

Pak Choi Growth and Yield Response to NPK Fertilizer Formulations in Controlled Irrigation

Ardy Kisworo*, Dharend Lingga Wibisana, Okti Purwaningsih, Nuning Dita Wardaniyati

Department of Agrotechnology, Faculty of Agriculture, Universitas PGRI Yogyakarta, Bantul, Special Region of Yogyakarta, 55182, Indonesia

ABSTRACT

This research aims to evaluate the effect of various NPK fertilizer formulations on the growth and yield of pak choi in sandy media. The research used a single-factor Completely Randomized Design (CRD) with five treatments: no fertilizer, NPK 20-10-10, NPK 16-16-16, NPK 15-09-20, and NPK 13-11-21, each replicated three times. The observed parameters included plant height, leaf number, root length, fresh weight, dry weight, and yield per unit area. The results showed that the NPK treatment had a very strong effect on all of the parameters. NPK 20-10-10 provided the best growth with a plant height of 25.43 cm, 20.67 leaves, a fresh weight of 270.57 g, and a dry weight of 21.03 g. NPK 16-16-16 gave the longest root length, which was 53.00 cm. The highest yield was achieved with NPK 20-10-10, at 12.18 kg per 4.05 m², equivalent to 30.06 tons ha⁻¹, which was significantly higher than the control (4.08 tons ha⁻¹). These results indicate that formulations with a higher proportion of nitrogen are more effective in increasing the growth and yield of pak choi on sandy media.

Keywords: Fertilizer formulation; Growth and yield; Measured irrigation; Pak choi; Sandy soil

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INTRODUCTION

Pak choi (*Brassica rapa* L.) is becoming increasingly popular in Indonesia as public awareness of healthy and nutritious eating patterns grows. Consumer interest in this vegetable shows an increasing trend and is projected to have continued market growth potential in the coming years (Batubara and Saputri 2023). This condition reflects positive market demand growth for pak choi in Indonesia, in line with the shift in consumer preferences toward consuming high-quality, environmentally friendly fresh vegetables.

This increase in consumption has implications for the growing need for domestic production. However, expanding fertile land is not an easy solution due to

the limited land resources in Indonesia. Therefore, efforts to improve cultivation efficiency and explore alternative land are important strategies to meet market demand without sacrificing environmental sustainability (Febrianti et al 2022).

Indonesia has a very long coastline with the potential for sandy coastal land that has not been optimally utilized. This sandy soil can be a promising alternative growing medium, especially in regions that lack access to fertile agricultural land. Exploring marginal lands like this becomes relevant given the increasingly limited productive land in inland areas (Imbiri et al 2021). Besides expanding production areas, utilizing sandy soil also supports the

*Corresponding Author: kisworoardy@gmail.com (E-mail)

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diversification of horticultural cultivation locations and enhances regional food security.

As the demand for pak choi continues to rise and productive agricultural land becomes increasingly limited, the expansion of cultivation into non-traditional areas such as sandy coastal soils has become increasingly important. Sandy soils represent a substantial but underutilized land resource in Indonesia and offer advantages such as good aeration and drainage. However, the successful cultivation of pak choi on sandy soils remains challenging because their large pore structure promotes rapid water infiltration and nutrient leaching, resulting in low water-holding capacity and low cation exchange capacity (Lestari et al 2022). This condition makes sandy soil less than ideal as a growing medium if not balanced with proper nutrient and water management. Therefore, a fertilization strategy is needed that can efficiently and sustainably maintain nutrient availability according to the plant's needs.

One effective approach to overcoming these limitations is through the use of NPK compound fertilizer. This fertilizer contains three essential macronutrients: Nitrogen (N), Phosphorus (P), and Potassium (K), each of which plays an important role in plant growth. Nitrogen supports chlorophyll formation and leaf tissue, phosphorus is involved in root development and energy production (ATP), while potassium helps regulate water balance, translocation of photosynthetic products, and strengthening of plant tissues (Maulanda et al 2024). The combination of these three elements works synergistically to support the vegetative growth of leafy plants like pak choi (Mutini et al 2022).

In the context of sandy media, nutrient management becomes a crucial aspect. The soil's susceptibility to leaching necessitates the use of fertilizers that can efficiently provide nutrients in the correct ratios. Choosing the NPK formulation that suits the plant's needs and growing medium conditions is an important step in improving nutrient absorption efficiency. Different formulations have varying ratios of N, P, and K elements, which can lead to different growth responses (Bukhari et al 2022).

For example, the NPK 20-10-10 formulation has a high nitrogen content, making it suitable for supporting the vegetative phase of leafy plants. NPK 16-16-16 contains balanced nutrients that can be used for various growth phases, while NPK 15-09-20 and 13-11-21 with higher potassium levels tend to support root formation and resistance to environmental stress (Rosariastuti et al 2023). Thus,

the chosen fertilizer formulation must be adjusted to the growth phase and growing medium conditions to compensate for the limitations of sandy soil.

Besides fertilization, water management is also an important component in the cultivation system on sandy soil. Because this medium has a low water-holding capacity, controlled irrigation is necessary to keep the soil moisture stable without causing nutrient loss due to excessive leaching. Precise control of water distribution through a drip irrigation system has been shown to improve water use efficiency and maintain nitrogen availability in the plant root zone (Dou and Sun 2024). In this study, controlled irrigation was not used as a treatment but rather as a supporting method to ensure optimal media conditions for plant growth.

Although various NPK formulations have been widely used in vegetable production systems, information regarding their comparative effectiveness for pak choi cultivation in sandy growing media remains limited. Most previous studies have focused on evaluating fertilizer effects in conventional soils with higher nutrient retention capacities, while the response of pak choi to different NPK nutrient ratios under sandy soil conditions has received less attention. Considering the high susceptibility of sandy soils to leaching nutrients, identifying the most suitable NPK formulation is essential to improve nutrient-use efficiency and support sustainable pak choi production on marginal lands.

This research focuses on evaluating the influence of various NPK fertilizer formulations on the growth of pak choi in sandy growing media. The main objective is to determine the most effective fertilizer formulation in supporting plant vegetative growth, particularly in terms of plant height, leaf number, root length, and biomass weight. Because the nutrients N, P, and K directly contribute to biomass accumulation and plant protein synthesis (Damayanti et al 2019). This approach is important for identifying how differences in the N, P, and K element ratios can affect plant growth performance under less-than-ideal media conditions.

The results of this research are expected to provide an empirical basis for the efficient application of fertilizer practices on sandy land and to serve as a reference for farmers in choosing the appropriate NPK formulation. Practically, these findings can help optimize fertilizer use on marginal land, while academically, this research fills a gap in studies related to the effectiveness of various NPK fertilizer formulations on pak choi plants in sandy growing

media. Most previous studies still focus on conventional media such as clay or garden soil, which have a high organic matter content (Rosariastuti et al 2023).

Thus, this research not only contributes to the development of technology for cultivating pak choi in non-conventional media but also supports the concept of sustainable agriculture on marginal land. Through the use of the right fertilizer formulations and the application of measured irrigation, sandy soil previously considered less productive can be managed into a potential growing medium for high-value horticultural commodities like pak choi.

MATERIALS AND METHODS

The research was conducted at the Research Facilities of PT. Lentera Agropedia Nusantara, located in Hargomulyo Village, Kokap District, Kulon Progo Regency, at coordinates 7°52'5.336" S and 110°3'43.353" E, with a location altitude of 17 meters above sea level and an average daily temperature of 28–32°C, from October 2025 to November 2025. Data analysis and result processing activities were carried out at the Plant Production Laboratory of PT. Lentera Agropedia Nusantara.

The materials used in this study include pak choi (*Brassica rapa* L.) seeds, Nauli F1 cultivar, NPK fertilizer with four different formulations (20-10-10, 16-16-16, 15-09-20, and 13-11-21), clean water for irrigation, and planting media consisting of sandy soil taken from the coastal area of Karangwuni Village, Wates District, Kulon Progo Regency, coordinates 7°55'12.700" S and 110°5'4.100" E. Other materials used include treatment labels and aluminum foil for the oven. The equipment used includes buckets and hoes for media preparation, water pumps, 16 mm irrigation hoses, 5 mm irrigation hoses, various irrigation hose connectors, stick drippers, timers, precision digital scales, rulers and measuring tapes for plant height and root measurement, drying ovens, and stationery and computer equipment for data processing.

The research was conducted using a Completely Randomized Design (CRD) with one factor, namely NPK fertilizer formulation, which consisted of five levels: P0 = no fertilization, P1 = Sprinter 20-10-10 NPK fertilizer, P2 = Mutiara 16-16-16 NPK fertilizer, P3 = Grower 15-09-20 NPK fertilizer, and P4 = Palmae 13-11-21 NPK fertilizer, each replicated three times, resulting in 15 experimental plots, each containing 3 plants, for a total of 45 polybags.

Observations were made on five main parameters, namely plant height (cm) measured from the base of the stem to the tip of the highest leaf, number of leaves (sheets) counted for all fully opened leaves, root length (cm) measured from the base of the stem to the tip of the longest root, fresh weight (g) weighed immediately after harvest using a digital scale, and dry weight (g) measured after the plants were oven-dried at 70°C for 48 hours until a constant weight was reached. The observation data were analyzed using Analysis of Variance (ANOVA) at a 95% confidence level. If there was a significant effect between treatments, the analysis was continued with Duncan's Multiple Range Test (DMRT) at a 5% level to determine the differences between treatment means. The DMRT test was chosen because it has a high sensitivity in distinguishing between biological and applied treatments and is commonly used in agronomic research to more accurately rank the effectiveness of fertilization treatments.

This research began by sowing pak choi seeds from the Nauli F1 cultivar in a 50-hole seedling tray filled with ordinary soil. Then, 12-day-old seedlings (DAS) that had developed at least three leaves were planted in 30 X 30 cm polybags with a media volume of approximately 6 liters. This polybag contains sieved and homogenized sandy soil, taken from coastal soil without any mixing. Fertilization was applied by drenching 200 ml per plant, as the NPK fertilizer used is water-soluble. Each plant sample received the same fertilizer dosage at specific intervals: 2 g l⁻¹ at 5 days after planting (DAP), 3 g l⁻¹ at 10 DAP, 4 g l⁻¹ at 15 DAP, and 5 g l⁻¹ at 20 DAP, resulting in a total of 2.8 g of NPK fertilizer used per plant across all treatments. The amount of fertilizer applied and the timing of the application were based on the best practices used by coastal farmers.

Maintenance actions include weed, pest, and plant disease control, as well as daily plant watering using a drip irrigation system that only uses raw water. Watering is done using controlled irrigation, controlled by a timer. Watering is performed 16 times per day, starting at 6 am and ending at 6 pm. The total daily watering volume per plant for plants aged 1-15 days after planting (DAP) is 640 ml, while for plants aged 16-30 DAP, it is 1,120 ml.

RESULTS AND DISCUSSION

Growth of Pak Choi Crops

The results of the Analysis of Variance (ANOVA) showed that the application of various NPK fertilizer

formulations had a highly significant effect on all vegetative growth parameters of pak choi plants in sandy growing media, including plant height, number of leaves, root length, fresh weight, and dry weight (Table 1). All parameters showed a significant increase compared to the treatment without fertilizer (control). Generally, pak choi plants treated with NPK fertilizer grew better and more uniformly, as indicated by the low coefficient of variation (CV) value (<6%), which suggests stable growth responses across replicates.

As shown in Table 1, NPK fertilizer had a pronounced effect on plant height and leaf number of pak choi. The NPK 20-10-10 treatment produced the tallest plants (25.43 cm) and the highest number of leaves (20.67), significantly outperforming the control treatment while showing comparable performance to the other NPK formulations. The superior growth observed under NPK 20-10-10 highlights the critical role of nitrogen in supporting vegetative development in leafy vegetables. Nitrogen is a key component of chlorophyll, amino acids, proteins, and nucleic acids, all of which are essential for cell division, leaf expansion, and biomass accumulation (Rosariastuti et al 2023). Although the NPK 20-10-10 formulation contained a lower total nutrient content than the NPK 16-16-16, 15-09-20, and 13-11-21 formulations, its higher nitrogen proportion was more closely aligned with the nutritional requirements of pak choi during the vegetative growth stage. As a leafy vegetable, pak choi prioritizes shoot and leaf development over reproductive growth, resulting in a greater demand for nitrogen than for phosphorus or potassium. Moreover, the sandy growing medium used in this study is characterized by low nutrient retention and

high leaching potential, which may increase the likelihood of nitrogen becoming the primary limiting nutrient. Consequently, providing a higher proportion of nitrogen appeared to be more beneficial for vegetative growth than supplying greater overall nutrient concentrations through more balanced or potassium-rich formulations.

Interestingly, despite having a higher total nutrient content (48%), NPK 16-16-16 did not outperform NPK 20-10-10 (40%). This indicates that the correct nutrient ratio is more important than the total amount of nutrients applied, especially in sandy media with low cation exchange capacity (CEC) and a high risk of nitrogen loss through leaching (Lestari et al., 2022).

According to Table 1, root length growth shows a different pattern compared to vegetative parameters. The treatments with NPK 16-16-16 and NPK 13-11-21 resulted in the longest roots (53 cm and 52.87 cm), which were significantly different from the other treatments. The result indicates that higher P and K content significantly contributes to root growth. Phosphorus plays a role in the formation of meristematic tissue and lateral root growth, while potassium improves the efficiency of water and nutrient absorption (Dou and Sun 2024). Thus, although high N formulations like NPK 20-10-10 excel in leaf growth, formulations with a higher balance of P and K have the potential to strengthen the root system, which is crucial for nutrient absorption in low-water-retention media. The combination of P and K also plays a vital role in improving crop yield quality, plant resistance to environmental stress, and water use efficiency, which is crucial for cultivation in sandy media (Syamsiyah et al 2023).

Table 1. Growth of pak choi crops with fertilizer composition treatments at 30 DAP

Treatments	Plant Height (cm)	Number of Leaves	Root Length (cm)	Fresh Weight of Biomass (g)	Dry Weight of Biomass (g)
Control (Without Fertilizer)	15.97 ± 1.10 c	12.67 ± 0.93 b	32.90 ± 1.45 c	36.80 ± 2.15 c	3.80 ± 0.24 c
Fertilizer of NPK 20-10-10	25.43 ± 0.92 a	20.67 ± 0.64 a	45.57 ± 1.21 b	270.57 ± 4.36 a	21.03 ± 0.47 a
Fertilizer of NPK 16-16-16	23.50 ± 1.06 b	20.47 ± 0.69 a	53.00 ± 1.12 a	229.57 ± 4.75 ab	19.37 ± 0.32 ab
Fertilizer of NPK 15-09-20	24.67 ± 1.11 ab	20.57 ± 0.77 a	45.10 ± 1.05 b	269.67 ± 5.08 a	19.70 ± 0.39 ab
Fertilizer of NPK 13-11-21	24.20 ± 1.02 ab	20.13 ± 0.72 a	52.87 ± 0.98 a	232.53 ± 4.83 ab	18.17 ± 0.28 b
CV (%)	4.21	4.07	3.98	5.14	3.89
Sig. (p)	<0.01 **	<0.01 **	<0.01 **	<0.01 **	<0.01 **

Remarks: Average numbers followed by the same letter in the same column indicate no significant difference according to the Duncan Multiple Range Test at a 5% level. CV = Coefficient of Variation; ** = Highly significant; Sig: Significance ($p < 0.01$)

As presented in Table 1, fresh plant weight is an indicator of biomass accumulation resulting from the process of photosynthesis. The results indicated that NPK 20-10-10 and NPK 15-09-20 treatments yielded the highest fresh weight, 270.57 g and 269.67 g, respectively, followed by NPK 16-16-16 (229.57 g) and 13-11-21 (232.53 g). Treatment without fertilizer only yielded 36.80 g. The fresh weight of pak choi is an important parameter for evaluating the plant's response to NPK fertilizer treatment, as this parameter directly reflects biomass accumulation and nutrient availability (Rosariastuti et al 2023).

Table 1 also shows that a similar pattern was observed for dry weight, where NPK 20-10-10 yielded the highest value (21.03 g), followed by NPK 15-09-20 (19.7 g). The high N content in the 20-10-10 formulation directly contributes to accelerating the formation of structural tissues and increasing total biomass yield (Mutini et al 2022). Additionally, the N:P:K element ratio that meets the physiological needs of plants in the vegetative phase has been proven to increase photosynthetic efficiency and carbon assimilation, thereby increasing plant weight. The appropriate NPK element ratio will maximize nutrient absorption efficiency by pak choi, promoting significant vegetative growth and biomass (Subur et al 2021).

Meanwhile, although NPK 16-16-16 and 13-11-21 have higher total nutrient content, the resulting biomass growth is no greater. This reinforces the findings of previous research by Maulanda et al (2024) that nutrient absorption efficiency is more influenced by the balance of nutrient ratios and media conditions than the total nutrient content of the fertilizer. Sandy media with high porosity allows for nutrient loss through leaching, especially N due to its high solubility and weak interaction with sand particles. Therefore, NPK fertilizer formulations need to consider strategies to improve N retention in the root zone (Tando 2019). This study explains that formulations with a higher N ratio are more effective in supporting the vegetative growth of pak choi.

In general, increased plant height and leaf number are followed by increased fresh and dry weight of the plant. This indicates a positive correlation between photosynthetic activity and plant biomass accumulation. Adequate N availability from NPK 20-10-10 plays an important role in increasing the rate of photosynthesis because it stimulates the formation of leaf chlorophyll, which is directly and positively correlated with plant biomass accumulation (Launuru et al 2020).

Good root growth in the NPK 16-16-16 and NPK 13-11-21 treatments also contributed to more efficient

water and nutrient absorption, although this was not always directly proportional to total biomass yield. The sufficient P content in both NPK formulations supports the development of a strong root system, enabling plants to absorb water and nutrients more efficiently from the sandy medium, which is prone to nutrient loss (Mohamed et al 2024).

The presence of P balanced with sufficient K also has its own impact, especially when considering how plants adapt to certain stresses. P and K work synergistically to increase plant resistance to environmental stresses, including drought and salinity, which are often characteristics of sandy coastal land (Gustina et al 2021). The results of this study confirm that the correct nutrient ratio and the efficiency of nutrient uptake are the main factors determining the success of pak choi cultivation in sandy media, not simply the total nutrient content in the fertilizer. Optimal NPK formulation not only ensures nutrient availability but also improves nutrient absorption efficiency by plants in sandy media (Guaya et al 2020). With consistent controlled irrigation, nutrient loss due to leaching can be minimized, making the plant's response to fertilization more stable.

In this study, the application of controlled irrigation served as a supporting method to maintain the moisture content of the sandy medium near field capacity, thus reducing nutrient availability fluctuations due to leaching. Irrigation with constant volume and frequency allows nutrient supply from NPK fertilizer application to be synchronized with plant needs during the early vegetative phase, which is particularly important for high-nitrogen formulations (NPK 20-10-10). With proper water management, the efficiency of nutrient uptake increases and the differences in response between formulations become clearer, as nitrate loss through percolation is minimized (Dou and Sun 2024). Therefore, agronomic recommendations for sandy soil must incorporate fertilizer formulations suitable for controlled irrigation patterns.

Yield of Pak Choi Crops

The application of NPK fertilizer formulations has a very significant impact on the yield of pak choi plants cultivated in sandy media. Based on the research results in Table 2, NPK fertilizer treatment significantly increased crop yield compared to the control ($p < 0.01$). On a research plot area of 4.05 m², the harvest yield increased from 1.66 kg in the control to 12.18 kg with NPK 20-10-10 treatment. When converted to a larger area scale, this yield is equivalent to 3.01 tons per 1000 m² or 30.06 tons per hectare, which is significantly higher than the control's 4.08 tons per hectare.

Table 2. Yield of pak choi crops with fertilizer composition treatment at 30 DAP

Treatments	Productivity per 4.05 m ² (kg)	Productivity per 1000 m ² (ton)	Productivity per hectare (ton ha ⁻¹)
Control (Without Fertilizer)	1,66 ± 0,39 b	0,41 ± 0,09 b	4,08 ± 0,95 b
Fertilizer of NPK 20-10-10	12,18 ± 2,95 a	3,01 ± 0,73 a	30,06 ± 7,30 a
Fertilizer of NPK 16-16-16	10,33 ± 4,42 a	2,55 ± 1,09 a	25,51 ± 10,92 a
Fertilizer of NPK 15-09-20	12,14 ± 0,45 a	2,99 ± 0,11 a	29,96 ± 1,12 a
Fertilizer of NPK 13-11-21	10,47 ± 2,18 a	2,58 ± 0,53 a	25,84 ± 5,38 a
CV (%)	27.62	27.63 ±	27.64
Sig. (p)	<0.01 **	<0.01 **	<0.01 **

Remarks: Average numbers followed by the same letter in the same column indicate no significant difference according to the Duncan Multiple Range Test at a 5% level. CV = Coefficient of Variation; ** = Highly significant; Sig: Significance ($p < 0.01$)

NPK formulations 15-09-20 and 16-16-16 also showed results that were not significantly different from NPK 20-10-10, indicating that the balance of the N:P:K ratio plays an important role in supporting biomass formation and leaf productivity in pak choi plants. This is in line with the research by [Siaga and Lakitan \(2021\)](#), which reported that NPK fertilizer formulations can increase fresh harvest yields.

Physiologically, increased crop yields are related to sufficient N availability to support chlorophyll formation and leaf growth, P for root system development, and K, which plays a role in the translocation of photosynthetic products and the formation of healthy leaf tissue ([Philip et al 2024](#)). On sandy media, which have low cation exchange capacity and water retention, fertilizer formulations with higher nitrogen content (such as NPK 20-10-10) become more effective because they can promote faster and optimal vegetative growth.

These findings are consistent with the research by [Hidayat and Suharyana \(2019\)](#), which showed that increasing the dose of liquid organic fertilizer from leucaena leaves significantly increased the yield of the pak choi variety Nauli-F1, primarily by increasing leaf biomass and root length. Research by [Dewanti \(2022\)](#) also confirms that applying organic nutrient sources to sandy soil increases nitrogen availability and the yield of pagoda mustard (*Brassica narinosa*). Research findings: [Plocek et al \(2024\)](#) reported that the balance of NPK nutrients in a hydroponic system affects the increase in biomass and photosynthetic efficiency in *Brassica rapa* var. *chinensis*. [Philip et al \(2024\)](#) add that a deficiency in any of the N, P, or K elements can reduce leaf area and chlorophyll content, thereby suppressing crop yield.

In their research, [Esposito et al \(2025\)](#) found that a high nitrogen ratio can increase the fresh weight and leaf yield of leafy vegetable crops without reducing the storage quality of the harvest. The results of [Ardhayani et al \(2023\)](#) research show that the application of compound NPK fertilizer increases the growth and yield of green mustard greens. According to [Lehar et al \(2024\)](#), the application of POC from cow rumen can increase the dry biomass weight of mustard green plants. Based on these findings, it can be interpreted that on sandy media, NPK formulations with a higher nitrogen ratio, such as 20-10-10, can provide optimal results because they efficiently support the formation of vegetative tissue, while the balance of phosphorus and potassium remains important for supporting the plant's overall physiological system. NPK formulation 20-10-10 is recommended for intensive pak choi cultivation on sandy land because it yields the highest productivity both on an experimental scale (4.05 m²) and on a hectare scale. A balanced N:P:K fertilization approach has been proven not only to increase total crop yield but also to support nutrient use efficiency and maintain leaf quality, which is a major part of the harvest.

CONCLUSIONS

Research shows that the application of NPK fertilizer has a highly significant effect on the growth and yield of pak choi grown in sandy media. All observation parameters increased significantly compared to the treatment without fertilizer. The NPK 20-10-10 formulation produced the best growth and the most optimal vegetative response compared to other formulations, even though it had a lower total nutrient content. This proves that a higher nitrogen

(N) ratio is more effective for the vegetative phase of leafy plants in sandy media with low cation exchange capacity and limited water retention. Additionally, the balance of nutrient ratios (N:P:K) is more crucial for plant performance than the total amount of nutrients overall. In terms of yield, the application of NPK fertilizer also significantly increased productivity, with the NPK 20-10-10 treatment producing the highest harvest weight of 12.18 kg per 4.05 m² or equivalent to 3.01 tons per 1000 m² and 30.06 tons ha⁻¹, which is much higher than the control, which only reached 1.66 kg per 4.05 m² or about 4.08 tons ha⁻¹. These results indicate that fertilizer formulations with a high nitrogen ratio and the correct balance of nutrients not only promote optimal vegetative growth but are also capable of significantly increasing harvest yields, making the NPK 20-10-10 formulation the best choice for pak choi cultivation on sandy land with low fertility.

Conflict of Interest Declaration

The authors declare that they have no known competing interests that could have appeared to influence the work reported in this paper.

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