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Interactive effects of NPK fertilizer and paclobutrazol concentration on growth and yield of hanjeli (*Coix lacryma*-jobi L.)

Abstract The balance between growth and crop yield can be manipulated by exploiting nutrient and retardant interactions. This study is aiming to assess the effects of various combinations of NPK 16-16-16 fertilizer in different doses, along with the application of multiple concentrations of paclobutrazol on the growth and yield of hanjeli. This experiment was carried out in the experimental field of Ciparanje, Faculty of Agriculture Universitas Padjadjaran, Jatinangor, Sumedang from February 2021 to August 2021. This research was conducted in a split-plot design with three replications. The main plot consisted of 200 kg ha^{-1}, 250 kg ha^{-1}, and 300 kg ha^{-1}. The subplot consisted of 2000 ppm, 3000, and 4000 ppm. The results show that there were interaction effects between different doses of NPK fertilizer and paclobutrazol concentrations on plant height and 100-grain weight. The best combination came from the application of 200 kg ha^{-1} NPK fertilizer with 3000 ppm of paclobutrazol, which gave higher results in plant height and 200 kg ha^{-1} NPK fertilizer with 2000 ppm of paclobutrazol on 100-grain weight.

Keywords: Doses · Hanjeli · Nutrients · Paclobutrazol · Retardant

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Introduction

Hanjeli is a food crop that has potential to support the food diversification program. According to previous study by Qosim & Nurmala (2011) the chemical component of hanjeli is comprised of 71.81% carbs, 10.89% protein, 1.38% ash, and 5.18% lipid. This shows hanjeli may be used as a substitute food crop. However, the yield potential of hanjeli needs to improve. One of the constraints is the harvest time for hanjeli is classified as long, due to it being a perennial plant.

Fertilization is one of many important ways for improving growth and yield of hanjeli crop. Ramadhan et al. (2022) stated that NPK Mutiara 16-16-16 fertilizer contains optimal and balanced amounts of nitrogen (N), phosphorus (P) and Potassium (K) nutrients and contains additional nutrients in the form of Ca and Mg for increasing the growth of the plant. N is known for its effectiveness in helping plants grow quickly, it also accelerates the seed as well as fruit production (Gojon, 2017). Phosphorus is a major player when it comes to photosynthesis and has great significance helping plant grow (Lovio-Fragoso et al., 2021). K helps greatly in photosynthesis, improving the quality of fruits, protein building, and disease reduction (Hasanuzzaman et al., 2018).

In contrast to fertilization, paclobutrazol may reduce shoot growth while increasing root-shoot ratios. The application of Paclobutrazol improved stem diameter, modified root architecture, decreased plant height, and contributed to enhanced yield (Syahputra et al., 2016; Pal et al., 2016). Application of paclobutrazol on crops modifies hormonal balance and growth, leading to increased yield. Paclobutrazol can inhibit cell elongation and stem internode elongation by inhibiting gibberellin biosynthesis, causing a decrease in the rate of cell division (Desta & Amare, 2021). In addition to providing an inhibitory effect on stems, application of paclobutrazol can also shorten harvest time and increase grain yields. This is because paclobutrazol can decrease the rate of cell release which results in the plant resting the growing point and diverting photosynthetic results in the generative phase to fill the pods and seeds so that the harvest time is shortened (Zulfaniah et al., 2020).

The combination of NPK fertilizer with paclobutrazol is expected to be a cultivation technique that can increase yield of hanjeli. Aldini et al., (2022) showed that different NPK fertilizer doses and paclobutrazol could increase growth and yield in tomato plants. However, there is no information regarding the interaction of the application of NPK fertilizer and concentration of paclobutrazol in hanjeli plants. In this research, we employed NPK fertilizer (16-16-16) in different doses and concentrations of paclobutrazol (*Coix lacryma-jobi* L.) thus providing a theoretical basis for efficient fertilizer and retardant application.

Materials and Methods

This research was conducted from February to August 2021 at the Experimental Field of the Faculty of Agriculture, Universitas Padjadjaran, Jatinangor, Sumedang Regency, West Java. The altitude of the research location was 737 m above sea level. The soil order in growing location was Inceptisols with the climate type of C3 according to Oldeman's classification. Rainfall intensity during the study period was 118 mm (February), 490 mm (March), 44.5 mm (April), 120.5 mm (Mei), 85.5 mm (June), 16 mm (July) and 10 mm (August). The characteristic of soil media used in present experiment was pH 5.96 (slightly acidic soil), C-organic 01.7% (very low), N total 0.12% (low), C/N 7.08 (moderate), P_2O_5 total 60.65 mg/100 g (very high), available P_2O_5 10.70 ppm (moderate), K_2O 11.60 mg/100 g (low), and cation exchange capacity 22.51 me 100 g^{-1} (moderate).

The tools that were used for this research included a meter gauge, analytical scale with 0.01 gram accuracy, and a camera. The materials that were used included the seeds of hanjeli var. ma-yuen, NPK 16–16–16 fertilizer, plant growth regulator of paclobutrazol, and Profenofos insecticide.

This research was done using an experimental method, i.e., Split Plot Design, with doses of NPK fertilizer as the first factor and paclobutrazol as the second ones. The first factor consisted of 3 levels, 200 kg ha^{-1} (n_1), 250 kg ha^{-1} (n_2), and 300 kg ha^{-1} (n_3), while the second factor consisted of 3 levels, 2000 ppm (p_1), 3000 (p_2), and 4000 ppm (p_3). All treatments were repeated three times, so there were 27 plots. Each plot was 5.1 m^2 that consisted of 18 plants.

Land preparation involved of weed removal, plowing, and plots making. The plots were 3 m width and 1.7 m length. The distance between plots was 0.3 m, while replication distance was 1 m. Plant spacing was 60 cm x 50 cm. Experimental plots were fertilized with manure at a dose of 2 tons/ha a week before planting. Healthy and well sprouted hanjeli were planted in a hole with 3 cm depth and covered by soil. The application of NPK according to treatment was given gradually over three times at 3 week after sowing (WAS), 8 WAS and 13 WAS by side dressing. Paclobutrazol treatment was applied to the plant gradually over two times at 13 WAS (early flowering stage) and 15 WAS (14 days after the flowers appeared). Plant cultivation included watering, weeding, pest and disease control. Plants received water via surface irrigation. Weeds was removed by mechanical weeding. Pest was controlled by spraying insecticide, while black mildew was managed by fungicide. Hanjeli are harvested 165 days after sowing (DAS), or when the seed reaches physiological maturity. Dry and yellowish leaves on the plant physically suggested that seeds were ready to be harvested.

Four hanjeli plants were selected to measure growth and yield attributes consisting of plant height, leaf area, number of productive tillers, root-shoot ratio, 100-grain weight, and grain weight per plot. Plant height was measured from the level of ground surface to the tip of the main stem using roll meter at 90% flowering before harvest and the mean values were computed for further analysis. Leaf area was calculated using the regression equation method for hanjeli y = 0.277 +0.683 (widht x length), (R2 = 94.5%) at vegetative stage. Similarly, number of productive tillers was recorded by counting the tillers that produce flowers at 18 WAS (reproductive stage). Root-shoot ratio obtained by comparing the dry weight of shoot with the dry weight of root plant after harvest. 100-grain weight and grain weight per plot were measured after harvest using an analytical scale at 14% moisture content.

Data collected were subjected to analysis of variance (ANOVA) procedure for a Split Plot design and where treatment means were significant, they were separated using Duncan's test at 5% level of probability using SmartstatXL statistical software.

Results and Discussion

Plant height. The ANOVA result in Figure 1 showed that the NPK fertilizer and paclobutrazol concentration interaction is significant for plant height. The combination of NPK fertilizer doses of 200 kg ha^{-1} and concentration of paclobutrazol 3000 ppm was considered as the lowest plant height, 202.08 cm, but is not the best combination because it produced a low yield component (Figure 4). The combination of NPK fertilizer doses of 200 kg ha^{-1} with concentration of paclobutrazol 2000 ppm is considered to be the best treatment on the character of plant height, which classified as a desirable low height and produced a fairly high yield of 100-grain weight.

This is due to the role of NPK fertilizer on plant height. An increased nitrogen dose may have delayed the crop's reproductive phase by lengthening the vegetative phase (Gul et al., 2015). Then, phosphorus and potassium application promote the formation of new cells, increases plant vigor and accelerates leaf development (Sankadiya & Sanodiya, 2021). Therefore, in this study, the function of paclobutrazol in terms of inhibiting plant growth is thought to be limited by the role of these nutrients, so that the decrease in plant height growth is also very dependent on the number of doses of NPK fertilizer given.

Leaf area Leaf area is an important indicator reflecting the growth status of plant. Based on the result of the statistical data analysis in Table 1, showed that there was no interaction between the doses of NPK fertilizer and the concentrations of paclobutrazol on leaf area. Single effect of NPK fertilizer and paclobutrazol concentration did not affect the leaf area of hanjeli. The range of total leaf area from the single effect of NPK doses was 145.28-148.87 cm^2, while the range of total leaf area from the single effect of paclobutrazol application was 145.78-148.39 cm^2.

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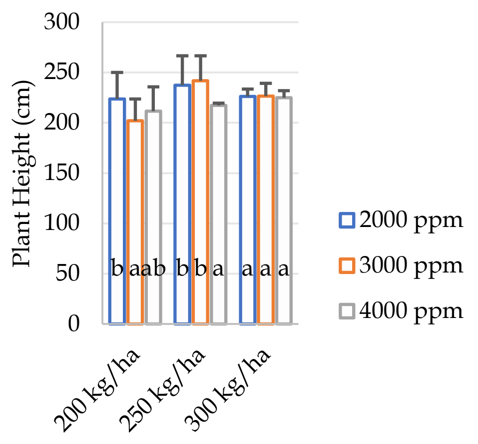
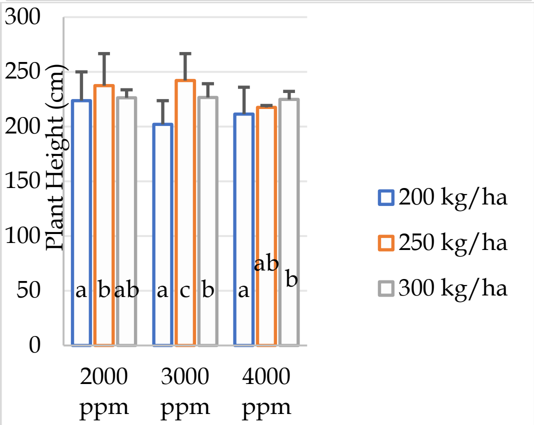
Table 1. Effects of NPK fertilizer doses and paclobutrazol concentrations on the leaf area and number of productive tillers of Hanjeli

Treatment	Leaf area (cm^2)	Number of productive tillers
n_1: NPK 200 kg ha^{-1}	148.87	6.47
n_2: NPK 250 kg ha^{-1}	145.28	7.50
n_3: NPK 300 kg ha^{-1}	146.21	7.81
p_1: Paclobutrazol 2000 ppm	145.78	7.11
p_2: Paclobutrazol 3000 ppm	148.39	7.44
p_3: Paclobutrazol 4000 ppm	146.18	7.22

Note: The mean value is not significantly different according to ANOVA test.



a. NPK fertilizer dose x paclobutrazol concentrations



b. Paclobutrazol concentration x NPK fertilizer dose

Figure 1. Interaction effect of NPK fertilizer dose and paclobutrazol concentration on plant height

Note: Plant height affected by NPK fertilizer dose and paclobutrazol concentration (a) A similar letter inside the bar chart indicates no significant difference between paclobutrazol concentration treatments per NPK dose. (b) A similar letter inside the bar chart indicates no significant difference between NPK dose treatments per paclobutrazol.

There was no significant difference in the leaf area after application of NPK fertilizer doses and paclobutrazol concentration, apparently it was due to the needs of leaf nutrients have been met while the concentration of paclobutrazol used was not appropriate. As reported by Mustofa (2022) there was no real effect on leave area from different concentration of liquid organic fertilizers. Nitrogen promote leaf area during vegetative development and help to maintain functional leaf area during the growth period. Nitrogen plays a large role in the production of nucleotides and phosphatides, which increases the concentration of phosphorus in the plants. Phosphorus are related to carbon assimilation metabolism and influence leaf photosynthesis (Xing & Wu, 2014). Potassium is in charge of preserving the right water potential, turgid pressure, and encouraging cell elongation in the leaves. Potassium also influences the uptake and transport of nitrate within the plant (Xu et al., 2020). Along with NPK fertilizer, the action of paclobutrazol in promoting plant growth may be connected to how it affects leaf. Roseli et al., (2012) stated that paclobutrazol's inhibitory effects reduce the leaf area *S. myrtifolium* but no abnormal leaf formation.

Number of productive tillers Table 1 showed that there was no interaction between the dose of NPK fertilizer and the concentration of paclobutrazol on number of productive tillers. Single effect of NPK fertilizer and paclobutrazol concentration also did not affect number of productive tillers of hanjeli**.** The range of number of productive tillers from single effect of NPK doses was 6.47-7.81, while the range of number productive tillers from the single effect of paclobutrazol application was 7.11-7.44.

We theorize that water, hormone balance, and nutrient were sufficient at the beginning of the growth phase, thus the number of productive tillers were relatively same. NPK fertilizer affects the increase in photosynthetic yield which is then directed to the formation of plant vegetative organs such as initiation of tillers and roots so that the final yield increases (Firmansyah et al., 2017). Similar result was reported by Nagar et al., (2021) that the application of paclobutrazol did not have a significant effect on the number of tillers in wheat plants.

Root-shoot ratio Table 2 showed that there was no interaction between the doses of NPK fertilizer and the concentration of paclobutrazol on root-shoot ratio. Single effect of NPK fertilizer and paclobutrazol concentration also did not affect root-shoot ratio of hanjeli. The range of root-shoot ratio from the single effect of NPK doses was 5.3-6.7, while the range of NPK doses from the single effect of paclobutrazol application was 5.2-6.4.

Based on the result of the statistical data analysis in the Table 2, it shows that the NPK fertilizer application and paclobutrazol concentration did not have a significant effect on the root-shoot ratio of hanjeli plants. According to Irwan et al., 2017 the ideal root-shoot ratio for cereal crop is 3. In this research, the root-shoot ratio that is higher than 3 is thought to be due to NPK fertilizer application and genetic response. The optimum N and P availability positively affects the above-ground part of the plant, including the leaf area and the photosynthetic capacity per unit of leaf area (Luo et al., 2016). Besides nitrogen and phosphorus, the potassium function is to production of ATP by regulating the rate of photosynthesis (Sardans & Peñuelas, 2021). In addition to NPK fertilizer, paclobutrazol had no impact on root-shoot ratio. We assumed that genetic factors influence the result.

Table 2. Effect of NPK fertilizer dose and paclobutrazol concentration on root-shoot ratio

Treatment	Root-shoot ratio
n_1: NPK 200 kg ha^{-1}	6.72
n_2: NPK 250 kg ha^{-1}	5.80
n_3: NPK 300 kg ha^{-1}	5.36
p_1: Paclobutrazol 2000 ppm	6.14
p_2: Paclobutrazol 3000 ppm	5.28
p_3: Paclobutrazol 4000 ppm	6.44

Note: The mean value is not significantly different according to ANOVA test.

100-grain weight Figure 2 showed that there was an interaction between the doses of NPK fertilizer and the concentration of paclobutrazol on 100-grain weight. In the two-way table shown in Table 4, the application of paclobutrazol with a concentration of 2000 ppm was significantly different compared to other treatments at the same NPK dose (200 kg ha^{-1}). Meanwhile, the increasing dose of NPK fertilizer at each level of paclobutrazol application did not show an increase in the 100-grain weight of hanjeli var. Ma-yuen.

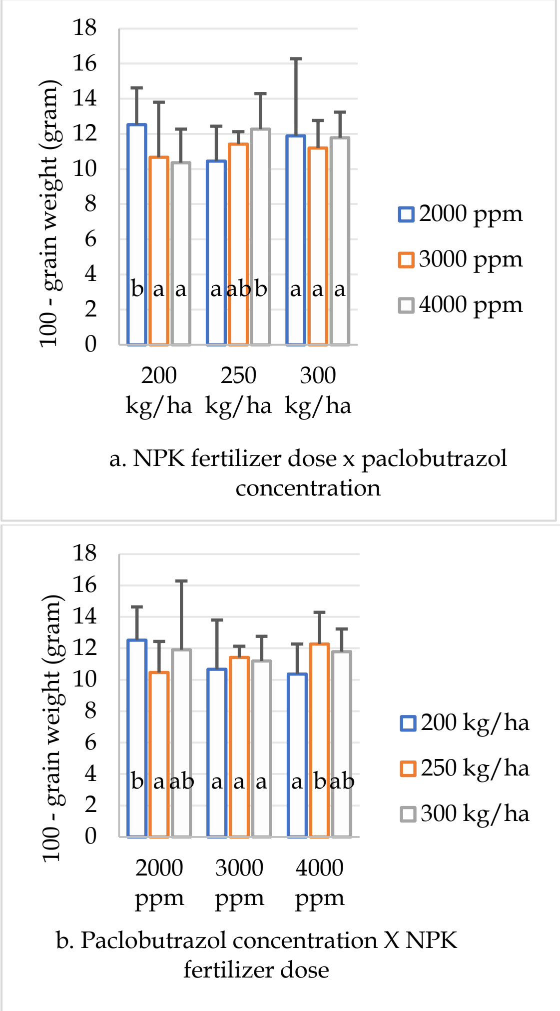


Figure 2. Interaction effect of NPK fertilizer dose and paclobutrazol concentration on 100-grain weight

Note: 100-grain weight affected by NPK fertilizers and paclobutrazol concentrations (a) A similar letter inside the bar chart indicates no significant difference between paclobutrazol concentration treatments per NPK dose. (b) A similar letter inside the bar chart indicates no significant difference between NPK dose treatments per paclobutrazol.

The 100-grain weight of hanjeli is affected by genetics and environment. In this study, the addition of the NPK dose did not necessarily increase 100-grain weight of hanjeli at each level of paclobutrazol application, this indicates hat the paclobutrazol treatment is affected by the NPK dose and vice versa. paclobutrazol has the ability to uniform seed weight, seed formation and ripening by deactivating the hormone gibberellin (Xiang et al., 2017), while NPK fertilizer plays role in optimizing photosynthates and their distribution. Hardiyanti & Andriani (2022) reported that the application of NPK fertilizer in the right dose had an impact on the

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increase of plant height, number of leaves, shoot dry weight, root dry weight, root shoot ratio and total dry weight. Later, paclobutrazol application served to increase the dry matter partition into grain yield (Kamran et al., 2018).

Grain weight per plot Statistical analysis showed that there was no interaction between NPK fertilizer doses and paclobutrazol concentrations on grain weight per plot. The single effect of the NPK fertilization doses and paclobutrazol application is presented in Table 3. The dose of NPK treatment showed that the grain weight per plot ranged from 1025 g to 1339 g and the paclobutrazol application treatment ranged from 1146 g to 1235 g.

Table 3. The grain weight per plot of hanjeli plants under different NPK fertilization doses and paclobutrazol concentrations

Treatment	Grain weight (g)
n_1: NPK 200 kg ha^{-1}	1025
n_2: NPK 250 kg ha^{-1}	1339
n_3: NPK 300 kg ha^{-1}	1177
p_1: Paclobutrazol 2000 ppm	1159
p_2: Paclobutrazol 3000 ppm	1235
p_3: Paclobutrazol 4000 ppm	1146

Note: The mean value is not significantly different according to ANOVA test.

The addition of nutrients in this study did not show any significant differences in the character of grain weight per plot. We suspected that the presence of phosphorus is very crucial and it required in large quantities to support grain formation. Phosphorus is one of the macro elements needed by plants in the process of energy transfer, signal transduction, and enzyme activation (Wang et al., 2017). In cereal crops such as wheat, limited phosphorus supply can reduce grain yields by limiting the number of productive tillers (El Mazlouzi et al., 2020). Beside fertilization, paclobutrazol didn't give a significant effect on grain weight per plot. We predicted that abscisic acid and ethylene plays a more important role than gibberellin in grain production, hence why paclobutrazol has no discernible impact.

Conclusion

Hanjeli productivity can be regulated by NPK fertilizer and paclobutrazol concentration. There were interactions between doses of NPK fertilizer and the concentrations of paclobutrazol on the character of plant height and the 100-grain weight. The combination of 200 kg ha^{-1} of NPK and 3000 ppm paclobutrazol resulted in the best character of plant height which is 202.08 cm. Alternatively, 200 kg ha^{-1} of NPK and 2000 ppm paclobutrazol gave the best combination for grain weight, while the other characters did not show any interactions.

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