International Journal of Plant & Soil Science

Volume 36, Issue 10, Page 305-317, 2024; Article no.IJPSS.124270
ISSN: 2320-7035

Analyzing the Contribution of *Moringa oleifera* (Lam.) to the CO_2 Stock and Other Advantages for Urban Residents

K. K. Chandra [a], Rajesh Kumar [b*], Bhavana Dixit [a], Pusala Praveen Nayak [a], Atul Kumar Bhardwaj [a], S. K. Pandey [c++], Arun Kumar Shukla [a], Anish Kumar Singh [a] and Astha Singh [a]

[a] Department of Forestry, Wildlife and Environmental Sciences, Guru Ghasidas Vishwavidyalaya (Central University), Bilaspur- 495009, India.
[b] Department of Forest Products and Utilization, Mahatma Gandhi University of Horticulture and Forestry, Sankara, Patan, Durg, 491111, India.
[c] IGNOU Regional Centre Gandhi Bhawan, B.H.U. Campus, Varanasi- 221005, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.9734/ijpss/2024/v36i105080

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/124270

Original Research Article

Received: 01/08/2024
Accepted: 02/10/2024
Published: 17/10/2024

[++]Assistant Regional Director;
**Corresponding author: E-mail: rajesh.dewangan0506@gmail.com;*

Cite as: *Chandra, K. K., Rajesh Kumar, Bhavana Dixit, Pusala Praveen Nayak, Atul Kumar Bhardwaj, S. K. Pandey, Arun Kumar Shukla, Anish Kumar Singh, and Astha Singh. 2024. "Analyzing the Contribution of Moringa Oleifera (Lam.) to the CO2 Stock and Other Advantages for Urban Residents". International Journal of Plant & Soil Science 36 (10):305-17. https://doi.org/10.9734/ijpss/2024/v36i105080.*

ABSTRACT

Moringa oleifera Lam. is a tree with high nutritive values with essential nutrients, minerals, and vitamins. It makes the tree best for the urban residents in South Asian countries. The *Moring*a trees in Bilaspur city of Chhattisgarh, India, were enumerated, and their potential yield and CO_2 storage were estimated. The resident response to the benefits of *Moringa* was explored through interviews. The main objectives of the study are analyzing of the CO_2 stock in urban areas and the importance of *moringa* species for the growth of urban residences. Forty-eight sample plots of 50m x 50m size were laid out randomly across the city. The total number of *Moringa* trees in the city was 84499, accounting for 0.23 trees per capita. The increase in human density in urban sites negatively correlated with *Moringa* populations (R^2=0.328). Young trees of 20-30cm diameter were abundant in the urban environment, which yield four to19kg tree^{-1} pods and 3 to 10kg leaf tree^{-1}. An average *Moringa* tree stored 0.04tonne CO_2, and overall, the stock was 3380tons of CO_2 in these trees of the city. Eighty-five percent of the urban residents ranked first to the *Moringa* fruit followed by leaf and these were identified as the reason for the domestication of the trees by the urban resident. More than 58% of urban residents use different parts of the *Moringa* plant 15 - 25 times a year, and 27% of people use it more than 25 times as vegetables. The tree was most beneficial for urban residents, contributing to food security and climate change.Therefore the concept of "one house one *Moringa*" may be advocated for implementing the climate-smart urban policy.

Keywords: Urban; climate change; CO_2storage; food security; environmental management.

1. INTRODUCTION

The urban residents are more vulnerable to pollutants and climate change and are at higher risk of diseases and disorders than the rural areas [1-4]. Therefore, urban residents must be aware of planting species that serve food, fodder, wood, minerals, and vitamins and protect the environment by cleaning the air and providing shade. Drumstick (*Moringa oleifera* Lam.) is a favorite family tree for Asian homes that praise its health benefits for thousands of years. Though it is native to India, now being grown worldwide, particularly in Asia, the Caribbean, Pacific Islands, Europe, Latin America, and Africa [5,6]. In the United States and European Union, where fresh *Moringa* is unavailable, *Moringa*-based supplements products like capsules, teas, leaf powder, and juice have filled the void. The species may contain nine times more proteins than yogurt, ten times vitamin A than carrot, 25 times iron than spinach, 15 times potassium than bananas, and 17 times calcium than milk [7-9]. On a dry matter basis, *Moringa* leaves contain 27% protein, 17% fat, and 38.6% carbohydrates [10]. All these demonstrate how *Moringa* can contribute to the food security of the urban population. India, export the diversified products of *Moringa* to developed countries where it fetches a high price. The global *Moringa* Products market size has been valued at USD 5.5 billion in 2018 and is anticipated to expand in the future [11].

The CO_2 sequestration potential of *Moringa* reports 50 times higher when compared to the Japanese cedar tree and twenty times higher than that of other vegetation due to the fast-growing behavior of the species [12-14]. The study on *Moringa* concerning global warming revealed that one person emits 320kg of CO_2 year^{-1}, which two adult *Moringa* trees may completely absorb. All other species also contribute to CO_2 absorption via photosynthesis and are considered efficient natural carbon sinks. Therefore tree planning is a step toward climate change mitigation, and if managed appropriately, urban plantations can attain higher carbon accumulation than natural forests [15-17]. The selection of trees with the highest CO_2 offset should be given weightage to urban forestry, and by any means, *Moringa* may be a powerful tool for protecting the urban environment and nutrition for the urban residents.

The Indian people consume the *Moringa* plant since the century as an essential ingredient in food items [18]. Recently, value-added product of *Moringa*is available in the market, such as leaf powder, green tea, and seed oil. It contains a vital food commodity for natural nutrition with rich antioxidants, and bioactive compounds contribute to nutrition [19-24]. It is known as the miracle tree of India and mother's best friend' in the Philippines because of its ability to increase woman's milk and prescribed for anemia [25-28]. *Moringa* seeds exhibit the property of natural coagulants useful in purifying dirty water in sewage treatment plants [29,30] and seeds contain 30-35% oil highly nutritive for human consumption with medicinal value [31-33]. Undoubtedly, *M. oleifera* adds substantial health benefits to meet the objectives of sustainable developmental goals like zero hunger, good health and wellbeing, and climate action [21,23,34]. Looking at its potential, India has started the commercial cultivation of *Moringa* in about 0.1 million ha and produced 1.2 million tons of fruits [32]. Numerous species and varieties of *Moringa* have evolved, but *M. oleifera* is the most widely utilized species [35-38].

Despite the great potential of this species and its widespread domestication by inhabitants, their potential is underutilized, particularly on urban environmental aspects. The carbon estimates of *Moringa* will help improve the understanding of trees' role in the global carbon cycle and mitigation strategies for climate change in urban areas [39-41]. Moreover, identifying the usefulness of the *Moringa* tree to urban people will also benefit the raising of green belts around cities. The present study includes the distribution pattern of *Moringa*, their CO_2 storage, and its significance to the urban dwellers of Bilaspur city, Chhattisgarh, India.

2. MATERIALS AND METHODS

2.1 Location of Study Area

Bilaspur is the second-largest residence city in the Chhattisgarh**.** The city Bilaspur lies between 82°06' to 81°38'E and 22°33' to 21°14' N in Chhattisgarh State of Central India. It locates on the banks of the river Arpa, which originates from the high hills of the Maikal mountain Range from Central India. The city's minimum temperature touches 10°C in January, and the maximum ranges from 42 to 46°C during May and June. Annual rainfall in the city recorded 1280 mm year^{-1} due to South-West and South-East monsoon. The city area slopes toward the river Arpa from west to east and forms a shape like a saucer at the city's Centre. The city sprawls over 25500 ha and currently supporting 365579 populations.

2.2 Survey Methods and Sample Plot Description

The present study started in July and ends in March 2020, where the population status of *Moringa oleifera* Lam. planted in house premise, private fields were surveyed. The entire area of the city divides into six sites, namely Koni area (site-1), Tifra area (site-2), railway colony (site-3), Sarkanda area (site-4), ManglaChowk area (site-5), and Sadar Bazar area (Site-6) using Google Earth (Fig. 1). These sites were chosen based on the varying density of the urban inhabitants. Forty-eight sample plots of size 50×50m (0.5 ha) were laid out randomly in different locations of various sites to cover the entire areas of the city under field surveys. This plot size accommodates many *Moringa*trees planted by urban residents near properties and in familiar places in the city. The geographical coordinates for each plot identify with the help of a Global positioning system (GPS). All the *Moringa*within the plot enumerate for DBH (diameter at breast height, cm), tree height (m), number of tree counts within plots, and relative abundance (RA) of the tree were calculated by counting trees occurring in all samples plots of the site then divided by the total number of trees in all sample plots of the city and multiplied by 100. The tree's height was determined by applying Abney's level's tangent method, while DBH was measured by measuring tape. Data on individual trees estimates the volume of the trees. The volume of trees was calculated for non-pollarded and pollarded trees as owner pollard/cut *Moringa* stem/branches from 2 to 2.5m height every year for fruit yield harvest. The branch volume of the tree adds with the stem volume to get the final volume of the tree. Final tree volume determined by using the formula:

$$V= \frac{s1-s2}{2} * h$$

Where V is log volume (m^3), s1 is a primary basal area (m^2), s2 is the end basal area (m2), and h height of the tree (m) [42]. Above-ground biomass (AGB) was estimated by formula AGB (t) = V (m^3) ×SG (kg m^3). *Moringa's* specific gravity (SG) determine by extracting the core of wood samples from bark to pith of the stem taken near the ground, breast height (BH), and branches. Took three samples for each girth class, and the mean of the SG was determined. The collected samples were weighted fresh and oven-dried at 105°C for 48 hours, applying standard procedure [43]. The below-ground biomass (BGB) finds multiplying the AGB by 26% [44]. The total biomass value finds by adding ABG and BGB, and carbon storage estimates by multiplying the total dry biomass with the default carbon fraction of 0.475. The estimated carbon storage converts into CO_2 storage by multiplying the carbon stock by 3.666 to determine the CO_2 storage in tree biomass [45,46].

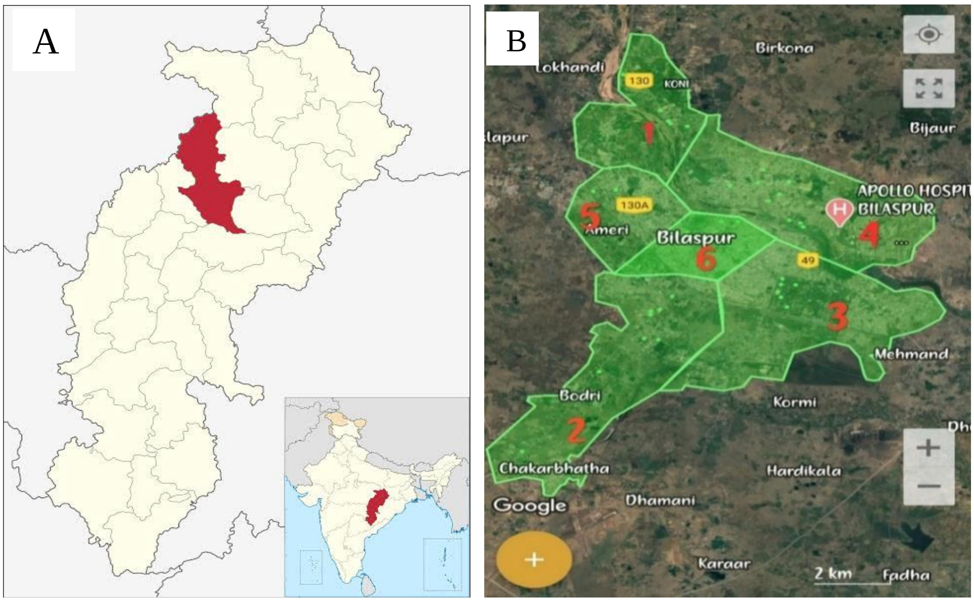

Fig. 1. (A) Location map of district Bilaspur, Chhattisgarh, India. (B) Map shows different sites of Bilaspur city

2.3 Identification of Benefits from the *Moringa* trees

To identify the benefits of *Moringa* to the urban residents, 75 *Moringa* plant owners/ residents planted trees in their houses, and 60 other respondents, including *Moringa* raw vegetableseller and its buyers/users (N=135) of the Bilaspur city, were selected. A technical sheet was provided to the selected respondents to fill their responses based on the benefits of the *Moringa* plant. We requested them to rank the benefits already mentioned in the sheets as most important (I), important (II), less important (III), and no important (IV) according to their local knowledge and usefulness of the tree [47].

2.4 Statistical Analysis

Data of the study were analyzed statistically by employing SPSS 16.0 version. The standard deviation was determined for the mean variation, while the critical difference (CD for the mean value comparison at 5% probability. The correlation value R^2 applies between human density and plant population drawn by using excel software.

3. RESULTS AND DISCUSSION

3.1 Population Distribution of *Moringa* Trees

Moringa is one of the most preferred and popular trees adopted by residents in the city. The urban residents have domesticated one or two trees of this species near homes for family uses and a higher number (maximum 25 plants) to fetch income from the farming. The distribution of trees varied in different sites of the city. A maximum of 33 tree ha^{-1} was found in site 3 (Railway station area), while a minimum population of *Moringa* in sites 5 and 6 (Table 1). The results revealed that the increase in population density tends to cause a reduction in *Moringa* trees in different sites of the study (R^2 = 0.328). The total number of *Moringa* trees estimated across the city area was 84499 trees. The diameter class distribution of plants was found significant (<P 0.05) in different sites, where 20-30 diameter plants were most abundant, followed by trees below 20cm diameter in the city (Fig. 2). *Moringa* trees of size 20-30cm diameter shared 50 percent while 30-50cm diameter trees contributed 28 percent of the total *Moringa* population of the city (Fig. 3, Table 2). These plants attained 20cm diameter within four years, 30-40cm in 6 to 10 years, and 40-50cm by spending ten years' time period. The yield (green pod) of the *Moringa* showed variation significantly in respect to the diameter class, where a maximum (19kg $tree^{-1}$) yield obtained from trees of diameter class 40-50 cm and minimum yield (4.6 kg $tree^{-1}$) from trees below 20cm diameter (Table 2). The yield of the pod/fruits was in the range between 2 to 25kg tree-1 with an average of 11.37kg yield $tree^{-1}$. Green leaf yield was a maximum 10.01kg $tree^{-1}$ rendered by 40-50 cm diameter trees and lowest

3.5kg leaf tree^{-1} from 0-20cm diameter class trees. Though a large number of *Moringa* occurred across the city, the population varied significantly with sites. The high human density showed a lower tree population than the low human density sites 2 to 4. The high population lies in the market/ commercial sites where no/fewer spaces are available for tree planting compared to the less populated sites. Moreover, the high property values of these sites reduce the avenue of tree planting, where people live in multistory buildings with less space than the low-density sites where spacious houses with backyard space were commonly available [48] also reported more trees with decreased population density in large cities like New York, Sao Paulo, and Paris. The increasing interest in planting Moringa in urban people of the city reflects in the high value of per capita *Moringa* in the city. The preponderance of young trees within ten years of age contributes to 78% of the *Moringa* population in the city. It is because about 75% of the plant of this species is grown through stem/branch cutting. The owners harvest the fruit-yielding trees by cutting off the branches, and again, these cut branches or stems are used either by the owner or by neighbors/others as planting material. Therefore, *Moringa* occupied a considerable population in the city area following increasing trends. Just after planting, trees start new flush in the same year which provides leaf vegetable to the owner and next year fruits develop on the trees. Thus without delay, *Moringa* plants bear yields create interest in urban people. Depending upon the age and diameter size, the tree yields an average of 11.37kg pod tree^{-1} and 6.34kg leaf tree^{-1} that is quite enough for the requirement of *Moringa* by one family of 4-6 members. However, the yield showed variation with the age and diameter of the trees. The high diameter trees yielded more than the low diameter trees due to well-developed canopy and branches facilitate higher fruiting.

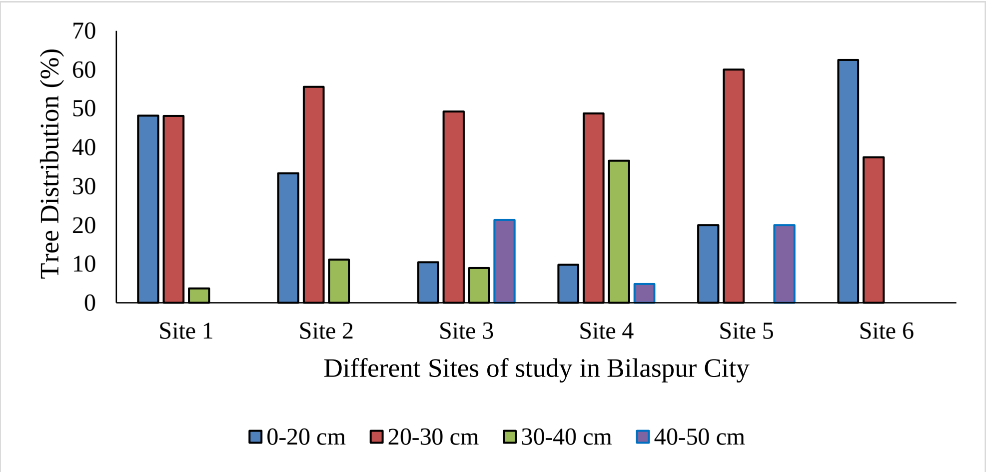

Fig. 2. Diameter class distribution of *M. oleifera* trees in different sites of Bilaspur city. inter site value of mean diameter found non-significant (F =0803) at P<0.05

Table 1. The estimated population of *Moringaoleifera* trees in different sites of Bilaspur, Chhattisgarh, India. (± Standard deviation) CD (Critical Difference <P 0.05)

Sites	No of sample plots	Human Population density (no./ km^2)	No of tree ha^{-1}	Estimated tree population (Nos)
1	8	6070	15±4.42	5466±233
2	8	7682	10±3.18	17628±2650
3	8	6035	33±9.50	37455± 4875
4	8	7850	14±5.00	14594±2710
5	8	8310	4±1.10	5954±687
6	8	9250	6±2.65	3402± 750
Total/AVG	48	7533	13.66±4.30	84499±1988
F value P<0.05			8.11	798.32

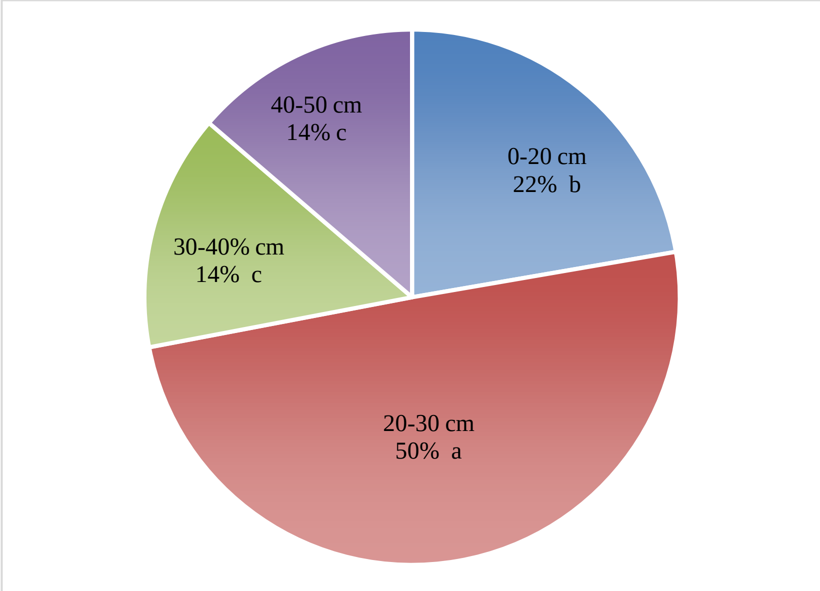

Fig. 3. Relative abundance (%) of different diameter classes of *M. oleifera* trees present in Bilaspur city. (DMR- Duncan Multiple Range test, value with different letters indicated significant difference at P<0.05)

Table 2. Tree inventory of *Moringa* trees encountered in urban areas of Bilaspur, Chhattisgarh, India. (F value at P <0.01)

Attributes	**Diameter Classes(cm)**				**F value P<0.01**
	0-20	**20-30**	**30-40**	**40-50**	
Average age (Year tree^{-1})	0 - 4	4 - 6	6 -10	> 10	
Green pods/fruit yield (kg tree^{-1})	4.60	8.50	13.40	19.00	4.01
Green leaf yield (kg tree^{-1})	3.50	5.18	6.70	10.01	3.22
Volume (m^3 tree^{-1})	0.058	0.059	0.064	0.075	10.46
Dry biomass (ton tree^{-1})	0.021	0.022	0.023	0.027	10.51
CO_2 storage (ton tree^{-1})	0.036	0.038	0.040	0.047	10.61

3.2 Volume, Biomass, and CO_2 Storage

The tree volume showed variation with diameter classes and different sites (Tables 2 and 3). Both volume and biomass of the *Moringa* trees were exhibited increasing trends with the improvement in diameter. Tree volume was a maximum of 0.075m^3 tree^{-1} for 40-50cm diameter trees and a minimum of 0.058m^3 tree^{-1} for 10-20cm trees. A similar trend follows the biomass and CO_2 storage pattern in *Moringa*, as exhibited by the volume of the trees (Table 2). There were 28.50% and 30.50% higher biomass and CO_2 storage in trees belonging to 40-50cm diameter than the lowest diameter trees (<20 cm). The average volume, biomass, and CO_2 storage of *Moringa* in the city was 0.063 m^3 trees^{-1}, 0.023tonne tree^{-1}, and 0.04tonne tree^{-1}, respectively. It estimates 3380tons of total CO_2stocks in the city by *Moringa* trees. Site-specific variations exist on volume, biomass, and CO_2, highest in site 3 (2.081m^3 ha^{-1}, 0.749tonne ha^{-1}, and 1.305tons ha^{-1}) and lowest for site 6 (0.351m^3 ha^{-1}, 0.127tonne ha^{-1}, and 0.221tonne ha-1), respectively. It demonstrates 5.90 times more biomass and CO_2 storage in *Moringa* between the highest and the lowest tree occurring sites. *Moringa* is ideal for inverting climate change for urban areas while growing food if planted at a larger scale in urban sites. The rate of CO_2 sequestration by the *Moringa*tree was reported very impressive compared to some other species. *Moringa* and climate change study revealed that two *Moringa* of two years could completely absorb CO_2 emit by one person (320kg CO_2year^{-1}) [49]. It demonstrates how well this tree has the potential for climate change mitigation for urban areas. An average *Moringa* tree accumulates 36 to 570kg CO_2 irrespective of diameter classes and sites when planted in urban areas, which looks similar to the findings [50]. Luyssaert [51] have suggested ten tree species with the highest CO_2 storage potential for roadside plantations in urban areas of Bilaspur city. These species are *T. indica* (10.16tonnes tree^{-1}), *A. lebbeck, F. religiosa, S. saman, E. camaldulensis, F. benghalensis, Pithecellobiumdulce, T. arjuna, D. sissoo,* and *P. pterocarpum* (0.95tonnne tree^{-1}). The species develops a giant canopy, long life, and sequester high CO_2 but cannot accommodate small spaces near home or backyard. Fortunately, *Moringa* is most suitable under such conditions for resident plantings to exploit their benefits results in higher acceptability.

As the tree grows fast and fruits early, trees and branches are cut every year to harvest yield, resulted in limited tree volume, b, and CO_2 storage. The issue may resolve by postponing the destructive harvesting of commercially valued trees by allowing the tree to be giant [52]. Ndubuaku et al. [53] demonstrated that the difference in CO_2 for the tree species was related to the species' variations in growth and increment pattern. A similar finding obtained in the present study also supports the previous study that older trees with large girth sizes and taller trees have larger carbon pools [54,55]. Nevertheless, even with the poor carbon stocking on the tree, about 338tons of CO_2 was intact with *Moringa* in Bilaspur city. Besides, the tree produces new flushes just after cutting the branches even in summer months act as a good source of vegetables, green fodder for livestock, it helps to reduce house temperature through dense leaf shade, and also a good sink for CO_2 [7,56]. To combat climate change and global warming efficiently and food shortages, *Moringa* is the most reasonable effort to expand in other urban areas.

3.3 Other benefits of *Moringa*in Urban Areas

Result of the respondents and their reaction to the usefulness of *Moringa* shows that they are growing the plant mainly for fruit/pod and therefore 85% of urban residents ranked Ist to the pod/fruit. Similarly, the importance of leaf was ranked Ist by 65% of the residents, while 5% of respondents denied using *Moringa* leaves (Fig. 4). About 30% of the growers maintained *Moringa* for income generation. Though the dependency of urban people on firewood now has been reduced considerably with LPG, about 50% of *Moringa* growers utilize its branches as fuelwood. It observes that 27% of *Moringa* owners consume leave, fruit, and wood, more than 25 times a year, while 58% of growers utilize *Moringa* plant parts 15 to 25 times yearly (Fig. 5). The results show that the *Moringa* owner uses the trees parts higher than the non-owner residents of the city.

Moringa fascinates through its versatile uses such as vegetables, medicine, vitamin, minerals, and high amount of CO_2 from the atmosphere [12,8,48,23,20]. Due to its multiple-use, it has become the most planted tree species in urban homes of the study area.*M. oleifera* is known to thrive in extreme arid conditions, and all parts of the plant, including the leaf, seed, root, bark, flower, seedpod, gum, oil, and fruits, are utilized due to their various environmental applications and multiple health benefits both to humans and animals [57]. Among other reasons for planting *Moringa* were the fast-growing behavior of the tree, demand less care and fruit early, and its adaptability to fit in small spaces near home and backyard. Moreover, the tremendous coppicing ability of the tree, easy establishment frombranch/stem cutting and seed, and wide adaptability to soil and environment make thespecies "Never die" trees [58,59]. Even a few trees yield enough for own family use and

Table 3. Estimated volume (m^3), dry biomass and carbon storage (ha^{-1}) of *Moringa* trees in different Sites of Bilaspur, Chhattisgarh, India. (F value at P<0.01)

Site	Volume (m^3 ha^{-1})	Dry biomass (tonne ha^{-1})	CO_2 Storage (tonne ha^{-1})
Site 1	0.949	0.341	0.594
Site 2	0.665	0.239	0.416
Site 3	2.081	0.749	1.305
Site 4	0.789	0.284	0.494
Site 5	0.365	0.131	0.228
Site 6	0.351	0.127	0.221
F value P< 0.05	11.77	11.31	11.56

marketable produce to fetch good income, and because of this, 30% of growers adopted Moringa only as a source of income in the city. Another reason for the higher acceptability of Moringa by urban dwellers is their N_2 fixing behavior, which helps them establish a wider soil environment without dependence on chemical fertilizers. Moreover, whatever output produces from the plants is organic and nutritionally rich as no pesticides apply.

Other benefits of *Moringa*, such as fodder, firewood, income, and medicine, were also crucial to urban residents as identified through respondent's interviews as all these save money by curtailing their expenditure. Dawit et al. [60] have also reported the high acceptance of *Moringa* plants in urban dwellers of Nigeria based on resident interviews to the benefits of *Moringa* plants and their diversified products like soup, tea, pap, and yam. They have concluded

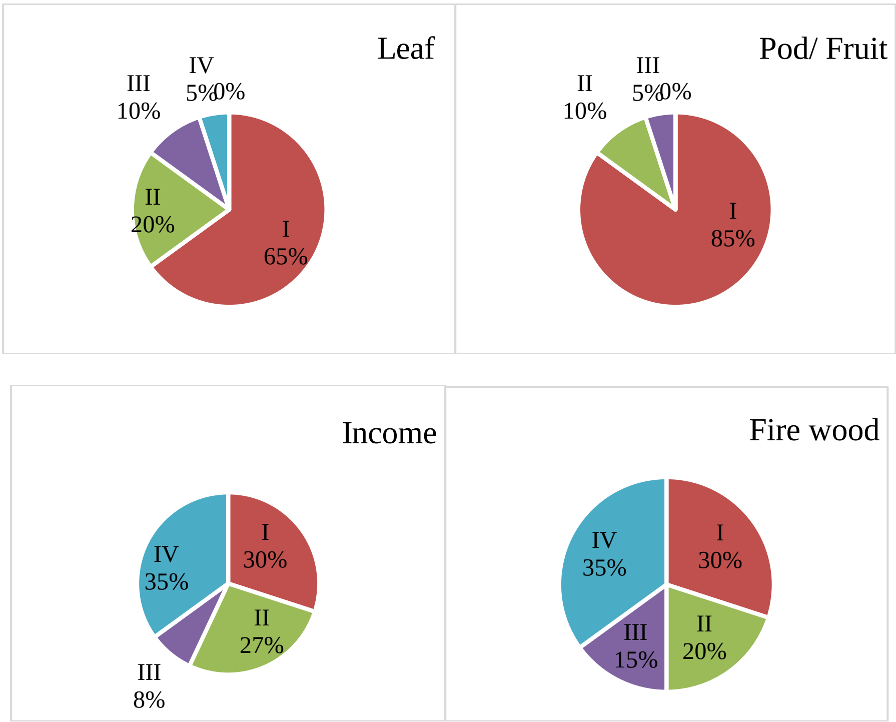

Fig. 4. Benefits of *Moringaoleifera* (Lam) in urban areas based on respondents interviews (n = 135). (I) Most important, (II) Important (III) less important, and (IV) no important

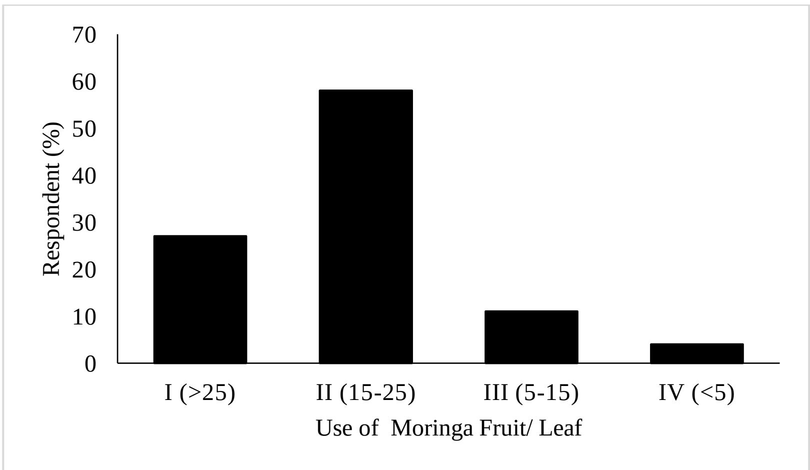

Fig. 5. Usefulness of fruit/pods and leaves of *M. oleifera* (Lam) for urban residents of Bilaspur city, Chhattisgarh, India (n = 135)

their research with a remark that *Moringa* is of great economic importance to the populace and should be more public awareness to enlighten people on its benefit and uses.

4. CONCLUSION

Moringa is one of the preferable and popular species for urban greenery programs, which can invert climate change while growing trees for direct benefits for urban residents. The tree grows fast and fruits just after one year of planting. The owner cut the branches/stem to harvest fruit yields every year. This practice has resulted in a limited volume, biomass, and CO_2 storage. If other methods may apply for harvesting fruits from the tree, the higher quantity of CO_2may stock but keeping the tree size suitable for small space near the home and backyard of the urban area is an essential operation adopted by tree owners. The increased age of the tree improves the CO_2 stock in *Moringa* due to the thickening of tree diameter and biomass. Results revealed that sites with higher human density exhibited lower tree populations and vice-versa. Thus the promotion of *Moringa* can be more effective in less settled areas than the area with higher human density where the property values are high and no spaces available for tree planting. A large-scale *Moringa* planting should be done by popularizing *Moringa* for every urban community to accelerate the climate change mitigation efforts. As the species has multiple outputs and versatile use, its planting may benefit nutrition and food sustainability under changing climate scenarios in urban areas.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (Chat GPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

ACKNOWLEDGEMENT

Authors are thankful to Dean, School of Natural Resources, Guru Ghasidas Vishwavidhyalaya (A Central University), Head, Department of Forestry, Wildlife and Environmental Sciences, Bilaspur, Chhattisgarh, India for providing necessary facilities for the research work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Kramer U, Sugiri D, Ranft U, Krutmann Von Berg A, Berdel D. Eczema, respiratory allergies, and traffic-related air pollution in birth cohorts from small-town areas. J. Dermatology Sci.2009; 56: 99-105.
   Available:http://doi:10.1016/j.jdermsci.2009.07.014
2. Ragula A, Chandra KK. Tree species suitable for roadside afforestation and carbon sequestration in Bilaspur,India. Carbon Management. 2020;11(4):369-380.
   Available:https://doi.10.1080/17583004.2020.1790243
3. Chandra KK, Omesh V, Bhadouria R.Guru Ghasidas University Campus Greenery for offsetting Carbon Dioxide and Improving Students'Academic Performance. Current World Environment. 2022;17(1):1-13.
4. Kumar R, Bhardwaj AK, Chandra KK, Singh AK. Mycorrhizae: An historical journey of plant association. Chhattisgarh Journal of Science and Technology. 2022c;19(4):437-447.
5. Lim TK. *M. oleifera*. In Lim TK (Ed.) Edible medicinal and non-medicinal plants. Fruits Ist Ed. London, Springer. 2012;3:453-485.
   Available:http://doi.10.1007/978-94-007-2534-8
6. Bhardwaj AK, Chandra KK, Kumar R. Inoculants of arbuscular mycorrhizal fungi influence growth and biomass of*Terminalia arjuna* under amendment and Anamendment Entisol. Mycobiology, 2024;1-12.
   Available:https://doi.org/10.1080/12298093.2024.2360750
7. Rockwood JL, Anderson BG, Casamatta DA.Potential uses of *Moringa oleifera* and an examination of antibiotic efficacy conferred by *Moringa oleifera*seed and leaf extracts using crude extraction techniques available tounder-served indigenous populations. Int J Phototherapy Research. 2013;3:61–71.
8. Mawouma S, PankaR, Mbofung CM. Acceptability and solubility of Iron and Zinc contents of modified *M. oleifera* sauces consumed in the far north region of

Cameron. Food Science Nutrition. 2016;5(2):344-348.

Available:https://doi.org/10.1002/fsn3.398

9. Kamesh, Singh BP, Misra S, Verma KK, Singh CK, Kumar R. An emerging adsorption technology and its applicability on trees as an adsorbent for the remediation of water pollution: Areview. Eco. Env. & Cons.2023;29(2):627-640.

Available:http://doi.org/10.53550/EEC.2023.v29i02.014

10. Yameogo CW, Bengaly MD, Savadogo A, Nikiema PA, Traore SA. Determination of chemical composition and nutritional values *Moringa oleifera* leaves. Pak J Nutrition 2011;10:264-268. Available:https://doi.10.3923/pjn.2011.264.268

11. Market Research Report. *Moringa* products market size, share *and* trends analysis report by product (leaf powder, tea, oil, seeds), by distribution channel (online, offline), by region, and segment forecasts, 2019 – 2025. Grand view Research Report; 2019. ID: GVR-2-68038-898-5.

Available:https://www.grandviewresearch.com/industry-analysis/*Moringa*-products-market

12. Villafuerte LR, Villafurte-Abonal L. Data taken from the forestry agency of Japan in *Moringa malunggay*, Philippines, Apples of Gold Publishing, Singapore. 2009;240.

13. Kumar R, Bhardwaj AK, Chandra KK, Dixit B, Singh AK. Diverse role of mycorrhiza in plant growth and development: Review. Solovyov Studies ISPU. 2024a;72(2):37-61.

14. Kumar R, Singh CK, Kamesh, Misra S, Singh BP, Bhardwaj AK, Chandra KK. Water biodiversity: ecosystem services, threats, and conservation. Biodiversity and Bioeconomy, editor: Singh K, Ribeiro MC, Calicioglu O. Elsevier.2024b;537-565.

15. Hutyra LR, Yoon B, Alberti M. Terrestrial carbon stocks across a gradient of urbanization: a study of the Seattle, WA region. Glob Chang Biol 2011;17(2):783-797.

DOI:10.1111/j.1365-2486.2010.02238.x.

16. Tang YJ, Chen AP, Zhao SQ.Carbon Storage andsequestration of urban street trees in Beijing. Front EcolEvol. 2016;4: 53.

Available:http://doi:10.3389/fevo.2016.00053.

17. Darro H, Swamy SL, Kumar R, Bhardwaj AK. Comparison of Physico-chemical Properties of Soils under different forest types in dry tropical Forest rcosystem in Achanakmar-Amarkantak Biosphere Reserve, India.Eco. Env. & Cons. 2022;28:S163-S169.

18. Iqbal S, Bhanger MI. Effect of season and production location on antioxidant activity of *Moringaoleifera* leaves grown in Pakistan. J Food Composition Analysis 2006;19:544-551.
Available:https://doi.10.1016/j.jfca.2005.05.001

19. Anwar F, BhangerMI. Analytical characterization of *Moringaoleifera* seed oil grown in temperate regions of Pakistan. Journal of Agricultural and Food Chemistry. 2003;51(22):6558-6563.

Available:https://doi.10.1021/jf0209894

20. Fahey JW. *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic and prophylactic properties. Tree life Journal 2005;1(5):1-15.

Available:https://www.tfljournal.org/article.php/20051201124931586

21. Anwar F, Latif S, Ashraf M, Gilani AH. *Moringa oleifera* a food plant with multiple medicinal uses. PhytotherapyResearch 2007;21(1):17-25.

Available:https://doi.org/10.1002/ptr.2023

22. Oduro I, Ellis WO, Owusu D. Nutritional potential of two leafy vegetables *M. oleifera* and *Ipomeabaatas* leaves. Scientific Research Essay 2008;3(2):57-60.

23. Brilhante RSN, Sales JA, Pereira VS, Castelo-Branco DSCM, Cordeiro RA, Sampaio CS, Paiva MANP, Santos JBF, Sidrim JJC, Rocha MFG. Research advances on the multiple use of *M. oleifera*: A sustainable alternative for socially neglected population. Asian Pacific J Tropical Medicine 2017;10(7):621-630.

Available:http://dr.doi.org/10.1016/japjtm.2017.07.002

24. Limanpure Y. and Kumar R. Effect of Different Levels of Inorganic Fertilizers on the Growth and Yield of Barley (*Hordeumvulgare L)* Under Teak (*Tectonagrandis*) Based Agrisilviculture

System.Trends in Biosciences. 2018;11(6):881-886.

25. Siddhuraju P, Becker K. Antioxidant properties of various solvent extracts of total phenolic constituents from three different agro-climatic origins of drumstick tree (*Moringa oleifera* Lam.) leaves. J Agric Food Chem 2003;51:2144-2150.

    Available:https://doi.10.1021/jf020444+

26. Gopala Krishnan L, Doriya K, Santhosh kumar D.*Moringa oleifera* – A review on nutritive importance and its medicinal applications. Food Science Human Wellness. 2016;5(2):49-56.

    Available:https://doi.org/10.1016/j.fshw.2016.04.001

27. Kumar R. Ramchandra. Effect of nitrogen levels on growth and yield of onion varieties under poplar based agroforestry system.Trends in Biosciences. 2018;11(3):283-286.

28. Kumar R. Ramchandra. Performance of Organic Manures on Growth and Yield of Tomato (*Lycopersicon esculentum* L.) Under Jatropha Based Alley Cropping System.Indian Forester. 2021;147(6):578-583.

29. NdabigengesereA, Narasiah KS.Quality of water treated by coagulation using *Moringa oleifera* seeds. Water Research. 1998;32:781-791.

    Available:https://doi.org/10.1016/S0043-1354(97)00295-9

30. Kumar R, Bhardwaj AK, Chandra KK. Levels of natural and anthropogenic disturbances and assessment of their impact on plant community functional diversity. Forestist. 2023a;73(1): 108-116.

    DOI:10.5152/forestist.2022.22025

31. Somali MA, Bejneid MA, Al-Fhaimani SS. Chemical characteristics of *M. peregrine* seed and seeds oil. J American Oil Chemists Soc. 1984;61(1):85-86.

    Available:https://doi.org/10.1007/BF02672051

32. Radovich T. Farm and forestry production and marketing profile for *Moringa*. In: Specialty crops for Pacific island Agroforestry. C.R. Elevitch (ed.). Permanent Agriculture Resources (PAR), Holualoa Hawaii; 2011.

    Available:http://agroforestry.net/scps

33. Bhardwaj AK, Chandra KK, Kumar R. Water stress changes on AMF colonization, stomatal conductance and photosynthesis of *Dalbergia sissoo* seedlings grown in entisol soil under nursery condition. Forest Science Technology. 2023a;9(1):1-13.

    Available:https://doi.org/10.1080/21580103.2023.2167873.

34. Kumar R, Bhardwaj AK, Chandra KK. Effects of arbuscular mycorrhizal fungi on the germination of *Terminalia arjuna* plants grown in fly ash under nursery conditions. Forestist. 2023b;74:142-146.

    DOI:10.5152/forestist.2023.23015

35. Paliwal R, Sharma V, Pracheta. A review on horse radish tree (*Moringaoleifera*): A multipurpose tree with high economic and commercial importance. Asian J Biotech. 2011;3(4):317–328.
    Available:https://doi.10.3923/ajbkr.2011.317.328

36. Chandra KK, Bhardwaj AK, Singh A, Kumar R. Impact of drought on tropical forests and plant mechanisms to mitigate drought stress. Tropical Dry Forest: Emerging Features and Ecology Perspectives. (Eds. Chaturvedi RK, Singh R., Bhadouria R.), Nova Science Publisher, New York, USA. 2021a;367-383.

    ISBN. 978-1-53619-543-9(ebook).

37. Chandra KK, Kumar R., Baretha G. Vandalism: A Review for Potential Solutions. Tree Benefits in Urban Environment and Incidences of Tree. (Eds. Bhadouria R., Singh P., Upadhyay S., Tripathi S.), John Wiley & Sons, Inc., Hoboken, NJ, USA; 2021b.

    ISBN: 9781119807186.

38. Kumar R, Bhardwaj AK, Chandra KK. A review on agroforestry practices for improving socioeconomic and environmental status.Indian Forester. 2022b;148(5):474-478.

39. Khanal Y, Sharma RP, Upadhyaya CP Soil and vegetation carbon pools in two community forests of Palpa district Nepal. BankoJanakari. 2010;20:34-40.

    Available:https://doi.org/10.3126/banko.v20i2.4800

40. Kumar R, Darro H, Bhardwaj AK, Chandra KK. Forest Fire and its Influence on Environmental conditions: A Review.Bull.

Env. Pharmacol. Life Sci. 2022a;10(12):258-267.

41. Bhardwaj AK, Chandra KK, Kumar R. Mycorrhizal inoculation under water stress conditions and its influence on the benefit of host microbe symbiosis of *Terminalia arjuna* species. Bulletin of the National Research Centre. 2023b;47(89):1-13.
Available:https://doi.org/10.1186/s42269-023-01048-3
42. Zobeiry M. Forest Inventory (Measurement of Tree and Stand). 1st Edn. Tehran University Publisher, Iran; 2000.
43. Jothivel S. Diversity of wood specific gravity among forest trees Kolli hills Southern Tamilnadu, India. Int. J. Environmental Biology. 2015;6(1): 29-33.
44. Eggleston HS, Buendia L, Miwa K, Ngara T, Tanabe K. Guidelines for national greenhouse gas inventories. IPCC national greenhouse gas inventories programme, Hayama, Japan; 2006.
45. Chandra KK, Bhardwaj AK. Growth, biomass and carbon sequestration by trees in nutrient deficient bhata land soil of Bilaspur, Chhattisgarh, India In. Energy and Environment, Water Science and Technology Library 80. V.P. Singh.(Eds.) Springer Nature Singapore; 2018. Available:https://doi.org/10.1007/978-981-10-5798-4_4
46. Kanime N, Kaushal R, Tewari SK, Raverkar KP, Chaturvedi S, Chaturvedi OP. Biomass production and carbon sequestration in different tree based systems of Central Himalayan Tarai region.Forest Trees Livelihoods 2013;22:38-50.
Available:https://doi.org/10.1080/14728028.2013.764073
47. Wagner S, Rigal C, Liebig T, Mremi R, Hemp A, Jones M, Price E, Preziosi E. Ecosystem services and importance of common tree species in coffee-agroforestry systems: Local knowledge of smallscale farmers at Mt. Kilimanjaro, Tanzania. Forests. 2019;10(11):963. Available:https://doi:10.3390/f10110963
48. Oyewole MF, Adetoro FT, Meludu NT. Level of acceptability of *Moringa oleifera* diversified products among rural and urban dwellers in Nigeria. International Journal of Agricultural and Biosystems Engineering. 2020; 8(12): 1-10.
Available:https://doi:10.13140/RG.2.2.18786.68804
49. Assmuth A, RamoJ, Tahvonen O. Optimal carbon storage in mixed species size-structured forests. Environ Resource Econ. 2021;79: 249-275.
Available:https://doi.org/10.1007/s10640-021-00559-9
50. Yin HW, Yin M, Zhao L, Yand L. Research on the measurement of carbon storage in plantation tree trunks based on the carbon storage dynamic analysis method. Int J Forestry Res. 2012;1-10.
51. Luyssaert S. Old growth forests as global carbon sinks. Nature. 2008;455:213-215.
52. Chavan BL, Rasal GB. Sequestered carbon stock in selective tree species grown in university campus of Aurangabad, Maharashtra, India.Int J Engi Sci and Tech. 2010;2:3007-3009.
53. Ndubuaku UM, Ndubuaku TC, Ndubuaku NE. Yield characteristics of *Moringaoleifera*across different ecologies in Nigeria as an index of its adaptation to climate change. Sustainable Agric Res. 2014;3(1):95-100.
Available:https://doi.10.5539/sar.v3n1p95
54. Daba M. Miracle Tree: A review on multi-purposes of *Moringaoleifera* and its implication for climate change mitigation. J Earth Science and Climate Change. 2017;7:366.
Available:https://doi.10.4172/21577617.1000366
55. Pop OL, Kerezsi AD, Ciont C. A comprehensive review of *moringa oleifera* bioactive compounds—cytotoxicity evaluation and their encapsulation. Foods. 2022;11(23):1–18.
Available:https://doi.org/10.3390/foods11233787
56. Hernandez OL, Tomes AV, Gonzalez DT, Cabrera IP, Pino IY, Gort DDCG. Calculation of carbon sequestration and soil fauna associated with *Moringa oleifera* Lam. in living fences. Centro Agricola. 2015;42(1):75-81.
57. Chandra KK, Singh AK. Carbon stock appraisal of naturally growing trees on farmlands inplain zone districts of Chhattisgarh, India. Tropical Ecology. 2018;59(4): 679-689.
58. Mulugeta G, Fekadu A. Industrial and agriculture potential of *Moringa*. J Natural Sci Res. 2014; 4(14):57-63.

59. Fuglie LJ. New Uses of *Moringa* Studied in Nicaragua. ECHO Development; 2000, Notes#68.Available:http://www.mapabcdf.com.ph/documents/submitted%20papers/NEW%20USES%20OF%20MORINGA%20STUDIED%20IN%20NICARAGUA.pdf

60. Dawit S, Regassa T, Mezgebu S, Mekonnen, D. Evaluation of two *Moringa*species for adaptability and growth performance under Bako conditions. J. Natural Sciences Research. 2016;6:76-82. Available:https://www.iiste.org/Journals/index.php/JNSR/article/view/30786

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/124270