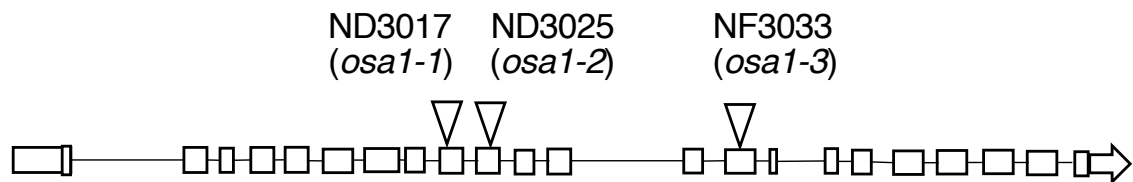
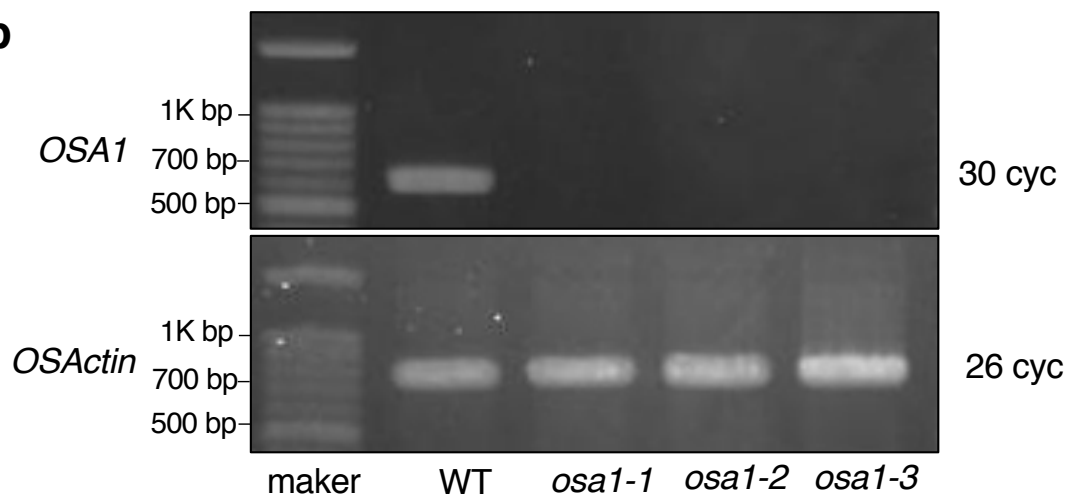
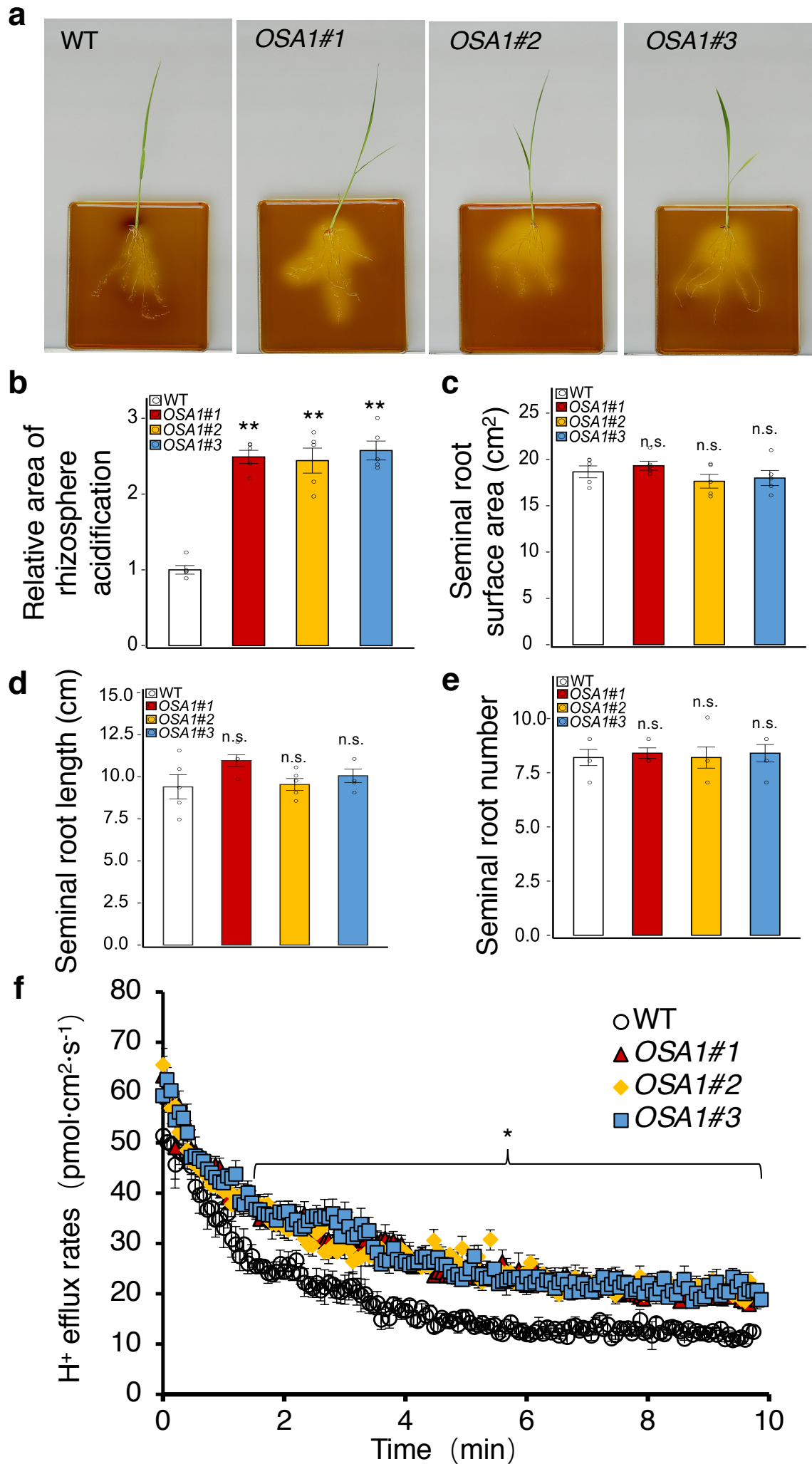


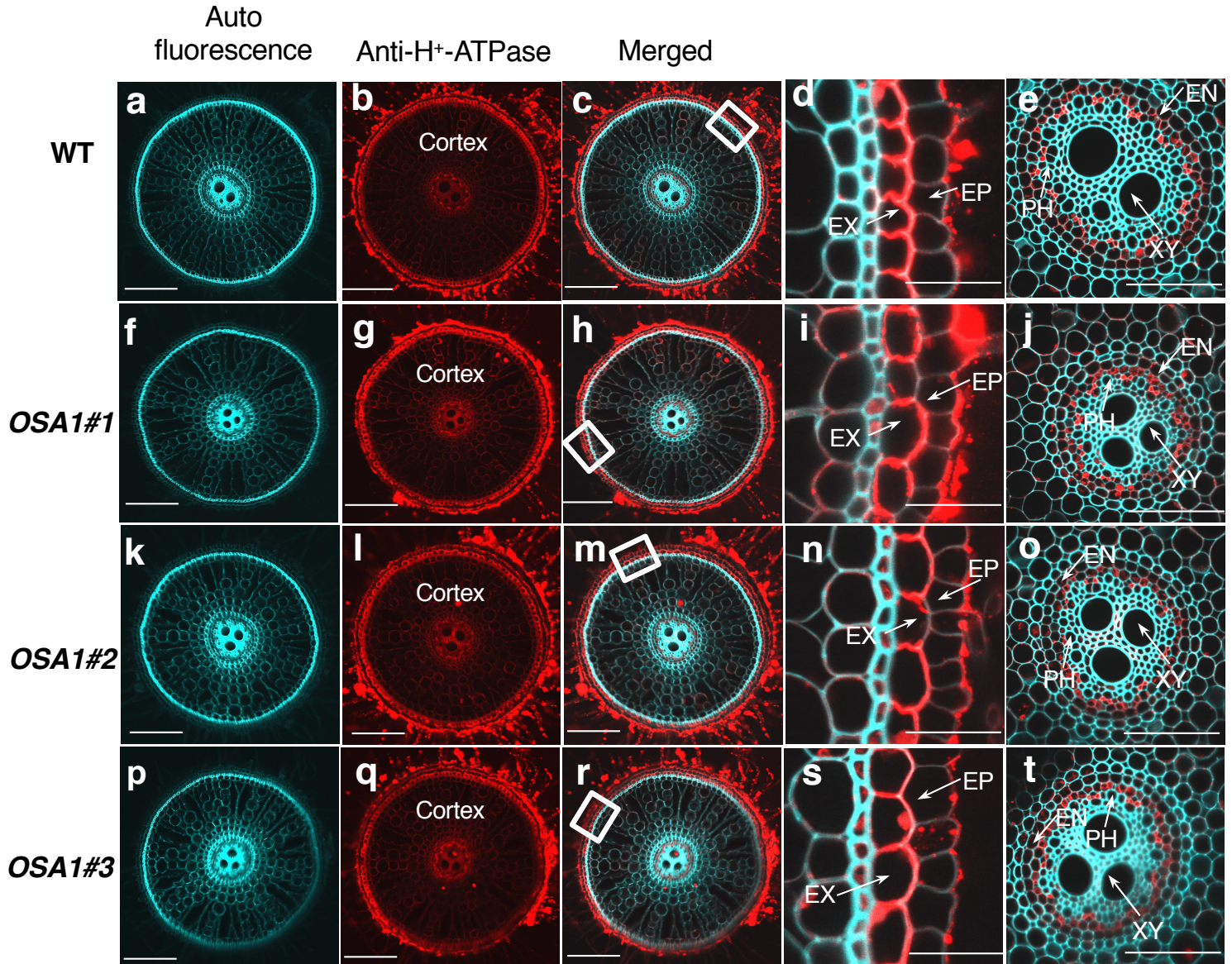
a**b**

Supplementary Figure 1 TOS17 insertion site and RT-PCR of *OSA1* in *osa1* mutants. a Schematic diagram of the genome structure of *OSA1*. Lines represent UTRs and introns. Exons are represented by white boxes. Positions of the *TOS17* insertion are indicated by small triangles. **b** *OSA1* expression in the roots of WT and *osa1* mutants by RT-PCR. Experiments were repeated three occasions with similar results.

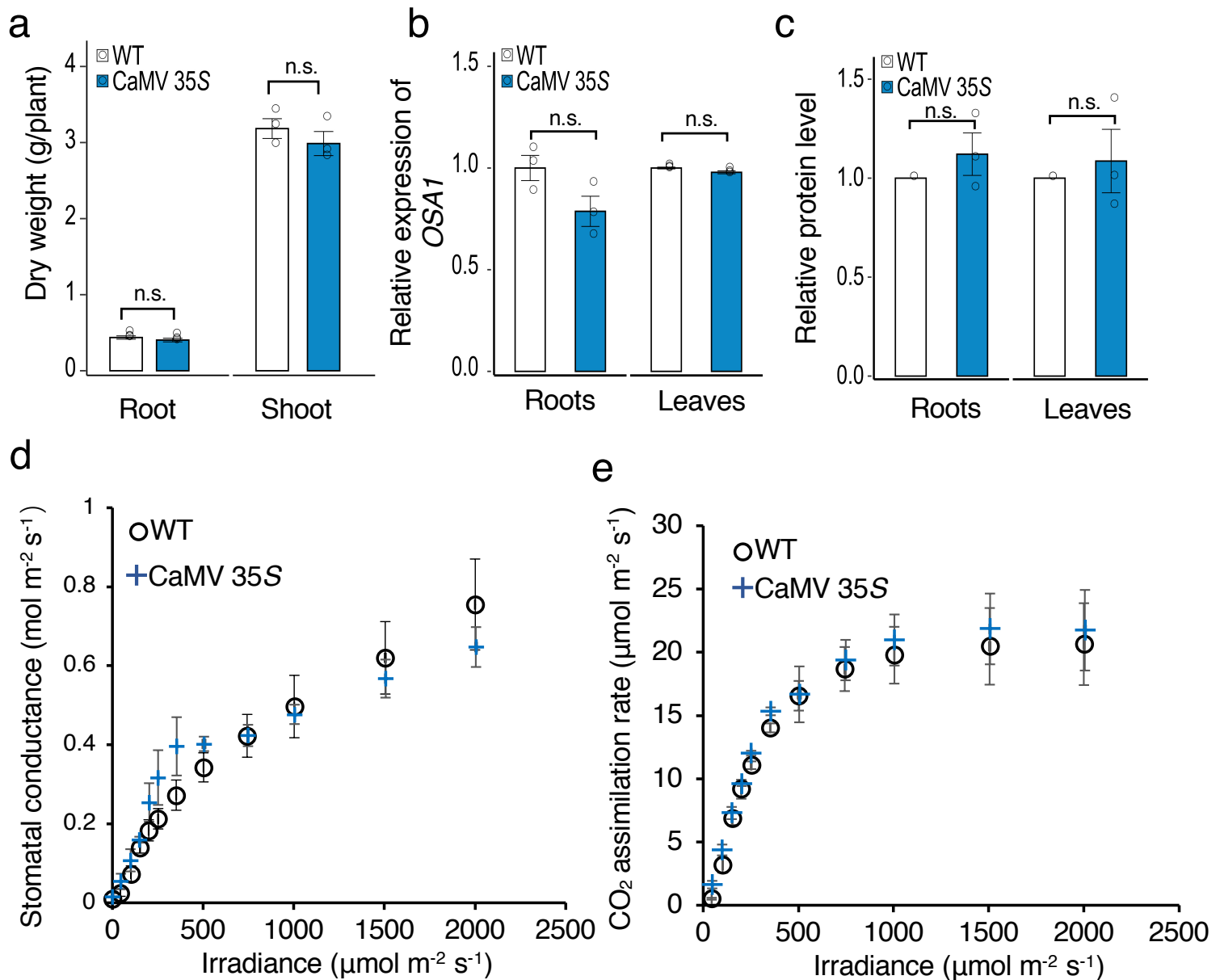


Supplementary Figure 2 Rhizosphere acidification and H⁺ efflux properties of WT and *OSA1*-oxs rice.

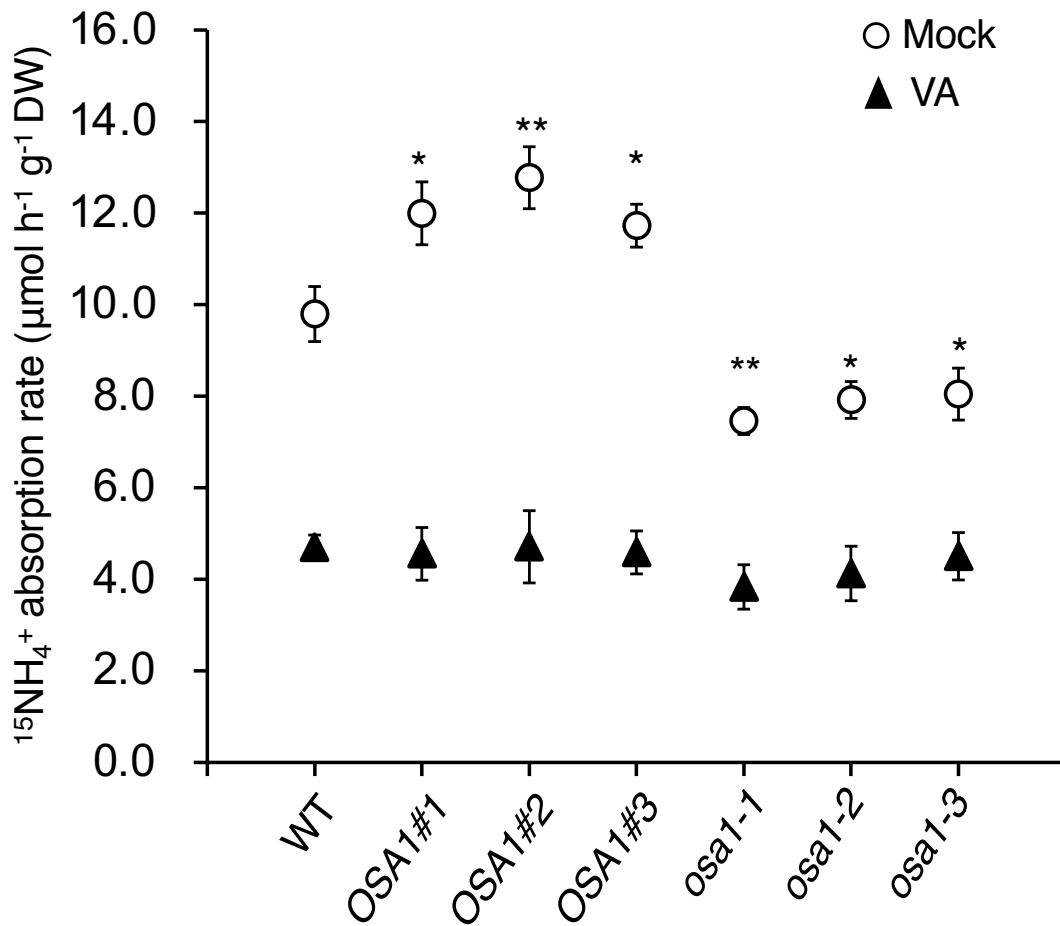
a Monitoring of rhizosphere acidification around WT and *OSA1*-oxs rice roots. Plants were grown in nutrient solution for 7 days. After washing with deionized water, roots were carefully spread onto solid medium containing 0.02% (w/v) bromocresol purple and 0.7% (w/v) agar adjusted to pH 5.6. After incubation for 12 hr in the dark, the plates were photographed. **b** Relative area of rhizosphere acidification (yellow area) on the surface of agar plates. **c-e** Surface area (**c**), length(**d**) and number (**e**) of seminal roots in WT and *OSA1*-oxs. Small circles represent the data points of individual experiments were performed. Values are mean $\pm$ SEs (n = 5). **f** Quantification of H⁺ efflux rates from WT and *OSA1*-oxs roots. Intact roots (3-5 cm in length from the root tips) were equilibrated in the measuring solution for 10 min. Values are mean $\pm$ SEs (n = 6). Differences were evaluated using the two-tailed Student's *t*-test (**P* < 0.05; ***P* < 0.01, n.s., not significant). The exact p values are provided in the Supplementary Data 5.



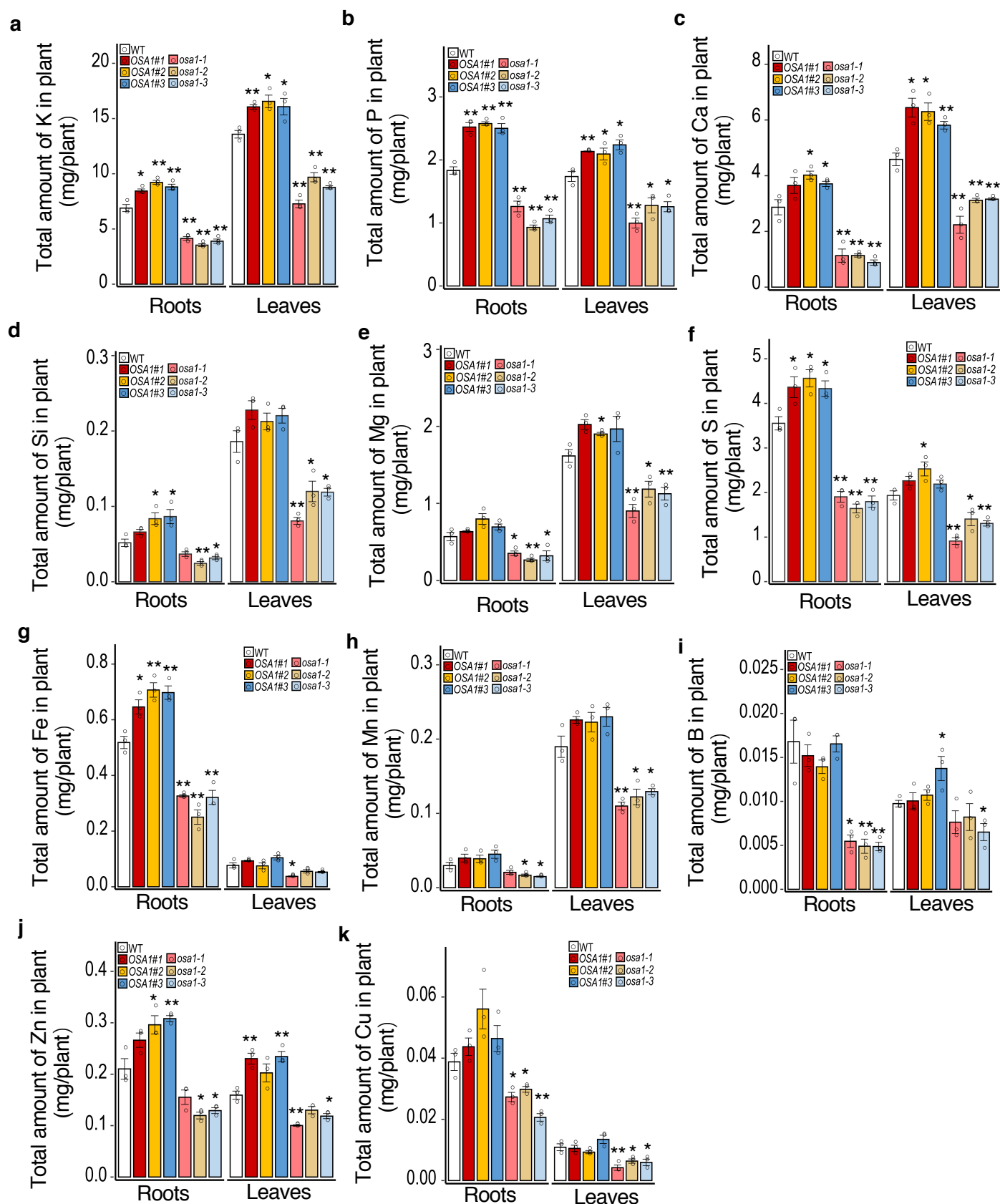
Supplementary Figure 3 Localization of PM H⁺ ATPase in rice roots. Immunohistochemical staining of 3-weeks-old seedlings in WT and *OSA1*-oxs, with polyclonal antibodies recognizing rice PM H⁺-ATPase (anti-H⁺-ATPase) was performed in rice root. Red color shows the signal of anti-H⁺-ATPase (b, j), blue color shows autofluorescence of cell wall stained by DAPI(a, f), and the merged image (c-e and h-j). EP, epidermis; EX, exodermis; EN, endodermis; PH, phloem; XY, xylem. Bars = 150 μm (a-c, f-h, k-m and p-r) ,20 μm (d, i, n and s) and 60 μm (e, j, o and t). Experiments were repeated three occasions (a-t) with similar results.



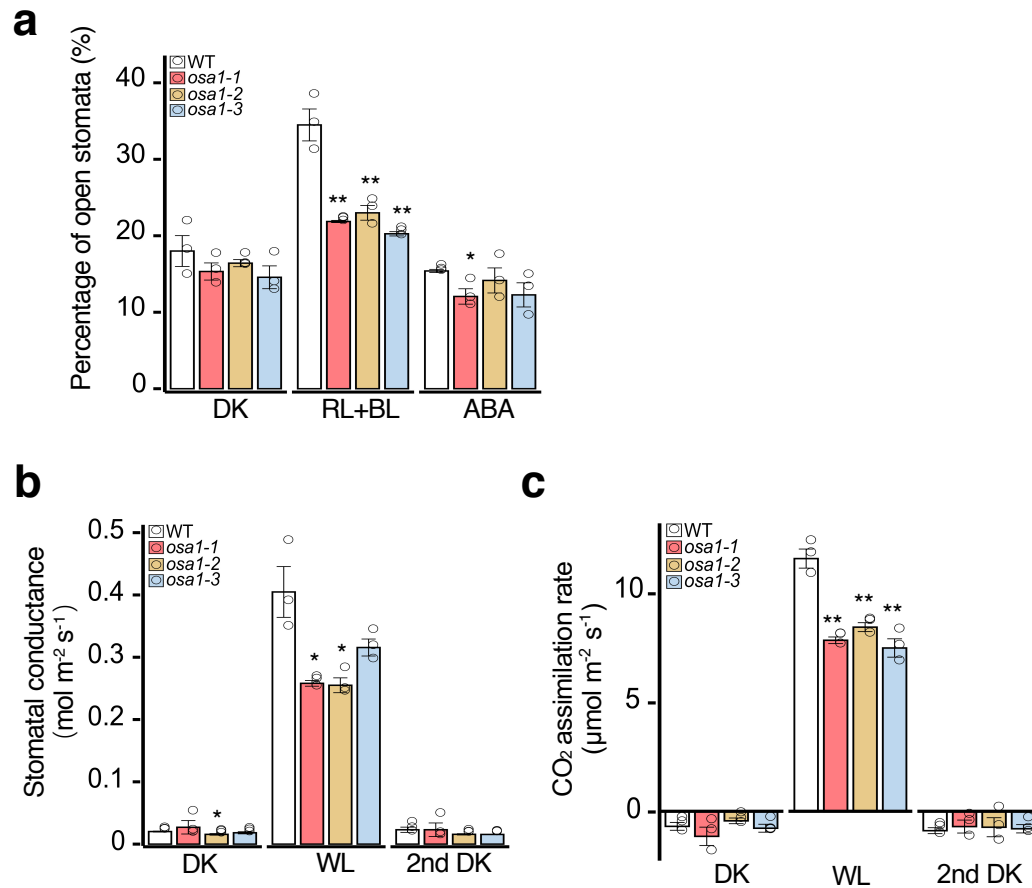
Supplementary Figure 4 Plant growth and gas-exchange properties in CaMV 35S empty vector transformed rice. **a** Dry weights of root and shoot in WT and CaMV 35S empty vector transformed plants. **b** Relative expression level of *OSA1* in the roots and leaves of WT and CaMV 35S empty vector transformed plants. **c** Relative PM H⁺-ATPase protein levels in the roots and leaves WT and CaMV 35S empty vector transformed plants. **d**, **e** Stomatal conductance (**d**) and CO₂ assimilation rate (**e**) in response to light in WT and CaMV 35S empty vector transformed plants. Small circles in (**a-c**) represent the data points for individual experiments and three biological replicates were performed. Values in (**a-c**) are presented as the means $\pm$ SEs ($n = 3$) and those in (**d**, **e**) are the means $\pm$ standard deviations ($n = 3$). Differences in (**a-c**) were evaluated using the two-tailed Student's t-test (* $P < 0.05$; ** $P < 0.01$).



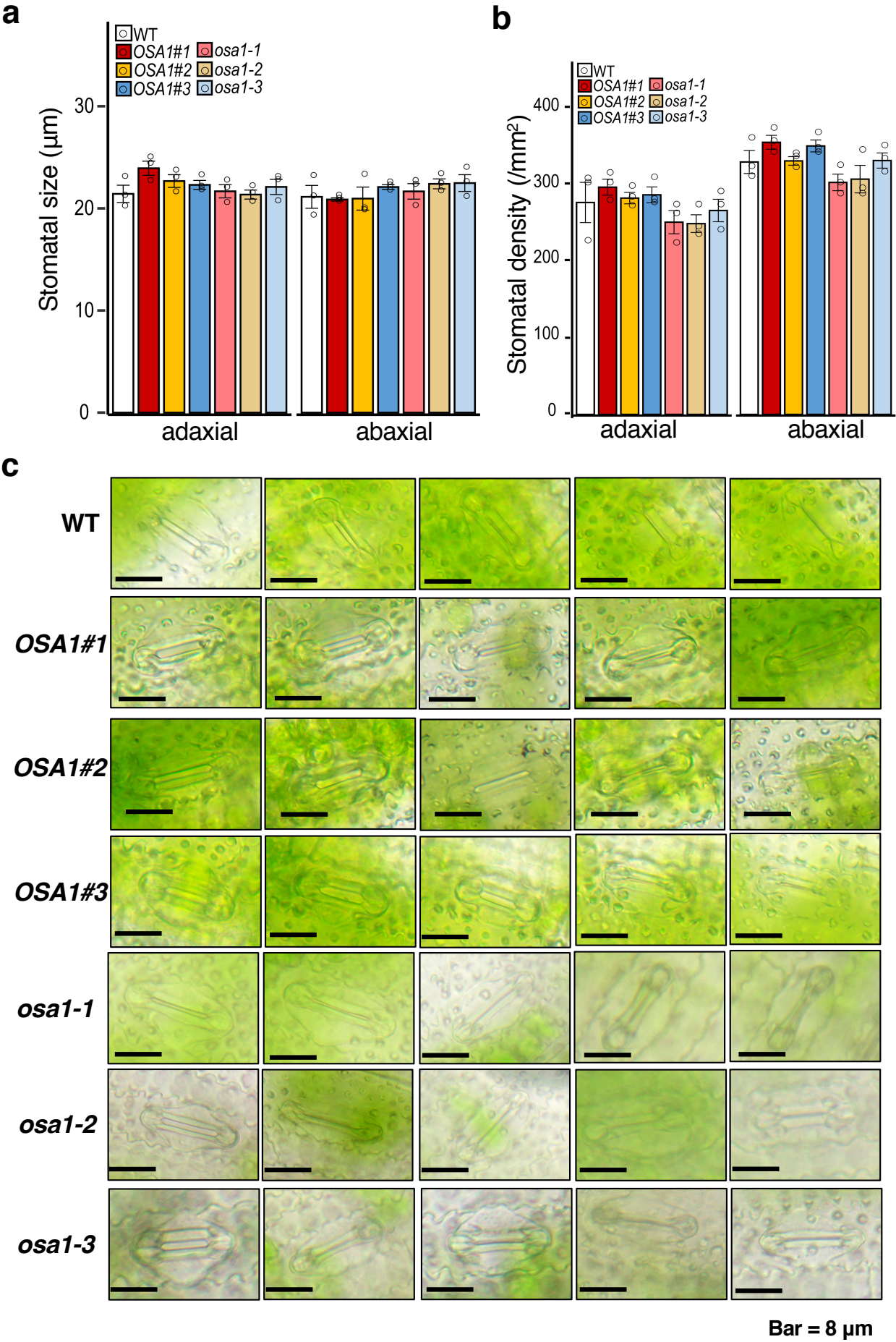
Supplementary Figure 5 ^{15}N absorption rate by WT and *OSA1*-oxs, and *osa1* mutants. Rice plants were grown hydroponically in a greenhouse for 4 weeks. To determine $^{15}\text{NH}_4^+$ absorption rates, seedlings were incubated in 2 mM $^{15}\text{NH}_4^+$ solution for 30 min under darkness with the treatment of 350 μM vanadate (VA) for rice roots. Values are the mean $\pm$ SEs ($n = 3$). Differences were evaluated using the two-tailed Student's *t*-test (* $P < 0.05$; ** $P < 0.01$). The exact *p* values are provided in the Supplementary Data 5.



Supplementary Figure 6 *OSA1* overexpression promotes nutrition elements uptake in rice. **a-k** Total amount of K (**a**), P (**b**), Ca (**c**), Si (**d**), Mg (**e**), S (**f**), Fe (**j**), Mn (**h**), B (**i**), Zn (**j**) and Cu (**k**) in WT and *OSA1*-ox and *osa1* mutant plants. Plants were grown hydroponically in a greenhouse for 3 weeks. Small circles in (**a-k**) represent the data points for individual experiments and three biological replicates were performed. Values in (**a-k**) are presented as the means $\pm$ SEs ($n = 3$). Differences were evaluated using the two-tailed Student's *t*-test (* $P < 0.05$; ** $P < 0.01$). The exact *p* values are provided in the Supplementary Data 5.

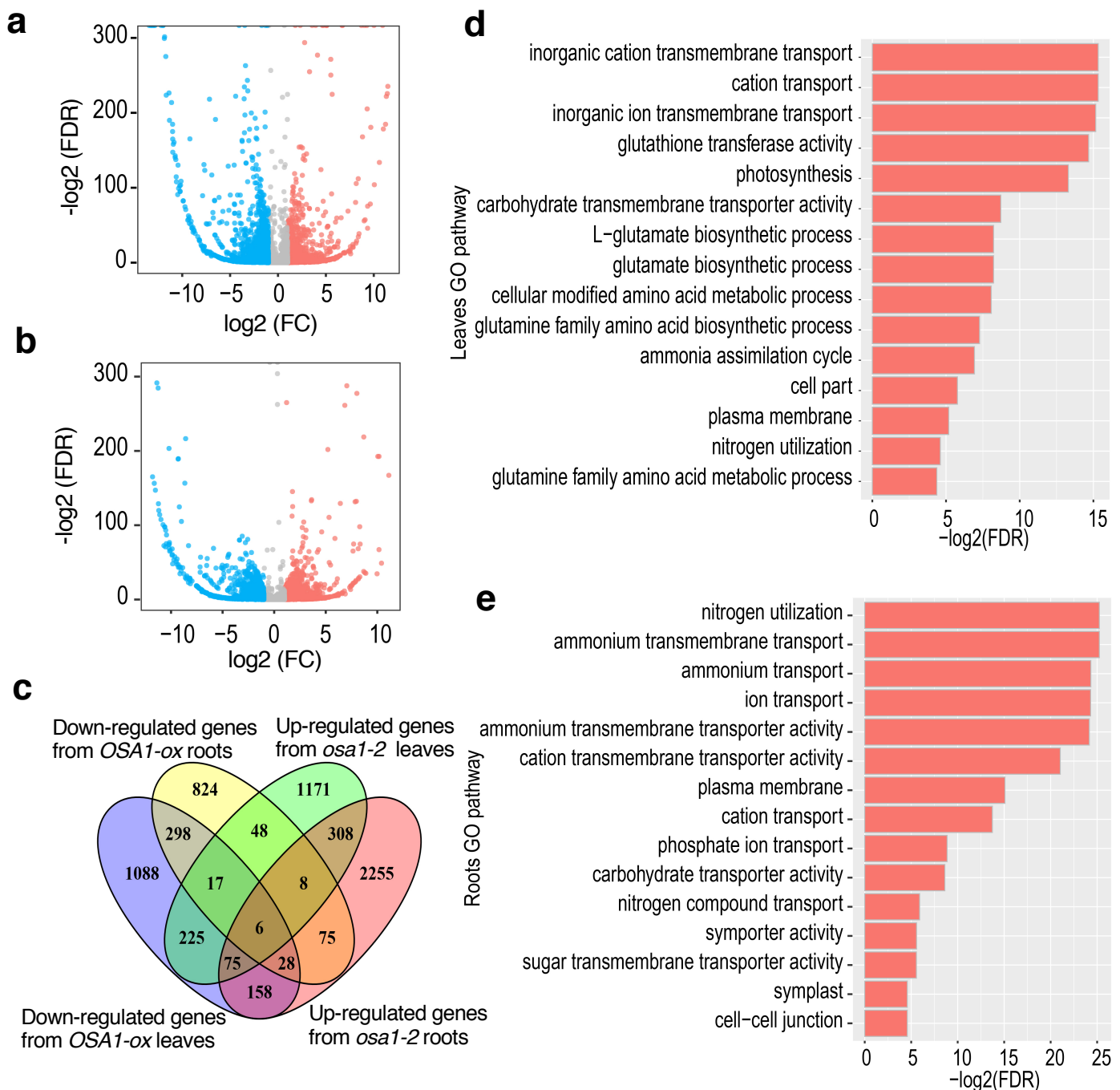


Supplementary Figure 7 Gas-exchange properties of *osa1* mutants. **a** Percentage of open stomata observed after 3 h of DK, RL+BL, or RL+BL in the presence of 20 μM ABA in WT. Differences were assessed using the Student's *t*-test. Error bars represent the SE ($n = 3$; at least 100 stomata observed under each condition). **b, c** Stomatal conductance (**b**) and CO_2 assimilation rate (**c**) in the DK (30 min), WL (2 h), and a 2nd DK treatment (30 min) in WT and *osa1* mutants, where light intensity was 1,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Small circles in (a) to (c) represent the data points for individual experiments and three biological replicates were performed. Values in (**a–c**) are presented as the means $\pm$ SEs ($n = 3$). Differences in (**a–c**) were evaluated using the two-tailed Student's *t*-test (* $P < 0.05$; ** $P < 0.01$). The exact *p* values are provided in the Supplementary Data 5.

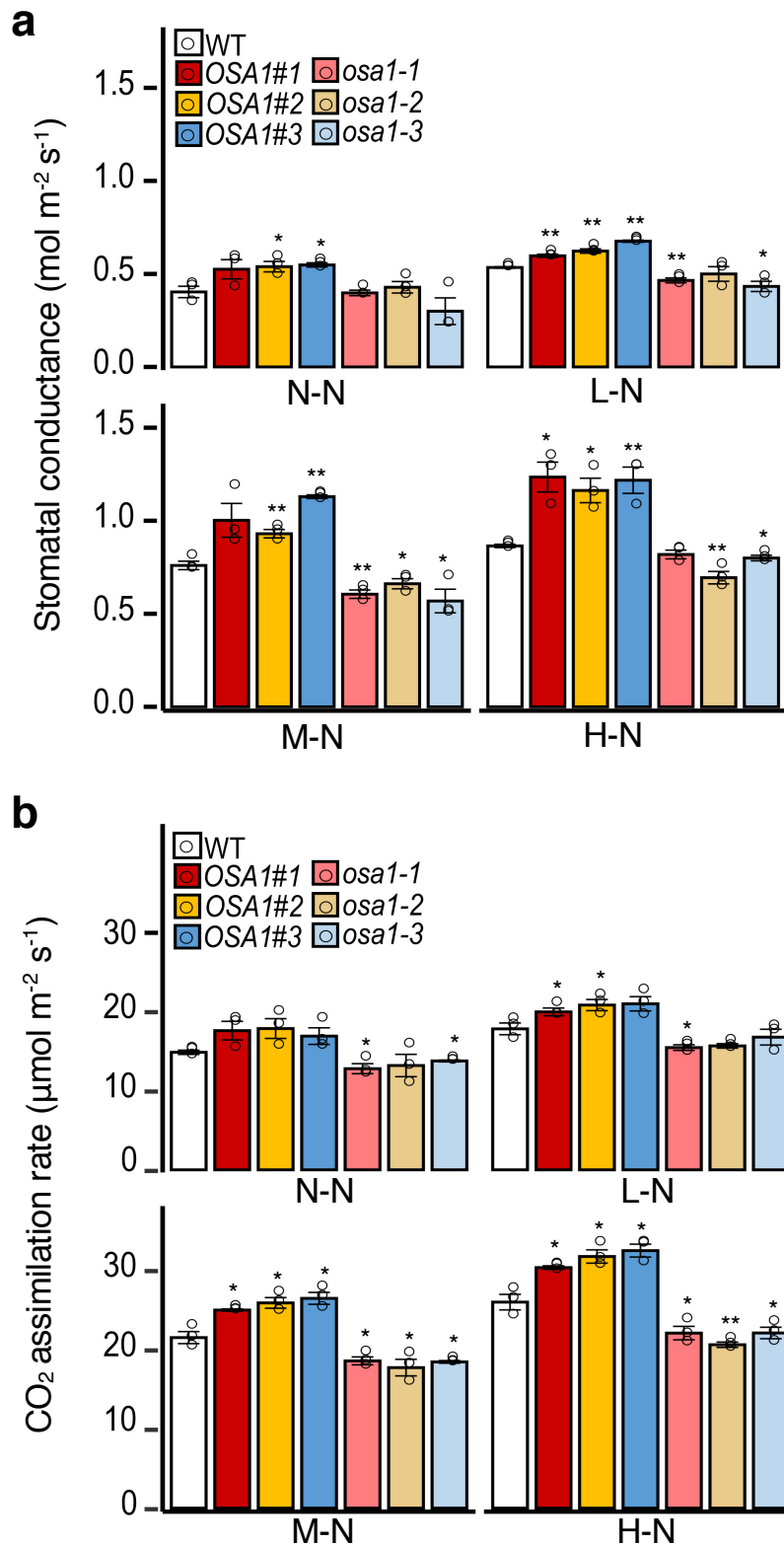


Supplementary Figure 8 Stomatal density, size, and shape in WT, *OSA1*-oxs and *osa1* mutant plants. **a** Stomatal size in WT, *OSA1*-oxs, and *osa1* mutants (in each experiment, 60 stomata were examined). **b** Stomatal density in WT, *OSA1*-oxs, and *osa1* mutants (in each experiment, 5 microphotographs were examined). **c** Randomly selected stomata observed after 3 h of red light and blue light (RL+BL) in WT, *OSA1*-oxs, and *osa1* mutants. Experiments were repeated three occasions with similar results. Small circles in **(a)** and **(b)** represent the data points for individual experiments and three biological replicates were performed. Values in **(a, b)** are presented as the means $\pm$ SEs ($n = 3$). Differences in **(a, b)** were evaluated using the two-tailed Student's *t*-test, and no significant difference was found.

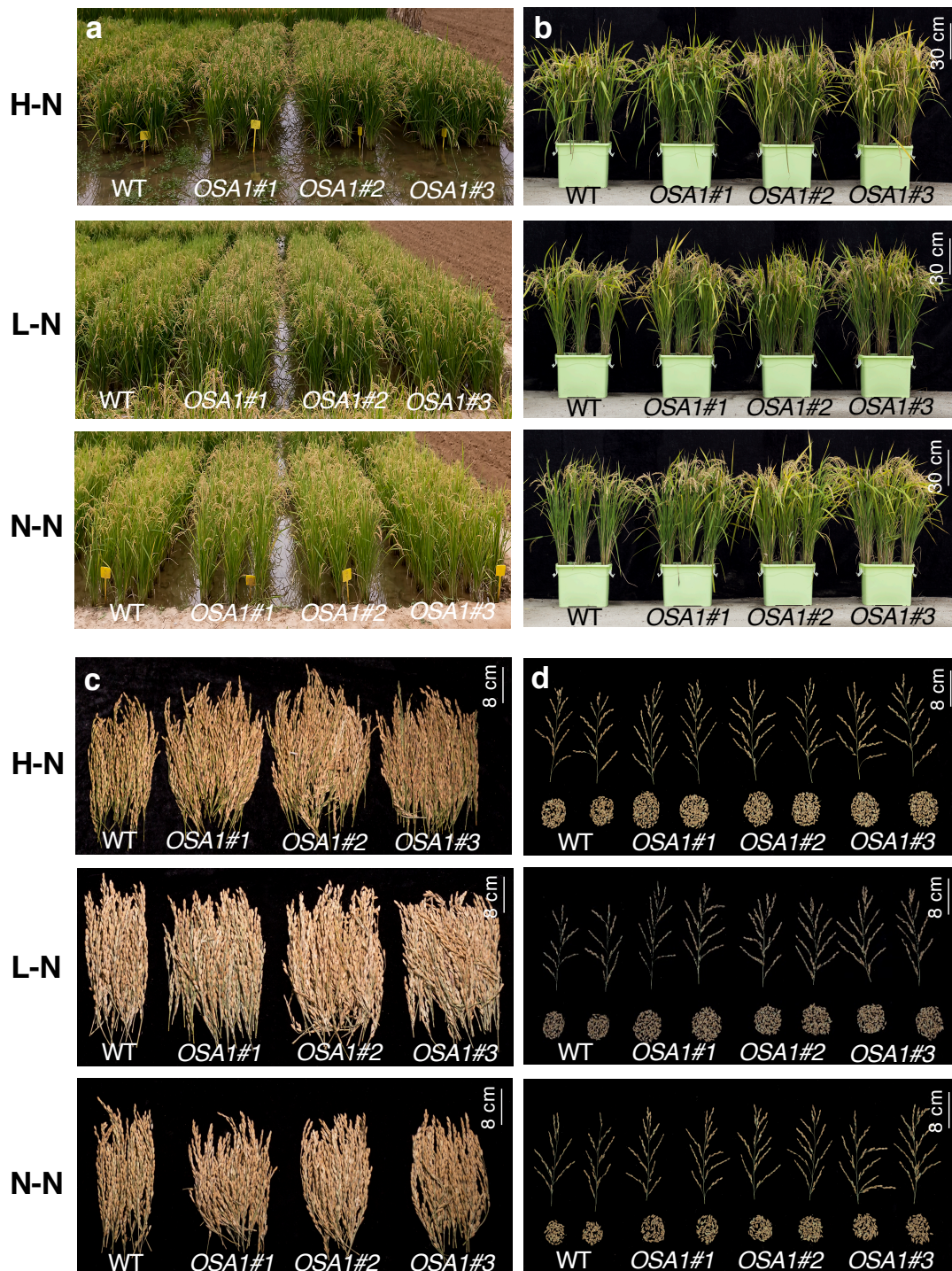
Supplementary Figure 9



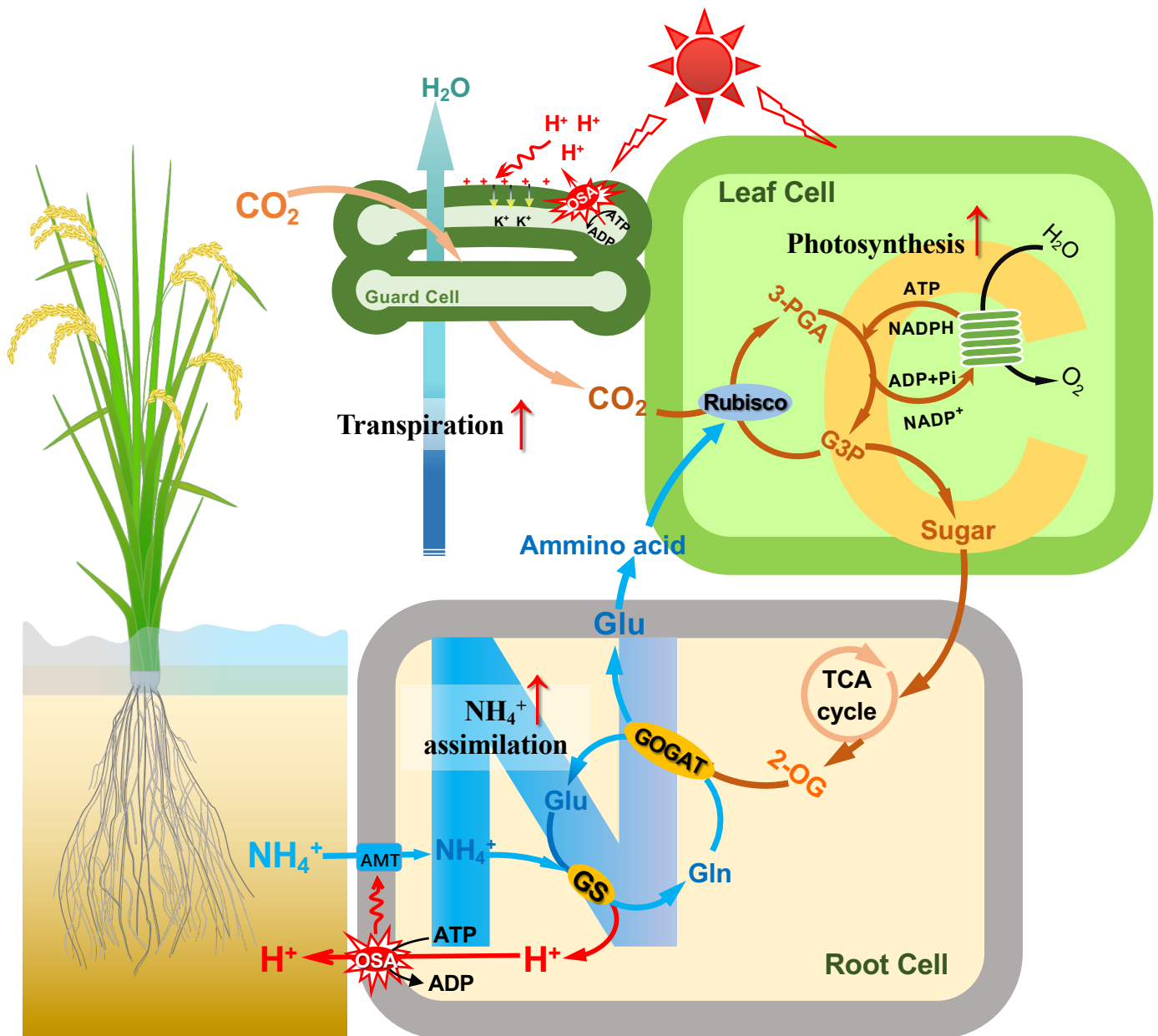
Supplementary Figure 9 The DEGs and GO enrichment caused by modification of *OSA1*. Plants were grown hydroponically in a greenhouse for 4 weeks. **a** DEGs of *OSA1-ox* plants in leaves. **b** DEGs of *OSA1-ox* plants in roots. Small pink circles in (a-b) represent the up-regulation of individual gene, blue circles represent the down-regulation gene, grey circles represent the not significantly regulated gene. **c** Venn diagram representing the overlaps of the down-regulated genes in *OSA1-ox* and the up-regulated genes in *osa1-2* mutant (*osa1*) from roots and leaves ($FDR < 0.05$). **d-e** The significant GO analysis of genes in leaves (d) and roots (e), which were up regulated by *OSA1* overexpression, and down regulated by mutation of *OSA1* ($FDR < 0.05$).



Supplementary Figure 10 Gas-exchange properties of WT, *OSA1*-oxs, and mutant plants in the field. Stomatal conductance (**a**) and net photosynthetic rate (**b**) in WT, *OSA1*-oxs, and *osa1* mutants. Plants were grown in the summer of 2017 at Nanjing-N under N-N (0 kg N/ha), L-N (100 kg N/ha), M-N (200 kg N/ha), or H-N (300 kg N/ha) fertilisation. Measurements were conducted at ambient $[\text{CO}_2]$ ($\sim 400 \mu\text{L L}^{-1}$) at the flowering stage. Leaf temperature and relative humidity in the leaf chamber were maintained at 28°C and 40–50% (Pa/Pa), respectively. Small circles in (**a**) and (**b**) represent the data points for individual experiments and three replicates were performed. Values in (**a**, **b**) are presented as the means $\pm$ SEs ($n = 3$). Differences were evaluated using the two-tailed Student's *t*-test (* $P < 0.05$; ** $P < 0.01$). The exact *p* values are provided in the Supplementary Data 5.

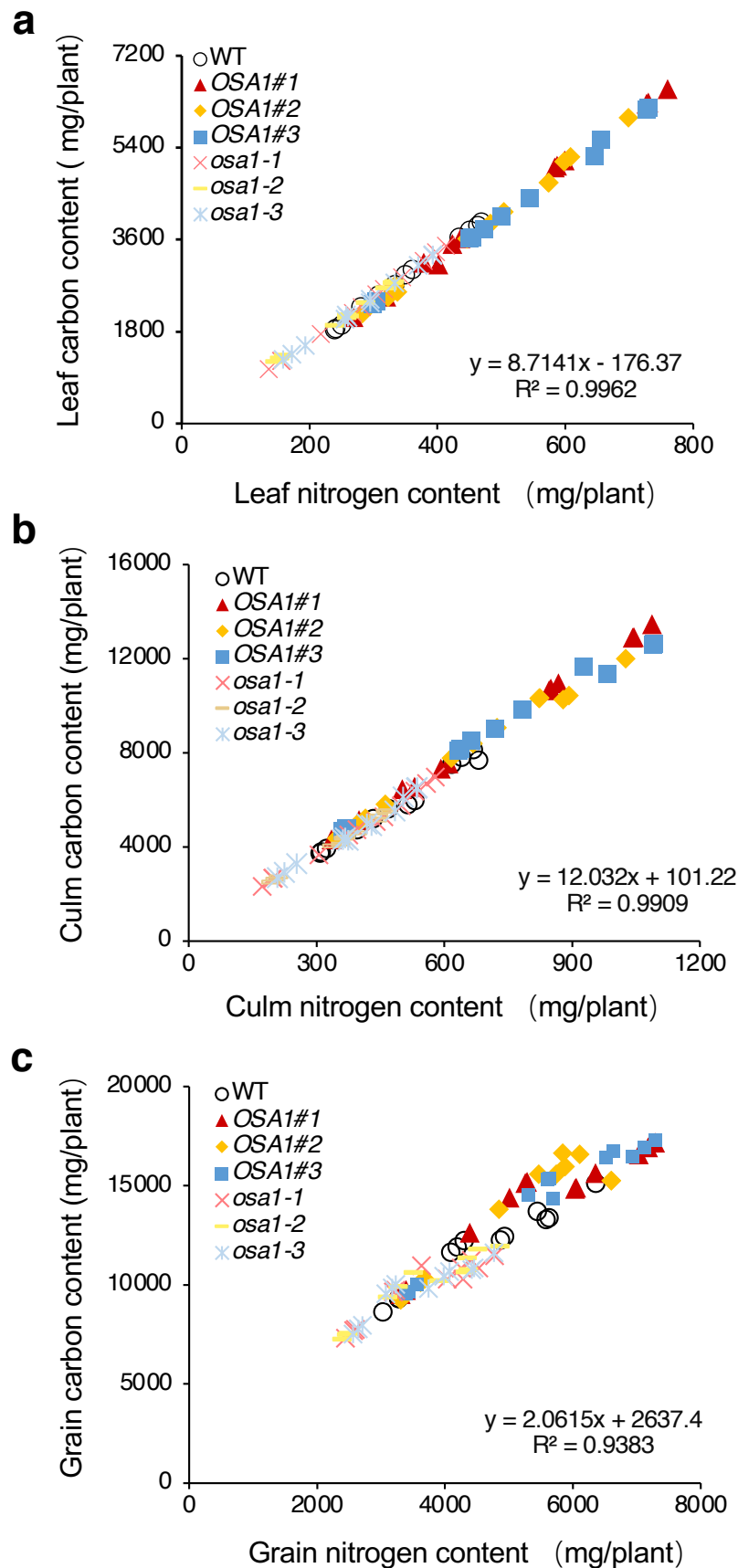


Supplementary Figure 11 Overexpression of *OSA1* increases grain yield in the field. a-d Photographs of 100-day-old WT and *OSA1*-oxs plants under H-N (300 kg N/ha), L-N (100 kg N/ha), or N-N (0 kg N/ha) fertilisation in the field (a) and in pots (b) in the summer of 2017 at Nanjing-N. c, d panicles (c) and spikelets (d) under different N fertilisation levels.



Supplementary Figure 12 Schematic diagram of the model for the effect of overexpression of *OSA1* on the interaction between C and N uptake and metabolism in paddy rice. Overexpression of *OSA1* in roots facilitates NH_4^+ uptake and also pumps excessive H^+ outside the root cells to guarantee the assimilation of NH_4^+ in cytoplasm. As the result, efficient utilization of NH_4^+ in rice roots provide amino acids and protein for the plant growth and photosynthesis. On the other side, overexpression of *OSA1* in guard cells polarized the membrane potential and trigger the K^+ influx for the opening of stomatal under light, which enhanced the uptake of CO_2 and improve the photosynthesis, which can provide carbon skeleton (2-OG) for the assimilation of NH_4^+ in roots. In addition, the enhanced transpiration by stomatal opening also improves the nutrients uptake due to the accelerated water transport in plants.

AMT: ammonium transporter, GS: glutamine synthetase, Gln: Glutamine, GOGAT: glutamate synthase, Glu: Glutamate, 2-OG: 2 oxoglutarate, TCA: Tricarboxylic acids, PGA: Phosphoglycerate, G3P: Glyceraldehyde 3-phosphate, Rubisco: Rubisco ribulose-1,5-bisphosphate carboxylase.



Supplementary Figure 13 Correlations of N and C content in WT, *OSA1*-oxs, and *osa1* mutant plants under various fertilisation levels in the field. Correlations between N content and C content in leaves (a), culms (b), and grain (c) of all rice genotypes harvested in the summer of 2017 at Nanjing-N.

Supplementary Table 1

Supplementary Table 1 Relative expression of *OSA* (*OSA2*, *OSA3*, *OSA4*, *OSA5*, *OSA6*, *OSA7*, *OSA8*, *OSA9*, *OSA10*) genes in rice leaves and roots of WT, *OSA1*-oxs, and *osa1* mutant lines. There were no significant difference among *OSA* isoforms. Differences were evaluated using the two-tailed Student's *t*-test. n.d. represents the gene expression that cannot be detected.

Root	<i>OSA2</i>	<i>OSA3</i>	<i>OSA4</i>	<i>OSA5</i>	<i>OSA6</i>	<i>OSA7</i>	<i>OSA8</i>	<i>OSA9</i>	<i>OSA10</i>
WT	1.00±0.08	1.00±0.26	n.d.	1.00±0.09	n.d.	1.00±0.18	1.06±0.08	1.27±0.16	1.10±0.19
<i>OSA1#1</i>	1.18±0.22	1.52±0.20	n.d.	0.93±0.11	n.d.	1.33±0.28	1.19±0.21	1.68±0.14	1.29±0.24
<i>OSA1#2</i>	1.23±0.25	1.31±0.18	n.d.	0.87±0.04	n.d.	1.22±0.11	1.16±0.10	1.71±0.36	1.23±0.13
<i>OSA1#3</i>	1.04±0.13	1.60±0.40	n.d.	1.18±0.20	n.d.	1.38±0.23	1.18±0.14	1.43±0.13	1.16±0.26
<i>osa1-1</i>	1.23±0.13	1.17±0.08	n.d.	0.98±0.16	n.d.	1.21±0.11	0.96±0.07	0.90±0.24	1.03±0.15
<i>osa1-2</i>	1.13±0.20	1.13±0.24	n.d.	0.92±0.23	n.d.	1.25±0.07	1.10±0.16	1.01±0.24	1.04±0.20
<i>osa1-3</i>	1.34±0.28	1.36±0.16	n.d.	1.05±0.25	n.d.	1.13±0.15	0.93±0.18	0.97±0.20	1.05±0.16
Leaf	<i>OSA2</i>	<i>OSA3</i>	<i>OSA4</i>	<i>OSA5</i>	<i>OSA6</i>	<i>OSA7</i>	<i>OSA8</i>	<i>OSA9</i>	<i>OSA10</i>
WT	1.00±0.06	1.10±0.17	n.d.	1.33±0.40	n.d.	1.14±0.10	1.16±0.07	n.d.	n.d.
<i>OSA1#1</i>	0.87±0.04	1.25±0.14	n.d.	1.64±0.44	n.d.	1.23±0.08	1.32±0.29	n.d.	n.d.
<i>OSA1#2</i>	1.09±0.05	1.44±0.21	n.d.	1.41±0.39	n.d.	1.33±0.16	1.15±0.16	n.d.	n.d.
<i>OSA1#3</i>	0.87±0.09	1.35±0.18	n.d.	1.32±0.39	n.d.	1.32±0.23	1.24±0.11	n.d.	n.d.
<i>osa1-1</i>	0.70±0.11	0.67±0.08	n.d.	1.64±0.34	n.d.	1.11±0.19	1.12±0.22	n.d.	n.d.
<i>osa1-2</i>	0.82±0.11	0.73±0.07	n.d.	1.18±0.47	n.d.	1.05±0.21	1.11±0.22	n.d.	n.d.
<i>osa1-3</i>	0.68±0.20	0.68±0.08	n.d.	1.55±0.73	n.d.	1.14±0.20	1.35±0.29	n.d.	n.d.

Supplementary Table 2 Gas-exchange properties of WT, *OSA1*-oxs, and mutant lines of hydroponically grown rice plants. Measurements were conducted at 400 $\mu\text{L L}^{-1}$ CO_2 . Light intensity was 1,000 $\mu\text{mol m}^{-2} \text{s}^{-1}$. Leaf temperature and relative humidity of leaf chamber were maintained at 24°C and 60–75% (Pa/Pa), respectively. Water use efficiency was calculated as the ratio between the CO_2 assimilation rate and transpiration rate. Differences were evaluated using the two-tailed Student's *t*-test (* $P < 0.05$; ** $P < 0.01$) $\pm$ SEs ($n = 3$).

	WT	<i>OSA1</i> #1	<i>OSA1</i> #2	<i>OSA1</i> #3
CO_2 assimilation rate ($\mu\text{mol m}^{-2} \text{s}^{-1}$)	11.61 $\pm$ 0.53	14.62 $\pm$ 0.87* ($P=0.023$)	14.88 $\pm$ 1.39 ($P=0.055$)	14.59 $\pm$ 0.78* ($P=0.018$)
Stomatal conductance ($\text{mol m}^{-2} \text{s}^{-1}$)	0.41 $\pm$ 0.05	0.73 $\pm$ 0.02** ($P=0.002$)	0.88 $\pm$ 0.08** ($P=0.003$)	0.83 $\pm$ 0.07** ($P=0.003$)
Ci ($\mu\text{L L}^{-1}$)	336.67 $\pm$ 8.46	349.05 $\pm$ 3.62 ($P=0.175$)	354.34 $\pm$ 4.80 ($P=0.090$)	353.53 $\pm$ 1.16 ($P=0.073$)
Transpiration rate ($\text{mmol m}^{-2} \text{s}^{-1}$)	3.48 $\pm$ 0.37	4.96 $\pm$ 0.18* ($P=0.012$)	5.61 $\pm$ 0.12** ($P=0.003$)	5.06 $\pm$ 0.42* ($P=0.027$)
Water use efficiency	3.38 $\pm$ 0.23	2.94 $\pm$ 0.20 ($P=0.150$)	2.66 $\pm$ 0.29 ($P=0.075$)	2.90 $\pm$ 0.14 ($P=0.089$)

Supplementary Table 3 Agronomic traits and grain yields of WT, *OSA1*-oxs, and *osa1* mutant lines in the field (2016 Nanjing-S). Plant height, tiller number, panicle numbers, panicle length, spikelets, 1,000 grain weight, filled grains, and grain yield for plants grown in 2016 at Nanjing-S under 0 kg N/ha (N-N), 100 kg N/ha (L-N), 200 kg N/ha (M-N) and 300 kg N/ha (H-N) fertilisation. Differences were evaluated using one-way ANOVA. Values are the mean $\pm$ SEs ($n \geq 3$). Letters indicates significant differences at $P < 0.05$ and the order starts with *OSA1*-oxs.

2016 Nanjing-S	Material	Plant height (cm)	Tiller number per hill	Panicles number per hill	Panicles length (cm)	spikelet number per panicle	1000 grain weight (g)	Filled grains rate (%)	Yield (kg/ha)
N-N (0 kg N/ha)	WT	81.3 $\pm$ 1.1a	26.6 $\pm$ 1.1b	24.9 $\pm$ 0.8ab	17.2 $\pm$ 0.5a	63.8 $\pm$ 1.3b	26.1 $\pm$ 0.5a	84.0 $\pm$ 0.6a	6931 $\pm$ 214b
	<i>OSA1#1</i>	83.0 $\pm$ 1.4a	30.3 $\pm$ 1.7a	27.4 $\pm$ 1.4a	16.5 $\pm$ 0.6a	69.1 $\pm$ 1.4a	25.1 $\pm$ 0.7a	86.7 $\pm$ 1.3a	8191 $\pm$ 423a
	<i>OSA1#2</i>	83.3 $\pm$ 1.1a	33.8 $\pm$ 1.3a	26.4 $\pm$ 1.0a	16.8 $\pm$ 0.2a	68.9 $\pm$ 3.2a	25.4 $\pm$ 0.6a	88.2 $\pm$ 1.4a	8091 $\pm$ 297a
	<i>OSA1#3</i>	81.7 $\pm$ 0.8a	32.8 $\pm$ 2.3a	26.3 $\pm$ 2.3a	16.8 $\pm$ 0.2a	69.5 $\pm$ 2.1a	26.1 $\pm$ 0.3a	86.1 $\pm$ 2.4a	8157 $\pm$ 721a
	<i>osa1-1</i>	77.0 $\pm$ 3.1ab	25.1 $\pm$ 0.6ab	22.5 $\pm$ 0.7b	16.8 $\pm$ 0.7a	58.4 $\pm$ 1.5c	25.5 $\pm$ 0.6a	84.6 $\pm$ 0.8a	5644 $\pm$ 176c
	<i>osa1-2</i>	78.0 $\pm$ 3.1ab	25.3 $\pm$ 0.7b	22.5 $\pm$ 0.8b	16.5 $\pm$ 0.6a	58.0 $\pm$ 1.5c	25.0 $\pm$ 0.5a	85.4 $\pm$ 1.2a	5554 $\pm$ 187c
	<i>osa1-3</i>	74.3 $\pm$ 4.1b	24.6 $\pm$ 0.7b	22.1 $\pm$ 0.6b	16.3 $\pm$ 0.5a	58.1 $\pm$ 1.6c	25.6 $\pm$ 1.0a	83.0 $\pm$ 4.1a	5448 $\pm$ 144c
L-N (100 kg N/ha)	WT	87.0 $\pm$ 2.1a	29.8 $\pm$ 1.2b	25.9 $\pm$ 0.8b	19.5 $\pm$ 0.9a	79.1 $\pm$ 0.8b	25.8 $\pm$ 0.4a	84.0 $\pm$ 2.9a	8836 $\pm$ 262b
	<i>OSA1#1</i>	91.7 $\pm$ 5.7a	37.3 $\pm$ 1.4a	30.8 $\pm$ 1.1a	21.0 $\pm$ 1.5a	83.5 $\pm$ 2.0a	26.3 $\pm$ 0.9a	87.4 $\pm$ 0.4a	11757 $\pm$ 414a
	<i>OSA1#2</i>	86.7 $\pm$ 0.8a	38.0 $\pm$ 0.9a	31.1 $\pm$ 1.9a	18.9 $\pm$ 0.6a	84.3 $\pm$ 1.8a	26.1 $\pm$ 0.4a	88.1 $\pm$ 0.8a	12018 $\pm$ 729a
	<i>OSA1#3</i>	85.3 $\pm$ 0.8a	39.1 $\pm$ 1.6a	32.3 $\pm$ 1.7a	19.5 $\pm$ 0.4a	85.0 $\pm$ 1.9a	25.3 $\pm$ 0.3a	87.4 $\pm$ 2.2a	12088 $\pm$ 632a
	<i>osa1-1</i>	84.7 $\pm$ 3.6a	26.5 $\pm$ 0.6c	22.9 $\pm$ 0.7b	18.4 $\pm$ 1.0a	74.1 $\pm$ 0.9c	25.4 $\pm$ 0.8a	84.7 $\pm$ 1.2a	7268 $\pm$ 217c
	<i>osa1-2</i>	84.0 $\pm$ 2.5a	26.3 $\pm$ 0.4c	22.8 $\pm$ 0.5b	18.5 $\pm$ 0.9a	74.8 $\pm$ 0.7c	24.6 $\pm$ 1.3a	83.7 $\pm$ 1.8a	6987 $\pm$ 149c
	<i>osa1-3</i>	83.3 $\pm$ 2.5a	26.3 $\pm$ 0.7c	22.9 $\pm$ 0.4b	18.4 $\pm$ 1.2a	75.5 $\pm$ 1.0bc	25.6 $\pm$ 0.6a	84.8 $\pm$ 1.0a	7463 $\pm$ 122c
M-N (200 kg N/ha)	WT	95.7 $\pm$ 3.3a	33.5 $\pm$ 2.0b	27.8 $\pm$ 1.7b	20.0 $\pm$ 1.3a	82.3 $\pm$ 1.5b	25.1 $\pm$ 1.3a	84.6 $\pm$ 2.5a	9672 $\pm$ 588b
	<i>OSA1#1</i>	96.7 $\pm$ 1.5a	40.6 $\pm$ 2.2a	33.3 $\pm$ 1.2a	20.0 $\pm$ 0.7a	88.6 $\pm$ 1.0a	25.6 $\pm$ 0.5a	86.9 $\pm$ 3.4a	13060 $\pm$ 454a
	<i>OSA1#2</i>	95.0 $\pm$ 4.9a	41.6 $\pm$ 2.0a	32.8 $\pm$ 1.0a	19.7 $\pm$ 1.5a	89.8 $\pm$ 1.0a	25.9 $\pm$ 0.3a	87.0 $\pm$ 1.9a	13211 $\pm$ 414a
	<i>OSA1#3</i>	96.0 $\pm$ 2.4a	41.5 $\pm$ 1.4a	32.6 $\pm$ 0.9a	19.3 $\pm$ 0.4a	90.4 $\pm$ 2.2a	26.6 $\pm$ 0.3a	85.8 $\pm$ 2.6a	13393 $\pm$ 370a
	<i>osa1-1</i>	92.3 $\pm$ 4.3a	29.5 $\pm$ 0.9c	25.1 $\pm$ 0.9b	18.1 $\pm$ 1.2a	76.5 $\pm$ 1.5c	25.2 $\pm$ 0.8a	83.9 $\pm$ 2.3a	8097 $\pm$ 294c
	<i>osa1-2</i>	91.7 $\pm$ 3.3a	30.1 $\pm$ 0.8c	25.8 $\pm$ 0.9b	18.5 $\pm$ 0.7a	76.0 $\pm$ 1.5c	25.2 $\pm$ 0.9a	83.8 $\pm$ 2.2a	8243 $\pm$ 272c
	<i>osa1-3</i>	92.3 $\pm$ 2.2a	30.5 $\pm$ 0.7c	25.9 $\pm$ 0.6b	18.7 $\pm$ 1.1a	75.5 $\pm$ 1.6c	25.8 $\pm$ 0.3a	83.4 $\pm$ 3.1a	8370 $\pm$ 190c
H-N (300 kg N/ha)	WT	95.3 $\pm$ 2.0b	35.5 $\pm$ 1.4b	30.0 $\pm$ 0.8b	20.0 $\pm$ 1.0a	84.5 $\pm$ 1.9b	26.1 $\pm$ 0.3a	83.7 $\pm$ 1.0ab	11044 $\pm$ 298b
	<i>OSA1#1</i>	104.0 $\pm$ 3.2a	42.1 $\pm$ 1.3a	34.9 $\pm$ 2.2a	21.4 $\pm$ 0.6a	92.5 $\pm$ 1.7a	25.7 $\pm$ 0.9a	85.6 $\pm$ 1.8a	14120 $\pm$ 883a
	<i>OSA1#2</i>	104.7 $\pm$ 0.8a	43.8 $\pm$ 2.2a	35.9 $\pm$ 1.2a	21.5 $\pm$ 1.1a	93.4 $\pm$ 1.9a	25.7 $\pm$ 0.6a	85.7 $\pm$ 0.5a	14684 $\pm$ 478a
	<i>OSA1#3</i>	102.7 $\pm$ 0.4a	41.5 $\pm$ 1.4a	36.0 $\pm$ 1.6a	21.2 $\pm$ 0.5a	93.1 $\pm$ 1.3a	26.4 $\pm$ 0.1a	86.4 $\pm$ 0.7a	15205 $\pm$ 677a
	<i>osa1-1</i>	95.7 $\pm$ 1.6b	30.9 $\pm$ 0.8c	26.8 $\pm$ 0.6c	20.5 $\pm$ 0.9a	78.6 $\pm$ 1.8c	26.1 $\pm$ 0.3a	83.2 $\pm$ 1.0ab	9091 $\pm$ 214c
	<i>osa1-2</i>	94.3 $\pm$ 2.3b	30.6 $\pm$ 1.0c	26.5 $\pm$ 0.7c	20.1 $\pm$ 0.2a	78.9 $\pm$ 1.6c	26.1 $\pm$ 0.1a	83.0 $\pm$ 0.5ab	9008 $\pm$ 228c
	<i>osa1-3</i>	96.0 $\pm$ 1.2b	29.4 $\pm$ 0.7c	25.5 $\pm$ 0.5c	19.8 $\pm$ 0.2a	78.5 $\pm$ 1.3c	25.3 $\pm$ 0.7a	81.6 $\pm$ 2.7b	8232 $\pm$ 146c

Supplementary Table 4 Agronomic traits and grain yields of WT, *OSA1*-oxs, and *osa1* mutant lines in the field (2017 Nanjing-N). Plant height, tiller number, panicle numbers, panicle length, spikelets, 1,000 grain weight, filled grains, and grain yield for plants grown in 2017 at Nanjing-N under 0 kg N/ha (N-N), 100 kg N/ha (L-N), 200 kg N/ha (M-N) and 300 kg N/ha (H-N) fertilisation. Differences were evaluated using one-way ANOVA. Values are the mean $\pm$ SEs ($n \geq 3$). Letters indicates significant differences at $P < 0.05$ and the order starts with *OSA1*-oxs.

2017 Nanjing-N	Material	Plant height (cm)	Tiller number per hill	Panicles number per hill	Panicles length (cm)	spikelet number per panicle	1000 grain weight (g)	Filled grains rate (%)	Yield (kg/ha)
N-N (0 kgN/ha)	WT	81.7 $\pm$ 1.5ab	25.0 $\pm$ 1.2b	22.8 $\pm$ 1.0bc	18.0 $\pm$ 0.6a	64.7 $\pm$ 2.9b	26.5 $\pm$ 0.8a	81.3 $\pm$ 1.5a	6340 $\pm$ 265b
	<i>OSA1#1</i>	83.3 $\pm$ 1.1a	30.4 $\pm$ 1.9a	25.8 $\pm$ 0.3a	17.3 $\pm$ 1.2a	68.7 $\pm$ 0.5ab	26.3 $\pm$ 0.4a	80.8 $\pm$ 5.0a	7517 $\pm$ 98a
	<i>OSA1#2</i>	83.7 $\pm$ 1.1a	34.4 $\pm$ 2.1a	23.8 $\pm$ 0.8ab	17.6 $\pm$ 0.7a	71.7 $\pm$ 1.8a	26.4 $\pm$ 0.6a	82.6 $\pm$ 0.9a	7422 $\pm$ 240a
	<i>OSA1#3</i>	82.0 $\pm$ 0.7ab	32.1 $\pm$ 2.1a	24.5 $\pm$ 1.6ab	17.6 $\pm$ 0.4a	72.5 $\pm$ 3.0a	26.6 $\pm$ 0.7a	78.0 $\pm$ 4.7a	7347 $\pm$ 493a
	<i>osa1-1</i>	79.0 $\pm$ 2.1ab	23.0 $\pm$ 0.9b	20.2 $\pm$ 1.1cd	17.5 $\pm$ 0.6a	64.0 $\pm$ 0.8b	26.5 $\pm$ 0.8a	81.3 $\pm$ 1.3a	5539 $\pm$ 315b
	<i>osa1-2</i>	78.7 $\pm$ 3.3ab	23.1 $\pm$ 0.8b	20.3 $\pm$ 0.9cd	17.1 $\pm$ 0.7a	63.7 $\pm$ 0.6b	26.4 $\pm$ 1.0a	84.0 $\pm$ 0.8a	5717 $\pm$ 247b
	<i>osa1-3</i>	76.7 $\pm$ 3.6b	22.8 $\pm$ 0.6b	19.8 $\pm$ 0.7d	17.3 $\pm$ 0.2a	64.7 $\pm$ 0.6b	26.4 $\pm$ 0.4a	83.5 $\pm$ 3.2a	5633 $\pm$ 187b
L-N (100 kgN/ha)	WT	90.7 $\pm$ 1.1a	29.5 $\pm$ 1.6b	25.2 $\pm$ 1.0b	19.2 $\pm$ 2.1a	74.5 $\pm$ 0.8b	25.9 $\pm$ 0.4a	83.1 $\pm$ 3.1a	8034 $\pm$ 305b
	<i>OSA1#1</i>	95.7 $\pm$ 3.2a	35.0 $\pm$ 2.7a	27.8 $\pm$ 0.9ab	19.4 $\pm$ 1.9a	82.7 $\pm$ 2.0a	26.6 $\pm$ 0.7a	82.5 $\pm$ 4.7a	10067 $\pm$ 314a
	<i>OSA1#2</i>	90.7 $\pm$ 3.6a	38.5 $\pm$ 2.8a	28.5 $\pm$ 1.3a	18.5 $\pm$ 1.7a	84.0 $\pm$ 2.2a	25.9 $\pm$ 0.8a	85.4 $\pm$ 3.7a	10533 $\pm$ 499a
	<i>OSA1#3</i>	89.3 $\pm$ 4.3a	36.8 $\pm$ 2.2a	29.0 $\pm$ 2.1a	19.2 $\pm$ 1.8a	85.0 $\pm$ 3.6a	25.6 $\pm$ 0.7a	81.0 $\pm$ 6.0a	10176 $\pm$ 743a
	<i>osa1-1</i>	88.3 $\pm$ 2.9a	24.9 $\pm$ 0.6b	22.0 $\pm$ 1.0c	19.2 $\pm$ 0.9a	68.8 $\pm$ 1.1c	26.1 $\pm$ 0.8a	85.7 $\pm$ 1.3a	6747 $\pm$ 300c
	<i>osa1-2</i>	88.0 $\pm$ 2.5a	24.8 $\pm$ 0.8b	21.8 $\pm$ 0.4c	18.5 $\pm$ 1.1a	69.0 $\pm$ 1.0c	26.6 $\pm$ 0.4a	84.8 $\pm$ 0.4a	6762 $\pm$ 136c
	<i>osa1-3</i>	88.3 $\pm$ 2.5a	24.9 $\pm$ 0.7b	21.7 $\pm$ 0.6c	18.9 $\pm$ 0.8a	69.2 $\pm$ 0.9c	26.4 $\pm$ 1.3a	84.9 $\pm$ 2.4a	6687 $\pm$ 189c
M-N (200 kgN/ha)	WT	92.7 $\pm$ 5.1a	30.3 $\pm$ 1.2c	26.2 $\pm$ 1.6b	19.9 $\pm$ 2.7a	79.2 $\pm$ 2.1b	25.6 $\pm$ 0.7a	86.7 $\pm$ 0.8a	9177 $\pm$ 556b
	<i>OSA1#1</i>	93.7 $\pm$ 1.8a	35.9 $\pm$ 1.4b	31.3 $\pm$ 1.8a	20.0 $\pm$ 1.9a	87.5 $\pm$ 1.6a	26.1 $\pm$ 0.7a	81.4 $\pm$ 5.5a	11615 $\pm$ 660a
	<i>OSA1#2</i>	92.0 $\pm$ 4.4a	39.1 $\pm$ 1.8a	31.5 $\pm$ 2.1a	19.5 $\pm$ 2.7a	90.2 $\pm$ 1.9a	26.0 $\pm$ 0.7a	80.2 $\pm$ 4.8a	11785 $\pm$ 797a
	<i>OSA1#3</i>	93.0 $\pm$ 3.5a	38.5 $\pm$ 1.1ab	30.8 $\pm$ 1.1a	19.7 $\pm$ 1.5a	90.0 $\pm$ 1.4a	25.8 $\pm$ 1.0a	82.8 $\pm$ 5.3a	11834 $\pm$ 426a
	<i>osa1-1</i>	91.7 $\pm$ 2.7a	26.9 $\pm$ 0.7d	23.2 $\pm$ 1.3b	19.6 $\pm$ 0.5a	73.3 $\pm$ 2.0c	24.9 $\pm$ 0.7a	84.6 $\pm$ 1.0a	7139 $\pm$ 413c
	<i>osa1-2</i>	89.0 $\pm$ 2.8a	26.3 $\pm$ 0.6d	22.7 $\pm$ 0.7b	19.1 $\pm$ 1.3a	73.5 $\pm$ 2.0c	26.1 $\pm$ 1.1a	84.1 $\pm$ 2.7a	7298 $\pm$ 235c
	<i>osa1-3</i>	90.7 $\pm$ 3.3a	26.9 $\pm$ 0.7d	23.7 $\pm$ 0.6b	19.6 $\pm$ 1.0a	74.2 $\pm$ 1.8c	26.9 $\pm$ 0.8a	81.2 $\pm$ 8.5a	7648 $\pm$ 197c
H-N (300 kgN/ha)	WT	97.3 $\pm$ 6.7a	31.6 $\pm$ 0.8b	30.0 $\pm$ 0.9b	20.2 $\pm$ 1.5a	82.2 $\pm$ 2.8b	25.4 $\pm$ 0.7b	82.0 $\pm$ 1.4ab	10230 $\pm$ 305b
	<i>OSA1#1</i>	106.0 $\pm$ 5.8a	38.1 $\pm$ 2.7a	32.5 $\pm$ 1.8ab	21.6 $\pm$ 2.0a	92.7 $\pm$ 2.3a	25.4 $\pm$ 0.7b	86.2 $\pm$ 1.7ab	13119 $\pm$ 729a
	<i>OSA1#2</i>	106.7 $\pm$ 4.6a	40.0 $\pm$ 1.2a	34.7 $\pm$ 1.0a	21.7 $\pm$ 1.5a	95.3 $\pm$ 2.8a	25.8 $\pm$ 0.4ab	78.1 $\pm$ 6.8b	13273 $\pm$ 370a
	<i>OSA1#3</i>	104.7 $\pm$ 5.2a	40.1 $\pm$ 0.8a	34.2 $\pm$ 0.8a	21.4 $\pm$ 1.7a	96.8 $\pm$ 1.5a	25.9 $\pm$ 0.7ab	82.9 $\pm$ 0.6ab	14162 $\pm$ 319a
	<i>osa1-1</i>	97.7 $\pm$ 6.4a	29.5 $\pm$ 0.6b	26.5 $\pm$ 0.8c	20.6 $\pm$ 1.2a	78.2 $\pm$ 1.3b	26.9 $\pm$ 0.6ab	83.9 $\pm$ 0.9ab	9315 $\pm$ 277b
	<i>osa1-2</i>	96.0 $\pm$ 4.4a	29.4 $\pm$ 0.4b	26.5 $\pm$ 0.4c	20.4 $\pm$ 1.8a	78.0 $\pm$ 1.6b	26.4 $\pm$ 0.6ab	87.0 $\pm$ 3.7a	9450 $\pm$ 133b
	<i>osa1-3</i>	98.0 $\pm$ 6.3a	28.9 $\pm$ 0.6b	27.0 $\pm$ 0.7c	20.0 $\pm$ 1.6a	77.8 $\pm$ 1.3b	27.7 $\pm$ 1.2a	82.3 $\pm$ 0.4ab	9558 $\pm$ 245b

Supplementary Table 5 Agronomic traits and grain yields of WT , *OSA1*-oxs, and *osa1* mutant lines in the field (2017 Fengyang). Plant height, tiller number, panicle numbers, panicle length, spikelets, 1,000 grain weight, filled grains, and grain yield for plants grown in 2017 at Fengyang under 0 kg N/ha (N-N), 100 kg N/ha (L-N), 200 kg N/ha (M-N) and 300 kg N/ha (H-N) fertilisation. Differences were evaluated using one-way ANOVA. Values are the mean $\pm$ SEs ($n \geq 3$). Letters indicates significant differences at $P < 0.05$ and the order starts with *OSA1*-oxs.

2017 Fengyang	Material	Plant height (cm)	Tiller number per hill	Panicles number per hill	Panicles length (cm)	spikelet number per panicle	1000 grain weight (g)	Filled grains rate (%)	Yield (kg/ha)
N-N (0 kgN/ha)	WT	72.0 $\pm$ 1.4a	24.5 $\pm$ 1.5b	23.5 $\pm$ 0.9a	16.8 $\pm$ 0.9a	63.0 $\pm$ 1.3b	25.8 $\pm$ 0.4a	86.5 $\pm$ 2.1a	6588 $\pm$ 247b
	<i>OSA1#1</i>	73.7 $\pm$ 1.1a	28.7 $\pm$ 1.4a	25.5 $\pm$ 1.2a	16.2 $\pm$ 1.7a	69.0 $\pm$ 1.6a	25.8 $\pm$ 0.8a	86.1 $\pm$ 5.9a	7798 $\pm$ 381a
	<i>OSA1#2</i>	73.7 $\pm$ 1.8a	29.8 $\pm$ 1.6a	24.5 $\pm$ 0.5a	16.5 $\pm$ 1.1a	69.4 $\pm$ 1.0a	26.3 $\pm$ 0.2a	83.3 $\pm$ 1.5a	7404 $\pm$ 137a
	<i>OSA1#3</i>	72.3 $\pm$ 0.4a	30.0 $\pm$ 1.7a	24.9 $\pm$ 0.8a	16.5 $\pm$ 1.3a	71.5 $\pm$ 1.2a	25.7 $\pm$ 1.3a	87.1 $\pm$ 6.3a	7935 $\pm$ 269a
	<i>osa1-1</i>	69.7 $\pm$ 1.8a	22.8 $\pm$ 1.1b	20.5 $\pm$ 0.9b	16.4 $\pm$ 0.8a	58.5 $\pm$ 1.3c	25.9 $\pm$ 0.5a	84.3 $\pm$ 2.9a	5212 $\pm$ 235c
	<i>osa1-2</i>	70.0 $\pm$ 1.4a	22.3 $\pm$ 0.6b	20.5 $\pm$ 0.7b	15.9 $\pm$ 0.5a	57.5 $\pm$ 1.5c	26.1 $\pm$ 0.6a	84.3 $\pm$ 0.2a	5162 $\pm$ 183c
	<i>osa1-3</i>	69.7 $\pm$ 2.2a	22.7 $\pm$ 1.0b	20.3 $\pm$ 0.6b	16.0 $\pm$ 1.4a	57.5 $\pm$ 1.7c	26.8 $\pm$ 0.7a	85.0 $\pm$ 1.9a	5292 $\pm$ 165c
L-N (100 kgN/ha)	WT	87.0 $\pm$ 1.9a	28.2 $\pm$ 0.9b	23.8 $\pm$ 1.2b	18.7 $\pm$ 1.2a	72.1 $\pm$ 1.3c	25.7 $\pm$ 0.3a	86.0 $\pm$ 3.0ab	7545 $\pm$ 378b
	<i>OSA1#1</i>	91.7 $\pm$ 3.5a	39.2 $\pm$ 2.3a	27.9 $\pm$ 1.8a	19.7 $\pm$ 0.8a	80.4 $\pm$ 1.5ab	26.2 $\pm$ 0.7a	87.1 $\pm$ 4.2a	10177 $\pm$ 645a
	<i>OSA1#2</i>	87.0 $\pm$ 4.2a	39.0 $\pm$ 4.2a	28.8 $\pm$ 0.9a	18.6 $\pm$ 1.2a	79.9 $\pm$ 1.3b	27.2 $\pm$ 1.3a	79.4 $\pm$ 1.7b	9884 $\pm$ 301a
	<i>OSA1#3</i>	85.7 $\pm$ 5.0a	39.5 $\pm$ 2.7a	28.1 $\pm$ 1.1a	18.7 $\pm$ 1.5a	84.0 $\pm$ 1.4a	26.4 $\pm$ 0.9a	81.8 $\pm$ 1.9ab	10144 $\pm$ 382a
	<i>osa1-1</i>	84.7 $\pm$ 2.7a	25.0 $\pm$ 1.3b	21.1 $\pm$ 0.7b	17.3 $\pm$ 1.5a	67.0 $\pm$ 1.5d	25.4 $\pm$ 0.9a	83.2 $\pm$ 0.3ab	5955 $\pm$ 193c
	<i>osa1-2</i>	84.3 $\pm$ 3.3a	25.3 $\pm$ 0.5b	21.3 $\pm$ 0.6b	17.4 $\pm$ 1.3a	66.0 $\pm$ 1.3d	26.2 $\pm$ 0.9a	79.5 $\pm$ 2.2b	5809 $\pm$ 163c
	<i>osa1-3</i>	84.7 $\pm$ 3.6a	25.3 $\pm$ 0.8b	21.4 $\pm$ 0.5b	17.6 $\pm$ 1.4a	68.0 $\pm$ 1.6d	26.1 $\pm$ 0.7a	84.5 $\pm$ 2.2ab	6386 $\pm$ 147c
M-N (200 kgN/ha)	WT	87.7 $\pm$ 4.5a	30.3 $\pm$ 1.8b	25.4 $\pm$ 0.8b	19.0 $\pm$ 1.4ab	76.1 $\pm$ 1.1c	26.4 $\pm$ 0.9ab	82.6 $\pm$ 2.2a	8400 $\pm$ 250b
	<i>OSA1#1</i>	88.7 $\pm$ 1.6a	40.3 $\pm$ 1.7a	29.8 $\pm$ 1.3a	19.7 $\pm$ 0.6ab	84.6 $\pm$ 1.2b	24.8 $\pm$ 0.4b	88.9 $\pm$ 2.9a	11044 $\pm$ 490a
	<i>OSA1#2</i>	87.0 $\pm$ 3.7a	42.0 $\pm$ 1.7a	30.4 $\pm$ 0.7a	20.1 $\pm$ 0.7a	84.1 $\pm$ 0.9b	25.3 $\pm$ 1.0ab	85.3 $\pm$ 3.9a	10995 $\pm$ 242a
	<i>OSA1#3</i>	88.0 $\pm$ 3.2a	40.2 $\pm$ 2.3a	29.3 $\pm$ 0.7a	19.3 $\pm$ 0.5ab	88.6 $\pm$ 1.8a	25.8 $\pm$ 0.8ab	86.3 $\pm$ 6.2a	11494 $\pm$ 272a
	<i>osa1-1</i>	83.0 $\pm$ 4.6a	27.3 $\pm$ 1.5b	22.3 $\pm$ 0.5c	17.7 $\pm$ 1.0b	71.0 $\pm$ 1.0d	26.9 $\pm$ 0.6a	80.7 $\pm$ 1.5a	6822 $\pm$ 161c
	<i>osa1-2</i>	85.3 $\pm$ 2.9a	27.0 $\pm$ 0.8b	22.0 $\pm$ 0.5c	17.8 $\pm$ 0.2ab	71.4 $\pm$ 0.8d	25.1 $\pm$ 0.4ab	84.4 $\pm$ 0.7a	6615 $\pm$ 149c
	<i>osa1-3</i>	83.3 $\pm$ 3.9a	28.0 $\pm$ 0.7b	22.8 $\pm$ 0.4c	18.5 $\pm$ 0.9ab	71.8 $\pm$ 0.7d	25.6 $\pm$ 0.8ab	83.0 $\pm$ 2.4a	6909 $\pm$ 119c
H-N (300 kgN/ha)	WT	93.0 $\pm$ 3.9ab	32.0 $\pm$ 1.1b	28.0 $\pm$ 0.5b	19.4 $\pm$ 1.2a	79.0 $\pm$ 1.8b	25.1 $\pm$ 0.6b	83.9 $\pm$ 2.3a	9267 $\pm$ 150b
	<i>OSA1#1</i>	101.3 $\pm$ 4.5a	42.2 $\pm$ 1.4a	31.3 $\pm$ 1.5a	21.4 $\pm$ 2.6a	88.9 $\pm$ 2.0a	26.0 $\pm$ 1.4ab	84.3 $\pm$ 2.5a	12117 $\pm$ 569a
	<i>OSA1#2</i>	101.7 $\pm$ 2.5a	42.0 $\pm$ 1.9a	31.6 $\pm$ 0.9a	20.9 $\pm$ 1.3a	89.6 $\pm$ 1.2a	24.9 $\pm$ 0.5b	86.9 $\pm$ 9.0a	12233 $\pm$ 349a
	<i>OSA1#3</i>	99.7 $\pm$ 2.9ab	42.3 $\pm$ 1.9a	31.6 $\pm$ 1.3a	20.9 $\pm$ 1.7a	93.3 $\pm$ 2.5a	27.1 $\pm$ 0.4a	79.9 $\pm$ 4.6a	12742 $\pm$ 533a
	<i>osa1-1</i>	93.3 $\pm$ 3.6ab	30.8 $\pm$ 0.8b	24.9 $\pm$ 0.4c	19.7 $\pm$ 1.3a	73.4 $\pm$ 1.8c	25.8 $\pm$ 0.4ab	88.1 $\pm$ 0.5a	8263 $\pm$ 141c
	<i>osa1-2</i>	91.7 $\pm$ 1.6b	30.8 $\pm$ 0.7b	24.8 $\pm$ 0.6c	20.1 $\pm$ 1.9a	73.5 $\pm$ 1.9c	25.1 $\pm$ 0.1b	82.2 $\pm$ 0.9a	7477 $\pm$ 170c
	<i>osa1-3</i>	93.7 $\pm$ 3.9ab	31.3 $\pm$ 0.8b	24.5 $\pm$ 0.5c	19.6 $\pm$ 1.9a	73.8 $\pm$ 1.4c	25.1 $\pm$ 0.8b	84.8 $\pm$ 2.3a	7659 $\pm$ 141c

Supplementary Table 6 Agronomic traits and grain yields of WT , *OSA1*-oxs, and *osa1* mutant lines in the field (2016 Hainan). Plant height, tiller number, panicle numbers, panicle length, spikelets, 1,000 grain weight, filled grains, and grain yield for plants grown in 2016 at Hainan under 0 kg N/ha (N-N), 100 kg N/ha (L-N), 200 kg N/ha (M-N) and 300 kg N/ha (H-N) fertilisation. Differences were evaluated using one-way ANOVA. Values are the mean $\pm$ SEs ($n \geq 3$). Letters indicates significant differences at $P < 0.05$ and the order starts with *OSA1*-oxs.

2016		Plant	Tiller	Panicles	Panicles	spikelet	1000 grain	Filled grains	
Hainan	Material	Height	number	number per	length	number per	weight	rate (%)	Yield (kg/ha)
		(cm)	per hill	hill	(cm)	panicle	(g)		
N-N (0 kgN/ha)	WT	67.2 $\pm$ 2.1ab	16.8 $\pm$ 0.7b	14.5 $\pm$ 0.5c	16.4 $\pm$ 0.4a	60.5 $\pm$ 2.6bc	25.1 $\pm$ 0.2a	78.6 $\pm$ 2.5a	3446 $\pm$ 127c
	<i>OSA1#1</i>	70.8 $\pm$ 1.6a	18.6 $\pm$ 0.8ab	16.0 $\pm$ 0.6abc	15.9 $\pm$ 0.7a	65.5 $\pm$ 2.2ab	24.5 $\pm$ 1.3a	80.6 $\pm$ 2.4a	4112 $\pm$ 164b
	<i>OSA1#2</i>	70.2 $\pm$ 1.1ab	20.2 $\pm$ 1.0ab	17.3 $\pm$ 0.4a	16.8 $\pm$ 0.8a	67.7 $\pm$ 2.4a	24.3 $\pm$ 0.9a	81.7 $\pm$ 1.0a	4607 $\pm$ 104a
	<i>OSA1#3</i>	71.2 $\pm$ 2.4a	20.0 $\pm$ 2.1ab	16.8 $\pm$ 0.9ab	17.1 $\pm$ 0.8a	67.5 $\pm$ 1.6a	25.5 $\pm$ 0.7a	81.4 $\pm$ 1.8a	4663 $\pm$ 237a
	<i>osa1-1</i>	65.6 $\pm$ 2.9ab	17.8 $\pm$ 1.2ab	14.8 $\pm$ 0.8c	16.8 $\pm$ 1.4a	51.0 $\pm$ 1.4d	24.7 $\pm$ 0.7a	79.6 $\pm$ 2.4a	2948 $\pm$ 155d
	<i>osa1-2</i>	65.4 $\pm$ 2.3ab	20.0 $\pm$ 0.8ab	15.1 $\pm$ 0.6bc	16.7 $\pm$ 0.8a	57.5 $\pm$ 3.1cd	24.4 $\pm$ 0.9a	78.4 $\pm$ 3.1a	3313 $\pm$ 121cd
	<i>osa1-3</i>	64.0 $\pm$ 3.0b	20.6 $\pm$ 1.0a	15.0 $\pm$ 0.6bc	16.4 $\pm$ 1.0a	56.5 $\pm$ 2.9cd	24.4 $\pm$ 0.8a	79.0 $\pm$ 3.7a	3248 $\pm$ 138cd
L-N (100 kgN/ha)	WT	77.2 $\pm$ 3.0a	31.8 $\pm$ 1.7b	21.9 $\pm$ 0.9b	19.5 $\pm$ 1.6a	69.0 $\pm$ 4.0bc	25.5 $\pm$ 0.3a	80.3 $\pm$ 2.4a	6160 $\pm$ 251b
	<i>OSA1#1</i>	80.4 $\pm$ 1.4a	39.0 $\pm$ 0.6a	25.0 $\pm$ 0.4a	21.1 $\pm$ 0.8a	77.2 $\pm$ 3.7ab	25.7 $\pm$ 0.5a	81.4 $\pm$ 3.0a	8032 $\pm$ 130a
	<i>OSA1#2</i>	82.2 $\pm$ 2.0a	38.0 $\pm$ 2.3a	25.4 $\pm$ 0.6a	19.2 $\pm$ 0.7a	76.5 $\pm$ 2.9ab	26.2 $\pm$ 1.0a	82.1 $\pm$ 1.8a	8309 $\pm$ 209a
	<i>OSA1#3</i>	82.0 $\pm$ 2.7a	40.8 $\pm$ 0.9a	25.0 $\pm$ 0.3a	19.9 $\pm$ 1.1a	79.2 $\pm$ 3.1a	25.5 $\pm$ 0.7a	82.5 $\pm$ 0.8a	8298 $\pm$ 95a
	<i>osa1-1</i>	74.2 $\pm$ 4.6a	30.6 $\pm$ 2.1b	20.1 $\pm$ 0.9bc	16.3 $\pm$ 0.3b	64.0 $\pm$ 2.5c	24.4 $\pm$ 0.8a	80.7 $\pm$ 5.0a	5058 $\pm$ 224c
	<i>osa1-2</i>	75.8 $\pm$ 3.9a	29.4 $\pm$ 1.8b	19.3 $\pm$ 0.7c	16.3 $\pm$ 1.5b	61.3 $\pm$ 3.3c	24.4 $\pm$ 1.2a	79.3 $\pm$ 1.5a	4547 $\pm$ 164c
	<i>osa1-3</i>	75.4 $\pm$ 3.7a	29.8 $\pm$ 1.0b	17.4 $\pm$ 0.6d	16.3 $\pm$ 0.4b	65.8 $\pm$ 2.0c	25.1 $\pm$ 0.5a	82.8 $\pm$ 1.6a	4736 $\pm$ 165c
M-N (200 kgN/ha)	WT	83.8 $\pm$ 2.3a	33.8 $\pm$ 1.4b	24.3 $\pm$ 0.8b	19.1 $\pm$ 1.2a	73.8 $\pm$ 3.1bc	24.7 $\pm$ 0.5a	81.0 $\pm$ 2.6a	7119 $\pm$ 228c
	<i>OSA1#1</i>	86.2 $\pm$ 2.4a	42.6 $\pm$ 1.9a	27.6 $\pm$ 0.7a	20.1 $\pm$ 1.3a	80.3 $\pm$ 2.7ab	25.1 $\pm$ 0.5a	83.5 $\pm$ 2.4a	9286 $\pm$ 235ab
	<i>OSA1#2</i>	85.6 $\pm$ 1.9a	42.4 $\pm$ 2.0a	28.3 $\pm$ 0.6a	19.4 $\pm$ 1.2a	80.5 $\pm$ 2.8ab	24.2 $\pm$ 0.5a	82.9 $\pm$ 2.1a	9087 $\pm$ 203b
	<i>OSA1#3</i>	85.0 $\pm$ 2.1a	43.4 $\pm$ 1.2a	27.4 $\pm$ 0.5a	19.1 $\pm$ 0.9a	85.5 $\pm$ 3.6a	24.5 $\pm$ 0.6a	84.4 $\pm$ 2.5a	9662 $\pm$ 174a
	<i>osa1-1</i>	83.4 $\pm$ 3.0a	34.8 $\pm$ 0.8b	20.6 $\pm$ 0.6c	18.7 $\pm$ 0.7a	65.7 $\pm$ 2.9d	24.1 $\pm$ 1.8a	83.5 $\pm$ 1.0a	5431 $\pm$ 168de
	<i>osa1-2</i>	80.0 $\pm$ 4.9a	31.6 $\pm$ 1.0bc	21.1 $\pm$ 0.9c	18.3 $\pm$ 0.6a	67.5 $\pm$ 2.8cd	25.0 $\pm$ 0.2a	81.8 $\pm$ 1.3a	5814 $\pm$ 245d
	<i>osa1-3</i>	81.6 $\pm$ 3.4a	29.2 $\pm$ 2.2c	20.0 $\pm$ 0.6c	18.6 $\pm$ 1.8a	64.5 $\pm$ 2.2d	24.6 $\pm$ 0.7a	80.2 $\pm$ 1.7a	5074 $\pm$ 162e
H-N (300 kgN/ha)	WT	89.0 $\pm$ 2.4ab	33.8 $\pm$ 3.0b	26.8 $\pm$ 0.5b	20.1 $\pm$ 1.2a	77.3 $\pm$ 2.6bc	24.4 $\pm$ 0.8a	84.1 $\pm$ 2.1a	8469 $\pm$ 153c
	<i>OSA1#1</i>	91.0 $\pm$ 2.4a	40.0 $\pm$ 1.5a	29.1 $\pm$ 0.6a	21.1 $\pm$ 0.4a	83.3 $\pm$ 2.2ab	25.2 $\pm$ 0.3a	81.6 $\pm$ 5.4a	9933 $\pm$ 200b
	<i>OSA1#2</i>	92.2 $\pm$ 2.1a	40.8 $\pm$ 1.0a	29.9 $\pm$ 0.5a	21.5 $\pm$ 0.8a	85.2 $\pm$ 2.0a	25.5 $\pm$ 0.7a	83.1 $\pm$ 1.5a	10723 $\pm$ 184a
	<i>OSA1#3</i>	91.2 $\pm$ 1.6a	44.0 $\pm$ 1.7a	29.3 $\pm$ 1.0a	21.1 $\pm$ 1.4a	85.7 $\pm$ 1.9a	24.7 $\pm$ 0.6a	84.0 $\pm$ 0.9a	10361 $\pm$ 341ab
	<i>osa1-1</i>	82.0 $\pm$ 1.4b	34.0 $\pm$ 1.3b	23.5 $\pm$ 0.7c	20.4 $\pm$ 1.3a	71.5 $\pm$ 1.6c	25.4 $\pm$ 1.4a	82.5 $\pm$ 0.9a	7017 $\pm$ 200de
	<i>osa1-2</i>	85.2 $\pm$ 3.5ab	34.6 $\pm$ 1.6b	23.9 $\pm$ 0.7c	20.2 $\pm$ 0.6a	72.7 $\pm$ 2.5c	26.0 $\pm$ 0.3a	82.1 $\pm$ 0.9a	7368 $\pm$ 229d
	<i>osa1-3</i>	85.6 $\pm$ 4.5ab	33.8 $\pm$ 0.8b	23.4 $\pm$ 0.7c	20.4 $\pm$ 0.6a	73.2 $\pm$ 3.8c	24.3 $\pm$ 0.6a	80.8 $\pm$ 2.1a	6684 $\pm$ 200e

Supplementary Table 7 List of primers used in this study.

Gene name	Forward (F)/ Reverse (R)	Sequences (5'–3')	Application
<i>OSA1</i>	F	AGGTCGACTCTAGAGGATCCTAGGGTCAGCATAGCAGT	Transformation
	R	CTCAGATCTACCATGGTACCGGAGGCGACCTCCCACACCT	
<i>OsActin</i>	F	GGAAGTGGTATGGTCAAGGC	RT-PCR
	R	AGTCTCATGGATAACCGCAG	
<i>OSA1</i>	F	TGGCTGGCATGGATGTTCTT	RT-PCR
	R	TTCCTAGACGACGCCCTGTT	
<i>OsActin</i>	F	TTATGGTTGGGATGGGACA	quantitative RT-PCR
	R	AGCACGGCTTGAATAGCG	
<i>OsGAPDH</i>	F	TCAAATGCTAGCTGCACCAC	quantitative RT-PCR
	R	GCAGTGATGGCATGAACAGT	
<i>OSA1</i>	F	GTGTTTGGGTTTATGCTGCT	quantitative RT-PCR
	R	GTATCCACCCAGCACAACCTC	
<i>OSA2</i>	F	ACTGAGCCAGGCCTTAGTGT	quantitative RT-PCR
	R	TCATTGAGGATGGCAATGAT	
<i>OSA3</i>	F	GAGGAGAGGGAGCTCAAGTG	quantitative RT-PCR
	R	CACAACCGATTCTACATGCC	
<i>OSA4</i>	F	TCAGCATCGTCACCTTCTTC	quantitative RT-PCR
	R	CTCTTCCCGTAGTCCAGCTC	
<i>OSA5</i>	F	TCTGGCTCTACAGCATCGTC	quantitative RT-PCR
	R	TCCCGTAATCCTTCTTGCTC	
<i>OSA6</i>	F	TCAGCGTGGTGACCTACTTC	quantitative RT-PCR
	R	CCCGTAGTCGTTCTTGTTCA	
<i>OSA7</i>	F	GGGCTGGGCTGGCGTTATCT	quantitative RT-PCR
	R	TTGAAGAGCGTGTTGGAGGC	
<i>OSA8</i>	F	TCAACCAAATGGCTGAAGAG	quantitative RT-PCR
	R	CCACAGATTCCACCTTTCCT	
<i>OSA9</i>	F	GTCCTTCCTCGAGAGACCTG	quantitative RT-PCR
	R	GCGTAGAACACCAGGCTGTA	
<i>OSA10</i>	F	GCGGATGAAGAACTACACCA	quantitative RT-PCR
	R	CTTGAGATGGTCATGATGG	
<i>OsGS1.2</i>	F	TGTTTCTCCTCATCCCTGC	quantitative RT-PCR
	R	TCACAGTCCTCGCTTTGC	
<i>OsGS2</i>	F	GGAGAGGTCATGCCTGGTCAGT	quantitative RT-PCR
	R	ACTACACCAGCCTGCTCCGTTA	
<i>OsNADH-GOGAT1</i>	F	GTGCAGCCTGTTGCAGCATAAA	quantitative RT-PCR
	R	CGGCATTTACCATGCAAATC	
<i>OsNADH-GOGAT2</i>	F	CCTGTCTGAAGGATGATGAAGGTGAAACC	quantitative RT-PCR
	R	TGCATGGCCCTACTATCTTCGCATCA	
<i>OsAMT1.1</i>	F	GGTTTCTCTCCCTCTCCGAT	quantitative RT-PCR
	R	CCACCTTCACACCACACATT	
<i>OsGRF4</i>	F	GAAAGCCTGTGGAAACGCA	quantitative RT-PCR
	R	CAACGCCGAGCCAAATGAG	