Introduction

Ever since man evolved on earth its interaction with plants never ceased. Infact it will be an appropriate statement that the man co - evolved with plants. If the only living planet of ours draws its sustenance from the plants, the man could not escape its absolute dependence on anything and everything that plants produced and provided him with- be it food, clothing, shelter, health, entertainment, luxury, wealth anything (Shuab *et al.*, 2013; Dursum *et al.*, 2004).

The net chemical composition of living organisms have predominantly been discussed under two main metabolic sources; the primary and the secondary. The metabolites of almost necessity for the life sustenance constitute the primary metabolites. These primary metabolites, when consumed and synthesized by other metabolic pathways generate variable structured components considered to be secondary metabolites or natural products including alkaloids, phenolics, terpenes, rubbers, sterols, steroids, betanins, and many of the other plant materials which contribute to the welfare of mankind (Shuab *et al.*, 2013). The majority of known

secondary products are of plant origin but many are found in fungi, bacteria, or animals (Firn and Jones, 2009).

There are only few prominent examples, which indicate that a strict line between primary and secondary metabolism is difficult to be drawn. Hence, in contrast to the traditional meaning of 'less important', the term 'secondary' is now interpreted as an indispensable layer of functionality. It is inherent to plant metabolic networks and contributes significantly to the plasticity of plant metabolism, which is required to afford the sessile life style of a land plant under changing environmental conditions (Hartmann, 2007). In recent years, the combined application of the upcoming - omics technologies for gene, protein and metabolite analysis begins to discern many interactions within the network of secondary metabolism and between secondary and primary metabolism (Bottcher *et al.*, 2008). This paves the way to a better understanding of plant metabolism in its outstanding complexity and will support targeted metabolic engineering approaches to generate plants with altered metabolite contents for food industry or pharmaceutical use (Dixon, 2001). In the last decade, of several enzymes involved in plant secondary metabolism, unexpected homologs with functions in primary metabolism have been detected (Steffens, 2000; Ober and Hartmann, 1999). This has encouraged novel research strategies aimed at understanding the evolution of metabolic diversity.

In natural systems, plants face a plethora of antagonists and thus possess a myriad of defences and have evolved multiple defence mechanisms by which they are able to cope with various kinds of biotic and abiotic stresses for adaptation (Rawlinson *et al.*, 2015; Khan *et al.*, 2015; Ncube *et al.*, 2014; Shuab *et al.*, 2013; Ballhorn *et al.*, 2009). These display a tremendous metabolic plasticity that is well

illustrated by their ability to synthesize myriads of so-called secondary organic compounds ('natural products') that seem to be dispensable for growth and development (De Klerk *et al.,* 2011). Investigation of these plant products was initiated about 200 years ago by Friedrich Wilhelm Serturner, who confined the active principle of opium poppy to a single organic substance, known as morphine. Since then, the structures of more than 200,000 plant natural products have been elucidated and assigned to the groups of terpenoids, alkaloids, polyketides or phenylpropanoids and phenols/polyphenols (Hartmann, 2007; Wink, 1988).

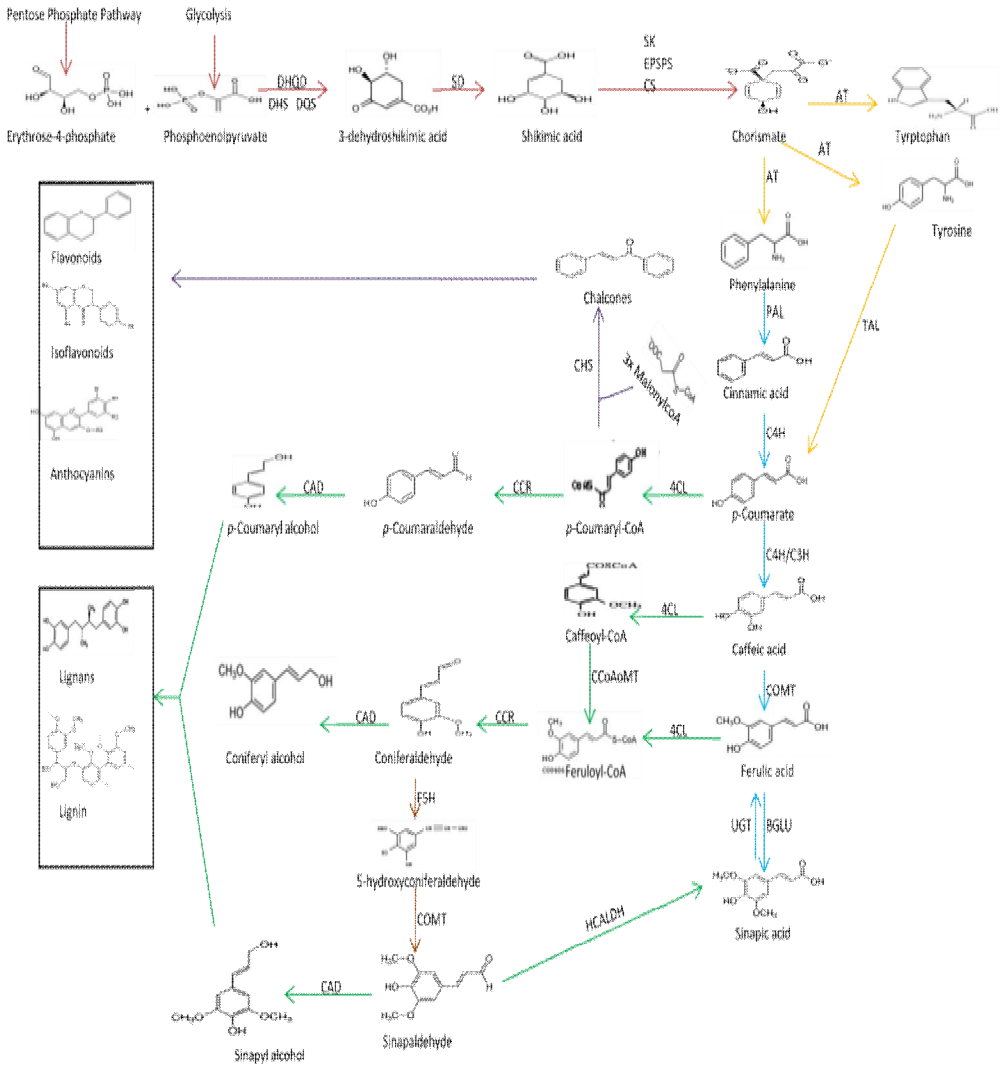
One of the major secondary plant metabolites are the phenolics. Approximately 8000 naturally occurring compounds belong to the category of phenolics. All of these share a common structural feature of having an aromatic ring with at least one hydroxyl substituent (Chirinos *et al.,* 2009; Croteau *et al.,* 2000; Harborne, 1980). The term encompasses simple phenols, phenolic acids, coumarins, flavonoids, stilbenes, hydrolysable and condensed tannins, lignans and lignins (Khoddami *et al.,* 2013). Naturally occurring phenolic acids contain two distinctive carbon frameworks - the hydroxycinnamic and the hydroxybenzoic. Although the basic skeleton in the two remains the same, the numbers and positions of the hydroxyl and methyl groups on the aromatic ring make the difference and establish the variety. Caffeic, *p*-coumaric, vanillic, ferulic, and protocatechuic are acids present in nearly all plants (Robbins, 2003). Other acids e.g., gentisic, and syringic are found in selected natural sources.

All higher plant polyphenols are formed from shikimate, through shikimic acid pathway (Sim *et al.,* 2015; Tzin and Galili, 2010; Chen *et al.,* 2006a, b). Erythrose-4-phosphate and phosphoenol pyruvate (PEP) both products of the general

carbohydrate metabolism, enter the shikimate pathway to produce aromatic amino acids phenylalanine, tyrosine and tryptophan (Corea *et al.,* 2012; Orcaray *et al.,* 2011; Yamada *et al.,* 2008; Cho *et al.,* 2007). However, it is the earlier two of these three amino acids which on deamination by enzymes phenylalanine ammonia lyase (PAL) yield cinnamate and tyrosine ammonia lyase (TAL) yield *p*-hydroxy cinnamic acid respectively (Dixon and Lamb, 1990). One more enzyme cinnamate-4-hydroxylase (C4H) converts cinnamate, produced from PAL action on phenylalanine, into *p*-hydroxy cinnamic acid (Pina *et al.,* 2012; Bi *et al.,* 2011; Mir Derikvand *et al.,* 2008; Leple *et al.,* 2007; Shadle *et al.,* 2007; Yamamura *et al.,* 2001). These are subsequently converted to various substituted cinnamate derivatives like *p*-coumaric, ferulic, caffeic and sinapic acids (Gang, 2005). Further substitutions and modifications of these cinnamate derivatives generate precursors for mono, oligo and polyphenol synthesis such as tannin and lignin (Sim *et al.,* 2015; Vanholme *et al.,* 2012a,b; Vanholme *et al.,* 2010; Ralph, 2010; Zanardo *et al.,* 2009; Dos Santos *et al.,* 2008; Kovacik *et al.,* 2007; Ralph *et al.,* 2006; Santos *et al.,* 2004; Ralph *et al.,* 2004; Rohde *et al.,* 2004; Hahlbrock and Scheel, 1989). Plant natural products like phenylpropanoids are important for both plant, human and animal health (Sharma, 2011; Dixon and Sumner, 2003; Dixon *et al.,* 2002, 1999).

The other sources for the synthesis of diverse basic plant phenolic structures and also other aromatic structures is through an acetate pathway (Boudet, 2007; Taiz and Zeiger, 2006; Whiting, 2001). These may be present individually or in combination with the compounds synthesized through shikimate pathway. For example, large group of flavonoid compounds, chalcones, anthocyanidins/ anthocyanins possessing two aromatic rings A and B, wherein A originates from

acetate pathway and B is that of shikimate pathway origin (Hatfield *et al.*, 2008; Boerjan *et al.*, 2003; Hatfield and Vermerris, 2001; Davin and Lewis, 2000; Sederoff *et al.*, 1999; Lewis and Yamamoto, 1990).



Biosynthesis and Subsequent Fate of Cinnamic Acid Presented here (After modification from various sources)

DHS, 3-deoxy-D-arabinoheptulosonate 7-phosphate synthase; DQS, 3-dehydroquinate synthase; DHQD, 3- dehydroquinate dehydratase; SD, shikimate dehydrogenase; SK, shikimate kinase; EPSPS, 5- enolpyruvylshikimate-3-phosphate synthase; CS, chorismate synthase; AT, amino transferase; TAL, tyrosine ammonia-lyase; PAL, phenylalanine ammonia-lyase; C4H, cinnamate 4-hydroxylase; 4CL, 4-coumarate: CoA ligase; C3H, *p*-coumarate 3-hydroxylase; CCoAOMT, caffeoyl-CoA O-methyltransferase; CCR, cinnamoyl-CoA reductase; F5H, ferulate 5-hydroxylase; COMT, caffeic acid O-methyltransferase; CAD, cinnamyl alcohol dehydrogenase; UGT, UDP-glucosyltransferase; HCALDH, hydroxycinnamaldehyde dehydrogenase; BGLU, b-glucosidase; CHS, Chalcone synthase.

Being ubiquitous in plants, phenolics have been extracted from every plant part such as, roots, stem, leaves, flowers, fruits and seeds. Inspite of their wide-spread occurrence in plant kingdom, understanding of their physiological role in plants is scanty (Shuab *et al.,* 2013). Some investigators believe that phenolics function as promoters (Choi *et al.,* 2011; Hassan and Ghareib, 2009; Hegab *et al.,* 2008; Hegab, 2005) while others consider these compounds to be inhibitory to growth and developmental phenomena (Siemens *et al.,* 2002; Stotz *et al.,* 1999). Some groups of workers, however, argue against any basic role of phenolic constituents in plant growth regulation (Firn and Jones, 2009). They constitute a diverse array of organic compounds that appear to have no direct functions in growth and development *i.e.* they have no general recognized roles in the process of photosynthesis, respiration, solute transport, translocation, nutrient assimilation and differentiation (Hartmann, 1991).

Cinnamic acid is an ubiquitous plant phenol. Aromatic amino acids phenylalanine and tyrosine are the precursors for the synthesis of this ubiquitous plant monophenol. Being, precursor for the synthesis of various di and polyphenols and also its substituted derivatives it seems to be an important phenol for plant growth and development. This aromatic chemical substance synthesized primarily by almost all forms of plants, seemingly involves itself in the regulation of various physiological processes. The must be presence of this monophenol in plants and its derivatives is an enough indication that these have been adopted by plants for various mechanisms.

Cinnamic acid is a plant production promoter as a lasting-effect fungicide used in high yield, corrosion prevention and freshness preservation of fruits and vegetables (Voigt and Rademacher, 2015). It has extensive applications, but the consumption in

the domestic market is very small today. With the development of the aspartame production and expansion of its consumption in various commercial sectors, the consumption of L-phenylalanine will become brisk and the cinnamic acid production will be promoted by many folds. The demand of L-phenylalanine in the world is around 15 thousand tons a year, needing 23 thousand tons of cinnamic acid. The demand of L-phenylalanine in China is around 2 thousand tons a year, needing around 3 thousand tons of cinnamic acid. The output of cinnamic acid in China is only less than 1 thousand tons today and the deficit has to be bridged by imports (CNCIC, 2006).

The interest in hydroxycinnamates as bioactive components of the diet, as structural and functional components of plant cell walls, and as precursors for flavours in the food industry has expanded rapidly in the last 10-15 years. As a result, the first ever international conference devoted solely to hydroxylcinnamates (e.g. ferulate, *p*-coumarate, sinapate, caffeate), Ferulate '98' was held in Norwich (UK) on 9-11 July 1998. There were five sections: Hydroxycinnamates in food - role in nutrition and health; Hydroxycinnamates in plant cell walls; Biosynthesis of hydroxycinnamates; Enzymology of biosynthesis and degradation; Exploitation of hydroxycinnamates.

Plant growth and development is governed by a mutual interaction among various plant growth regulators (Shuab *et al.*, 2013; Wang and Irving, 2011). Every plant biological activity is manipulated by more than one hormone, thus the biological phenomenon often reflects the combined interplay of several different hormones (Wang and Irving, 2011). Though salicylates have now almost been established for their having growth and developmental functions in plants and being recognized as

plant growth regulators, the cinnamates despite their ubiquitous presence (Hegab *et al.*, 2008) are yet to be identified as ones of any importance in plant growth regulation (Ghareib *et al.*, 2010; Firn and Jones, 2009).

Hence the objective of the present work is an effort in the direction to see whether cinnamate as such can be attributed with any growth regulation characterisation when compared to long established promoters and inhibitors.

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