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Review / Revue

An integrative genomics approach for deciphering the complex interactions between ascorbate metabolism and fruit growth and composition in tomato

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Abstract

Very few reports have studied the interactions between ascorbate and fruit metabolism. In order to get insights into the complex relationships between ascorbate biosynthesis/recycling and other metabolic pathways in the fruit, we undertook a fruit systems biology approach. To this end, we have produced tomato transgenic lines altered in ascorbate content and redox ratio by RNAi-targeting several key enzymes involved in ascorbate biosynthesis (2 enzymes) and recycling (2 enzymes). In the VTC (ViTamin C) Fruit project, we then generated phenotypic and genomic (transcriptome, proteome, metabolome) data from wild type and mutant tomato fruit at two stages of fruit development, and developed or implemented statistical and bioinformatic tools as a web application (named VTC Tool box) necessary to store, analyse and integrate experimental data in tomato. By using Kohonen's self-organizing maps (SOMs) to cluster the biological data, pair-wise Pearson correlation analyses and simultaneous visualization

Abbreviations: VTC: Vitamin C; AsA: Ascorbic acid; GME: GDP-d-mannose-3′,5′-epimerase; GalLDH: L-Galactono-1,4-Lactone Dehydrogenase; AO: Ascorbate oxidase; MDHAR, Monodehydroascorbate reductase.

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of transcript/protein and metabolites (MapMan), this approach allowed us to uncover major relationships between ascorbate and other metabolic pathways. ***To cite this article: V. Garcia et al., C. R. Biologies 332 (2009).***

Résumé

Approche génomique intégrative pour étudier les interactions complexes entre métabolisme de l'ascorbate, croissance et composition du fruit de tomate. Les interactions entre ascorbate (vitamine C) et métabolisme du fruit charnu ont été très peu étudiées jusqu'à présent. Afin d'approfondir notre connaissance des relations complexes entre la biosynthèse et le recyclage de l'ascorbate d'une part, et les autres voies métaboliques actives dans le fruit d'autre part, nous avons entrepris une approche intégrative de la biologie du fruit. Dans ce but, nous avons produit des lignées transgéniques de tomate dont la teneur et/ou le ratio redox de l'ascorbate étaient modulées, en ciblant par une stratégie d'ARN interférence (RNAi) plusieurs des enzymes clés de la biosynthèse (2 enzymes) et du recyclage (2 enzymes) de l'ascorbate. Dans le projet « ViTamine C du Fruit » (VTC Fruit) nous avons ensuite généré et collecté un ensemble de données phénotypiques et génomiques (transcriptome, protéome, métabolome) à partir de fruits de tomate à 2 stades de développement, pour chaque génotype. Afin de stocker, analyser et intégrer les données produites, nous avons mis en place une application Web du nom de VTC ToolBox intégrant différents outils bioinformatiques et statistiques. Grâce aux cartes auto-organisatrices (self-organizing maps) de Kohonen, aux analyses de corrélation de Pearson et à la visualisation simultanée des transcrits/protéines et des métabolites identifiés chez les fruits (MapMan), cette approche nous a permis de mettre en évidence des relations majeures entre voies de synthèse de l'ascorbate et d'autres voies métaboliques du fruit. ***Pour citer cet article : V. Garcia et al., C. R. Biologies 332 (2009).***

Keywords: Ascorbic acid; Tomato; Cell wall; Complex systems; Systems biology

Mots-clés : Ascorbate ; Tomate ; Paroi ; Systèmes complexes ; Biologie intégrative

1. Introduction

Ascorbate is an abundant metabolite in plants where it plays major roles for various aspects of plant life. Besides its well-studied role in photo protection and stress response, ascorbate is involved in the regulation of several aspects of plant development such as cell division and cell expansion. Intake of Vitamin C (L-ascorbic acid or AsA) is also crucial for humans, who have lost the ability to synthesize this compound. Indeed, like some other primates, humans carry a loss-of-function mutation in one of the obligatory steps of ascorbate biosynthesis. As a consequence, humans have to find vitamin C in their foodstuff, in particular by eating fruits and vegetables. Many fruits (e.g. the citrus and the kiwifruit) are rich in ascorbate. However, in many countries, tomato (*Solanum lycopersicum*) is the major source of vitamin C because it is consumed regularly and in large quantities. Tomato is also a model for fleshy fruits, allowing the development of methodologies, approaches and knowledge that can later be transferred to other species of edible fruits. To meet the health requirements and the growing demand of consumers for food items with high nutritional value, it is desirable to monitor and, if possible, to increase the tomato fruit content in vitamin C. Tomato fruit ascorbate content depends on a combination of genetic factors (various cultivars display large variability in ascorbate content), environmental factors (cultural practices and environmental conditions will affect ascorbate accumulation in the fruit), and postharvest storage conditions (changes in antioxidant capacity and fruit firmness of the fruit are closely linked in the stored fruit).

The major ascorbate biosynthesis pathway has been recently described [1]. Starting from mannose-1-P, it includes several successive steps catalyzed by GDP-mannose pyrophosphorylase (GMPP), GDP-mannose-3′,5′-epimerase (GME), L-galactose guanyltransferase [2], galactose dehydrogenase and L-galactono-1,4 lactone dehydrogenase (GalLDH). This pathway is directly connected to glycolysis through glucose-6-phosphate and fructose-6-phosphate. It is also connected to cell wall biosynthesis since GDP-mannose and GDP-L-galactose are intermediates of the major ascorbate biosynthesis pathway and precursors for the synthesis of non-cellulosic cell wall polysaccharides such as (galacto)glucomannans. Other alternative minor pathways connected at different levels to the major pathway have been demonstrated [3,4]. In addition, a specific ascorbate biosynthesis pathway using the galacturonic acid resulting from cell wall degradation of ripening fruit as a precursor has been found in strawberry [5]. Since vitamin C is present as three forms showing different oxidative states (ascorbate, monodehydroascorbate, dehydroascorbate) in plant tissues, the activities of the ascorbate recycling enzymes such as ascorbate oxi-