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Effects of Mixtalol and Paclobutrazol on Photosynthesis and Yield of Rape (*Brassica napus*)

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Abstract. Photosynthetic and yield effects of paclobutrazol and mixtalol sprayed, respectively, on rape at the three-leaf stage and shoot or anthesis stages were examined. They significantly increased chlorophyll content and photosynthetic rates, prolonged leaf longevity, and increased green pod area. Paclobutrazol-treated plants were shorter, more branched, and produced more seeds. Foliar sprays of mixtalol increased podding percentage, pods per plant, and seeds per pod. A high seed yield of 1809.0 kg/ha was obtained with mixtalol sprayed at anthesis, while significant yields were also achieved with treatments of mixtalol at the shoot stage and paclobutrazol at the three-leaf stage. The photosynthetic and yield effects of mixtalol or paclobutrazol were reduced when both growth regulators were applied together, and this led to yield reductions. No adverse effects from mixtalol or paclobutrazol were observed on seed oil content, erucic acid, and glucosinolate content. The total rape oil production with mixtalol sprayed at anthesis and shoot stages and paclobutrazol at the three-leaf stage increased significantly by 20.9%, 14.4%, and 13.4%, respectively, over the controls.

Transplanting is the main method for producing oilseed rape (*Brassica napus*) in Zhejiang Province, China. It has been shown that the seed yield is 20% higher in rape using vigorous seedlings than with weak seedlings. It has been difficult to have vigorous seedlings and high and stable seed yields in recent years because of inadequate seed beds, high seeding rate, and ineffective seedling management. Chemical plant growth regulators are increasingly being used to manipulate plant growth and yield. Paclobutrazol (PP333) is a plant growth retardant and has been extensively used to reduce seedling height and to prevent "high-foot" and weak seedlings (Scarisbrick et al. 1985, Shen et al. 1991, Wu 1987). Unlike PP333, the new plant growth regulator mixtalol (MTL, a mixture of long chain aliphatic alcohols varying in chain length from C24–C34) was applied at later growth stage (Malik et al. 1987, Menon and Srivastava 1984, Setia et al. 1989). Significant photosynthetic and yield effects using 4–2 ppm MTL sprayed at anthesis were experimentally achieved during 1989–1990 and 1990–1991 (Zhou et al. 1991, 1992). The objectives of the present experiments were to further determine the best stages for MTL application and the joint effects of PP333 and MTL on rape plants under field conditions.

Materials and Methods

Oil-seed rape (*Brassica napus*) cv. 601 was used in the experiment. A 15% water-dispersible powder of paclobutrazol (PP333) was provided by the Yixing Biochemical Factory of Jiangsu Province and a 2000 ppm suspension of mixtalol (MTL) by the Seed Regulator Lab. of Zhejiang Agricultural University. The experiments were conducted at the University farm during 1991–1992 and were based on the previous results of PP333 for 1989–1990 and MTL for 1990–1991 (Shen et al. 1991, Zhou et al. 1992). Six treatments were made as follows: PP333 (150 ppm PP333 sprayed on rape at the three-leaf stage), MTL1 (4 ppm MTL sprayed at shoot stage), MTL2 (4 ppm MTL sprayed at anthesis), PMTL1 (PP333 + MTL1), PMTL2 (PP333 + MTL2), and ck (distilled water). All treatments were applied at the rate of 750 L diluted solution/ha (PP333 at 150 ppm, MTL at 4 ppm). Seedlings were transplanted at the five-leaf stage into the experimental plots in a randomized block design using three replicates. Each bed was 4.0 m long and 1.7 m wide. Conventional methods of cultivation were used during the growing period.

Ten plants were used for physiological analyses and morphological measurements. Leaf and pod chlorophyll contents were determined by the method of Chen (1984). Leaf photosynthetic rate was measured using $14CO_2$ and leaf longevity (time at which ⅔ leaves turn to yellow) was recorded for the final 10 leaves (Zhou et al. 1992). The green pod area was measured using the

Table 1. Effects of MTL and PP333 on chlorophyll contents (mg/gFW) of rape leaves and pods.

	Weeks after MTL2 spraying						
	Leaf				Pod		
Treatment	1	2	3	4	4	5	6
MTL1	2.24 ± 0.14*	1.56 ± 0.09**	1.57 ± 0.08*	1.16 ± 0.07*	0.413 ± 0.03*	0.326 ± 0.03	0.289 ± 0.04
MTL2	2.34 ± 0.12**	1.54 ± 0.08*	1.65 ± 0.13**	1.22 ± 0.11**	0.398 ± 0.03	0.342 ± 0.04*	0.307 ± 0.05*
PP333	2.21 ± 0.09*	1.53 ± 0.10*	1.54 ± 0.12*	1.12 ± 0.07*	0.396 ± 0.02	0.322 ± 0.04	0.291 ± 0.03
PMTL1	2.03 ± 0.07	1.23 ± 0.05	1.46 ± 0.10	1.02 ± 0.04	0.384 ± 0.01	0.297 ± 0.03	0.278 ± 0.01
PMTL2	2.15 ± 0.10*	1.32 ± 0.03	1.49 ± 0.09*	1.04 ± 0.06	0.377 ± 0.02	0.319 ± 0.01	0.284 ± 0.02
CK	1.91 ± 0.11	1.30 ± 0.07	1.36 ± 0.11	1.02 ± 0.05	0.377 ± 0.02	0.304 ± 0.02	0.275 ± 0.01

* $p < 0.05$, **$p < 0.01$.

Table 2. Effects of MTL and PP333 on photosynthetic rate (cpm/cm^2) of rape leaves.

	Weeks after MTL2 spraying			
Treatment	1	2	3	4
MTL1	3847 ± 437.2*	2966 ± 132.7*	3164 ± 431.0*	2967 ± 235.6**
MTL2	4013 ± 590.7*	3398 ± 289.5**	3784 ± 478.1**	3539 ± 479.8**
PP333	4044 ± 686.0*	3372 ± 345.6**	3742 ± 597.5**	3131 ± 680.9**
PMTL1	3364 ± 335.5	2465 ± 402.7	2335 ± 327.0	2252 ± 239.7
PMTL2	3531 ± 278.1	2533 ± 371.3	2167 ± 711.7*	2328 ± 138.0
CK	3494 ± 639.4	2696 ± 381.4	2601 ± 250.5	2170 ± 370.5

* $p < 0.05$, **$p < 0.01$.

Clarke formula ($Sa = \pi dh1 + \frac{1}{3} \pi dh2$) (Liu 1987). Yield components and seed yield (combine harvested) were recorded at harvest, and seeds were analyzed for oil content, erucic acid, and glucosinolates (Chinese Academy of Agricultural Science 1990).

Results

Photosynthetic Effects

The chlorophyll content of leaves and pods was increased after spraying with MTL and PP333 (Table 1). The highest chlorophyll values were obtained using the MTL2 treatment, which gave readings of 22.5%, 18.5%, 21.3%, and 19.6% greater than the control at 1, 2, 3, and 4 weeks after MTL2 spraying for leaves, and 12.5% and 11.6% greater than the control at 5 and 6 weeks for pods, respectively. The chlorophyll content was also increased with MTL1 and PP333, suggesting that the degradation of chlorophyll was retarded. No clear increase or even decrease of chlorophyll content of leaves and pods was observed with PMTL1 and PMTL2, showing that the joint effect of PP333 and MTL was not synergistic.

MTL and PP333 also promoted the photosynthetic rate of leaves (Table 2). The best effect was obtained with MTL2 and PP333, suggesting that the MTL- and PP333-treated plants could still maintain a higher photosynthetic rate at the late growth stage. The photosynthetic rates of PMTL1 and PMTL2 were either close to or lower than the control; therefore, the promotive effect of MTL or PP333 was reduced when they were applied jointly.

Table 3. Effects of MTL and PP333 on leaf longevity and green pod area of rape.

	Prolonged leaf longevity (day)[a]			
Treatment	Top leaf 10	Leaf 7	Leaf 4	Green pod area (cm^2/pod)
MTL1	3.1	3.2	1.5	9.64 ± 0.42
MTL2	3.8	4.0	2.0	9.82 ± 0.39*
PP333	2.8	3.0	2.0	9.35 ± 0.48
PMTL1	2.3	2.5	1.4	9.28 ± 0.27
PMTL2	2.6	2.9	1.3	9.32 ± 0.36
CK	0	0	0	9.13 ± 0.40

[a] Time at which 2/3 leaves turn to yellow (ck as zero).
* $p < 0.05$.

The leaf longevity at the late growth stage was obviously prolonged after spraying MTL and PP333 (Table 3). The leaf longevities of top leaf 10, leaf 7, and leaf 4 were prolonged to 3.8, 4.0, and 2.0 days with MTL2 treatment. It was reported that if leaf longevity was prolonged 1 day at maturation, then a 2% increase in seed yield would be anticipated (Liu

Table 4. Effects of MTL and PP333 on podding percentage (%) of rape.

	Weeks after MTL2 spraying			
Treatment	1	2	3	4
MTL1	77.5 ± 2.5*	96.0 ± 1.7	95.0 ± 2.0	45.8 ± 2.6**
MTL2	88.0 ± 2.3**	97.5 ± 2.2	97.5 ± 2.3*	54.2 ± 4.0**
PP333	82.5 ± 3.9**	95.0 ± 2.0	92.5 ± 2.5	40.6 ± 2.5*
PMTL1	62.5 ± 3.9	95.0 ± 1.0	92.0 ± 2.5	37.5 ± 2.8
PMTL2	75.0 ± 5.0*	98.0 ± 1.7	95.0 ± 2.0	41.7 ± 1.5*
CK	60.0 ± 6.0	95.0 ± 1.0	87.5 ± 3.8	33.3 ± 4.2

* $p < 0.05$, **$p < 0.01$.

Table 5. Effects of MTL and PP333 on yield components and yield of rape.

Treatment	Plant ht (cm)	Stem width (cm)	Branch position (cm)	Primary branch (No.)	Second branch (No.)	Terminal raceme length (cm)	Ineffective terminal raceme length (cm)	Pod/ plant (No.)	Seed/ pod (No.)	1000 seed wt (g)	Seed yield (kg/ha)
MTL1	154.4	1.87	33.2	8.1	7.8	59.0	2.0	348.1	17.8	3.39	1722.0*
MTL2	157.6	1.94	31.8	8.3	8.2	56.8	1.8	364.3*	18.3	3.44	1809.0**
PP333	147.8	1.84	33.6	8.9*	7.9	55.2	2.2	329.0	18.2	3.51	1725.0*
PMTL1	151.0	1.89	33.8	8.0	8.1	55.9	2.1	352.9	17.5	3.36	1602.0
PMTL2	152.4	1.91	32.6	7.8	7.7	56.6	1.7	342.2	18.0	3.42	1653.0
CK	153.2	1.90	34.2	8.2	7.9	56.2	2.1	338.6	17.3	3.37	1536.0

* $p < 0.05$, **$p < 0.01$.

Table 6. Effects of MTL and PP333 on rapeseed quality.

Treatment	Oil content (%)	Oil yield (kg/ha)	Erucic acid (%)	Glucosinolate (μmol/g)
MTL1	39.65 ± 1.50	682.8 ± 40.7*	48.68 ± 0.45	109.9 ± 6.41
MTL2	39.92 ± 1.26	722.1 ± 86.9**	48.50 ± 0.78	112.6 ± 4.50
PP333	39.26 ± 0.70	677.2 ± 45.4*	49.27 ± 0.41	109.4 ± 7.46
PMTL1	38.90 ± 0.84	623.2 ± 67.2	50.15 ± 1.86	110.5 ± 1.50
PMTL2	38.88 ± 0.75	642.7 ± 53.5	49.60 ± 1.02	111.2 ± 3.32
CK	38.87 ± 0.58	597.0 ± 70.4	49.37 ± 0.73	110.4 ± 5.21

* $p < 0.05$, **$p < 0.01$.

1983). Meanwhile, the green pod area was also enlarged, and 7.6% and 5.6% increases over the controls were observed with MTL2 and MTL1 treatments (Table 3). During pod maturation, photosynthesis depends mainly on green pods (Liu 1987), and higher chlorophyll content and larger pod area were conducive to the accumulation and transformation of photosynthates.

Table 4 indicates that spraying with MTL and PP333 led to an increase in podding percentage, especially when there was less sunlight (as in the case of week 1) and at the pod maturation stage (week 4). Therefore, plants treated with MTL2, MTL1, and PP333 could withstand less favorable conditions and maintain relatively high podding percentages.

Yield Components and Seed Yields

There were certain effects of MTL and PP333 on the morphological characteristics of rape plants (Table 5). Plant height was slightly increased when sprayed with MTL, but was decreased with PP333. Apart from primary branching in PP333-treated plants which was increased 8.5% over the controls, the primary and secondary branches in the other treatments showed no significant difference. The effective length of the terminal racemes was enhanced when treated with MTL1 and MTL2, while no obvious differences in stem width and branching position was found between various treatments and controls.

Table 5 also shows enhancement in pods per plant following MTL treatment, with a slight decrease in pods per plant treated with PP333. The number of seeds per pod and seed weight of MTL2 and PP333 treatments were increased over controls. The seed yield of MTL2, MTL1, and PP333 treatments reached 1809.0 kg/ha, 1722.0 kg/ha, and 1725.0 kg/ha, respectively—a significant increase over the control of 17.8%, 12.1%, and 12.3%.

Seed Quality

The oil content, erucic acid, and glucosinolate content of rapeseed are important quality characters. Table 6 indicates that there was only a small increase (2.7–1.0%) in the seed oil content from plants treated with MTL and PP333, but the oil yield of MTL2, MTL1, and PP333 treatments increased significantly by 20.9%, 14.4%, and 13.4%, respectively, over the controls. No obvious difference of erucic acid and glucosinolate content of seed was observed between various treatments and the controls. In addition, the maturation of plants was not affected much by MTL and PP333. All plants were harvested on the same day.

Discussion

PP333 is a plant growth retardant. This chemical is a potent inhibitor of sterol biosynthesis which is induced by a reduction in the concentrations of endogenenous gibberellins and indole acetic acid and an increase in the content of endogenenous abscisic acid and ethylene within plants (Zhang et al. 1988, Zhou et al. 1993). Research on this regulator has revealed growth inhibition on several species, and it had been used commercially to raise strong rape seedlings in China. On the other hand, MTL was a new chemical that could stimulate plant growth, and has been reported to increase the chlorophyll content and the rate of photosynthesis, enhance carboxylation and photophosphorylation activities, control stomatal movement, and suppress the rate of photorespiration in C3 plants (Malik et al. 1987, Menon and Srivastava 1984, Zhou et al. 1992). Little is known about its regulation on endogenenous hormones within plants, and much research is needed before it can be practically applied.

The present experiment revealed that the combined application of the growth retardant (PP333) and the growth stimulator (MTL) counteracted and reduced their individual effects—that is, a certain antagonistic action existed with these two plant growth regulators. PP333 was sprayed at the three-leaf stage of growth in the seed bed, and it mainly regulated seedling growth; while MTL was applied at anthesis or shoot stage, and it promoted plant growth in the middle and late stages. There was about a 4-month gap between the application time of the two chemicals, and the function of raising strong seedlings using PP333 treatment was already brought into full play. Considering the long duration of its effect and wide activity of PP333, it would still, to some extent, counteract or reduce the stimulation of MTL on plant growth. Consequently, PP333 reduced the enhancement of chlorophyll content and the photosynthetic rate, and the improvement of yield components and seed yield of rape plant through MTL application. In the present experiment, the foliar spraying of MTL once at anthesis stage obviously increased the photosynthetic ability, and improved the morphological characters and yield components of the rape plant. Therefore, very significant increased yields were achieved.

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