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Clock-controlled genes in *Arabidopsis*

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Abstract

Large-scale expression profiling has revealed distinct clusters of circadian clock-regulated genes and identified a phase-specific *cis*-regulatory element.

Significance and context

In all types of organisms, a variety of physiological processes are subject to circadian rhythms controlled by an internal biochemical oscillator, the circadian clock. In plants, processes regulated by the circadian clock include, for example, induction of flowering, elongation of hypocotyls and opening of stomata. Harmer *et al*. have used oligonucleotide gene chips representing one third of the *Arabidopsis thaliana* genome for a global examination of clock-controlled changes in gene expression. This study is the first large-scale expression study of clock-controlled genes in eukaryotes.

Key results

Of roughly 8,200 different *Arabidopsis* genes on the chip that was used, 453 were found to be clock-regulated. These cycling genes were grouped into phase clusters according to their peak expression time. Many simultaneously cycling genes could be assigned to functional groups on the basis of their known or predicted function. For instance, 22 genes encoding proteins implicated in various photosynthetic reactions were found to be co-regulated. Their expressionpeaks around midday, when photosynthetic activity is highest. Furthermore, 23 genes, encoding enzymes of the phenylpropanoid biosynthetic pathway, simultaneously peak before dawn. The gene encoding the Myb transcription factor PAP1 is co-regulated with this cluster. Overexpression of this transcription factor had previously been shown to upregulate several phenylpropanoid biosynthetic genes. The authors suggest that PAP1 may act as a master regulator of clock-controlled transcription of these genes. Other interesting clusters comprise co-regulated genes potentially involved in chilling resistance, sugar catabolism, sugar transport, sugar storage, starch mobilization, and nitrogen and sulfur assimilation, as well as developmental processes such as flowering and cell elongation.

Using the AlignACE program, a nine-nucleotide motif, called 'evening element', was found to be strictly conserved within promoters of genes peaking towards the end of the subjective day. The promoter of the 'evening-specific' gene *CCR2* contains four copies of this motif. The *CCR2* promoter

was functionally dissected in transgenic *Arabidopsis* plants containing luciferase reporter constructs. By deletion and mutational analysis the evening element was shown to be required for phase-specific reporter gene expression.

Links

Supplementary data to *Science* 2000, **290:**2110-2113 are freely available.

Reporter's comments

Harmer *et al*. present a comprehensive description of the circadian clock-controlled transcriptome in *Arabidopsis* and relate their findings to a variety of known physiological processes. In addition, a novel phase-specific *cis*-regulatory element was identified solely by computational means. The confirmation of its function *in planta* demonstrates the high potential and reliability of gene chip-based expression-profiling approaches. A hypothesis based exclusively on the analysis of gene chip data was experimentally verified and may serve as a starting point for further studies addressing mechanistic details of clock-dependent gene regulation.

Table of links

Science

AlignACE

Supplementary data to *Science* 2000, **290:**2110-2113

References

1. Harmer SL, Hogenesch JB, Straume M, Chang H-S, Han B, Zhu T, Wang X, Kreps JA, Kay SA: Orchestrated transcription of key pathways in *Arabidopsis* by the circadian clock. Science. 2000, 290: 2110-2113. 0036-8075