

**MOLECULAR AND ECOLOGICAL BASIS OF
SECONDARY METABOLITE BIOSYNTHESIS IN *Cichorium
intybus* L. AND *Silybum marianum* L.**

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Abstract: This study investigates the molecular mechanisms and ecological regulation of secondary metabolite biosynthesis in *Cichorium intybus* L. and *Silybum marianum* L., two widely used medicinal plants with high pharmacological value. Particular attention is given to intracellular biosynthetic pathways, including phenylpropanoid, flavonoid, and polysaccharide metabolism, as well as their dynamic responses under abiotic stress conditions such as salinity, oxidative stress, and drought. The integration of metabolic networks with antioxidant defense systems and signal transduction pathways is analyzed. Results indicate that secondary metabolites are not merely by-products but essential components of plant adaptive responses. Enhanced accumulation of phenolic compounds, flavonoids, and specialized metabolites under stress conditions significantly contributes to cellular protection and metabolic stability. These findings provide deeper insights into the biochemical plasticity and pharmacological potential of the studied species.

Keywords: *Cichorium intybus*, *Silybum marianum*, secondary metabolites, phenylpropanoid pathway, flavonoids, salinity stress, oxidative stress, plant adaptation.

Introduction: From the perspective of modern plant biochemistry, secondary metabolites are integral components of plant adaptive systems rather than optional metabolic products. These compounds function as signaling

molecules, mediators of plant-environment interactions, and key elements of stress tolerance mechanisms. *Cichorium intybus* L. (chicory) and *Silybum marianum* L. (milk thistle) are medicinal plants characterized by high metabolic plasticity, enabling rapid adjustment of their biochemical profiles under varying environmental conditions. This adaptability is largely governed by genetic regulatory networks, including transcription factors such as MYB, bHLH, and WRKY, which control the expression of genes involved in secondary metabolism. In addition to their ecological significance, these species are valuable sources of pharmacologically active compounds. *Cichorium intybus* contains inulin-type polysaccharides and phenolic acids, while *Silybum marianum* is rich in silymarin, a complex of flavonolignans with potent hepatoprotective properties. These features make them important model systems for studying stress physiology and phytochemical adaptation.

The roots and aerial parts of *C. intybus* are rich in: Inulin (up to 11%) , Proteins (~4%)

Glycosides (intibin) responsible for bitter taste, Tannins and organic acids, Vitamins: thiamine, riboflavin, ascorbic acid, carotene, Coumarin glycosides (in flowers) Sesquiterpene lactones (lactucin, lactucopicrin), Seeds containing 15–28% fatty oil Pharmacologically, chicory exhibits: Antidiabetic effects (due to inulin), Digestive and sedative properties, Cardioprotective activity ,Antimicrobial and anti-inflammatory effects Appetite stimulation and antipyretic properties *Silybum marianum* L.

The primary bioactive complex in *S. marianum* is silymarin, consisting of: Silibin A and B Silychristin, Silydianin, Taxifolin derivatives, Silymarin demonstrates: Hepatoprotective activity, Membrane stabilization in liver cells, Reduction of lipid peroxidation, Activation of detoxification enzymes, Anti-inflammatory effects.

Materials and Integrated Methodological Approach

This research integrates multiple scientific approaches:

- Phytochemical profiling of metabolite classes
- Reconstruction of biosynthetic pathways
- Analysis of stress-induced metabolic changes
- Organ-specific distribution of metabolites

Environmental stress conditions modeled include: Salinity, Oxidative stress, Water deficiency. **Biosynthetic Pathways of Secondary Metabolites**

Secondary metabolite biosynthesis begins with the shikimate pathway, leading to the formation of phenylalanine. This amino acid enters the phenylpropanoid pathway, which generates a wide range of phenolic compounds.

Flavonoid biosynthesis is initiated by the enzyme chalcone synthase (CHS), followed by enzymatic modifications that produce structurally diverse polyphenols. These compounds:

- Strengthen cell walls, Protect against oxidative damage, Contribute to UV protection and pathogen resistance. In *Silybum marianum*, silymarin biosynthesis involves the convergence of two metabolic pathways:

- Phenylpropanoid pathway
- Flavonoid pathway

Their interaction through condensation reactions leads to the formation of flavonolignans with high biological activity.

Stress-Induced Metabolic Responses

Under salinity and drought conditions, plants undergo significant physiological and biochemical changes: Disruption of electron transport chains, Increased production of reactive oxygen species (ROS), Activation of antioxidant enzymes (SOD, CAT, POD) Induction of genes related to phenolic biosynthesis. As a result, the concentration of secondary metabolites increases significantly. This enhancement represents a key adaptive strategy for maintaining cellular homeostasis and protecting biomolecules.

In *Cichorium intybus*: Neutralization of ROS, Protection of membrane lipids from peroxidation. Increased resistance to microbial pathogens. Modulation of gut microbiota

In *Silybum marianum*: Stabilization of hepatocyte membranes, Reduction of oxidative stress, Enhancement of detoxification processes, Suppression of inflammatory mediators.

Comparative Analysis of the Two Species

Parameter	<i>Cichorium intybus</i>	<i>Silybum marianum</i>
Dominant metabolites	Polysaccharides (inulin)	Phenolic complexes (silymarin)
Metabolic focus	Carbohydrate storage	Phenolic biosynthesis
Stress response	Moderate	Strong
Pharmacological value	High	Very high
Adaptation mechanism	Osmotic regulation	Antioxidant defense

Results and Discussion: The obtained results demonstrate that secondary metabolite biosynthesis in both species is a highly regulated and integrated process involving gene expression, enzymatic activity, and environmental signaling.

Stress conditions significantly enhance the accumulation of phenolic compounds and flavonoids. This increase improves plant tolerance to adverse conditions and simultaneously enhances their medicinal value. The strong correlation between environmental stress and metabolite production suggests that controlled stress application may be used as a strategy to optimize the yield of bioactive compounds.

Conclusion: Secondary metabolite biosynthesis in *Cichorium intybus* L. and *Silybum marianum* L. represents a complex, tightly regulated biochemical

system. These processes are closely linked to ecological stress factors and are mediated by molecular regulatory mechanisms. The enhanced production of secondary metabolites under stress conditions plays a crucial role in plant adaptation and significantly increases their pharmacological potential. These findings contribute to a deeper understanding of plant biochemical plasticity and provide a scientific basis for the development of innovative cultivation strategies for medicinal plants.

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