

## Abstract

**[Background]** Radish (*Raphanus sativus* L.) is an important vegetable in China. The succulent root is its edible part, which is used as the main food and medicine resource. Thus, the productivity and quality of radish are essential to agricultural marketing. To date, hollowness in radish species is a long-standing issue that damaged sensory traits and commercial value. However, the mechanism of hollowness formation is still rarely known.

**[Results]** Thus, our work collected a series of radish varieties with different hollowness degrees and screened out the hollow-resistant radish variety (#3 and #5) and hollow-sensitive alternative (#7) (Figure 1). A negative relationship between the content of reduced sugar and the hollowness degree was observed (Figure 2). Furthermore, the concentrations of several phytohormones like ethylene precursor (ACC), jasmonic acid (JA), and abscisic acid (ABA) were extremely up-regulated in the hollowness-sensitive succulent root (Figure 3), indicating that ACC, JA, and ABA perhaps involved in the regulation of hollowness formation. It is well-known that the hollowness degree is positively associated with lignin content. Our study creatively found that the hollowness degree is the lignin-independent manner among different varieties (Figure 4A) but in the same varieties the positive relationship between lignin content in medulla tissue and hollowness degree could be observed (Figure 4B). Moreover, the water content in the hollowness-sensitive medulla tissue was lower than that of hollow-tolerance ones (Figure 5). However, the opposite result occurred in the radish peel (Figure 5). The interesting phenomenon manifested that water migration from the center of the root to its periphery is the key to the formation of hollowness. To further study the molecular mechanism of hollowness formation, whole-genome transcriptome analysis was used. Four cDNA libraries from hollow-sensitive or resistant shoots and roots of radish were constructed, namely, KY(hollowness-sensitive shoots), NKY (hollowness-tolerance shoots), KS (hollowness-sensitive roots), and NKS (hollowness-tolerance roots). Two compared cDNA libraries (KS/NKS and KY/NKY) displayed plenty of differentially expressed genes (DEGs) in Figure 6. GO and KEGG analysis revealed that DEGs were mainly enriched in "metabolic processes" and "cellular processes", in particular, which involved in "starch and sucrose metabolism" and "glycolysis/glycoisomerization" pathways. Combined with the findings of changes in reduced sugar in KS (Figure 2), the molecular result confirmed that the conversion of sugar metabolism may be associated with hollowness formation. We further focused on the biosynthesis pathway of these phytohormones interrupted by the hollowness (Figure 7). The gene LOC108832790 in the jasmonic acid pathway was found to be highly expressed in the hollow-tolerant species (Figure 7A). The gene LOC108853772 in the ethylene pathway were found to be highly expressed in the hollow-sensitive species (Figure 7B). These results showed that JA may be involved in the inhibition of hollowness formation, but ABA and ethylene may prompt the formation process. Overall, our work provided novel information pertaining to physiological and transcriptome responses to the hollowness of radish.

## Results

### The calculation Eq. for hollowness:

$$\text{Hollowness degree} = (X_1 \cdot a_1 + X_2 \cdot a_2 + \dots + X_n \cdot a_n) \cdot nT^{-1}$$

where, X represents the frequency of hollowness; a represents the degree of hollowness; T represents the number of plants

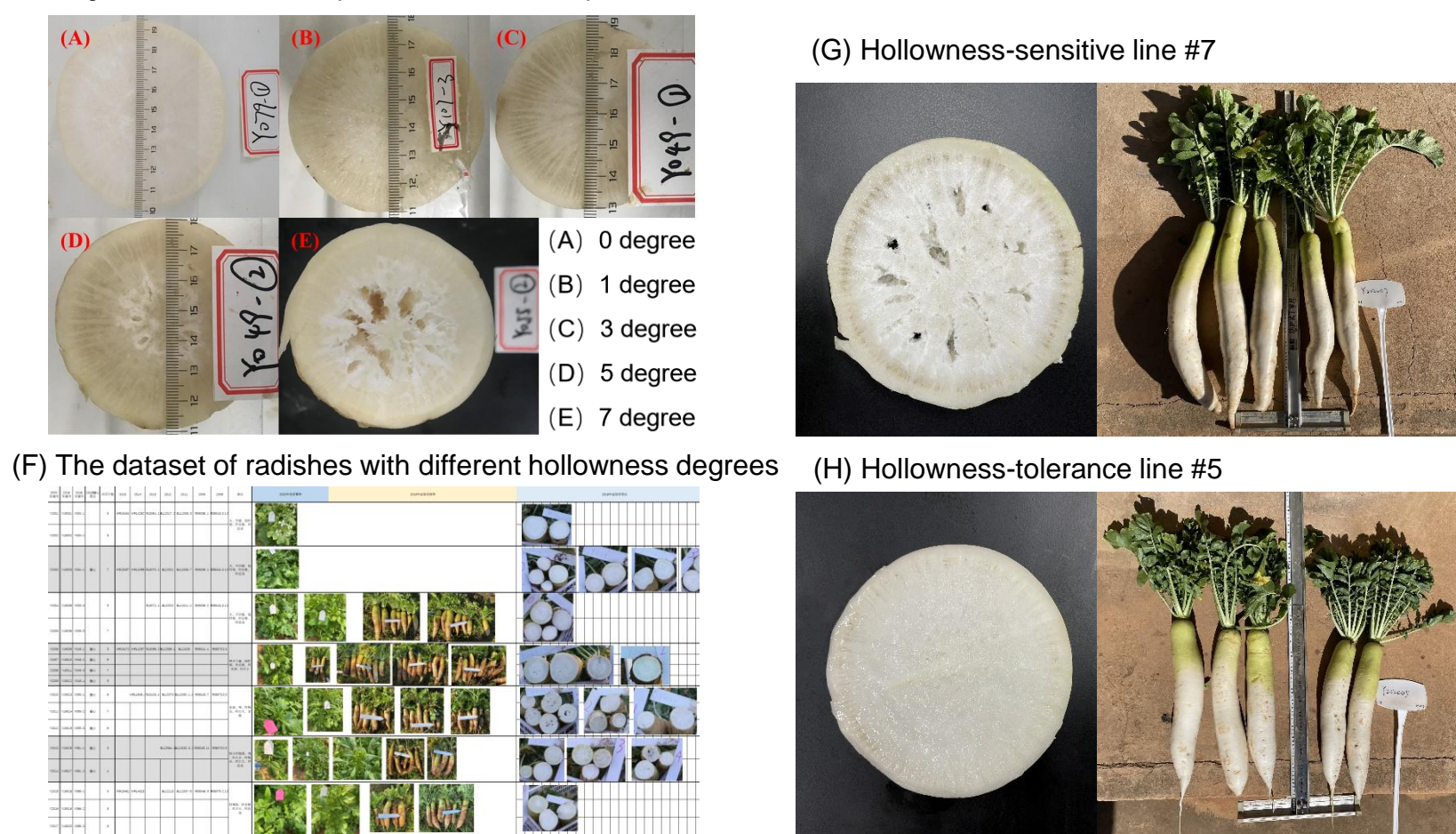


Figure 1. The phenotype profiles of hollowness-sensitive and tolerance radish species (Yun #1)

### (I) The generation relationship between #7 and #5

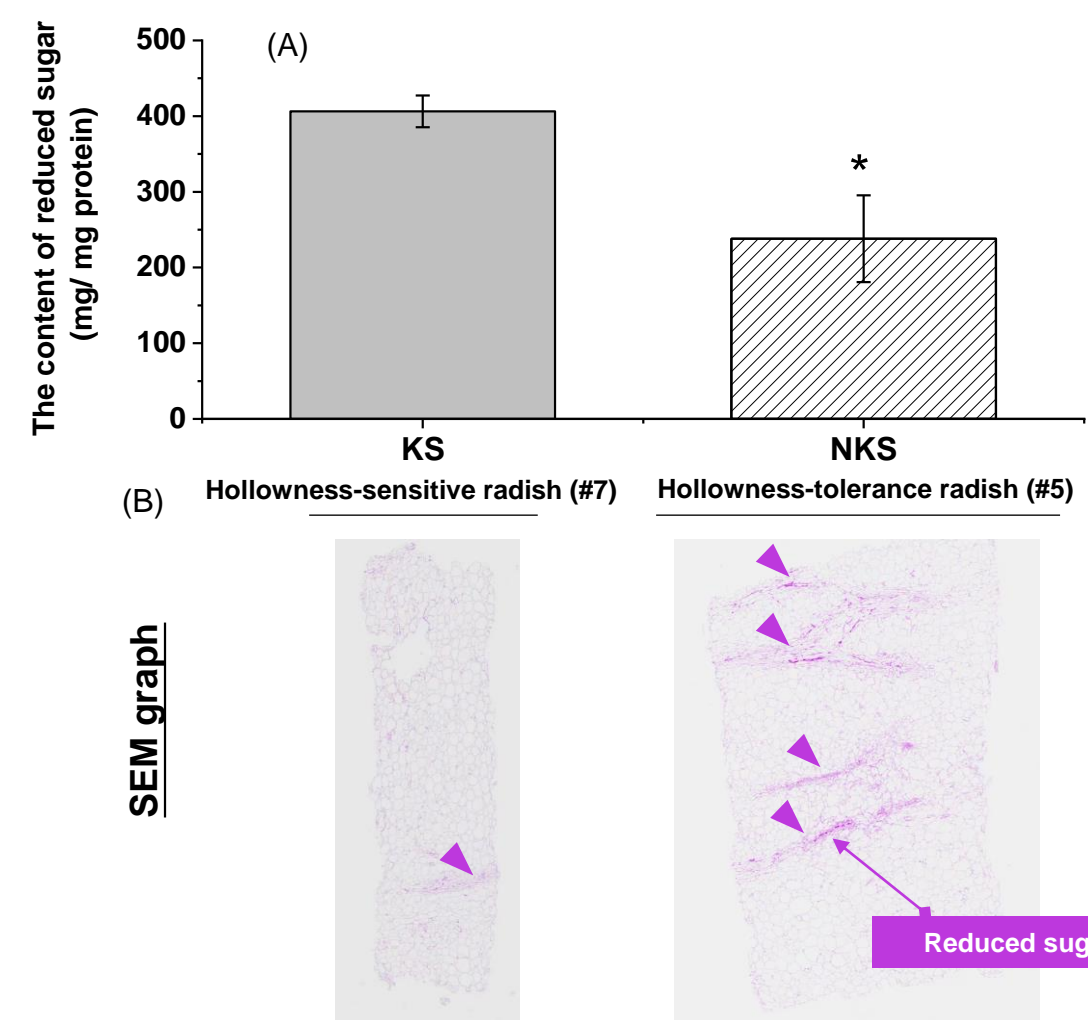
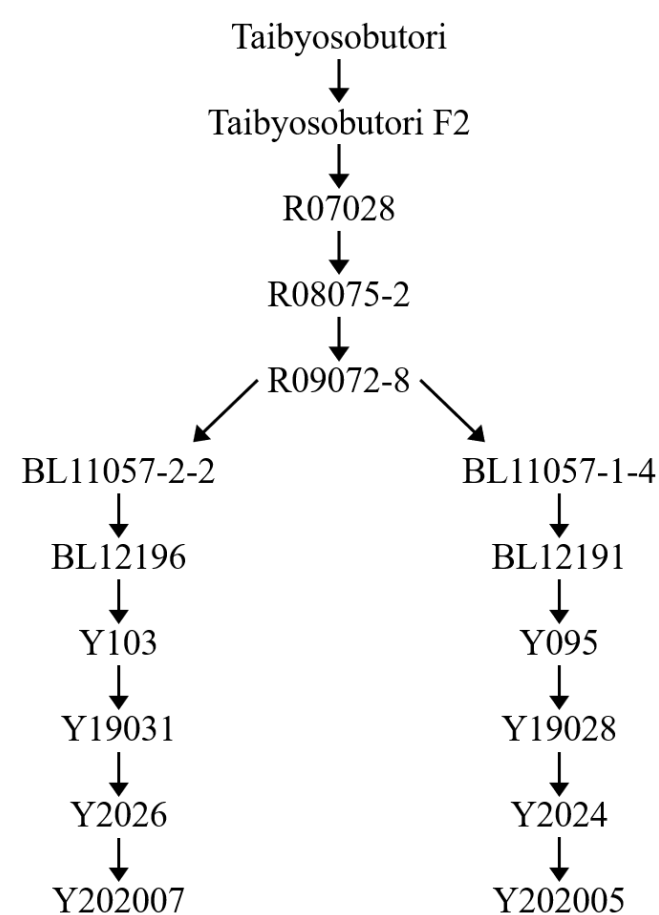


Figure 2. The content and distribution of reduced sugar in the root of hollowness-sensitive and tolerance radish

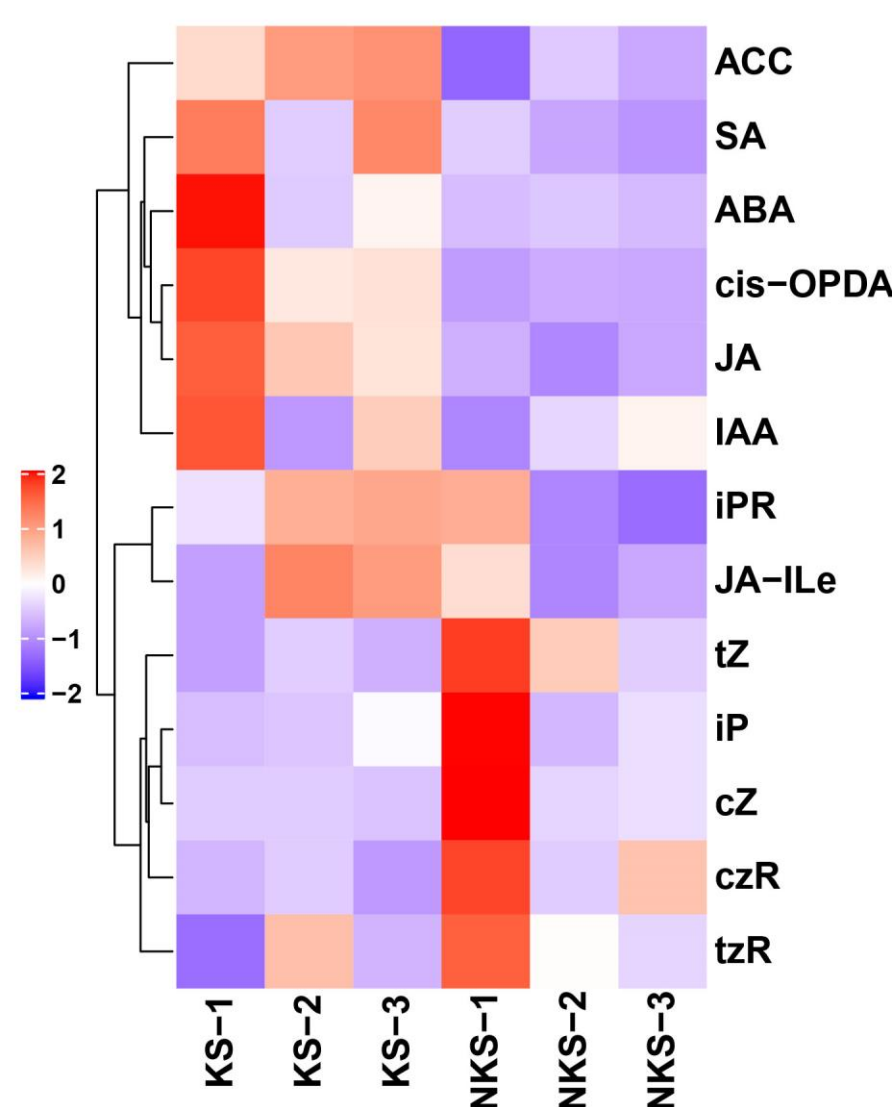


Figure 3. The content of phytohormones in the root of hollowness-sensitive (KS; #7) and tolerance radish (NKS; #5)

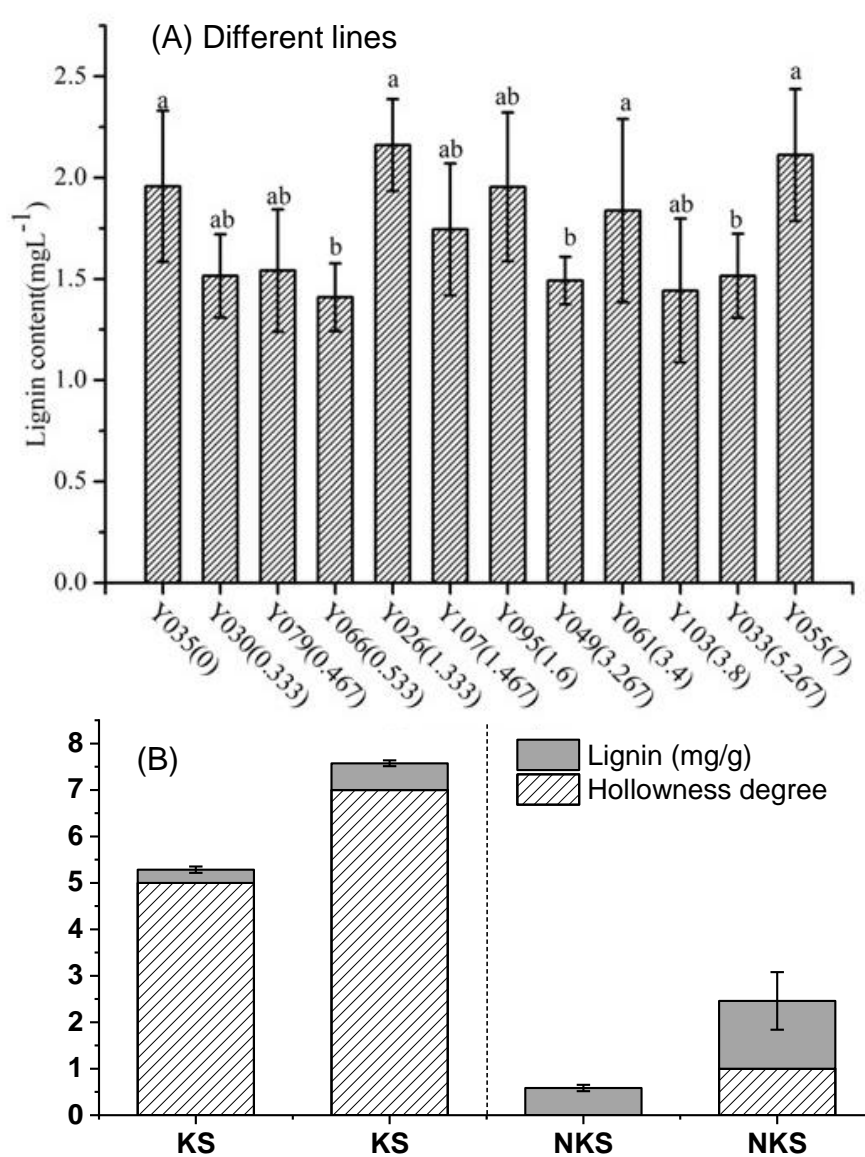


Figure 4. The content of lignin in the root of various species with different hollowness degree (A) and same species with different hollowness degree (B)

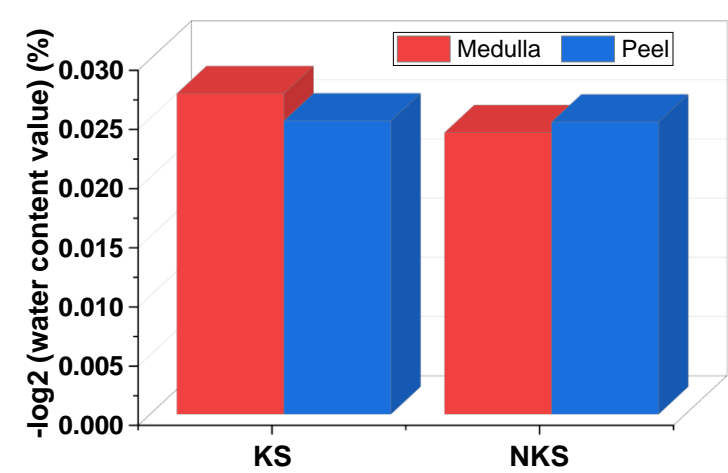


Figure 5. The content of water in medulla and peel of KS and NKS radish

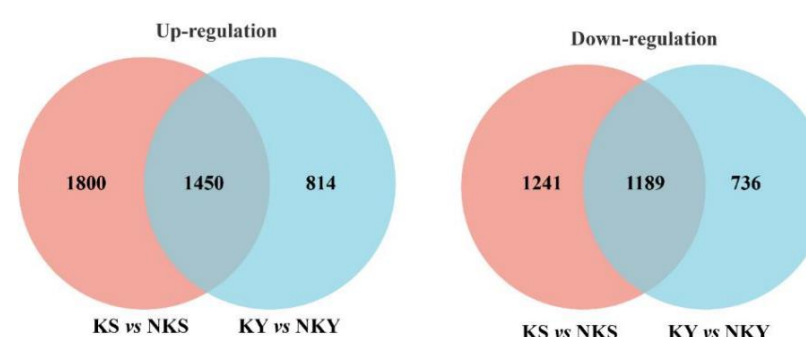


Figure 6. The DEGs in compared RNA-Seq libraries of root and shoot

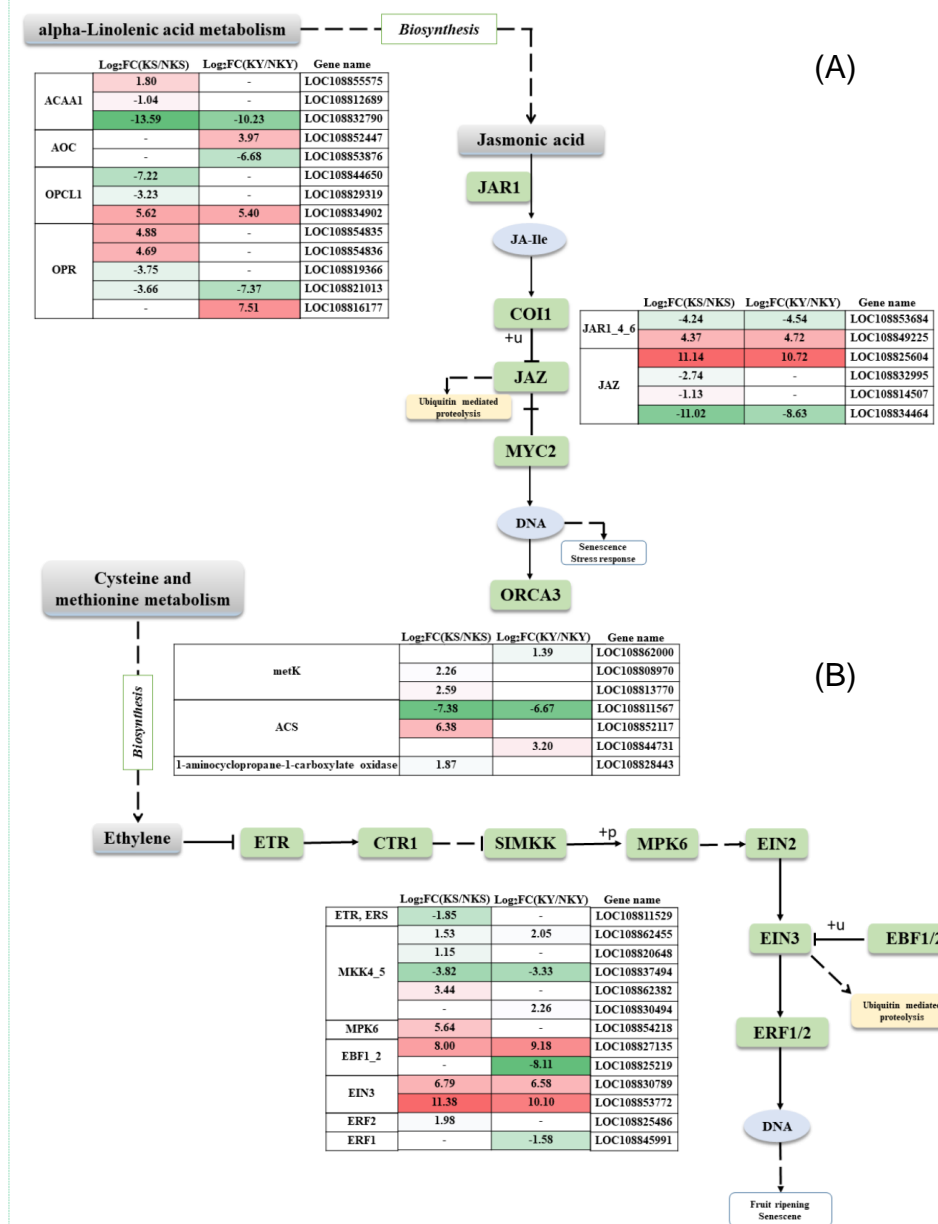


Figure 7. The changes of genes expression in JA and ethylene biosynthesis pathway in KS/NKS