

Managed Bee Pollination Enhances Yield and Seed Quality in *Brassica napus* through Flowering Duration and Agronomic Trait Modulation

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ABSTRACT

Managed bees are widely recognized as beneficial for agricultural production. However, their impacts vary across plant varieties, and the underlying mechanisms for this variation remain poorly understood. In the present study, the effects of bee pollination were investigated in nine *Brassica napus* varieties were investigated for flowering duration, fruiting duration, agronomic traits, fruit yield, and seed quality. These effects were then compared with those of non-bee pollination treatments. Bee pollination shortened the flowering duration by an average of 7.3 days and extended the fruiting duration by 2.3 days for all varieties. It also induced changes in agronomic traits in a subset of varieties, including reduced plant height and fewer primary and secondary branches. Correlation analysis indicated that a shortened flowering duration was conducive to enhancing both yield and quality. Increased fruiting duration and the total flowering and fruiting duration contributed to increased grain size-related parameters, including 1000-seed weight and number of seeds per silique. Reduced plant height increased yield by increasing the number of siliques (despite a concurrent decrease in 1000-seed weight), whereas significant reductions in branch number led to lower oleic acid and higher erucic acid content. These findings suggest that bee pollination may substantially improve fruit yield and seed quality, potentially by affecting plant nutrient allocation strategies. Notably, the contribution of a shortened flowering duration appears to be more universally applicable. For practical applications, pollination should be implemented before flowering, and varieties exhibiting favorable agronomic trait changes after bee pollination should be prioritized for promotion and cultivation.

Keywords: Bee pollination; *Brassica napus*; agronomic traits; flowering duration; plant pollination

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50 1. INTRODUCTION

51 Pollination is critical for plant reproduction and agricultural sustainability
 52 ([Alexandra-Maria et al., 2007](#)). Approximately 90% of the world's flowering plants
 53 and more than 75% of the crops rely on animals for pollination, with bees being among
 54 the most efficient pollinators ([Ollerton et al., 2011](#)). However, wild pollinator
 55 populations have declined dramatically with the increased demand for agronomic
 56 products, habitat loss, and pesticide misuse. To ensure effective pollination of
 57 economically important plants, managed pollinators, such as *Apis mellifera*, are
 58 introduced into plant systems ([Goulson et al., 2015](#)). In addition to plants traditionally
 59 believed to be insect-pollinated, some self-pollinated plants (such as *Brassica napus*)
 60 and wind-pollinated plants (such as *Castanea henryi*) also disperse pollen through
 61 insects, which increases fruit yield and seed quality ([Lindström et al., 2016](#); [Yuan et al.,](#)
 62 [2024](#)).

63 Introducing managed bees into orchards can effectively enhance the frequency of
 64 pollinator visits to flowers, thereby improving fruit yield and seed quality ([Garibaldi et](#)
 65 [al., 2013](#)). However, the impact of managed bees on plant production is influenced by
 66 bee variety, management practices, and plant traits ([Olsson et al., 2025](#); [Tourbez et al.,](#)
 67 [2025](#); [Tscharntke et al., 2025](#)). Current evidence indicates that bee pollination does not
 68 uniformly benefit all varieties of the same plant species ([K et al., 2014](#); [Marini et al.,](#)
 69 [2015](#)). This variability is likely because managed bees exhibit differential attraction to
 70 varieties, attributable to varied floral traits, such as petal coloration, flower odor, or
 71 nectar (volume and composition) ([Lai et al., 2025](#)). However, existing studies have
 72 focused predominantly on pre-pollination processes (such as pollinator attraction),
 73 overlooking post-pollination physiological responses across varieties ([Yi et al., 2017](#)).
 74 Successful pollination can cause double fertilization, which then initiates a cascade of
 75 developmental processes (such as corolla abscission and fruit set) that critically affect
 76 fruit yield and seed quality ([Ruan, 2014](#)). Consequently, the significance
 77 of variety selection in the context of managed bee pollination may have been
 78 underestimated. Such an underestimation could impede the identification of superior
 79 plant varieties in plant breeding programs, ultimately limiting the contribution of
 80 managed pollination to agronomic sustainability. When formulating agriculturally
 81 managed pollination strategies, it is necessary to base them on the traits of plant

varieties to maximize pollination benefits.

As *B. napus* plays a dual role in global oilseed production and ecosystem services, its industrial stability is crucial for food security. However, due to inconsistent effect of pollination on yield and quality among different varieties of *B. napus*, its industrial security remains challenging (Yang *et al.*, 2024). In the present study, we aimed to investigate nine widely cultivated *B. napus* varieties by measuring post-bee pollination changes in flowering duration and key agronomic traits to elucidate their how they contribute to seed yield and quality. We hypothesized that bee pollination enhances yield and quality by modulating flowering duration and agronomic trait expression.

2. MATERIALS AND METHODS

2.1 Plant Material and Field management

The experiment was conducted in Jinhua City, Zhejiang Province, China (29°27'30"N, 119°53'50"E) during the cultivation period of *B. napus* from March 2022 to July 2022. The following nine *B. napus* varieties were included in the study: ZheYou 163, ZheYou 505, ZheYou 83, ZheYou 51, ZheYouZa 59, ZheYouZa 313, YueYou 577, ZheNongYou 8, and ZheNongYou 3. Each variety was sown separately in one-acre fields on October 9, 2021. The treatments, sowing dates, soil fertility, and water and fertilizer management conditions of *B. napus* varieties in each field were identical.

2.2 Pollination treatment

To study the effects of bee pollination on different *B. napus* varieties, we established two treatments within the nine test plots by March 2022: a bee pollination group (BPG) and a non-bee pollination group (NBPG). For the BPG, we placed beehives (containing *Apis mellifera* and seven combs fixed longitudinally) at a density of one hive per 5 acres. Prior to hive placement, we set up the NBPG in each plot using three 2 m × 2 m × 2 m exclusion cages covered with 12-mesh nylon netting, which effectively prevented bees from entering.

2.3 Determination of key agronomic traits and seed quality of *Brassica napus*

After *B. napus* plants matured (during June 8–20), we randomly selected 24 plants from each sample plot, and traits such as plant height (cm), effective branch height (cm), number of primary branches, number of secondary branches, number of siliques per plant, number of seeds per silique, and 1000-seed weight were determined using a 5m steel tape measure (accuracy: 1 mm) and an electronic balance (range: 0–500 g/accuracy: 0.1 g). After harvesting, the average yield of the corresponding plots of the

different varieties of *B. napus* was calculated and converted to yield per unit area (kg/mu) using the following equation:

Yield per unit area (kg/mu) = total production (kg) / total area (mu),

2.4 Determination of *Brassica napus* quality

The freshly harvested seeds of *B. napus* were mixed thoroughly to ensure homogeneity. A representative random sample was drawn from the bulk for subsequent analysis. Approximately 100 g of seeds were used for near-infrared spectroscopy (NIRS).

The key seed quality traits, namely oil content (% dry weight basis), erucic acid (% of total fatty acids), glucosinolate ($\mu\text{mol/g}$, defatted dry meal basis), and oleic acid content (% of total fatty acids), were determined non-destructively using NIRS. The spectra of the sample set were processed using standard normal variate transformation and multivariate dispersed. Spectral preprocessing was conducted using different methods, including multiplicative shot correction and derivative processing methods (first and second derivatives). Exceptional sample spectra were eliminated using principal component analysis.

The analysis was performed using a Foss NIR System 5000 Near Infrared Spectrophotometer (Foss NIR Systems Inc., Silver Spring, USA). Whole seeds were scanned directly in the reflectance mode. The instrument utilizes pre-calibrated models developed from established reference methods (Soxhlet extraction for oil, gas chromatography for fatty acids, including erucic and oleic acids, and high-performance liquid chromatography or enzymatic methods for glucosinolate) to predict the concentrations of the target constituents based on the acquired NIR spectra. All measurements were performed at room temperature, according to the manufacturer's standard operating procedures and internal calibration algorithms ([Xie et al., 2016](#)).

2.6 Statistical analyses

SPSS version 23.0 (SPSS Inc., Chicago, IL, USA) statistical software was used to conduct independent sample t-tests and Pearson correlation coefficient, and the results were analyzed. The bee pollination data were analyzed after subtracting the flowering duration, fruiting duration, plant height, number of primary branches and number of secondary branches of plants after pollination by non-bee pollination. The least significant difference method was used to analyze group differences. The difference in the significance level was $p < 0.05$, and the highly significant level was $p < 0.001$. We

used Origin version 2024 (OriginLab, Massachusetts, USA) for data collation and figure drawing.

3. RESULT

3.1 Effect of bee pollination on flowering and fruiting duration of *B. napus*

Bee pollination significantly shortened *B. napus* flowering duration, with it being 23.4 days for BPG, which was significantly shorter than 30.7 days measured for NBPG ($p < 0.001$, Figure 1B). Simultaneously, bee pollination increased fruiting duration. The fruiting duration in BPG reached 40.3 days, which significantly exceeded the fruiting duration in NBPG of 38.0 days ($p < 0.05$). The reduction in flowering duration exceeded the increase in fruiting duration. The total flowering and fruiting duration was significantly shorter in the BPG than in the NBPG (Shortened by 5 days, $p < 0.05$). Bee pollination had consistent effects on flowering duration, fruiting duration, and total flowering and fruiting duration across all nine *B. napus* varieties (Figure S1A, S1B). This pattern suggests genotype-independent effects of bee pollination on total flowering and fruiting duration.

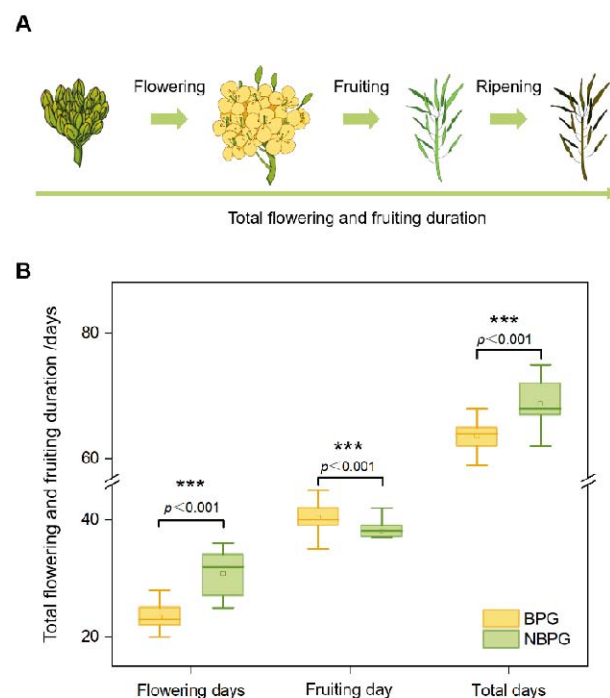


Figure 1 Effects of bee pollination on flowering and fruiting duration of *Brassica napus*. (A) Schematic representation of *B. napus* development from flowering to fruiting; (B) Effects of bee pollination on flowering duration, fruiting duration, and

total flowering and fruiting duration of *B. napus*. Data are represented as mean $\pm$ SEM. Statistical analysis included t-tests for all variables, *** $p < 0.001$. BPG: bee pollination group; NBPG: non-bee pollination group.

3.2 Effect of bee pollination on agronomic traits in *B. napus*

Overall, bee pollination shortened the plant height and reduced the number of primary and secondary branches in *B. napus*, with no significant effect on the effective branch height. Plant height in the BPG was significantly lower than that in the NBPG ($p < 0.05$, Figure 1 B, a). Specifically, the final plant height of *B. napus* in BPG was 144.06 cm, which was 7.09 cm shorter than that of plants in NBPG (151.15 cm). Bee pollination also significantly reduced the number of primary branches. The number of primary branches in the BPG was 6.96, compared with 7.51 in the NBPG ($p = 0.006$). Similarly, the number of secondary branches in *B. napus* also significantly reduced in BPG compared to NBPG, with a decrease of 5.01 ($p < 0.001$, Figure 2 B, d).

However, the effect of bee pollination on the number of primary branches was inconsistent across varieties. Specific changes were observed in agronomic traits of the nine *B. napus* varieties after bee pollination (Figure S2). No significant changes in the number of primary branches were observed in the seven varieties (ZheYou 163, ZheYou 83, ZheYou 51, ZheYouZa 59, ZheYouZa 313, ZheNongYou 8, ZheNongYou 3), with significant reductions only observed in ZheYou 505 and YueYou 577 ($p < 0.05$, Figure S2c). Bee pollination showed no significant reduction in the number of secondary branches in five varieties (ZheYou 163, ZheYou 505, ZheYouZa 59, and ZheNongYou 3), but showed a significant reduction in four varieties (ZheYou 83, ZheYou 51, ZheNongYou 313, YueYou 577, ZheNongYou 8, $p < 0.05$, Figure S2d). No significant difference in effective branch height was observed between the BPG and NBPG. The average effective branch height of *B. napus* in BPG was 41.47 cm, which was no significant difference compared with the average effective branch height of 44.04 cm in NBPG ($p = 0.356$). Among the agronomic traits, bee pollination significantly decreased plant height, number of primary branches, and number of secondary branches in *B. napus*, but these effects varied across the nine varieties (Figure S2 A, C and D).

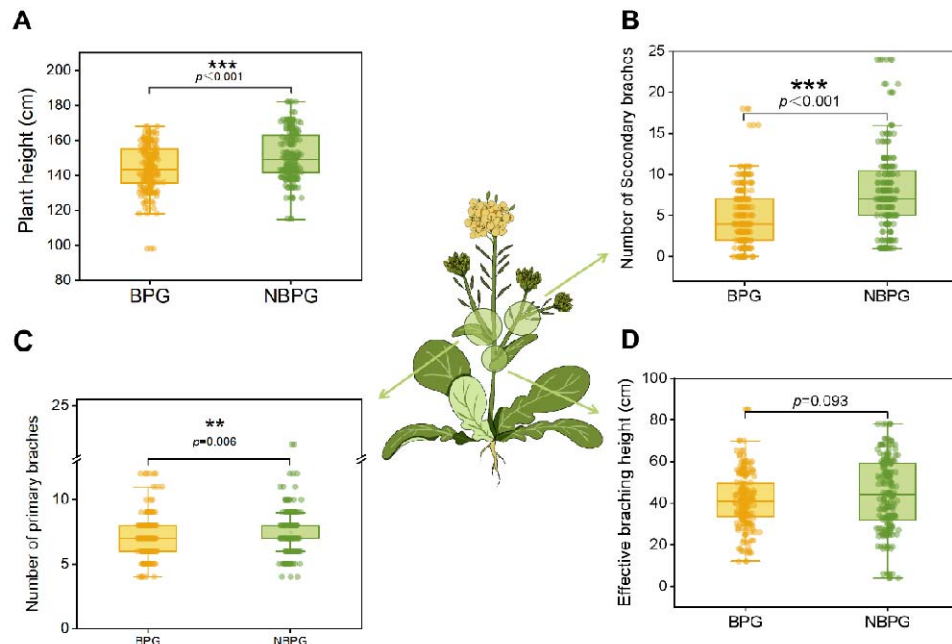


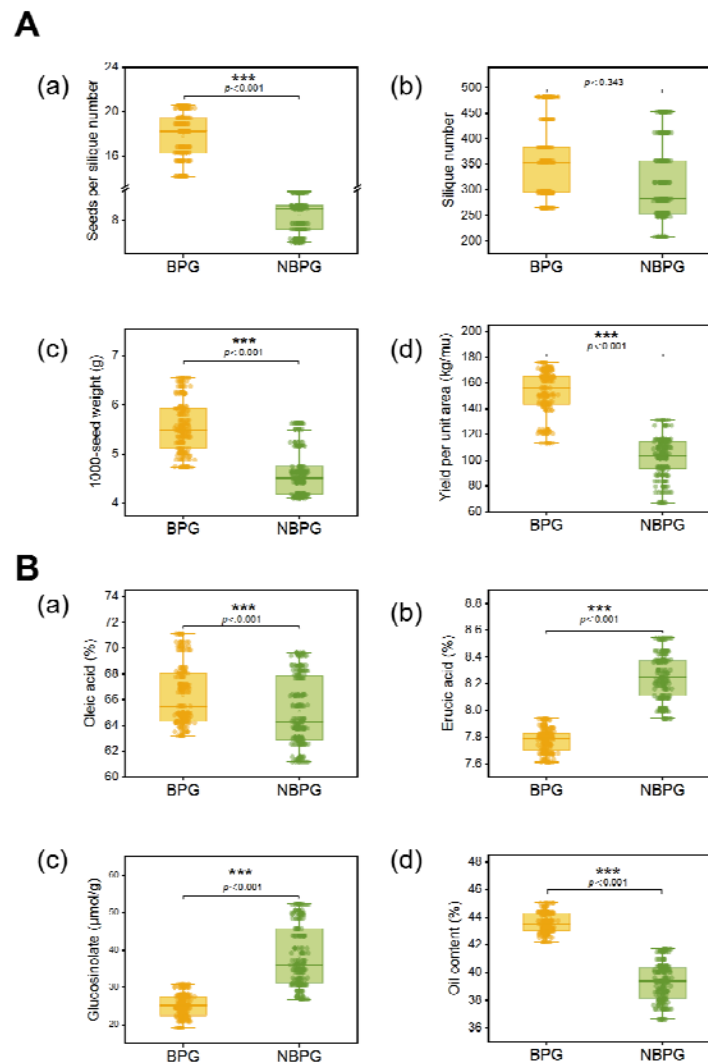
Figure 2 Effects of bee pollination on agronomic traits of *B. napus*. The effects on bee pollination on **(A)** plant height; **(B)** the number of secondary branches; **(C)** the number of primary branches; **(D)** the effective branches height. Data are represented as mean $\pm$ SEM, and statical analysis included t-tests for all variables, $***p < 0.001$, $**p < 0.01$. BPG: bee pollination group; NBPG: non-bee pollination group.

3.3 Effect of bee pollination on seed yield and quality

The seed yield results showed that although the number of siliques per plant in the BPG was higher than that in the NBPG, the difference was not statistically significant ($p = 0.343$). The other three indices, i.e. number of seeds per silique, weight of thousand seeds, and yield per unit area, of the BPG were significantly higher than those of the NBPG ($p < 0.001$, Figure 3A, a d).

Bee pollination increased oil content and oleic acid content and decreased erucic acid and glucosinolate content in *B. napus*. Oil content of *B. napus* in BPG was 43.58%, which was significantly higher than that of NBPG (39.32%, $p < 0.001$, Figure 3B, a). The oleic acid content in BPG was 66.33%, which was significantly higher than that in NBPG (65.09 %, $p < 0.001$, Figure 3B, b). The erucic acid content in the BPG was 7.78%, which was significantly lower than that in the NBPG (8.25 %, $p < 0.001$). Additionally, the glucosinolate content in the BPG was 25.20 $\mu\text{mol/g}$, which was significantly lower than the 38.21 $\mu\text{mol/g}$ measured in the NBPG ($p < 0.001$, Figure 3

221 B). The specific changes in yield and quality of different varieties of *B. napus* are
222 shown in Table S1 and S2.



223
224 **Figure 3** Effects of bee pollination on seed yield and seed quality of *B. napus*. Effect of
225 bee pollination on **(A)** seed yield of *B. napus*; **(B)** quality of *B. napus*. Data are
226 represented as mean $\pm$ SEM, and statistical analysis included t-tests for all variables,
227 *** $p < 0.001$. BPG: bee pollination group; NBPG: non-bee pollination group.

228 3.4 Correlation analysis between changes of different traits and the yield quality of 229 *Brassica napus*

230 The results of the Pearson correlation analysis showed that flowering duration was
231 negatively correlated with 1000-seed weight ($r = -0.552$), indicating that the shorter the
232 flowering duration, the more the increase in 1000-seed weight was inhibited. In
233 contrast, fruiting duration was positively correlated with 1000-seed weight ($r = 0.576$),

234 suggesting that the longer the fruiting duration, the heavier the 1000-seed weight.
 235 Fruiting duration was positively correlated with the number of seeds per silique ($r =$
 236 0.520), suggesting that extended fruiting duration contributed to an increase in the
 237 number of seeds per silique. The number of primary branches positively correlated with
 238 erucic acid content ($r = 0.532$), indicating that fewer primary branches corresponded to
 239 lower erucic acid content. Additionally, the number of secondary branches was
 240 significantly negatively correlated with oleic acid content ($r = -0.708$, $p < 0.05$),
 241 indicating that a reduction in the number of secondary branches significantly inhibited
 242 the increase of oleic acid content. In summary, flowering and fruiting durations
 243 primarily influenced yield-related indices, whereas agronomic traits mainly affected
 244 quality-related indices, which together improved the yield and quality of *B. napus*.
 245

Table 1 Correlation between difference in flowering duration, agronomic traits and changes in yield/quality indicators

	1000-seed weight	Yield per unit area	Number of siliques per plant	Number of seeds per silique	Erucic acid	oleic acid content	Glucosin olate	Oil content
Flowering duration	-0.552	-0.326	0.050	-0.409	0.040	-0.046	0.121	0.051
Fruiting duration	0.576	0.202	-0.062	0.520	0.195	-0.082	0.135	-0.284
Plant height	-0.470	0.300	0.493	0.222	-0.043	-0.151	0.299	0.051
Number of primary branches	0.057	-0.141	0.097	-0.375	0.532	-0.708*	0.378	-0.284
Number of secondary branches	-0.270	-0.253	0.073	0.495	0.231	-0.455	0.192	0.017

* T-tests for all variables, $P < 0.05$. "Difference" refers to the difference in indicators between the
bee pollination group and non-bee pollination group.

4. DISCUSSION

In this study, we found that bee pollination can improve the yield and quality of *B. napus* by shortening flowering duration and influencing agronomic traits. Specifically, among the nine *B. napus* cultivars included in the experiment, bee pollination significantly shortened the flowering duration and prolonged the fruiting duration. After bee pollination, plant height and the number of branches were reduced, but the impact of bee pollination were inconsistent across the nine *B. napus* varieties. We found that *B. napus* could improve yield (number of siliques per plant, number of seeds per silique, 1000-seed weight, and yield per unit area) and quality (oil content and oleic acid increased, and erucic acid and glucosinate decreased) through changes in flowering duration and agronomic traits.

Bee pollination significantly reduced the flowering duration of all nine varieties, which can be attributed to increase in efficiency of plant pollination by pollinators. Simultaneous correlation analysis showed that with a decrease in flowering duration the 1000-seed weight decreased. As the fruiting duration was extended, the heavier the 1000-seed weight, the greater the number of seeds per silique. Bee pollination enhances

266 stigma pollen deposition and promotes timely fertilization ([Yi et al., 2017](#)). After
267 fertilization, the plant starts fruit development, and the hormones in the plant also
268 change accordingly. The primary hormonal change after fertilization include increased
269 ethylene and auxin synthesis. The synergistic effects of ethylene and auxin trigger the
270 degradation of senescent cell walls of floral organs, ultimately shortening the lifespan
271 of individual flowers ([Chen et al., 2005](#); [J, 2006](#)). Finally, the simultaneous withering
272 of several flowers likely shortens the overall anthesis period of the population.

273 Crucially, this accelerated floral termination reallocates metabolic resources that
274 would otherwise be expended for floral maintenance, nectar production, and pollinator
275 attraction ([Can et al., 2018](#)). Longer flowering duration can result in higher fruiting
276 rates when plants are under-pollinated ([Ashman et al., 2004](#)). In contrast, managed bee
277 pollination is efficient, resulting in a shorter time for plants to achieve the same fruit-set
278 rate as under natural conditions ([Bommarco et al., 2012](#); [Ma et al., 2025](#)). The
279 preserved resources are then redirected to fruit development, prolonged fruiting
280 duration, and improved seed-filling capacity ([Harder and Johnson, 2025](#)). This
281 enhanced resource efficiency and yield gain achieved through managed bee pollination
282 directly contribute to sustainable agronomic intensification, a cornerstone of achieving
283 the UN Sustainable Development Goal 2 (SDG2), by boosting productivity per unit
284 area without necessarily expanding agronomic land or relying solely on chemical input.
285 This also indicates that bees should ideally be introduced in fields prior to flowering to
286 increase pollination efficiency.

287 In general, bee pollination can reduce plant height, the number of primary
288 branches, and the number of secondary branches in *B. napus* varieties, but the
289 performance of different varieties varies. Correlation analysis showed that with a
290 decrease in the number of primary branches, the erucic acid and oleic acid contents of
291 the plant decreased, suggesting that among annual herbaceous plants, varieties with
292 significant changes in agronomic traits after bee pollination under the same
293 management mode may have higher seed yield and seed quality ([Lai et al., 2025](#)). After
294 successful fertilization, hormonal network changes in plants involve not only changes
295 in auxin and ethylene content, but also changes in gibberellic acid (GA) content.
296 Increasing GA levels in plants after effective fertilization can reduce plant height and
297 the number of primary branches by inhibiting apical dominance ([Bao et al., 2020](#); [Kun
298 et al., 2021](#); [Shi et al., 2024](#)). However, the changes in plant hormones and the extent to
299 which they are affected are directly or indirectly regulated by genes. For example, high

expression of *the OsNCED3* gene in drought-tolerant rice varieties promotes the rapid accumulation of abscisic acid (ABA), which in turn induces stomatal closure ([PoKai et al., 2020](#); [Li et al., 2024](#)). Similarly, in plant tissue cultures, different genotypes have different requirements for the ratio of exogenous hormones (e.g., IAA/CK ratio) to induce cell differentiation, rooting, or dedifferentiation ([Li et al., 2024](#); [Wu et al., 2024](#)). Therefore, the changes in agronomic traits observed in this study may be attributed to differences in hormone secretion or hormone response abilities caused by different genotypes of different varieties. This also suggests that, in the agronomic production of future sustainable agriculture systems, changes in the agronomic traits of plants after bee pollination can be observed to select varieties that exhibit better yield and quality improvement. This approach leverages natural pollination services to enhance productivity and resource-use efficiency, aligning with the ecological intensification principles crucial for SDG2. Furthermore, the conservation and utilization of genetic diversity in crop responses to pollinators supports SDG15 by promoting agronomic practices that depend on and sustain biodiversity.

Collectively, our findings indicated that bee pollination mediates plant resource reallocation through two primary mechanisms: (1) changes in flowering duration, which were detected in all varieties, and (2) changes in agronomic traits, which were detected in only a few varieties. Therefore, shortening the flowering duration may be more important for yield and seed quality improvement because it is less affected by genotype, which explains why yield quality improved across all varieties. Meanwhile, shortening the flowering duration allowed plants to enter the harvest period earlier and increased the number of days required for the soil to recover. Although the agronomic traits of the different varieties changed differently after bee pollination, varieties with reduced plant height and number of primary branches had higher seed yield and quality than the other varieties. In the future, varieties with beneficial changes in agronomic traits (such as a decrease in plant height) post bee pollination can be selected to further improve the pollination effect of bees. Simultaneously, they can be used for agricultural extension and planting.

5. CONCLUSIONS

Our experimental results suggested that bee pollination may affect plant nutrient distribution by shortening flowering duration and modifying agronomic traits. These adjustments extend the fruiting duration, thereby enhancing both fruit yield and seed

quality. Bee pollination consistently reduced flowering duration across all varieties. Although agronomic traits (including plant height and number of secondary branches) generally decreased following bee pollination, responses varied among varieties, likely due to genotypic differences. Thus, the contribution of shortened flowering duration to improvements in seed yield and quality is more universal than that of agronomic trait changes. To fully capitalize on this benefit, the introduction of managed bee colonies prior to flowering is critical. Furthermore, future selective breeding programs should prioritize varieties with reduced plant height and fewer secondary branches after bee pollination to amplify these beneficial effects synergistically.

Funding

This research was supported by the Major Agricultural Technology Cooperative Promotion Plan of Zhejiang Province (2025ZDT18-01) and Modern Agriculture Industry Technology System (CARS-44).

Declaration of Competing Interest

The authors declare no conflict of interest.

Data Availability

All data generated in this study are provided as electronic supplementary material.

Ethics approval

This study does not involve ethical approval.

Consent to participate

This study does not involve human research.

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