Research Square

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Understanding the responses of tillering to 2,4-D in Setaria viridis L

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Research Article

Keywords: Setaria viridis, Tillering, Phytohormones, Gene expression, 2, 4-D isooctyl ester

Posted Date: January 12th, 2024

DOI: https://doi.org/10.21203/rs.3.rs-3835809/v1

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Additional Declarations: No competing interests reported.

Abstract

Background

Green foxtail [*Setaria viridis* (L.)] is one of the most abundant and troublesome annual grass weeds in alfalfa fields in Northeast China. Synthetic auxin herbicide is widely used in agriculture, while how auxin herbicide affects tillering on perennial grass weeds is still unclear. A greenhouse experiment was conducted to examine the effects of auxin herbicides 2,4-D on green foxtail growth, especially on tillers.

Results

In the study, 2,4-D isooctyl ester was used and there was an inhibition of plant height and fresh weight on green foxtail after application. The photosynthetic rate was dramatically reduced and there was an accumulation of MDA content. Moreover, applicating 2,4-D isooctyl ester significantly reduced the tillering buds at rates between 2100 and 8400 ga. i. ha^{-1}. Transcriptome results showed that applying 2,4-D on leaves can affect the phytohormone signal transduction pathways in plant tillers. Among them, there were significant effects on auxin, cytokinin, abscisic acid, gibberellin, and brassinosteroid signaling. Indeed, external ABA and GA on leaves can also limit tillering in green foxtail.

Conclusions

These data will be helpful to further understand the responses of green foxtail to 2, 4-D isooctyl ester, which may provide a unique perspective for the development and identification of new target compounds that are effective against this weed species.

Introduction

Green foxtail (*Setaria viridis* L.) is one of the most abundant and troublesome annual grass weeds in crop and alfalfa fields in China. Tillering is an important agronomic trait of Poaceae that greatly determines seed output [1]. For crops, strong tillering ability can increase food production [2, 3]. However, it will increase the production of weed seeds, accelerating their reproduction and improving the propagation coefficient [4]. Since weed infestation can cause losses of crop production, weed management is important for crop protection [5]. Thus, decreasing the number of tillering would be a strategy for controlling green foxtail.

Tillers are generally initiated by the establishment and elongation of tiller buds, which can be manipulated by phytohormones [6]. It is well-known that phytohormones like auxin, cytokinin, gibberellic acid (GA) and strigolactone (SL) play important roles in tillering of monocots and branching of dicots. Auxin is known as the first hormone to regulate shoot branching [7]. Removing the apex can abolish the inhibition of axillary bud outgrowth and plants will start branching [8]. External application of auxin can inhibit the growth of tiller buds in rice and wheat [9, 10]. Cytokinin plays a positive role in axillary bud outgrowth, and exogenous application of cytokinin promotes axillary bud outgrowth in plants [11]. GA

can inhibit tillering, mainly due to its antagonistic interaction with cytokinin [11]. SL has been reported to play a negative role in tiller or branch production [12, 13]. Studies have also revealed the interactions of auxin, cytokinin and SL in the regulation of tiller bud development [14, 15]. Thus, synthetic hormones would be a strategy for weeds control by decreasing plant tillers [16].

Synthetic auxins are used as growth regulators for yield improvement in agriculture, and as herbicides for weeds control [16]. The 2,4-dichlorophenoxy acetic acid (2,4-D) is one of the most widely used synthetic auxin herbicides to control weeds in pastures especially for some Poaceae crops, such as wheat and maize [17, 18]. 2,4-D controls many broadleaf weeds and spare monocots [19]. Monocots, particularly grasses, may perceive or respond differently to exogenous synthetic auxins compared to dicots. The 2,4-D has been reported to be used in controlling green foxtail growth, while many studies have recommended the use of clethodim and glyphosate to control green foxtail rather than 2,4-D [14, 17].Little is understood regarding the effects of 2,4-D isooctyl ester on plant and tiller bud growth in green foxtail under different application concentrations. Moreover, the mechanism of different tillering responses of 2,4-D isooctyl ester at different concentrations is still unclear.

Therefore, the objectives of this study are to (i) evaluate the effect of 2,4-D isooctyl ester on the outgrowth of tiller buds in *S. viridis* and (ii) identify metabolic pathways and candidate genes involved in the diverse tillering sensitivities at different concentrations of 2,4-D isooctyl ester by transcriptomic analysis. Undoubtedly, the results will be highly valuable to further understand the regulatory mechanism of auxin on tillering growth and provide new ideas for solving the challenges of plant hormone selectivity for green foxtail and other grass weeds.

RESULTS

Dose-dependent effects of 2,4-D isooctyl ester on plant growth in green foxtail

External 2,4-D isooctyl ester spraying had a significant effect on plant growth (Fig. 1). The plant height increased and then decreased significantly after high-dose application of 2,4-D isooctyl ester (Fig. 1A). There was no significant effect on plant fresh weight at lower concentrations of 525 and 1050 g a.i. ha^{-1}, but the plant height dramatically decreased at high concentrations (Fig. 1B). The plant net photosynthetic rate (Pn) displayed a dramatic reduction compared to plants under 2,4-D isooctyl ester treatment, as well as the stomatal conductance (gs) and the transpiration rate (Tr) (Fig. 2). Indeed, the MDA content accumulated in the leaves of green foxtail after 2,4-D isooctyl ester treatment when the level was above 2100 g a.i. ha^{-1} (Additional file 1: Figure S1). The POD, CAT, and SOD enzyme activities were enhanced in all treatments.

Effects of 2,4-D isooctyl ester on tiller production in green foxtail

The 2,4-D isooctyl ester treatment affected not only the plant height and fresh weight but also the tiller number (Fig. 3). It had no significant effect on the tiller development at 7 days after treatment (DAT) under 525 and 1050 g a.i. ha^{-1} compared to the control (Fig. 3B). When the dose was increased to 2100 g a.i. ha^{-1}, it showed a significant inhibition effect on tiller number (Fig. 3B). The 2,4-D isooctyl ester dose required for 50% growth inhibition of tiller was estimated to be approximately 5803.74 g a.i. ha^{-1} in green foxtail (Fig. 3C). Since the 50% growth inhibition effect on tiller was between T4 (4200 g a.i. ha^{-1}) to T5 (8400 g a.i. ha^{-1}), T4 was chosen for further analysis of effects of 2,4-D isooctyl ester on green foxtail tillers.

Differentially Expressed Genes of 2,4-D isooctyl ester treatment on tiller in green foxtail

To analyze the 2,4-D isooctyl ester effects on tiller growth, tillers treated with 0 and 4200 g a.i. ha^{-1} concentrations were used for transcriptome analysis. A total of 40.53 million reads to 56.80 million reads were obtained after RNA-Seq (Additional file 2: Table S1). Among them, 95.09–96.17% of the clean reads were successfully mapped to the green foxtail genome with a unique map ranging from 91.59–93.70% (Additional file 2: Table S1). The Pearson's correlation coefficient heated map showed that samples under treatment clustered together (Fig. 4A). A total of 5975 DEGs were detected in tiller buds, of which 2698 DEGs were up-regulated and 3277 were down-regulated under treatment at 7 DAT (Fig. 4B; Additional file 1: Table S2).

GO and KEGG Enrichment Analysis

To gain insights into the DEGs functional categories, GO enrichment analysis was used to evaluate the specific functional role of all DEGs. The "cellular process" and "metabolic process" were the top GO terms in the "biological process" group. The "cellular anatomical entity", "intracellular" and "protein-containing complex" were significantly enriched in "cellular component" group. The "binding", "catalytic activity" and "transporter activity" categories were the most enriched GO terms in the "molecular function" group (Additional file 1: Figure S2).

To understand the functional enrichment classification of DEGs, KEGG analysis was carried out. Carbon fixation in photosynthetic organisms, Photosynthesis-antenna proteins, Phenylpropanoid biosynthesis, Fatty acid elongation, Photosynthesis, Porphyrin and chlorophyll metabolism, ABC transporters, Cutin, suberine and wax biosynthesis, Glutathione metabolism, Plant hormone signal transduction, Starch and sucrose metabolism, Carotenoid biosynthesis, Flavonoid biosynthesis, Fructose and mannose metabolism, Diterpenoid biosynthesis, were the top 15 enriched pathways at 7 DAT ($q < 0.05$) (Fig. 4C).The plant net photosynthetic rate was reduced in the T4 (Fig. 2) and the SPAD was also reduced in the leaves (Additional file 1: Figure S3), which might explain the regulated genes in pathways of photosynthesis, porphyrin and chlorophyll metabolism, and photosynthesis-antenna proteins. Although the 2,4-D isooctyl ester was sprayed on the leaves, genes involved in plant hormone signal transduction

accumulated after treatment. It was speculated that 2,4-D might affect the plant hormone signal transduction and disturb the distribution and equilibrium of other plant hormones in the tillers.

Differentially Expressed Genes Analysis

Given the above speculation, plant hormone metabolism and signal transduction pathways were further analyzed. DEGs were highly enriched in the plant hormone signal transduction pathways in tiller buds of green foxtail under treatment (Fig. 4C). A total of 49 DEGs related to auxin signal transduction pathway were identified (Fig. 5A). Among them, the expression levels of GH3 genes were highly enhanced after 2,4-D isooctyl ester treatment (Fig. 5A). Clearly, the expression levels of AUX/IAA, ARF, and SAUR genes were also regulated after 2,4-D isooctyl ester treatment. To verify this result, nine DEGs related to auxin signal transduction were randomly selected and their expression levels were validated by qRT-PCR. Indeed, the data between RNA-seq and qRT-PCR were consistent (Fig. 5B).

Similar results were also found in the CTK, ABA, GA, and BR synthesis and signal transduction pathways (Fig. 6; Additional file 1: Table S3). Two DEGs (*Sevir.1G319700* and *Sevir.4G202400*) annotated as cytokinin receptors (histidine kinase 2/3/4, AHK2_3_4) were upregulated and cytokinin regulators encoding genes of cytokinin signaling response regulators Type-A and type-B were downregulated. The genes encoding gibberellin receptor GID1 (*Sevir.2G045600*, *Sevir.2G395200*, *Sevir.2G422700*, and *Sevir.8G084700*) were downregulated. Genes encoding abscisic acid receptor PYR/PYL family (*Sevir.3G213000*, *Sevir.7G137000*, and *Sevir.9G438800*) were downregulated and their downregulated genes encoding ABA responsive element binding factor (ABF; *Sevir.2G239700*, *Sevir.2G452300*, and *Sevir.4G081100*) were upregulated. In the BR signal transduction pathway, *TCH4*, encoding a xyloglucan endotransglycosylase, was downregulated after 2,4-D isooctyl ester treatment. Therefore, it was speculated that the different impacts of 2,4-D isooctyl ester on tillering growth in green foxtail were attributed to different plant hormone metabolism and signal transduction responses.

MIR156- regulatory module is well believed to be involved in branching and tillering development in plant species [20]. Besides the above-mentioned genes in the plant hormone signal transduction pathways, transcriptomic analysis showed that six DEG belonging to SPL (SQUAMOSA PROMOTER BINDING PROTEIN-LIKE) family (*Sevir.2G276900*, *Sevir.4G200400*, *Sevir.2G336300*, *Sevir.2G336100*, *Sevir.3G023500*, and *Sevir.1G065500*) was downregulated.

Effects of phytohormones on tiller in green foxtail

Since genes involved in the phytohormones signal transduction pathways were regulated after 2,4-D isooctyl ester treatment, it was speculated that spaying other phytohormones besides auxin might also change tiller growth in green foxtail. Indeed, spraying GA3 and ABA on leaves also inhibited tiller growth (Additional file 1: Figure S4). But there was no significant effect after CTK application on tiller number (Additional file 1: Figure S4). Here, spraying 2,4-D isooctyl ester can affect the leaf chlorophyll content and reduce its photosynthetic efficiency, which might reduce plant carbon fixation (Fig. 7). On the other way, the treatments would affect the plant hormone distribution in the tillering buds. The reduced energy and varied plant hormone distribution affected the tiller growth (Fig. 7).

Discussion

Synthetic hormones besides auxins are used as growth regulators for improving crop yield in agriculture, and as herbicides for controlling weeds [16]. The green foxtail is one of the most troublesome annual grass weeds in crop and alfalfa fields in China. The 2,4-D is one of the most widely used synthetic auxin herbicides for the control of weeds in pastures, especially for some Poaceae crops for the control of broadleaf weeds and spare monocots [17–19]. But the effects of 2,4-D on green foxtail, especially on tillering, are unclear. Here, the effects on plant growth especially for the tiller bud were analyzed under different dose of 2,4-D isooctyl ester. Our study showed that high dose application of 2,4-D inhibited plant growth and reduced the number of tiller buds significantly.

Tillering is controlled by genetic factors and environmental factors [21, 22]. Plant carbohydrate status is well known to affect tillering, and therefore reducing carbohydrate supply have been developed to account for how this factor modulates tillering under field conditions [23, 24]. Changes in photosynthetic leaf area affect the propensity of tiller buds for outgrowth in sorghum [25]. Sugars is necessary and sufficient for the release of axillary buds for their apical dominance [26]. Indeed, the SPAD value and photosynthetic efficiency were dramatically reduced. Application of 2,4-D reduced the plant photosynthesis, thereby reducing the carbon fixation. The declined carbon fixation and limited energy supply might suppress the growth of tillers. Here, it is speculated that the photosynthesis of green foxtail after 2,4-D treatment is weakened, unable to provide sufficient energy and produce less sugar for tiller bud development, which would partially explain the decrease in the number of tillers after the application of 2,4-D.

Phytohormones also play important roles in tiller bud outgrowth. The regulation of plant lateral growth by auxin has been reported in various plant species, but simulative and suppressive effects have also been reported depending on the plant species and auxin concentration [9, 10, 19]. No differences in giant foxtail control were observed among herbicide application methods for glyphosate using either dicamba or 2,4-D [19]. But the tiller buds are inhibited in crops such as rice and wheat after auxin was applied [9, 10]. Spraying indole-3-acetic acid (IAA) and naphthyl acetic acid (NAA, a synthetic auxin) on rice significantly restricted tiller bud elongation [9]. In wheat, tiller bud development was also completely inhibited by exogenous application of IAA [10]. Here, a relative high concentration of auxin on green foxtail would inhibit the tiller bud growth, which would reduce the seed production of weeds. Thus, application of synthetic auxin for weeds control depends on the species and the dosage.

Since the auxin pesticides were sprayed on leaves, it was unknown how it affected the tillering of green foxtail. Through the transcriptome data, the auxin transport and response genes were regulated after 2,4-D application. Clearly, the expression levels of GH3, AUX/IAA, ARF, and SAUR genes were also regulated after 2,4-D isooctyl ester treatment, suggesting that auxin may participate in the regulation of tillering through influencing the balances of endogenous auxin metabolism and signaling. 2,4-D can be moved throughout the plant through the phloem, and the reduction in tillers might cause by the variation of the phytohormone distribution in seedlings [19].

Besides the auxin response genes, other responses genes of phytohormones like CTK, GA, ABA, and BR were also regulated. Gene *TCH4*, encoding xyloglucan endotransglucosylase, was downregulated in tillers after 2,4-D application. BR is also a typical hormone controlling tiller initiation and there is a cross talk between auxin and BR signaling pathways [27–29]. *TCH4* can be regulated by BR because the promoter region of *TCH4* contains cis-regulatory element e-boxes binding to the transcription factor BES1 in the BR signaling pathway [30]. Genes involved in auxin were significantly upregulated in plant roots under BR treatment [27, 29]. CTK plays a positive role in axillary bud outgrowth and the CTK-mediated genes *A-ARR* have been reported to be required for bud release in *Arabidopsis* [31, 32]. Exogenous application CTK promotes axillary bud outgrowth, which is accompanied by increases in CK content in buds or adjacent nodes [11]. The CTK signal transduction genes, *A-ARR* and *B-ARR*, were found to be downregulated after 2,4-D application, which indicated that the application of 2,4-D could influence genes involved in CTK. Moreover, A-ARR may be the key factor in CTK signal transduction contributing to SLs-induced bud inhibition. SL represses auxin transport from the buds, thus inhibiting bud outgrowth whereas auxin up-regulates SL production to control apical dominance [12, 33]. Moreover, SLs can suppress the *A-ARR* expression independent of CTK signal transduction. ABA is associated with bud dormancy through an auxin-independent mechanism [34]. Therefore, application 2,4-D on the leaves affected the expression of several hormone signal transduction genes and might affect distribution of phytohormone levels in tillers. In addition to the hormone signal transduction genes, it is generally believed that the MIR156-SPL module participates in the regulation of plant architecture, including tillering [20]. In treated green foxtail plants, the expression levels of six SPL genes differed from those in untreated plants. It is speculated that variation of distribution of hormone levels would be another main reason affecting the tillering of green foxtail after 2,4-D treatment.

CONCLUSION

Tiller production is important for grass weeds control. The 2,4-D is one of the most widely used synthetic auxin herbicide to control weeds in pastures. However, how 2,4-D affects tillering in grass weeds is still unclear. This study aims to elucidate the roles and the underlying mechanisms of auxin in regulating tiller development. Green foxtail seedlings were treated with different concentrations of 2,4 isooctyl ester and dose-dependent inhibitory effects on tiller production were observed. Auxin-inhibition of tillering was mainly due to its effect on inhibition of photosynthesis and the distribution of other plant hormones, as shown by the changed plant hormone signal transduction expression in 2,4 isooctyl ester treated plants. Furthermore, auxin could act through regulating the expression of SPL specifically expressed in axillary buds to induce bud outgrowth. These results provide insights into the regulatory mechanisms of auxin for tiller bud outgrowth through crosstalk with phytohormones.

MATERIALS AND METHODS

Plant Material, growth conditions

Wild-type A10.1 seeds of green foxtail (*S. viridis*) were germinated in petri dishes for seven days. After emergence, green foxtail seedlings were sown to six uniform seedlings per pot containing a mixture of soil, vermiculite, and organic fertilizer (3:1:1, v/v/v) and grown under greenhouse conditions at a temperature of 25°C, with a 16 h/8 h photoperiod at a relative humidity of 65%. The plants were periodically watered weekly with Hoagland solution.

2,4-D isooctyl ester treatment

2,4-D isooctyl ester 50% emulsifiable concentrate (EC) was provided by Shandong Zhongshi Pharmaceutical Co., Ltd. (Liaocheng, China). Twenty-five-day-old seedlings, reached the 3- to 4-leaf stage and the length of the tiller bud in the first tiller bud was less than 5 mm, were treated with 2,4-D isooctyl eater at concentrations of 525, 1050, 2100, 4200, and 8400 g a.i. ha^{-1} (a.i., active ingredient). Deionized water spray was used as a control. Spraying was performed using a 3WP-2000 Walking Spray Tower (Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing, China). The tiller buds were measured in 30 seedlings per treatment at 7 DAT, and the experiment was conducted in three independent replicates.

External Application of ABA, GA3, and 6-BA

To ascertain the effects of exogenous ABA, GA and CTK on tiller growth, ABA, GA3, and 6-BA were applied to green foxtail. Uniform 20-day-old seedlings were treated with ABA, GA3 or 6-BA at concentrations of 300, 600, and 1200 $mg.L^{-1}$. Deionized water was applied as a control. Plants were sprayed twice with a 3WP-2000 Walking Spray Tower. Each treatment included five pots containing six seedlings each, and the experiment was repeated three times.

Measurement of Leave Photosynthetic Rate and Measurement of Enzyme Activity Assay

The photosynthetic rate of the uppermost expanded leaves was measured with an LI-6800 portable photosynthesis system at 7 DAT. The photosynthetically active radiation was set to 800 $\mu mol.m^{-2}.s^{-1}$. The freeze-dried and powered leaf samples were used to analyze the content of MDA and enzyme assay activities of CAT, POD, and SOD [35].

Sample Preparation for RNA Sequencing, qPCR Validation

Tiller buds of 1–2 cm were collected at 7 DAT and total RNA was extracted with the plant RNA kit (Vazyme, China) according to the manufacturer's instruction. RNA concentration and quality were assessed using a NanoDrop2000 and an Agilent 2100. The mRNA was obtained by enriching qualified RNA using magnetic beads equipped with oligo (dT). The library was constructed and the quality of the constructed libraries was strictly monitored before sequencing with an Illumina NovaSeq 6000.

A total of 1 μg RNA was used for the synthesis of first-strand cDNA for qRT-PCR (Vazyme, China). qPCR was carried out with SYBR Green (Takara, Tokyo, Japan) using the CFX96 (Bio-Rad, USA). The *β-actin* gene *Sevir.7G305900* was used as the reference gene to normalize the target gene expression levels in

green foxtail and the $2^{-\Delta\Delta CT}$ method was used to calculate the gene expression level. All qPCR primers are shown in Table S4.

Differential Expression and Gene Ontology enrichment Analysis

Quality control of raw reads was performed to remove adapter sequences and clean reads were mapped against the *Setaria viridis* reference genome (*Setaria viridis* v4.1). The comparison of gene expression differences was carried out between treatment (T4) and control (T0). All DEGs were subjected to Gene Ontology (GO) enrichment analysis using the GOseq R package. Additionally, Kyoto Encyclopedia of Genes and Genomes (KEGG) pathway analysis was also performed on the DEGs. The functional categories of DEGs were obtained from GO enrichment analysis using R package cluster Profiler [36]. A corrected $p < 0.05$ was set as the significance cutoff.

Statistical Analysis

All experiments were performed with three replicates, and the means and standard deviations were calculated. The 2,4-D isooctyl ester-dose response to tiller number was fit to a logistic nonlinear regression model using Origin software: $Y = A2 + (A1 - A2)/[1 + (X/X0)^b]$, where X is the dose or concentration of herbicide and Y is the response at herbicide concentration or dose X [37]. ANOVA was employed to evaluate the effect of external treatment with 2,4-D isooctyl ester using IBM SPSS software. Differences were distinguished by LSD test at the 0.05 probability level.

Abbreviations

2,4-D 2,4-dichlorophenoxy acetic acid

DEG Differential expression gene

DAT Days after treatment

FPKM Fragments per kilobase of exon model per million mapped reads

GA Gibberellic acid

GO Gene Ontology

IAA indole-3-acetic acid

NAA naphthyl acetic acid

KEGG Kyoto Encyclopedia of Genes and Genomes

Pn net photosynthetic rate

Tr Transpiration rate

SL Strigolactone

Declarations

Author Contributions

SJ, and XW conducted experimental design and manuscript writing. XW, JX, WQ, ZN, GH conducted the experiments. XW, WQ, and ZL participated in data collection and analysis. All authors approved the submitted version.

Funding

This work was supported by grants from China Agriculture Research System (CARS-34), Natural Science Foundation of Shandong Province (ZR2023MC071), Innovation Training Program for college students in Shandong province (S202310435231), and Qingdao Agricultural University high-level talent research fund (Grant No. 1120007).

Availability of data and materials

The data involved in this study are listed in the article and its additional files.

Ethics approval and consent to participate

This study does not address ethical issues.

Wild-type A10.1 seeds of green foxtail (*Setaria viridis*) were obtained from the GermplasmResources Information Network (GRIN, http://www.ars-grin.gov/), and it was used for research study only. All the study procedures were carried out in accordance with relevant guidelines.

Conflict of Interest

The authors declare that there is no conflict of interest.

Consent for publication

Not Applicable

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Figures

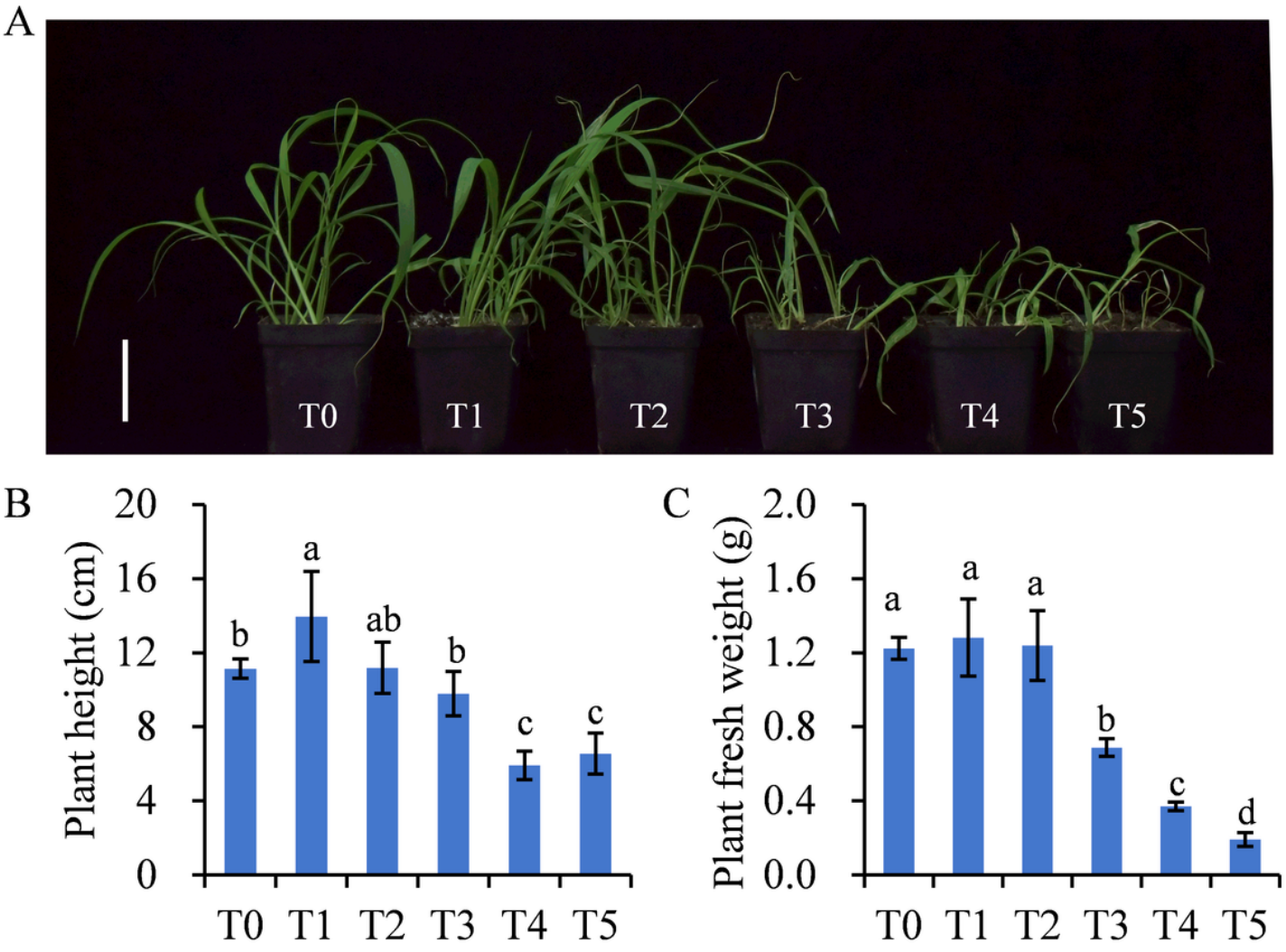


Figure 1

Effect of 2,4-D on green foxtail after 7 days treatment.

Plant phenotype (A), shoot height (B), and fresh weight (C) were measured after 7 days treatment. T0 to T5 represented concentrations of 0, 525, 1050, 2100, 4200, and 8400 g a.i. ha^{-1}, respectively. The bar in Figure 1A indicates 5 cm.

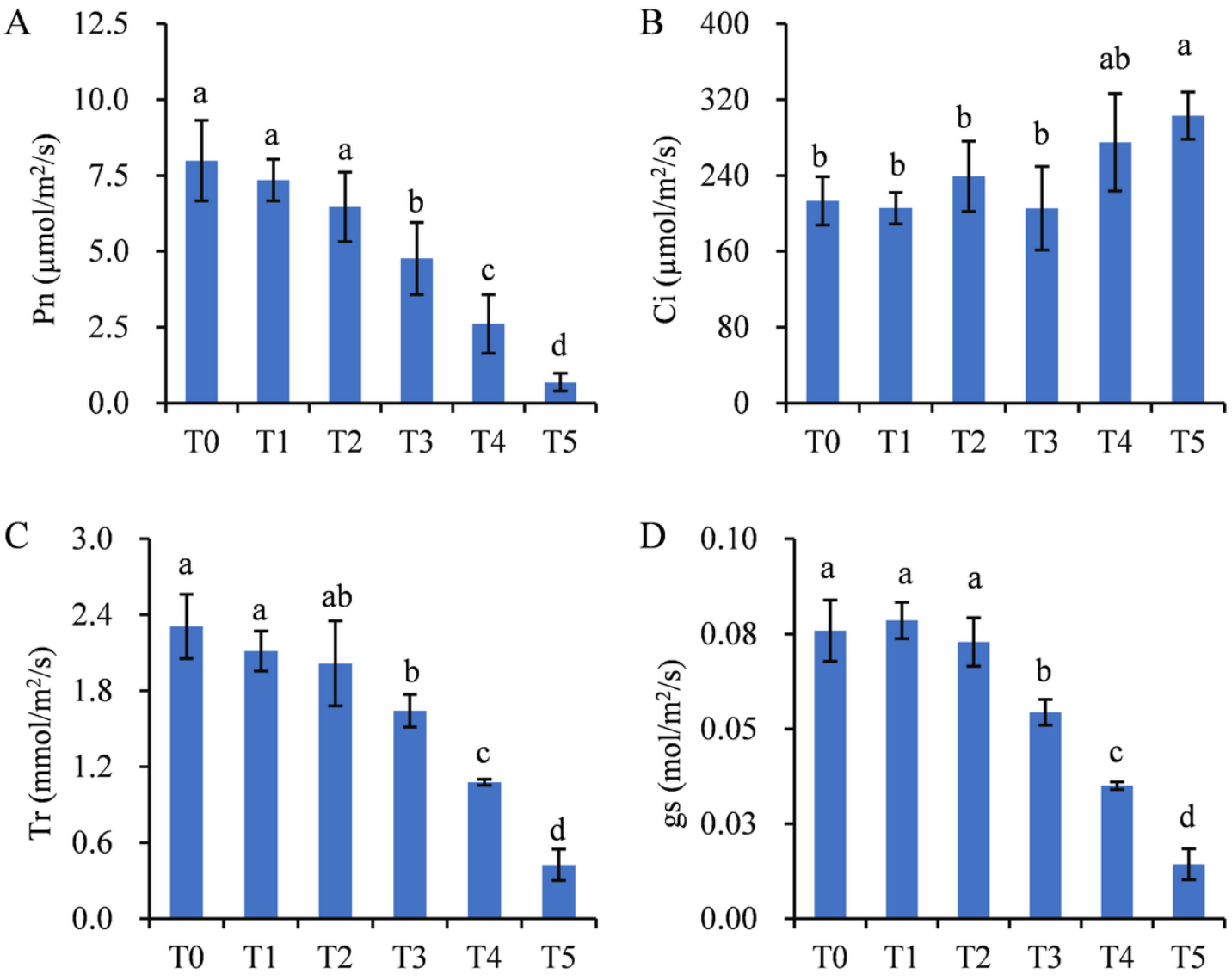


Figure 2

Effect of 2,4-D on leaf net photosynthetic rate (Pn), intercellular CO_2 concentrations (Ci), transpiration rate (Tr), and stomatal conductance (gs) of green foxtail after 7 days treatment. T0 to T5 represented concentrations of 0, 525, 1050, 2100, 4200, and 8400 g a.i. ha^{-1}, respectively.

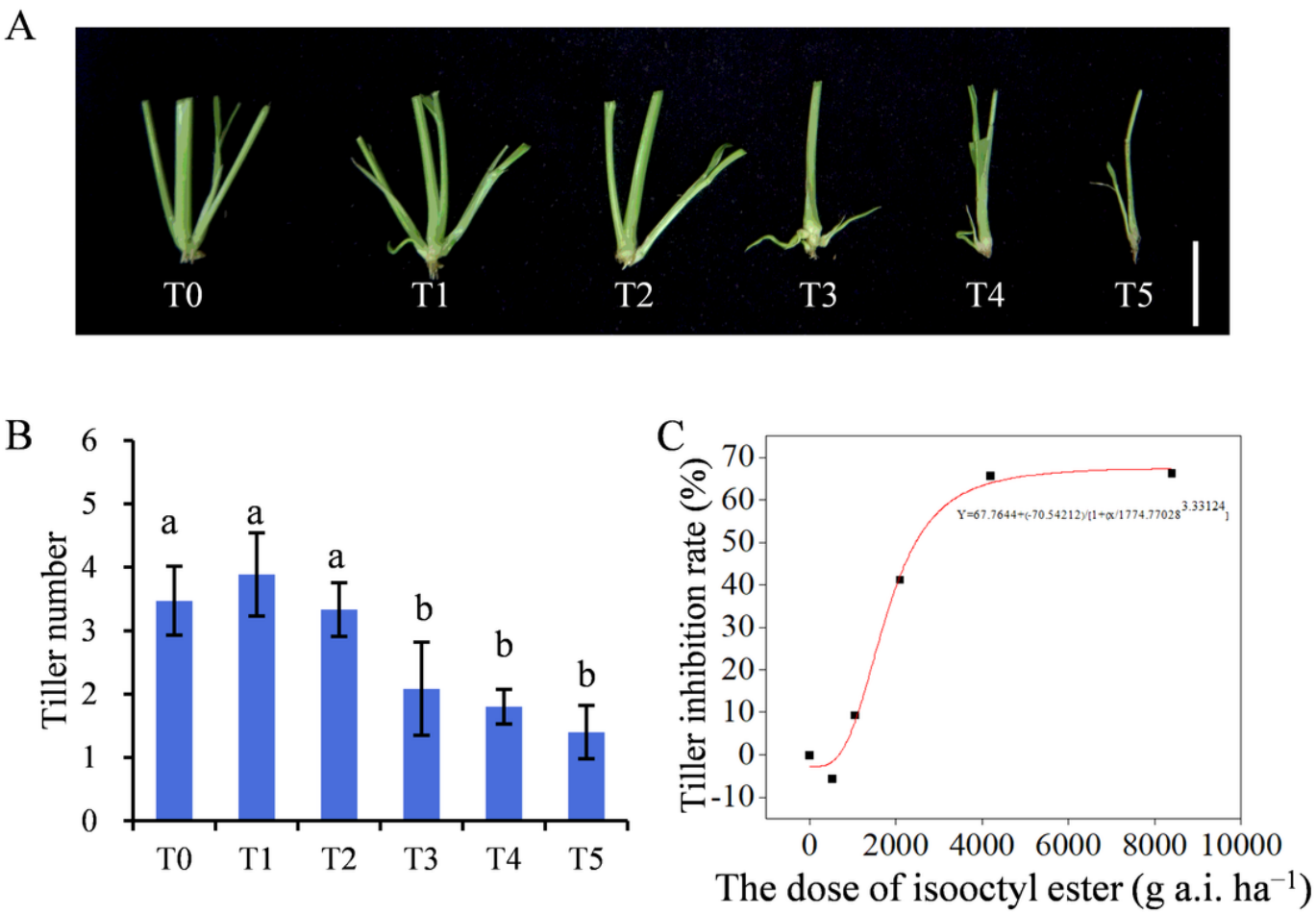


Figure 3

Effect of 2,4-D on tillers in green foxtail after 7 days treatment.

Plant tiller phenotype (A), tiller number (B), and dose response of tiller growth (C) were measured after 7 days treatment. T0 to T5 represented concentrations of 0, 525, 1050, 2100, 4200, and 8400 g a.i. ha^{-1}, respectively. The bar in Figure 3A indicates 2 cm

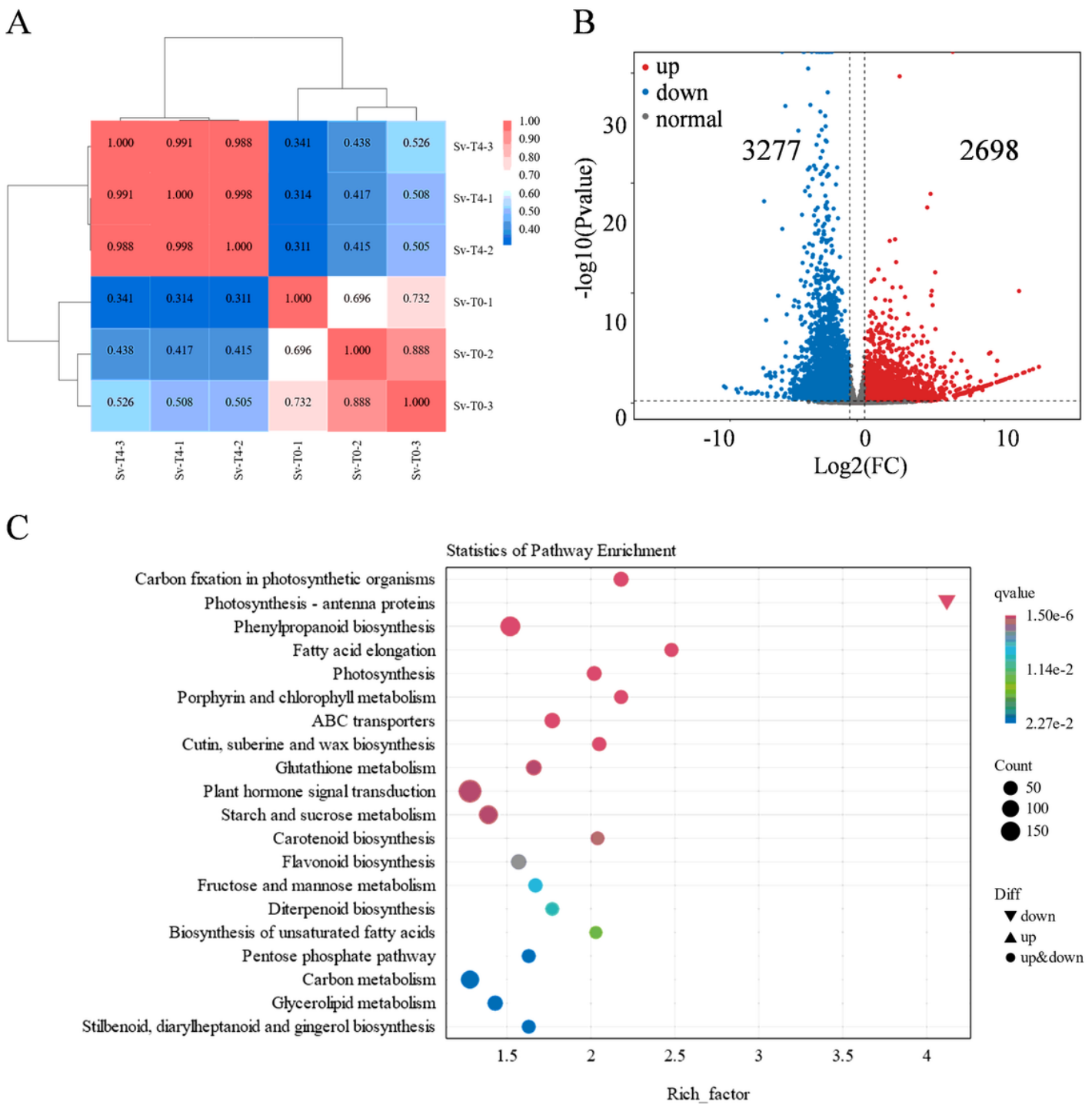


Figure 4

Pearson's correlation (A), differentially expressed genes (B), and KEGG enrichment analysis (C) in green foxtail. Fold enrichment in a pathway means the ratio of the number of observed DEGs and expected DEGs.

T0 and T4 represented concentrations of 0 and 2100 g a.i. ha^{-1}, respectively.

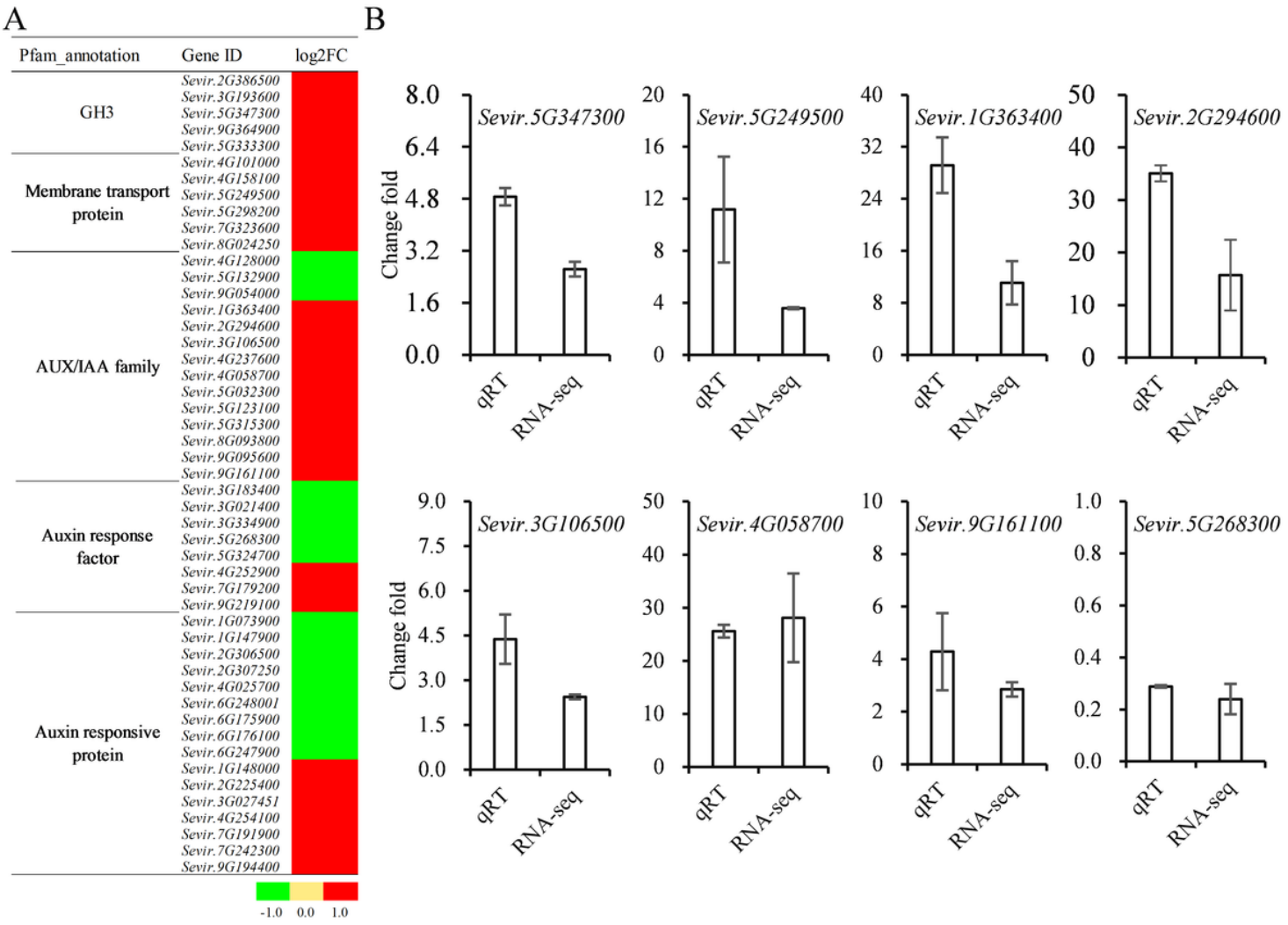


Figure 5

The expression level of DEGs related with auxin signal transduction in green foxtail based on log2 (fold change) with untreated plants as control. (A) DEGs related with auxin signal transduction in green foxtail log2 (fold change) are shown. (B) Change folds of qRT-PCR and RNA-seq of DEGs associated in green foxtail.

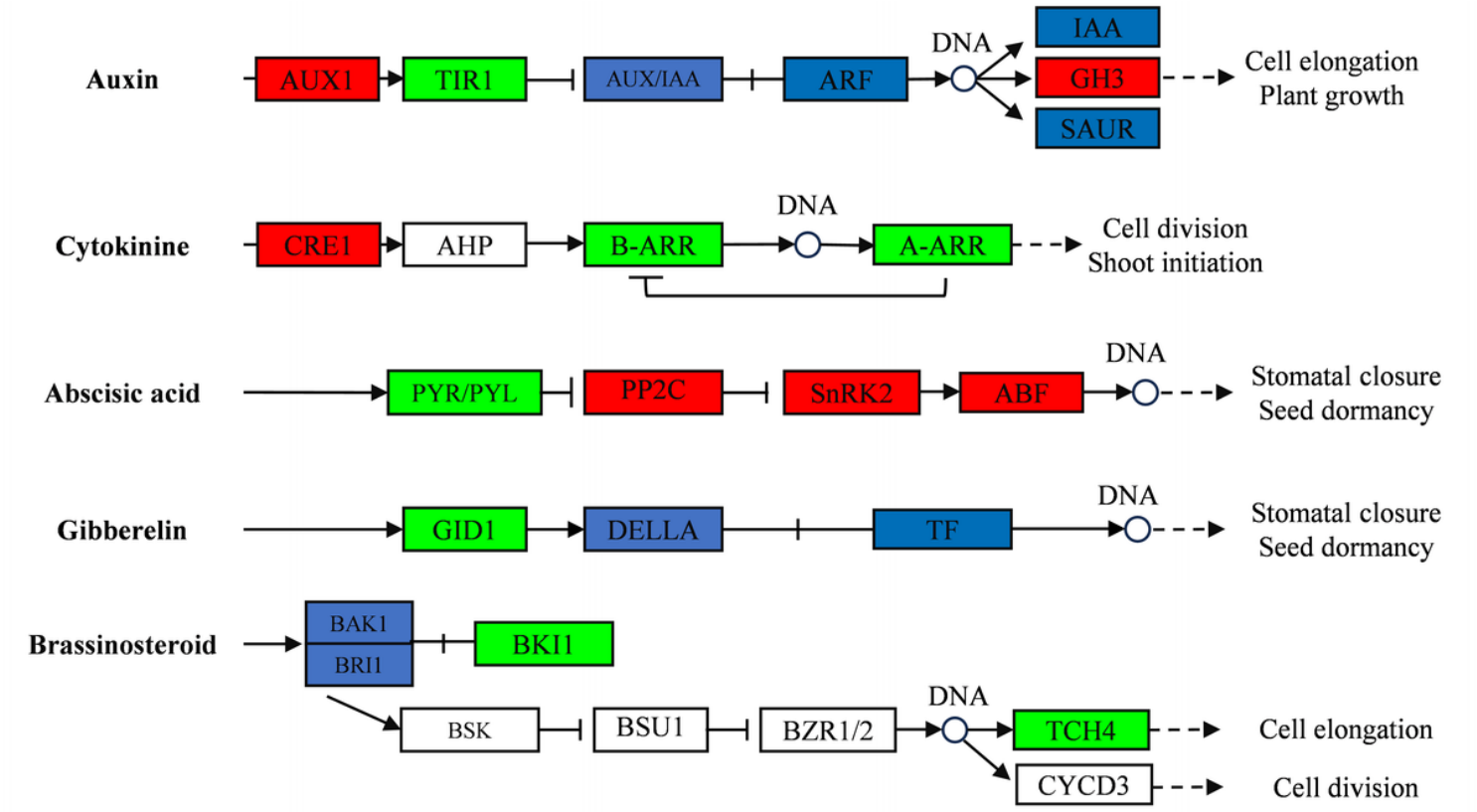


Figure 6

Map of the plant hormone signal transduction pathway.

The red and green rectangles indicate the DEGs upregulated and downregulated in the 2, 4-D treatment, respectively. The blue rectangle indicates that the DEGs containing both upregulated and downregulated.

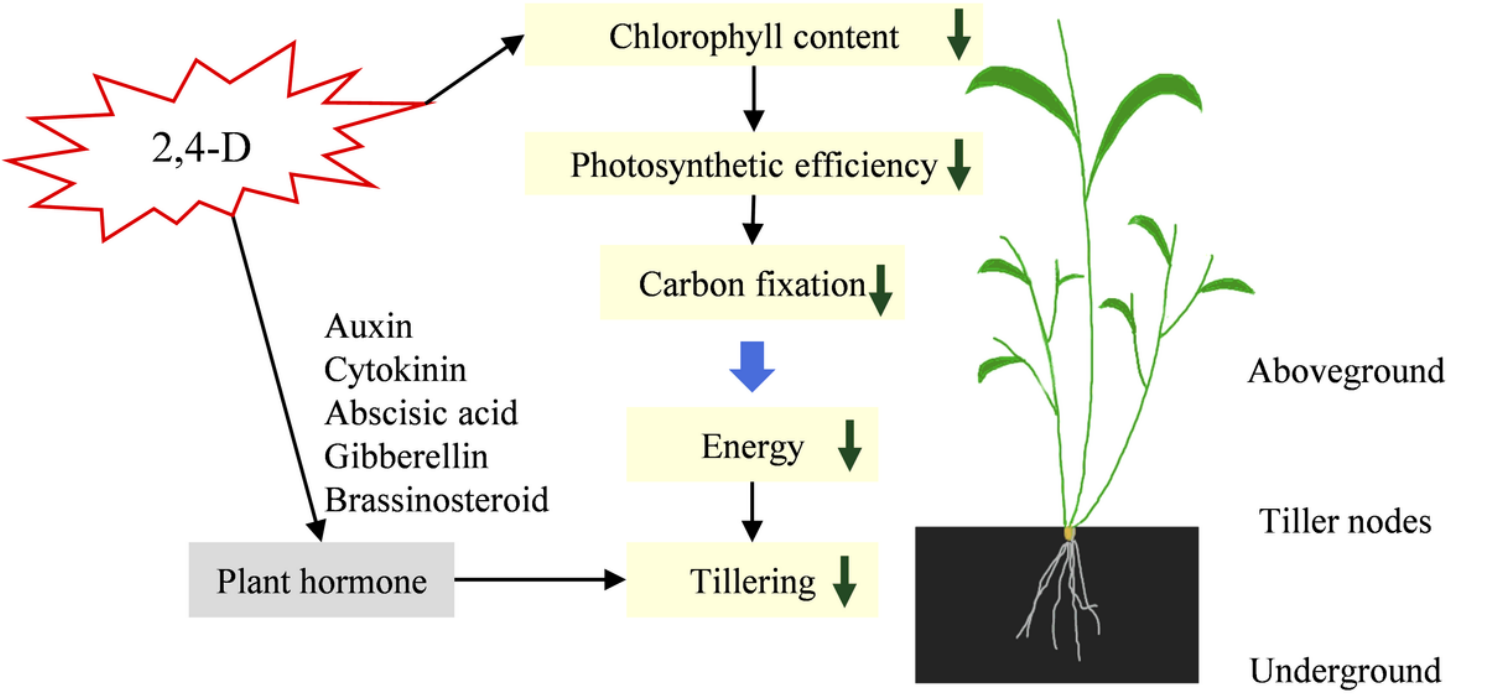


Figure 7

The regulatory network of green foxtail tillering response to 2,4-D.

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- Supplementaryfile1.docx
- Supplementaryfile2.xlsx