

Staggered harvesting of bokchoy (*Brassica rapa* subsp. *chinensis*) and lettuce (*Lactuca sativa* L.) as a simple technique to improve productivity and food availability in urban setting

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Abstract

Food insecurity is a serious problem in urban areas and increasing vegetable production and consumption is a strategic action. Many vegetables are one-time harvested which contributes to volatility of food supply and price. This study explored the potential of staggered harvesting in improving yield and extending supply from one cropping. Two common leafy vegetables - bokchoy (*Brassica rapa* subsp. *chinensis*) and lettuce (*Lactuca sativa* L. cv. Lollo Bionda) were grown in plastic bags and subjected to one-time harvesting at 4 weeks after transplanting (WAT) as control and staggered harvesting at weekly or two-week interval starting at 4 WAT up to 8 WAT. Leaf count, area and mass did not significantly differ with treatment during the first 4 weeks of growth. Thereafter, the two staggered harvesting methods markedly increased leaf production in both crops. Weekly harvesting was more promising, increasing yield by more than 2-fold based on leaf count and more than 4-fold based on leaf mass relative to that of one-time harvest. This yield increases more than compensated for the additional 4 weeks of the growing period.

1. Introduction

Vegetables are high-value nutritious crops with a short life cycle that enables quick response to food demands in normal and crisis times (Acedo and Buntong, 2021). The annual yield of vegetables per square meter of land is up to 50 kg or more, or about 136 g/day (Eigenbrod and Gruda, 2015). This is more than 50% of the World Health Organization (WHO) (2003) recommended minimum vegetable intake of 240 g per day to reduce the risk of death and morbidity due to cancer, heart attack, diabetes and other chronic diseases. Southeast Asian countries, except Lao PDR and Viet Nam, have persistently failed to meet the minimum vegetable intake (Thow *et al.*, 2020). Globally, vegetable and fruit production could satisfy the minimum requirement (400 g/day) of only half of the world's 8 billion population (Harris *et al.*, 2021).

Vegetable production is the most significant component of urban food production (Eigenbrod and Gruda, 2015). It has great potential to build sustainable communities, address food security, provide jobs and income to urban poor, and mitigate climate change through reduced food miles. The urban population in the Philippines stands at 52% of the total population of over

115 million in 2022; this is projected to increase to 62% in 2050 (Asian Development Bank, 2022). Metro Manila, an urban center, has 14.7 million people in 2022 and projected 16.8 million in 2030. In 2018, 54% of Filipino households were food insecure (Department of Science and Technology-Food and Nutrition Research Institute, 2018); this worsened during the COVID-19 pandemic. About 47% of the urban population is heavily dependent on food production in rural and peri-urban areas. Due to rapid urbanization and a lack of food supply, vegetable consumption in urban communities is decreasing and malnutrition is prevalent. Given these challenges, it is critical to improve urban vegetable production.

Bokchoy (*Brassica rapa* subsp. *chinensis*) and lettuce (*Lactuca sativa* L.) are among the major leafy vegetables in the Philippines grown in urban areas and upland farms for household consumption and additional income to smallholder farmers (Campilan *et al.*, 2001). Bokchoy, also known as pechay or pakchoi, belongs to the family Cruciferae and is used in popular Filipino soup dishes but can also be pickled, stir-fried, or eaten raw in salads, sometimes as a substitute for lettuce (Jimenez *et al.*, 2000). Lettuce belongs to the family

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Asteraceae and is primarily consumed raw in salads and sandwiches (Mou, 2008). Among urban systems, container farming is widely practiced owing to its advantage in portability, space maximization, and recyclability of materials (Ancog *et al.*, 2021). Leafy vegetables are popularly grown in urban farms due to their short gestation cycle (De Guzman, 2017) and are used as ground covers in edible landscapes allowing access to fresh and safe food (Tayobong *et al.*, 2013).

Bokchoy and lettuce are categorized under mono-harvested or single harvested vegetables, that is whole plants are harvested at one time when they reach maturity after about a month from planting. Staggered harvesting does not refer to the practice of stagger planting time so that harvesting can be done at different time periods. Staggered harvesting is synonymous with reaping and regrowth systems in tea in which few leaves are harvested or cut when the crop has reached maturity to allow the growth of new leaves for subsequent harvest (Fu, 2008). It is also referred to as piecemeal harvesting in sweet potato in which only large-sized and marketable roots are harvested without uprooting the whole plant (Mackay *et al.*, 1989; Ebreget *et al.*, 2007). Additionally, staggered harvesting is known as the pick-and-come-again method used in herbs and water spinach (Takagaki *et al.*, 2003). It can be done for leafy vegetables, such as spinach, mint, celery and sweet potato shoots, and fruit-vegetables whose fruits do not mature synchronously, such as tomato, cucumber, eggplant and pepper. Staggered harvesting in bokchoy and lettuce is still a strange thing, not until the conception of this research with the objective to spread out the supply of fresh produce from a single planting for household consumption and food security in urban areas. If single-harvested, there will be oversupply at the harvesting period and no supply at certain periods while the plants are growing unless staggered planting is employed which requires more space and inputs that are scarce in urban areas and among urban poor.

2. Materials and methods

2.1 Plant establishment

The study was conducted at a residential area in Marikina City, Metro Manila, from September to December 2022. The area was partially covered with a shade net and UV-treated plastic sheet. Bokchoy and lettuce (cv. Lollo Bionda) seeds (Ramgo, Philippines) were obtained from a local market and sown in seedling trays (105 holes per tray) with one seed per hole containing steam-sterilized 1:1 mixture of garden soil and vermicompost. Steam sterilization was performed by pouring and mixing hot water into the growing medium to contain soilborne microorganisms that may adversely

affect seed germination and seedling growth. After cooling the growing medium, seeds were sown and the growing medium was moistened with water before covering it with a black polyethylene sheet to initiate germination. The plastic sheet was removed after seedling emergence. After two weeks, the seedlings were hardened by gradual exposure to sunlight and less irrigation. Four weeks after germination when 3-4 true leaves had developed, the seedlings were transplanted to 12.7×12.7 cm seedling bags containing a sterilized growing medium of 1:1 mixture of garden soil and vermicompost.

About 5 g of urea (46-0-0) (Ramgo, Philippines), was applied basally at transplanting and sidedressed weekly thereafter. Manual irrigation was done daily by applying water until soil saturation marked by seepage of water at the bottom of the growing medium. Manual weeding was done occasionally.

2.2 Experimental design

The study was conducted in a Randomized Complete Block Design (RCBD) in triplicates. Three treatments were tested: one-time harvest as control, and staggered harvesting at one-week or two-week intervals. The control was the conventional harvesting of whole plants four weeks after transplanting (WAT). Staggered harvesting at weekly or two-week intervals was done starting at 4 WAT up to 8 WAT by harvesting two mature leaves at the lower portion of the plant at each harvest except at 8 WAT when the whole plant was harvested. Border effect manifested as better growth and yield of outermost plants because of less space competition was taken into account by excluding border plants surrounding the treatment plants from data acquisition.

2.3 Data collection

2.3.1 Environmental parameters

Temperatures throughout the experiment were obtained from the Climate and Agrometeorological Data Section, Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Department of Science and Technology (DOST), Quezon City, Metro Manila. Light intensity was measured using a mobile application, Lux Light Meter Pro. Minimum, maximum and mean values were taken.

2.3.2 Leaf production

Fully expanded leaves that measured not less than 5×5 cm² were counted every week starting at 1 WAT to 8 WAT.

2.3.3 Leaf area

At harvest starting at 4 WAT to 8 WAT, the leaf area of all marketable leaves of bokchoy and lettuce was measured using a metric ruler at the longest part of the leaf length (L) and widest part of the leaf width (W). The product (L×W) was multiplied by a correction factor (CF). In taking the CF, 10 sample leaves were traced on a piece of paper and the weight of the traced paper (actual leaf weight) was taken. The L and W of these ten sample leaves were used to make a parallelogram (square or rectangle) on the same type of paper and the weight was taken (parallelogram leaf weight). CF was the ratio of actual leaf weight and parallelogram leaf weight.

2.3.4 Productivity

The total number and weight of harvested leaves from each treatment were determined. The leaves were classified as marketable (greater than 5×5 cm² in size and defect-free) and non-marketable (small-sized, deformed and/or discolored/senesced). The percentage of increase in the number and weight of leaves over the control was calculated. Also, the percentage of marketable or non-marketable leaves of the total number or weight of leaves was determined.

2.4 Statistical analysis

The results were subjected to analysis of variance (ANOVA) and treatment mean comparison by the Least Significant Difference test (LSD) using the Statistical Tool for Agricultural Research (STAR) software (International Rice Research Institute, Philippines).

3. Results and discussion

3.1 Overall growth conditions

Growing temperatures averaged at 28°C throughout the experiment, with minimum and maximum temperatures ranging from 23-25°C and 30-32°C. Light intensities ranged from 2,629-4,643 lux. Overall, bokchoy and lettuce plants from one-time harvest and staggered harvest showed vigorous growth with typical

green leaves as the plants increased in size from 1 WAT to 8 WAT. Plants in staggered harvests produced bigger leaves and thicker stems; they appeared larger in size than plants from one-time harvests. Yellowing of leaves at the lower part of the crown (bokchoy) or lower part of the leaf blade (lettuce) was evident in plants harvested at 2-week intervals. Leaf yellowing and deformation in both crops and bolting and flower bud formation in lettuce were the main causes of unmarketability.

3.2 Leaf production

The number of leaves increased with increasing age of plants (Figure 1). In bokchoy, it was about 4-6 leaves per plant at 1 WAT in all treatments and 9-11 leaves per plant at 4 WAT when whole control plants (one-time harvest) were harvested. Thereafter, the remaining two staggered harvesting treatments further produced more leaves, particularly at 6-8 WAT. Plants harvested at the 2-week interval had more leaves (12-14 leaves per plant) than those harvested at weekly intervals (10-12 leaves per plant). However, differences among treatments were not statistically significant. The same trend was obtained for lettuce except that fewer leaves were produced than for bokchoy. At 1 WAT, 3-4 leaves were produced per plant and at 4 WAT, 6-7 leaves per plant regardless of treatment. The number of leaves further increased at 6-8 WAT for plants subjected to staggered harvesting at 2-week intervals (7-11 leaves per plant) and at 8 WAT for plants subjected to staggered harvesting at weekly intervals (8 leaves per plant) but again no statistical significance was obtained.

Leaf-cutting induces an increase in chlorophyll content and net photosynthesis of the remaining intact leaves of a plant to generate new leaves (Casierra-Posada et al., 2021). Khan and Lone (2005) further showed that partial defoliation in leaf mustard (*Brassica juncea* L.) increased leaf count and leaf area which resulted in increased photosynthetic rate. This may explain the increased number of leaves in the staggered harvest treatments relative to that of one-time harvesting.

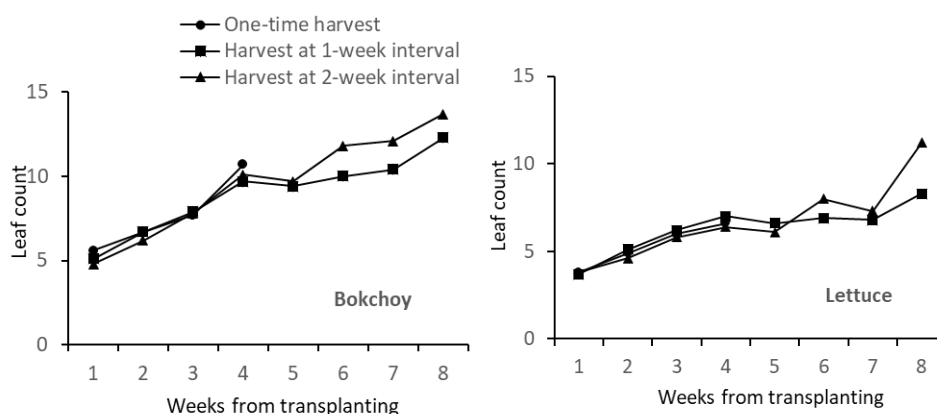


Figure 1. Number of leaves of bokchoy and lettuce from one-time and staggered harvesting.

3.3 Leaf area

At 4 WAT, leaf area did not significantly differ with treatment in both bokchoy and lettuce but the latter had a bigger leaf area (more than 100 cm²) than the former (less than 100 cm²) (Figure 2). Thereafter when the staggered harvest treatments remained, leaf area increased. In bokchoy, the increase in leaf area was significant for leaves harvested at the weekly interval at 6-8 WAT while that of leaves harvested at the 2-week interval was not significant relative to that at 4 WAT. In contrast, the leaf area of lettuce markedly increased at 5-8 WAT except for that of leaves harvested at weekly intervals at 8 WAT, which was statistically comparable to that at 4 WAT.

Carbohydrate reserves and photosynthetic leaf area play a significant role in the regrowth of new leaves in defoliated plants (Fu, 2008). The more reserves and photosynthetic leaf areas available, the more photosynthates can be used for the generation and expansion of new leaves, leading to higher leaf area. This is particularly exhibited in plants that are larger in size. This may account for the higher leaf area of

bokchoy and lettuce obtained after 5-8 WAT as compared to that at 4 WAT. Earlier in birch seedlings, the leaf area index increased in response to reduced leaf number when all lateral shoots were removed (Wareing *et al.*, 1968). Partial defoliation stimulated an increase in leaf area, chlorophyll content and photosynthetic capacity. Casierra-Posada *et al.* (2021) obtained an inverse relationship between leaf area and the number of leaves. In staggered-harvested plants, the decrease in number of leaves resulted in an increase in leaf area as a possible mechanism to restore balance in growth.

3.4 Productivity

The total yield (number and weight of leaves) of both bokchoy and lettuce increased considerably in response to staggered harvesting (Figure 3). The total number of leaves per 10 plants increased from 320 for the control to 530-610 for staggered harvesting in bokchoy and from 197 for the control to 457-490 for staggered harvesting in lettuce. The total weight of leaves followed the same trend, increasing from about 430 g for the control to 1780-1917 g for staggered harvesting in bokchoy and from 307 g for the control to

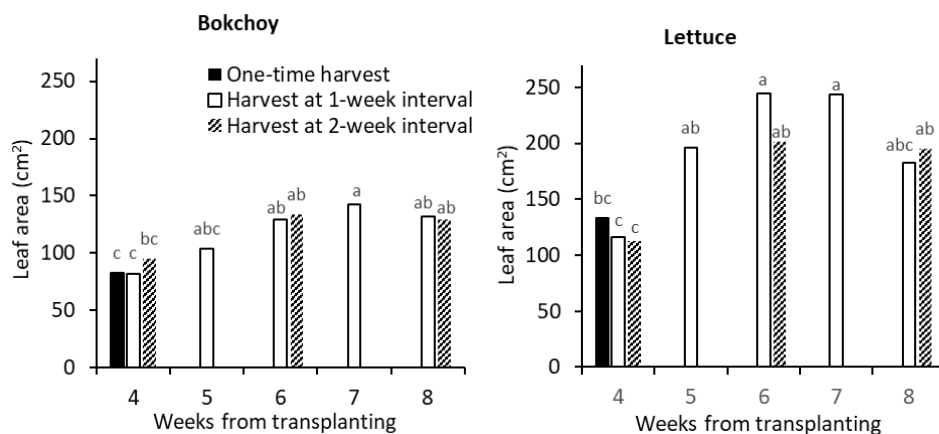


Figure 2. Leaf area of bokchoy and lettuce from one-time and staggered harvesting. Bars with different notations are statistically significantly different based on LSD, 5%.

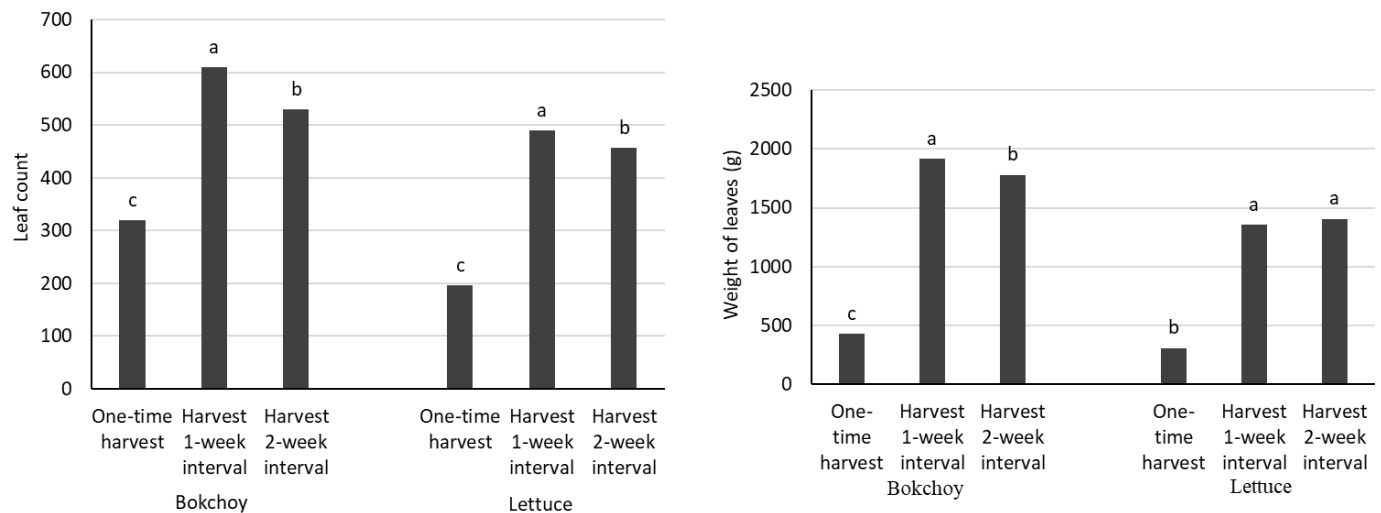


Figure 3. Total number and weight of leaves per 10 plants (1 plant/pot) of bokchoy and lettuce from one-time and staggered harvesting. Bars with different notations are statistically significantly different based on LSD, 5%.

Table 1. Total marketable yield (number and weight of leaves) per 10 plants (one plant/bag) of bokchoy and lettuce from one-time and staggered harvesting.

Crop/Treatment	Leaf count	Increase over control (times)	% of total yield	Leaf weight (g)	Increase over control (times)	% of total yield
Bokchoy						
One-time harvest (control)	243 ^c	-	76	117.6 ^c	-	90.9
Harvest 1-week interval	583 ^a	2.4	95.6	540.4 ^a	4.6	94
Harvest 2-week interval	450 ^b	1.8	84.9	437.0 ^b	3.7	81.8
Lettuce						
One-time harvest (control)	157 ^c	-	80	85.2 ^c	-	92.5
Harvest 1-week interval	477 ^a	3	97.3	379.1 ^a	4.4	93.3
Harvest 2-week interval	393 ^b	2.5	86.1	313.0 ^b	3.7	74.2

Means with different superscripts are statistically significantly different based on LSD, 5%.

1357-1407 g for staggered harvesting in lettuce. Harvesting at weekly intervals was better in increasing yield than harvesting at 2-week intervals.

Marketable yield (number and weight of leaves) similarly increased sharply with staggered harvesting which was more advantageous when done weekly, increasing leaf counts by more than 2-3 times and leaf weights by more than 4 times relative to that of one-time harvesting in both crops (Table 1). Harvesting at 2-week intervals resulted in lower increases in leaf counts and leaf weights due to a higher proportion of unmarketable leaves particularly in lettuce due to the yellowing of the base of the leaf blade.

Partial defoliation of plants can stimulate the production of new leaves. For example, in leaf mustard, partial defoliation of lower leaves resulted in the highest leaf count (Casierra-Posada *et al.*, 2021). The lower or bottom leaves of plants received less solar irradiation, reducing photosynthetic rates and contributing to increased competition for growth factors within the plant. Removing them, such as in staggered harvesting, allows plants to utilize light energy, water, and nutrients more efficiently to produce new leaves with higher photosynthetic capacity (Khan and Lone, 2005). Plants with large broad-shaped leaves usually have high water content and fresh weight (Huang *et al.*, 2019). However, if harvesting is delayed, such as in plants harvested at 2-week intervals, leaf senescence manifested as leaf yellowing could set in.

4. Conclusion

Staggered harvesting at weekly intervals was the most promising in improving the growth and productivity of bokchoy and lettuce. It increased the number and weight of marketable leaves by more than 2 to 4 times relative to that of one-time harvest. This yield increases more than compensated for the additional 4 weeks (total of 8 weeks) that the growing area is tied up to maintaining the plants relative to the one-time harvest (4 weeks).

Conflict of interest

The authors declare no conflict of interest.

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