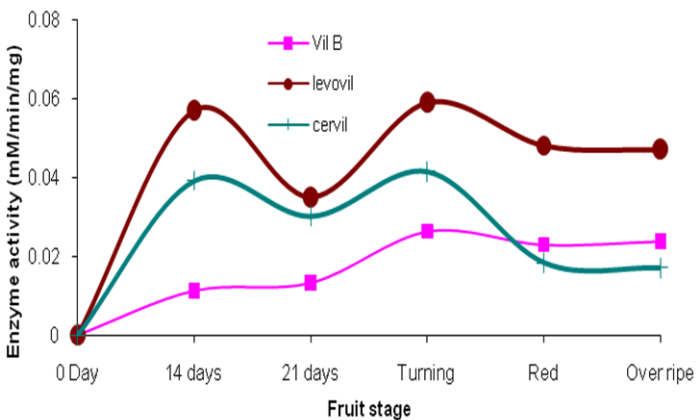
$\beta$ -D-glucoside glucohydrolase, EC 3.2.1.21, is the enzyme which acts upon  $\beta$ 1-4 bonds linking two glucose or glucose-substituted molecules (i.e., the disaccharide cellobiose). In this investigation weak activity was detected in the three cultivars with a relative higher activity in Levovil. The week activity of  $\beta$ -glucosidase in tomato may justify the scarcity related literature on tomato  $\beta$ -glucosidase. Among the three tomato species,  $\beta$ -glucosidase showed clear activity disparity at the five



**Figure 4:** Beta-glucosidase activity in varying development and ripening stages of Cervil, Levovil and VilB cultivars. Each point represent a mean of three independent experimnets.



**Figure 5:** Beta-Mannosidase activity in varying development and ripening stages of Cervil, Levovil and VilB cultivars. Each point is a mean of three independent experimnets.



**Figure 6:** Alpha-galactosidase activity in varying development and ripening stages of Cervil, Levovil and VilB cultivars. Each point is a mean of three independent experimnets.

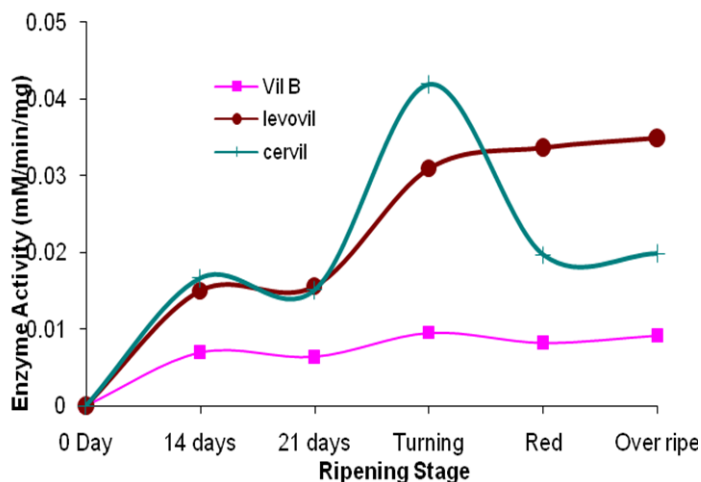
ripening stages. Interestingly, throughout Cervil development stages, the enzyme retained a plateau activity (Figure 4). This enzyme had been shown to localize in both periplasm as well as cytoplasm, with no clear assignment role in cell wall during ripening (ODOUX et al. 2003). This may clarify the weak activity of this enzyme in our cell wall preparation.

### $\beta$ -Mannosidase Activity

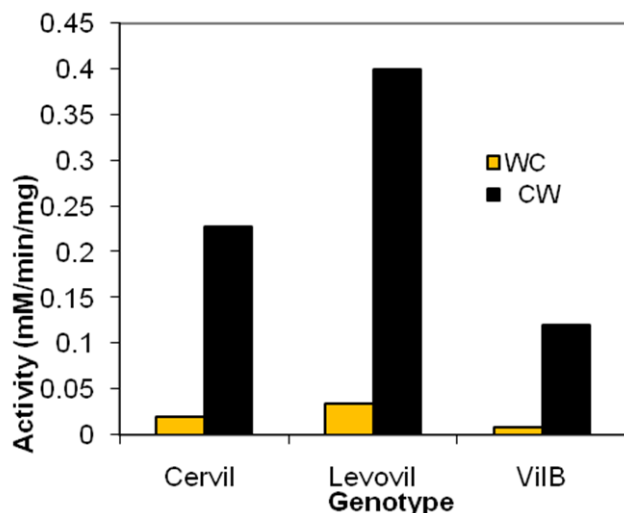
When activity of  $\beta$ -mannosidase at the 5 ripening stages was assayed in the 3 cultivars, activity disparity was noticed. These variations made any interpretation difficult (Figure 5). Glycosidases are usually found in isforms that are expressed at different development stages (Giannakouros et al. 1991; Jagadeesh et al. 2004; Morant et al. 2008).  $\beta$ -mannosidase from tomato seed was purified and studied to genetic level, in which a single gene was reported to code for this enzyme in tomato (Mo and Bewley 2002). Studies on tomato seeds Beta-Mannosidase and endo- $\beta$ -mannanase by Mo and Bewley indicated that these enzymes are involved in the mobilization of the mannan-containing cell walls of the tomato seed endosperm (Mo and Bewley 2002). However, another report published by Bewley and his colleagues who worked with tomato (*Lycopersicon esculentum* Mill.) fruit of the cultivar Trust, had shown the enzyme to tightly bound to the cell wall and removal of which would require a high salt buffer and is only detectable in the early stages of fruit development (Bewley et al. 2000). Since we used a buffer of a mild salt strength and a non-destructive experimental procedures, our results jointly taken with the work of (Mo and Bewley 2002) may reasonably allow us to conclude either the enzyme is sparingly extracted under our buffer system or the enzyme may not be playing a role in the development and ripening of tomato.

### $\alpha$ -Galactosidase Activity

Alpha-galactosidase is known to reside in both cell wall and cytoplasm (Bassel et al. 2001; Marraccini et al. 2005). In cell wall the enzyme involves in the modification or degradation of plant galactomannans and thereby assists in fruit softening. In the present study, we have found the enzyme to elevate, for Levovil and Cervil during both development (14DAP) and ripening (turning) stages. On the other hand, unlike the formers, VilB enzyme showed little activity rising in the ripening stage. Cervil  $\alpha$ -galactosidase weak activity however is not surprising since VilB possesses the longest shelf life as compare to Cervil and Levovil. In fact the enzyme activity is in a good agreement with these cultivars degree of softness. Levovil w is fleshy and very soft with minimal shelf life possesses the highest  $\alpha$ -galactosidase activity as compared to others (Figure 6).



**Figure 7:** Beta-galactosidase activity in varying development and ripening stages of Cervil, Levovil and VilB cultivars. Each point is a mean of three independent experiments.



**Figure 8:** Comparison between activities of Beta-galactosidase in the cell wall and whole cell extract WC-Whole Cell Extract; CW-Cell Wall Extract.

### B-Galactosidase Activity

( $\beta$ -gal, EC 3.2.1.23) enzyme activity is characterized by the ability to hydrolyze terminal nonreducing  $\beta$ -D-galactosyl residues from  $\beta$ -D-galactoside polymers. At least 7 isoforms of this enzyme has been reported to get expressed at different fruit development stages.  $\beta$ -galactosidase activity had shown to increase in parallel with tissue ripening (Smith and Gross 2000) and genetically inhibition of *TBG4*, gene of several other genes for the enzyme, delayed fruit softening

(Carey et al. 2001). In the current investigation, the enzyme activity was increased sharply just before the breaker stage when the fruit starts to get red. This increase was clear in case of both Cervil and Levovil, which are known for their shorter shelf life, whereas VilB which is characterized by high degree of firmness and preservation period showed minimal activity for the enzyme at development and ripening stages (Figure 7). These results will again emphasis on the implication of  $\beta$ -galactosidase in the fast fruit softening.

To further investigate on the wall localization of  $\beta$ -galactosidase. We assayed the enzyme activity in both cell wall and whole cell extract for the three cultivars at ripening stage. High increase in the enzyme activity was obtained for wall enzyme as compared to whole cell enzyme activity. As expected, Levovil possessed highest activity followed by Cervil and finally by the firmest cultivar VilB (Figure 8).

### CONCLUSION

Taken together, these results may allow us to conclude that studies of glycolytic activities in a single tomato cultivar cannot be generalized to whole species. On the other hand, the tight correlation between tomato softness status and the glycosidase activities may also affirm on direct involvement of these enzymes on fruit development and softening.

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