

Growth Response of Pakcoy Cultivated in Biodegradable Bioplastic Polybags with Different Urea Contents

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ABSTRACT

The widespread use of conventional plastic polybags in vegetable cultivation contributes to persistent plastic waste because of their poor biodegradability, creating an increasing demand for environmentally friendly planting alternatives. This study evaluated the growth performance of pakcoy (*Brassica rapa* subsp. *chinensis*) cultivated in biodegradable bioplastic polybags containing different incorporated urea contents under greenhouse conditions. Bioplastic polybags previously developed in our laboratory were employed as planting containers, in which urea was incorporated as a controlled nutrient source, and their agronomic performance was evaluated through plant height, leaf width, number of leaves, and chlorophyll content after 28 days of cultivation. Plant growth varied according to the incorporated urea content. Among the evaluated formulations, the bioplastic polybag **containing 0.75 g urea** produced the highest plant height (10.2 cm), leaf width (5.1 cm), number of leaves (12 leaves), and chlorophyll content (45.2 SPAD units), indicating superior vegetative development compared with the other treatments. These findings suggest that an appropriate level of urea incorporation is more effective in supporting plant growth than either lower or higher urea contents. Overall, the developed biodegradable bioplastic polybags demonstrated promising potential as environmentally friendly planting containers for vegetable cultivation and provide a practical approach for developing sustainable biodegradable planting systems with integrated nutrient supply. Further studies under field conditions and using different horticultural crops are recommended to validate their broader agricultural applicability.

KEYWORDS

Biodegradable Bioplastic; Pakcoy; Plant Growth; Sustainable Agriculture; Urea

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A. Introduction

The increasing demand for vegetables has intensified agricultural production, making efficient nutrient management a critical factor for sustaining crop productivity ([Wang et al., 2022](#)). At the same time, intensive vegetable cultivation relies heavily on conventional plastic polybags for seedling production and container-based cultivation. Although these polybags are inexpensive and durable, their poor biodegradability contributes to the accumulation of persistent plastic waste in agricultural environments, creating increasing environmental concerns and highlighting the need for sustainable planting alternatives ([Debie, 2024](#)). Leafy vegetables such as pakcoy (*Brassica rapa* subsp. *chinensis*) are suitable model crops for evaluating sustainable planting systems because of their short cultivation cycle, rapid vegetative growth, and relatively high nitrogen requirement, making their growth highly responsive to nutrient availability ([Anas et al., 2020](#)). Adequate nitrogen supply is essential to support vegetative growth, chlorophyll synthesis, and biomass accumulation. Conversely, nitrogen deficiency restricts leaf expansion, chlorophyll formation, and overall plant productivity, whereas excessive fertilizer application increases production costs and contributes to environmental degradation. Therefore, improving nutrient use efficiency remains an important objective in sustainable vegetable production.

Nitrogen fertilizers are among the most widely applied agricultural inputs; however, their utilization efficiency remains relatively low. A considerable proportion of applied nitrogen is lost through leaching, volatilization, surface runoff, and microbial transformation processes before it can be absorbed by plant roots. These losses reduce fertilizer efficiency while contributing to groundwater contamination, eutrophication, greenhouse gas emissions, and soil quality deterioration ([He et al., 2020](#)). Consequently, conventional fertilization practices often require repeated fertilizer applications throughout the growing season, increasing labor requirements and production costs. Developing nutrient delivery systems capable of minimizing nitrogen losses while maintaining nutrient availability has therefore become a major research priority ([Chen et al., 2023](#)).

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Slow-release fertilizers (SRFs) have emerged as an effective strategy to improve nutrient use efficiency by gradually releasing nutrients according to plant demand. Compared with conventional fertilizers, SRFs reduce nutrient losses, prolong nutrient availability in the rhizosphere, decrease fertilizer application frequency, and improve crop performance. Numerous slow-release systems have been developed using polymer coatings, hydrogels, mineral carriers, and biodegradable matrices. Nevertheless, many commercially available SRFs still rely on synthetic polymer coatings that exhibit limited biodegradability and may generate persistent plastic residues after fertilizer utilization. Accordingly, the development of biodegradable polymer-based slow-release systems has attracted increasing attention as a sustainable alternative capable of simultaneously improving fertilizer efficiency and reducing plastic pollution ([Zhu et al., 2023](#)).

Bioplastics have recently attracted considerable attention as sustainable alternatives to petroleum-based plastics because of their biodegradability, renewability, and environmental compatibility. Beyond packaging applications, biodegradable polymers have increasingly been explored as functional agricultural materials, including mulch films, seed coatings, seedling trays, and planting containers that can reduce plastic waste while supporting sustainable crop production. Recent advances have demonstrated the potential of biodegradable planting containers to replace conventional plastic nursery bags and improve the environmental sustainability of horticultural systems ([Dejene et al., 2026](#); [Susetyo et al., 2025](#)). Furthermore, incorporating nutrients into biodegradable polymer matrices provides an opportunity to combine planting support with nutrient availability in a single cultivation system. Such multifunctional materials may simplify crop management while reducing the environmental footprint associated with conventional plastic containers and repeated fertilizer application ([Kartini et al., 2020](#); [Syahriani et al., 2024](#)).

Although considerable progress has been achieved in developing biodegradable polymer-based materials for agricultural applications, most previous studies have primarily focused on material

synthesis, physicochemical characterization, biodegradability, and nutrient release behavior. Comparatively few studies have evaluated the agronomic performance of biodegradable planting containers under actual crop cultivation conditions. In particular, studies investigating bioplastic polybags containing different incorporated urea contents as both planting containers and nutrient-supporting systems remain very limited. Consequently, the influence of urea incorporation on plant growth and chlorophyll development under greenhouse cultivation has not been comprehensively investigated. Addressing this knowledge gap is essential for determining the practical feasibility of biodegradable bioplastic polybags for sustainable vegetable production.

Therefore, this study evaluated the agronomic performance of biodegradable bioplastic polybags with different incorporated urea contents during pakcoy (*Brassica rapa* subsp. *chinensis*) cultivation under greenhouse conditions. Plant growth was assessed through plant height, leaf width, leaf number, and chlorophyll content to identify the urea formulation that best supports vegetative development. The findings are expected to support the development of biodegradable planting containers for sustainable horticulture by providing an environmentally friendly alternative to conventional plastic polybags, particularly for nursery production, urban farming, and household vegetable cultivation.

B. Materials and Method

1. Materials
2. Bioplastic polybags used in this study were prepared from carboxymethyl cellulose (CMC), tannic acid (TA), ferric chloride hexahydrate ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$), glycerol (85%), montmorillonite clay, and urea. Pakcoy (*Brassica rapa* subsp. *chinensis*) seeds were obtained from a local commercial supplier. The planting medium consisted of topsoil and compost mixed at a ratio of 2:1 (v/v). Distilled water was used for irrigation throughout the cultivation experiment. Experimental Design

Bioplastic polybags prepared in our previous work were used ([Syahrani et al., 2024](#)). The present study focused exclusively on evaluating the agronomic performance of the bioplastic polybags rather than their preparation or physicochemical characterization.

A completely randomized design (CRD) was employed to investigate the effect of urea content incorporated into the bioplastic polybags on the growth of pakcoy (*Brassica rapa* subsp. *chinensis*). Five treatments were selected based on the preliminary optimization study:

- Control: without a bioplastic polybag
- P1: Bioplastic without urea (0 U)
- P2: Bioplastic containing 0.25 g urea
- P3: Bioplastic containing 0.75 g urea
- P4: Bioplastic containing 1.50 g urea

These formulations were selected to represent the control, nutrient-free bioplastic, low urea content, optimum urea content, and high urea content, respectively, thereby enabling evaluation of the agronomic response over a representative range of nitrogen levels.

3. Plant Cultivation

Each bioplastic polybag was filled planting medium. Pakcoy (*Brassica rapa* subsp. *chinensis*) seeds were directly sown into the bioplastic polybags and cultivated under greenhouse conditions for 28 days. Plants were irrigated regularly to maintain adequate soil moisture, and no additional fertilizer was applied throughout the experimental period.
4. Plant Growth Measurements

Plant growth was evaluated at 7 and 28 days after sowing (DAS). Plant height was measured from the soil surface to the tip of the longest leaf, leaf width was determined at the widest portion of the largest fully expanded leaf, and the number of fully expanded leaves was recorded manually. Chlorophyll content was determined at 28 DAS using a portable SPAD chlorophyll meter.

C. Result and Discussion

1. Growth Performance of Pakcoy Cultivated in Bioplastic Polybags Plant Height

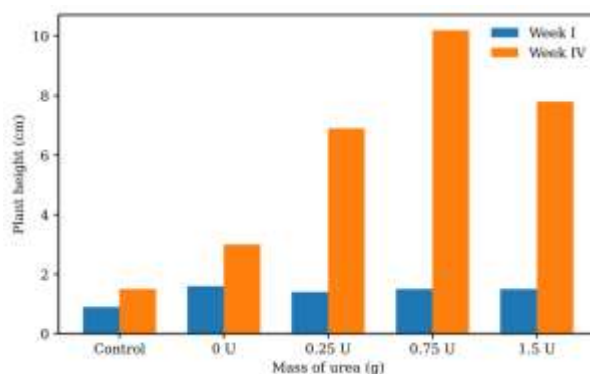


Figure 1 Effect of urea content on plant height of pakcoy at 7 and 28 days after sowing.

During the first week of cultivation, only slight differences in plant height were observed among treatments (Figure 1). This finding indicates that early seedling growth was primarily supported by nutrient reserves stored within the seeds, while the contribution of nutrients supplied from the bioplastic polybags was still limited. As plant growth progressed, clearer differences became evident at 28 days after sowing. Pakcoy cultivated in nutrient-containing bioplastic polybags exhibited greater plant height than the control treatment, with the 0.75 g urea formulation producing the tallest plants (10.2 cm), whereas the control treatment showed the lowest plant height (1.5 cm).

The enhanced plant height observed in the 0.75 g treatment can be attributed to improved nitrogen availability during vegetative growth. Nitrogen is an essential macronutrient required for amino acid, protein, nucleic acid, and chlorophyll synthesis, thereby promoting cell division, cell elongation, and biomass accumulation. Consequently, sufficient nitrogen availability directly stimulates stem and leaf growth, resulting in greater plant height ([Suman et al., 2023](#); [Xing et al., 2019](#)).

Interestingly, increasing the urea content to 1.5 g did not further enhance plant height. This observation suggests that plant growth is governed not only by the quantity of available nitrogen but also by the synchronization between nutrient availability and plant demand. Excessive nitrogen application may reduce nitrogen use efficiency because plants possess physiological limits in nutrient uptake and assimilation. Therefore, the 0.75 g formulation appeared to provide the most suitable nutrient balance for supporting vegetative growth under the present cultivation conditions ([Suman et al., 2023](#)).

Leaf Width

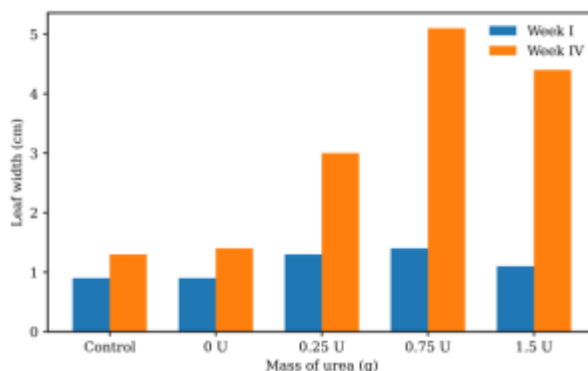


Figure 2 Effect of urea content on leaf width of pakcoy at 7 and 28 days after sowing.

Leaf width increased throughout the cultivation period for all treatments (Figure 2). At 7 days after sowing, differences among treatments were relatively small. However, after 28 days, plants cultivated in nutrient-containing bioplastic polybags exhibited substantially larger leaves than the control. The 0.75 g urea formulation produced the greatest leaf width (5.1 cm), followed by the 1.5 g treatment (4.4 cm), whereas the control treatment exhibited the smallest leaves.

Leaf expansion is highly dependent on nitrogen availability because nitrogen is required for protein synthesis, chloroplast development, and photosynthetic metabolism. Increased nitrogen supply enhances leaf area development, allowing plants to intercept more solar radiation and increase carbon assimilation. Larger leaf area consequently improves photosynthetic capacity, thereby supporting higher biomass production during vegetative growth ([Souri et al., 2019](#); [Zhang et al., 2023](#)).

Although higher urea incorporation increased nutrient availability, excessive nutrient input did not continuously improve leaf expansion. The decline observed at the 1.5 g treatment indicates that balanced nutrient availability is more beneficial than excessive fertilization. Efficient nitrogen utilization rather than maximum nitrogen concentration is therefore critical for optimizing vegetative development.

Number of Leaves

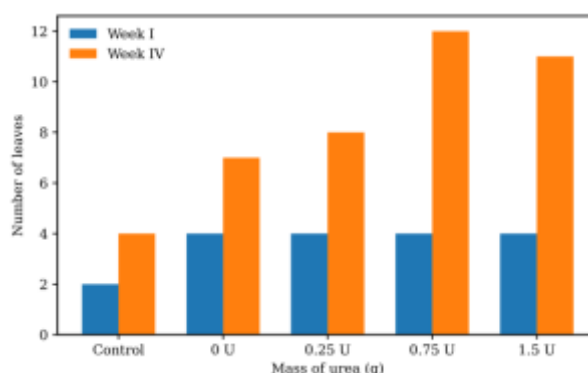


Figure 3 Effect of urea content on the number of leaves of pakcoy at 7 and 28 days after sowing.

The number of leaves increased progressively throughout the cultivation period in all treatments (Figure 3). During the first week, plants generally produced between two and four

leaves, indicating similar early vegetative development. By the end of the cultivation period, distinct differences became apparent. The 0.75 g urea treatment produced the greatest number of leaves (12 leaves), followed by the 1.5 g treatment (11 leaves), while the control treatment produced only four leaves.

Leaf initiation and expansion are closely associated with nitrogen nutrition because nitrogen promotes meristematic activity and the formation of new photosynthetically active tissues. Adequate nitrogen availability accelerates leaf emergence, increases canopy development, and enhances the photosynthetic surface area available for biomass production. Consequently, plants supplied with balanced nitrogen generally produce more leaves than nitrogen-deficient plants.

The superior vegetative performance observed in the 0.75 g treatment demonstrates that appropriate nutrient availability is more effective than excessive nutrient supply. The results therefore indicate that optimizing nutrient balance within biodegradable bioplastic polybags can effectively improve plant establishment and vegetative development while reducing the need for additional fertilizer application ([Anas et al., 2020](#); [Souri et al., 2019](#))

2. Effect of Urea Content on Chlorophyll Content

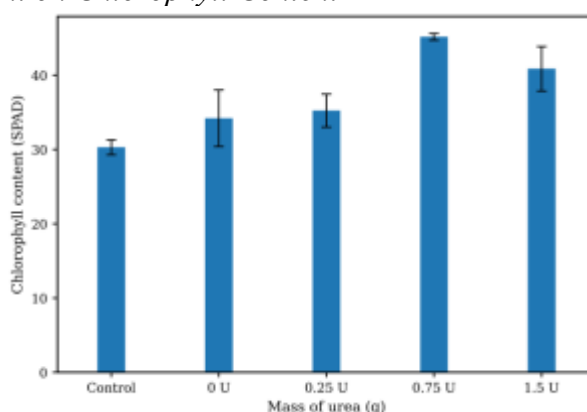


Figure 4 Effect of urea content on chlorophyll content of pakcoy at 21 days after sowing

Leaf chlorophyll content increased with nutrient incorporation into the bioplastic polybags (Figure 4). The control treatment exhibited the lowest chlorophyll content, whereas all nutrient-containing formulations produced higher SPAD values. Among the tested formulations, the bioplastic containing 0.75 g urea showed the highest chlorophyll content, indicating that this formulation provided the most favorable nutritional conditions for chlorophyll accumulation during vegetative growth. In contrast, increasing the urea content to 1.5 g did not further enhance chlorophyll content, suggesting that higher nitrogen availability did not necessarily translate into greater chlorophyll accumulation.

The observed increase in chlorophyll content can primarily be attributed to the nutrient availability from the bioplastic polybags. Nitrogen is an essential constituent of chlorophyll molecules and amino acids, making it indispensable for chloroplast development, protein synthesis, and photosynthetic metabolism. Adequate nitrogen supply promotes the biosynthesis of chlorophyll pigments, resulting in greener leaves with greater photosynthetic capacity. Consequently, plants receiving sufficient nitrogen generally exhibit higher SPAD values than nitrogen-deficient plants ([Anthony et al., 2020](#)).

Besides nitrogen, the incorporation of iron into the bioplastic formulation also contributed to chlorophyll accumulation. Iron also participates in the photosynthetic electron transport chain through iron-containing proteins such as cytochromes and ferredoxin, thereby maintaining photosynthetic efficiency. Therefore, the simultaneous availability of nitrogen and iron likely promoted chlorophyll formation more effectively than nitrogen alone ([Gao et al., 2022](#); [Rout & Sahoo, 2015](#)).

The higher chlorophyll content observed in the 0.75 g urea treatment is consistent with its superior vegetative growth performance. Increased chlorophyll concentration enhances light harvesting and carbon assimilation, thereby providing greater photosynthetic products for leaf expansion, stem elongation, and biomass production. This relationship explains why the treatment exhibiting the highest SPAD value also produced the greatest plant height, leaf width, and number of leaves. These findings suggest that optimizing nutrient availability through biodegradable bioplastic polybags can improve photosynthetic performance and subsequently support overall plant growth under sustainable cultivation systems.

D. Conclusion

The biodegradable bioplastic polybag containing 0.75 g urea exhibited the best agronomic performance, producing the highest plant height, leaf width, leaf number, and chlorophyll content after 28 days of pakcoy cultivation. These findings demonstrate that appropriate urea incorporation into biodegradable bioplastic polybags effectively supports vegetative growth and early crop establishment. Furthermore, the developed bioplastic polybags show strong potential as environmentally friendly planting containers that could serve as sustainable alternatives to conventional plastic polybags in vegetable cultivation. Future studies should investigate their long-term field performance, biodegradation behavior under different soil conditions, nutrient availability throughout the cultivation period, crop productivity until harvest, and economic feasibility to facilitate their practical implementation in sustainable horticulture.

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