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RESEARCH ARTICLE

PRODUCTIVITY AND PROFITABILITY ANALYSIS OF CAULIFLOWER AS SOLE AND INTERCROPPING WITH RED AMARANTH AND RADISH LEAFY VEGETABLE

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Abstract

By using natural resources and agricultural inputs more effectively, intercropping is a desirable technique to boost crop output and economic return. The present study was conducted to figure out the most lucrative crop mix for an intercropping system of cauliflower with red amaranth and radish leafy vegetable. A randomized complete block design with three replications was used to set up the experiment. Treatments included nine different cropping systems, including sole cauliflower, sole red amaranth, sole radish leafy vegetable, cauliflower-red amaranth intercropping (1:1), cauliflower-leafy radish intercropping (1:1), cauliflower-red amaranth-leafy radish intercropping (1:1:1), cauliflower-red amaranth-leafy radish intercropping (2:1:1), cauliflower-red amaranth-leafy radish intercropping (1:2:1) and cauliflower-red amaranth-leafy radish intercropping (1:1:2) Productivity parameters of three intercrops (cauliflower-red amaranth-leafy radish) were collected and measured based on their yield and yield contributing traits in different stages of their growth upto the final harvest. And equivalent yield and land ratio along with benefit cost ratio were analyzed to check their profitability. Result illustrated that cauliflower, red amaranth and leafy radish produced the highest yield of 25.4, 13.5 and 18.6 tha^{-1}, respectively when cultivated as a sole crop. However, when all of the three vegetables were grown as intercropping in different cropping system, cauliflower with red amaranth and leafy radish (1:1:1) produced the highest yield (33.2 tha^{-1}) followed by cauliflower-red amaranth-radish intercropping (1:2:1) and cauliflower-red amaranth-radish intercropping (2:1:1) with the yield of 30.0 t ha^{-1} and 29.8 tha^{-1}. After assessing the productivity and economic return, cauliflower with red amaranth and leafy radish (1:1:1) obtained the highest gross return (997102 Tk ha^{-1}) and net return (512102 Tk ha^{-1}) using the highest land equivalent ratio (2.0) followed by 900900 Tk ha^{-1} and 435900 Tk ha^{-1}, respectively in the cropping system cauliflower-red amaranth-radish intercropping (1:2:1). The present study concluded that intercropping leafy vegetables (red amaranth and leafy radish) and cauliflower boosted overall productivity and economic return more than sole intercropping cauliflower.

Keywords: Cauliflower, Intercropping, Leafy Radish, Productivity, Profitability and Red Amaranth

INTRODUCTION

In Bangladesh, intercropping is a common cropping method that maximizes the use of land, labor, and resource utilization, resulting the higher productivity (Suhi *et al.* 2022). Intercropping offers a significant contribution for lowering soil erosion, fixing atmospheric nitrozen, reducing the risk of crop failure or diseases (Han *et al.* 2023; Huss *et al.* 2022). Compared to mono-cropping, intercropping promotes production stability and higher resource use efficiency (Khanal *et al.* 2021; Mucheru-Muna *et al.* 2010). Small farmers make up 79.4% of the farming population in

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Bangladesh, and they are seeing a daily loss in the size of their farmed lands (MOA 2014). Regarding this, intercropping is one of the practical strategies to assure the effective use of their resources for enhanced production and family income (Ali *et al.* 2022; Bhuiyan *et al.* 2021). A combinations of vegetable crops as intercropping are valuable because they can enrich crops with different protein and carbohydrate contents aggregately (Chimonyo *et al.* 2023; Maitra *et al.* 2020).

Cauliflower (*Brassica oleraceae* var. botrytis) belongs to the Brassicaceae family, is frequently used in curries, salads, boiling dishes, pickling, and dehydrated dishes which provide a higher content of vitamins, phytochemicals, minerals and carbohydrates. Whereas, red amaranth (*Amaranthus cruentus*) and radish (*Raphanus sativus*) are leafy vegetable mostly used for reducing high blood pressure, kidney, and heart diseases (Blekkenhorst *et al.* 2018; Ruth *et al.* 2021). Cauliflower needs slightly medium to long duration to complete their life cycle. That's why a very short-durated vegetable like red amaranth and radish leafy vegetable can be successfully grown in the cauliflower field for better utilization of growth resources. In the meantime, cauliflower with other short durated crops like French bean, carrot, lettuce, clover, pea, beet, palak and coriander have been conducted earlier (Kabiraj *et al.* 2017; Mrnka *et al.* 2023; Shil and Nath 2015). However, intercropping cauliflower with red amaranth and radish leafy vegetable has not been carried out yet. Thus, assessment of the productivity and profitability of cauliflower intercropping with red amaranth and leafy vegetable of radish need to be examined.

Even in its distinct nature, variety plays a crucial role in the growth of a certain crop (Hossain *et al.* 2009; Islam *et al.* 2022; Yesmin *et al.* 2022). To examine the varietal performance, the connections between agronomic features and the environment factors need to be consider for achieving its high-yield potentiality (Hossain *et al.* 2017; Malek *et al.* 2012; Tabassum *et al.* 2021). For crop development, it is essential to comprehend the degree of genotypic and phenotypic variation in different locations (Malek *et al.* 2010; Monshi *et al.* 2014; Tabassum *et al.* 2015). Breeding strategies for vegetables profit from both quantitative and qualitative evaluation that results in morphological characterisation of the extent of trait variation present in genetic resources (Monshi *et al.* 2015; Sajid *et al.* 2022; Sarkar *et al.* 2021; Sarker *et al.* 2022). Morphological characterization comes first in the description and classification of genetic resources, followed by quantitative features (Atikunnaher *et al.* 2017; Paul *et al.* 2021, Sumi *et al.* 2022). Thus, the present research has been undertaken for the improvement of intercropping by assessing its genetically variable traits present in the studied crops.

Intercropping reduces component crop output while increasing system efficiency in terms of benefit cost ratio (BCR), net income, and land equivalent ratio (LER). This is because intercropping boosts agricultural profitability by effectively utilizing the resources of the land (Ahmad *et al.* 2016; Khan *et al.* 2018; Regmi *et al.* 2019). When crops are intercropped, they exhibit various competing behaviors that may be measured using the relative fertilizer use coefficient and the competitive ratio (Chen *et al.* 2023; Matusso *et al.* 2013). A land equivalent ratio (LER) is a common way to express the benefit. If the LER is greater than 1, then more solitary cropped land than intercropped land is needed to yield a given amount of product. It is crucial to maximize profitability, and it has been noted that intercropping grains with legumes can boost financial gains. For instance, sorghum-soybean intercropping systems increased productivity per unit area with the financial returns about 46% higher than that of the profit of solo crop (Iqbal *et al.* 2019). Because of a stronger land-equivalent ratios (LER) and other competitive indices, cereal-legumes intercropping systems produced crops with higher nutritional quality as well as higher economic returns (Chen *et al.* 2022; Daryanto *et al.* 2020).

In an intercropping system, the timing and spacing of planting are combined in order to reduce plant competition for growth-promoting substances, particularly during the plant's vital growth stages (Ahmed *et al.* 2020; Maitra *et al.* 2020). Planting timing, which greatly influences yield, has a substantial impact on the success of an intercropping system (Huss *et al.* 2022; Raseduzzaman and Jensen 2017). Because each plant has enough space for growth, plant spacing increases complementarity and reduces competition. Bangladesh is one of the world's most densely populated nations. Based on current growth projections with a present population of over 170 million it is predicted that population of the country will be well over 200 million by 2050 (USAID 2017). Considering the background, the present study was undertaken to assess the effectiveness of an intercropping system based on cauliflower in terms of crop growth, yield attributes, yield and quality as well as economic viability owing to the single crop and combined effects of intercrops.

MATERIALS AND METHODS

Experimental site and materials

The experiment was conducted at the farmers field in Debidwar, Comilla, Bangladesh (Figure 1) during August 2021 to January 2022. The experimental site is situated at 91° 10 E longitude and 23°27 N latitude. The soil taxonomy is Aeric Haplaquepts under the Debidwar series of Meghna River Floodplain soil in Argo Ecological Zone no. 16 (AEZ 16). The topography was a medium high land, fairly leveled with moderate silt (38%), clay (38%) and loamy in texture having a soil pH 5.9 along with 0.98% organic matter. A medium durated (95-105 days) cauliflower (*Brassica oleracea* L. var. *botrytis* cv: BARI fulkopi 1) along with short durated (45-50 days) red amaranth (*Amaranthus tricolor* cv: BARI lal shak 1) and short time leafy vegetable (40-45 days) radish (*Raphanus sativus* cv: BARI mula 1) were used as sole crop and intercrop in different cropping system. Cauliflower seeds were sown on 15 August 2021 in intensively cared seed bed. When the seedlings were 35 days old then the seedlings were transplanted in the main plot while red amaranth and radish seeds were sown in the same days. All the seeds used in this experiment were collected from Bangladesh Agricultural Research Institute (BARI), Gazipur, Bangladesh.

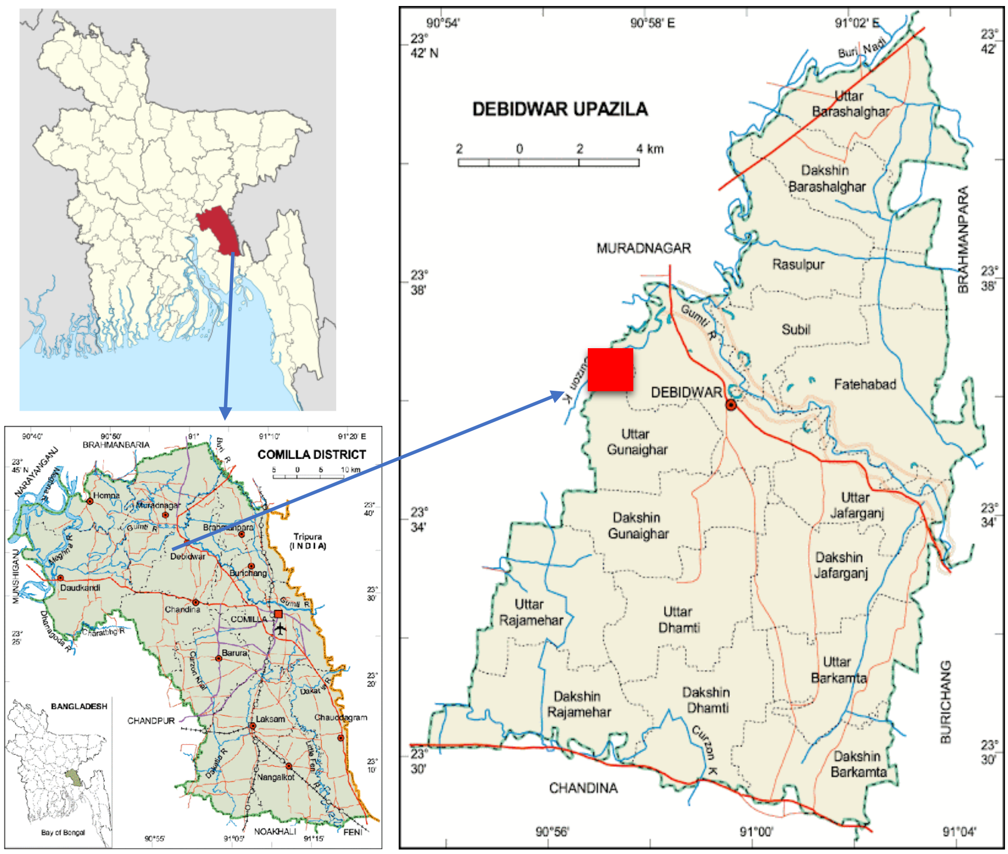

Figure 1: Map of the experimental site

Treatments and design

Treatments consisted of nine different cropping systems namely sole cauliflower cropping (T_1), sole red amaranth cropping (T_2), sole radish leafy vegetable cropping (T_3), cauliflower-red amaranth intercropping (1:1) (T_4), cauliflower-radish-leafy vegetable intercropping (1:1) (T_5), cauliflower-red amaranth-radish leafy vegetable intercropping (1:1:1) (T_6), cauliflower-red amaranth-radish leafy vegetable intercropping (2:1:1) (T_7), cauliflower-red amaranth-radish leafy vegetable intercropping (1:2:1) (T_8) and cauliflower-red amaranth-radish leafy vegetable intercropping (1:1:2) (T_9) assigned in the sub plot. A randomized complete block design with three replications was used to set up the experiment. Each plot was 2 m×2.25 m in size. To allow for various multicultural operations and proper drainage, a 0.5m gap was maintained between the blocks and the plots.

Crop husbandry

To create a favorable environment for seed germination and plant growth, the field was properly prepared by plowing and cross-ploughing with a rotavator. On the basis of a cauliflower crop with a high production purpose, a general fertilizer application (245-56-96-24-20 kg: N-P-K-Ca-S ha^{-1}) was recommended. Red amaranth and radish seeds were spread at a spacing of 30 cm×10 cm and cauliflower was sown with the standard spacing of 60 cm × 50 cm. Two rows of either red amaranth or radish leafy vegetable or in both were interplanted between the rows of cauliflower in intercropping system. The necessary intercultural activities, including irrigation, weeding, pest control, mulching, and others, were carried out.

Harvesting

The curd initiation and maturity periods in different plants were not uniform or comparable, it was not possible to harvest the cauliflower on a specific or predetermined date. This was likely due to various management techniques, genetic variations, or other causes like a combination of plant age and air temperature. A sharp knife was used to harvest only the mature, compact curds. Before the flower buds bloomed, the curds were picked when they were still tightly packed. The compactness of the cauliflower curd was assessed prior to harvest by pressing it between the thumbs. The crop under investigation was first harvested at the 90 day after transplanting, and it was last harvested up to 105 days after transplanting, when the experiment came to an end. Similarly, leafy vegetables of red amaranth and radish were harvested at almost 45 days after sowing and continued up to 60 days.

Collection of yield data

Except for curd yields, which were recorded plot-by-plot, five plants were chosen at random from the unit plot's center rows in order to prevent border effects. Cauliflower data were collected on plant height (cm), the width and length of largest leaf (cm), number of leaves plant^{-1}, stem length (cm), curd diameter (cm), individual curd yield (g), curd yield plot $^{-1}$ (kg), and yield per hectare (tha^{-1}). At 25, 40, 55, 70 days after transplanting (DAT) and at harvest, data on the plant's height, the number of leaves per plant, the greatest leaf's length, and its width were recorded. In the similar ways, number of leaves (plant^{-1}), plant height (cm), leaf breadth (cm), root length (cm), leaf length (cm), shoot diameter (cm), fresh root weight plant^{-1} (g), dry root weight plant^{-1} (g), fresh weight plant^{-1} (g), dry weight plant^{-1} (g), yield plot^{-1} (g) and total yield (tha^{-1}). Moreover, data on leafy radish were recorded based on plant height (cm), number of leaves plant^{-1}, leaf length (cm), leaf width (cm), root length (cm), root diameter (cm), fresh and dry weight of leaves (g), fresh and dry weight roots (g), individual plant weight (g), yield plot^{-1} (g), and total yield (tha^{-1}).

Using following equations, the yield of companion crops (red amaranth and radish) was converted into the yield of the main crop (cauliflower) based on the current market price (Anjancynlu *et al*. 1982)

$$\text{Cauliflower equivalent yield} = Ym + \frac{Yi \times Pi}{Pm} + \frac{Yj \times Pi}{Pm}$$

…………………………………......Eqn 01

Where, Where, Ym = Yield of intercrop cauliflower, Yi = Yield of intercrop red amaranth, Yj = Yield of intercrop radish, Pi = Market price of red amaranth, Pj = Market price of radish, Pm = Market price of cauliflower.

Land equivalent ratio (LER) was used to compare different treatments. LER values were computed from the grain yield data of the crops according to the following formula (Oyejola and Mead 1982).

$$LER = \frac{\text{Intercrop yield of cauliflower}}{\text{Sole crop yield of cauliflower}} + \frac{\text{Intercrop yield of red amaranth}}{\text{Sole crop yield of red amaranth}} + \frac{\text{Intercrop yield of radish}}{\text{Sole crop yield of radish}} \quad \textbf{......Eqn 02}$$

Total labor costs and the price of variable inputs utilized for various processes were gathered in order to calculate the variable cost of various treatments, which in turn allowed for the determination of the cost of production as a whole, gross return, and net return. The market price was multiplied by the grain or seed yield to get the gross return. The difference between gross return and total production costs was known as net return. Benefit cost ratio (BCR) was determined using the following formula to compare treatments' performance.

Benefit-cost Ratio= Gross return (Tk/ha)/ Total cost of production (Tk/ha)……..**Eqn 03**

Where, Tk means Taka and ha indicate hectare.

The PROC GLM technique, version 9.2, was used to statistically analyze the variance of the field experimental data of various parameters. Significant differences between and among the means were distinguished using Fisher's least significant difference (LSD) test at 5% probability level (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Yield contributing traits of cauliflower

Effect on plant height

A substantial impact on plant height in the cauliflower-red amaranth-leafy radish intercropping system was observed (Figure 2). In the sole crop system, the plant height gradually increased with time and produced the tallest (63.3 cm) cauliflower plant at the harvesting time. In the intercropping system, the tallest plant height (57.0 cm) was seen in cauliflower -red amaranth intercropping system (1:1) and the shortest plant height (46.9 cm) was seen in cauliflower-red amaranth-radish intercropping system (1:1:2) among the intercropping systems at harvest. Since the intercrop was competing with the cauliflower, the plant height was decreased after 40 days after transplanting (Figure 2). In the intercropping method of cauliflower with other crops, Kabiraj *et al.* (2017) noted a decreasing trend of cauliflower plant height with six other inter crops like six French bean, pea, beet, carrot, palak and coriander.

Effect on leaf traits

For leaf number plant^{-1}, leaf length, and leaf width of the cauliflower, there were significant changes between the intercropping systems (Table 1). In the sole cauliflower cultivation system, generally the highest leaves plant^{-1}, largest leaf length, and largest leaf width (10.2 plant^{-1}, 33.5 cm and 14.0 cm, respectively) were obtained. When cauliflower was intercropped with red amaranth and leafy radish, comparatively produced lower number of leaves plant^{-1}, leaf length, and leaf width of 7.6 plant^{-1}, 25.9 cm and 9.0 cm, respectively in cauliflower-red amaranth-radish intercropping system (1:1:2). However, in cauliflower-red amaranth intercropping system (1:1) exhibited the highest values for each of these criteria (8.4 plant^{-1}, 28.2 cm, and 11.7 cm, respectively). Tempesta *et al.* (2019) revealed that only growing cauliflower had higher number of leaf plant^{-1}, leaf length, and leaf breath than the intercropping system.

Effect on stem length

According to the experimental results, intercropping with other crops significantly affected stem length of cauliflower (Table 1). In the sole cauliflower alone (T_1) achieved the largest stem length (7.1 cm) measurements ever recorded. In the intercropping system decreases the stem length due to the competition for nutrient, space and sunlight. However, in cauliflower-red amaranth intercropping system (1:1) showed the considerable higher stem length (6.0 cm). The sole cauliflower's largest stem length may be the result of the plant taking full advantage of all available resources to complete its vegetative growth (Shil and Nath 2015; Turan *et al.* 2022).

Effect of cauliflower curd yield

Characteristics of the cauliflower that are associated with yield, such as its diameter (cm), individual curd weight (g), curd yield plot^{-1} (kg) and tha^{-1} showed statistically significance difference at 5% level among various intercropping schemes (Table 1). The maximum values for each of these parameters were recorded 11.2 cm, 857.5 g, 11.4 kg, and 25.4 tha^{-1}, respectively from the cauliflower sole crop. And in the intercropping system, cauliflower and red amaranth intercropping system (1:1) produced the highest diameter (8.12 cm), individual curd weight (696.6 g), curd yield plot^{-1} (7.9 kg) and curd yield (17.6 tha^{-1}) while cauliflower with red amaranth and radish intercropping (1:1:2) yielded the lowest diameter (7.0 cm), individual curd weight (567.9 g), curd yield plot^{-1} (7.0 kg) and curd yield (15.6 tha^{-1}). Mrnka *et al.* (2023) also reported that the yield of cauliflower under the single cauliflower system yielded relatively greater than that of its intercropping with other crops. Basically, during the intercropping system, cauliflower plant is competed with other intercrops for sufficient nutrients, water, sunlight and air, resulting the reduction of its curd yield (Kabiraj *et al.* 2017; Tempesta *et al.* 2019; Turan *et al.* 2022).

Yield contributing traits of red amaranth

Effect on leaf traits with plant height

The experimental results clearly showed that red amaranth as intercropping with cauliflower and radish leafy vegetable significantly affected the number of leaf, leaf breadth, leaf length, and plant height of red amaranth. The highest number of leaf (21.3), leaf breadth (5.2 cm), leaf length (7.0 cm), and plant height (24.5 cm) of red amaranth had been recorded from the sole red amaranth cropping system (Table 2). The sole red amaranth plant may have had the highest number of leaf, leaf breadth and leaf length because it took full advantage of every resource available to com-

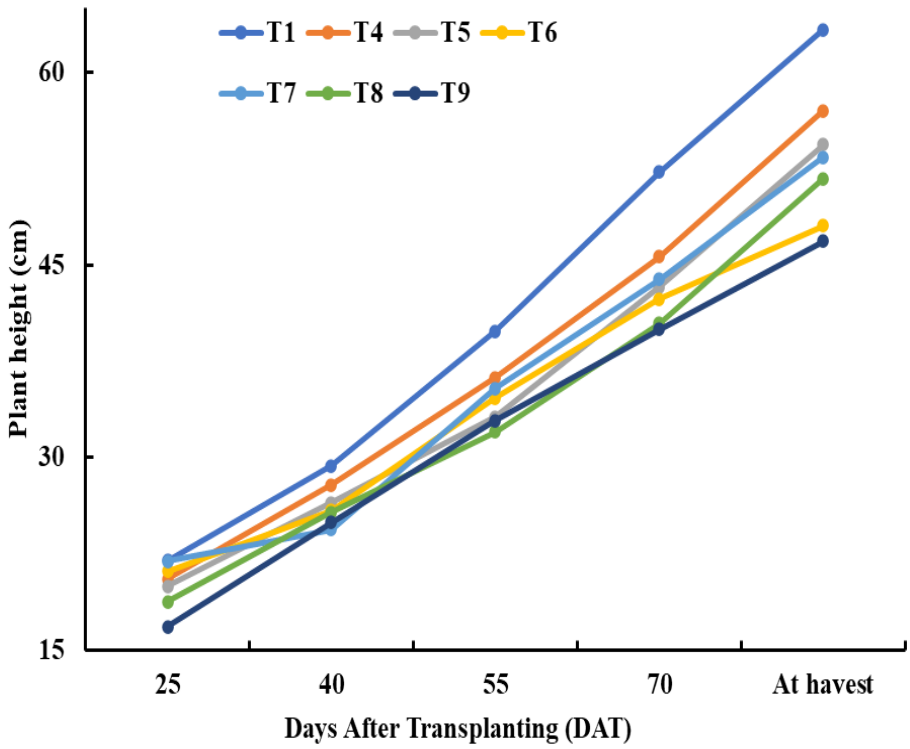

Figure 2: **Plant height of cauliflower at different days after transplanting**

Table 1: Yield and yield contributing characters of cauliflower

Treatment	Plant height (cm)	Number of leaves plant^{-1}	largest leaf length (cm)	largest leaf width (cm)	Stem length (cm)	Curd diameter (cm)	Individual curd wt. (g)	Curd yield (kg/ plot)	Curd yield (tha^{-1})
T_1	35.2	10.2	33.5	14.0	7.1	11.2	857.5	11.4	25.4
T_4	32.7	8.4	28.2	11.7	6.0	8.1	696.6	7.9	17.6
T_5	30.3	8.1	27.6	10.8	5.5	8.0	686.8	7.4	16.4
T_6	29.3	8.0	27.3	10.0	5.2	7.7	675.3	8.4	18.6
T_7	30.9	8.3	26.4	9.6	5.5	7.8	601.5	7.8	17.4
T_8	28.4	7.9	27.0	10.0	5.1	7.2	685.8	7.4	16.5
T_9	28.0	7.6	25.9	9.0	4.9	7.0	567.9	7.0	15.6
LSD0.01	2.0	0.5	0.3	1.0	0.5	0.4	7.2	0.2	1.5
Sig. level	**	**	**	**	**	**	**	**	**
CV (%)	4.4	2.0	3.2	2.1	1.7	1.5	12.4	1.4	5.8

** = Significant at 1% level of probability; Plant height, largest leaf length and largest leaf breadth data were recorded @ 70 days after transplanting (DAT)

T_1 = Sole cauliflower cropping, T_4= cauliflower-red amaranth intercropping (1:1), T_5= cauliflower –radish leafy vegetable intercropping (1:1), T_6=cauliflower-red amaranth-radish intercropping (1:1:1), T_7=cauliflower-red amaranth-radish intercropping (2:1:1), T_8=cauliflower-red amaranth-radish intercropping (1:2:1), T_9=cauliflower-red amaranth-radish intercropping (1:1:2)

plete their vegetative growth (Ali *et al.* 2022; Ruth *et al.* 2021). And in the intercropping system, cauliflower and red amaranth intercropping system (1:1) produced the highest number of leaf (19.6), leaf breadth (5.0 cm), leaf length (6.1 cm), and plant height (22.8 cm). As a result, the length, width and breadth of red amaranth leaves were consistent with those reported by Regmi *et al.* (2019) and Suhi *et al.* (2023), respectively.

Effect on root and shoot traits

The impact of various treatments on root and shoot were showed statistically significant in both sole and intercrop except dry root weight (Table 2). The highest root length (6.5 cm), shoot diameter (3.9 cm), fresh root weight plant^{-1} (0.9 g) and dry root weight plant^{-1} (0.1 g) were obtained in red amaranth sole cropping system. However, in the inter cropping system, cauliflower with red amaranth intercropping system (1:1) yielded the highest root length (5.3 cm), shoot diameter (3.1 cm), fresh root weight plant^{-1} (0.8 g) and dry root weight plant^{-1} (0.09 g) whereas the lowest root length (4.0 cm), shoot diameter (2.2 cm), fresh root weight plant^{-1} (0.5 g) and dry root weight plant^{-1} (0.06 g) were observed in the intercropping system of cauliflower with red amaranth and radish intercropping (1:1:2). According to Chen *et al.* (2022) and Suhi *et al.* (2023), differing intercropping systems have varied effects on the root and shoot growth patterns of amaranths.

Fresh and dry weight of plant

A substantial impact on plant fresh and dry weight was observed with a statistically significant difference (Table 2). According to Table 2, T_2 had the highest fresh weight plant^{-1} (11.9 g) and dry weight plant^{-1} (0.7 g) in sole red amaranth crop. In the intercrop, cauliflower with red amaranth intercropping (1:1). produced the highest fresh weight plant^{-1} (10.1 g) and dry weight plant^{-1} (0.7 g). These kinds of results suggested that intercropping with suitable crops had a beneficial impact on the growth in plant fresh weight and dry weight

(Khanal *et al.* 2021; Mucheru-Muna *et al.* 2010).

Yield traits

The plot and total yield of red amaranth varied significantly in both sole and intercropping system (Table 2). The findings showed that T_4 had the highest yield plot^{-1} (6.1 g) and total yield (13.5 tha^{-1}) in red amaranth sole cropping system. However, both the plot yield and total yield hampered when red amaranth is cultivated as intercropping. In the intercropping system, cauliflower with red amaranth intercropping (1:1). produced the highest plot yield (5.0 g) and total yield (11.1 tha^{-1}) while the lowest plot yield (3.0 g) and total yield (6.7 tha^{-1}) were found in cauliflower with red amaranth and radish intercropping system (1:1:2). Ali *et al.* (2022) and Ruth *et al.* (2021) reported that reduction of yield and its components in red amaranth upon intercropping with vegetables.

Yield contributing traits of leafy radish

Effect on leaf traits with plant height

The experimental results unmistakably shown that intercropping radish leafy vegetable with cauliflower and red amaranth altered the amount of leaves plant^{-1}, leaf breadth, leaf length, leaf fresh and dry weight plant^{-1} and the height of the plants (Table 3). The sole radish leafy vegetable cropping system had produced the highest number of leaves (14.6), leaf breadth (9.6 cm), leaf length (31.3 cm), leaf fresh weight plant^{-1} (55.7 g), leaf dry weight plant^{-1} (3.9 g), and plant height (50.7 cm). In intercropping also generated the maximum number of leaves (13.0), leaf breadth (8.0 cm), leaf length (28.8 cm), leaf fresh weight plant^{-1} (51.5 g), leaf dry weight plant^{-1} (3.6 g) and plant height (45.4 cm) with the

Table 2: Yield and yield contributing characters of red amaranth

Treatment	Plant height (cm)	No. of leaves (plant^{-1})	Leaf breadth (cm)	Leaf length (cm)	Root length (cm)	Shoot diameter (cm)	Fresh root weight plant^{-1} (g)	Dry root weight plant^{-1} (g)	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)	Yield plot^{-1} (g)	Yield (t ha^{-1})
T_2	24.5	21.3	5.2	7.0	6.5	3.9	0.9	0.10	11.9	0.7	6.1	13.5
T_4	22.8	19.6	5.0	6.1	5.3	3.1	0.8	0.09	10.1	0.7	5.0	11.1
T_6	21.9	15.4	4.1	5.4	5.1	2.9	0.8	0.08	9.4	0.6	4.1	9.2
T_7	20.9	14.8	4.0	4.9	4.6	2.6	0.5	0.07	7.8	0.5	3.2	7.0
T_8	21.1	17.6	4.4	5.0	4.7	2.5	0.6	0.08	7.0	0.5	3.8	8.4
T_9	19.3	12.6	3.9	4.1	4.0	2.2	0.5	0.06	6.5	0.5	3.0	6.7
LSD 0.01	3.0	3.5	0.9	0.8	0.7	0.5	0.1	0.05	0.8	0.2	1.0	2.4
Sig. level	**	**	**	**	**	**	**	NS	**	**	**	**
CV (%)	6.3	8.3	7.4	5.8	6.4	6.9	3.8	2.9	3.2	7.9	6.9	5.4

** = Significant at 1% level of probability, NS= non-significant

T_2 = Sole red amaranth cropping, T_4= cauliflower-red amaranth intercropping (1:1), T_6=cauliflower-red amaranth-radish intercropping (1:1:1), T_7=cauliflower-red amaranth-radish intercropping (2:1:1), T_8=cauliflower-red amaranth-radish intercropping (1:2:1), T_9=cauliflower-red amaranth-radish intercropping (1:1:2) cauliflower and radish leafy vegetable intercropping system (1:1) whereas the intercropping system cauliflower with red amaranth and radish leafy vegetable intercropping (1:2:1) yielded the minimum number of leaves (8.6), leaf breadth (6.2 cm), leaf length (22.9 cm), leaf fresh weight plant^{-1} (46.9 g), leaf dry weight plant^{-1} (2.2 g) and plant height (36.6 cm) (Table 3). According to Chimonyo *et al.* (2023), Daryanto *et al.* (2020) and Maitra *et al.* (2020) who reported that cropping techniques and soil fertility had an impact on the yield and yield-related characteristics of cereals-legumes intercropping.

Effect on root traits

The root traits like root length, root diameter, root fresh and dry weight plant^{-1} were statistically significant in both sole and intercropping system (Table 3). Radish leafy vegetable solo cropping system yielded the highest root length (18.7 cm), root diameter (5.7 cm), fresh root weight plant^{-1} (15.7 g), and dry root weight plant^{-1} (2.5 g). In the intercropping system, the cauliflower with radish leafy vegetable intercropping (1:1) produced the highest root length (16.5 cm), root diameter (5.2 cm), fresh root weight plant^{-1} (14.0 g), and dry root weight plant^{-1} (2.1 g) meanwhile the shortest root length (12.9 cm), root diameter (4.0 cm), fresh root weight plant^{-1} (13.0 g), and dry root weight plant^{-1} (1.3 g) were obtained in the intercropping system of cauliflower with red amaranth and radish leafy vegetable intercropping (1:2:1). Root growth and its development depends on the availability of the nutrients, water and adequate space with sunlight and air during the intercropping system obtained in the maize-soybean intercropping in different patterns (Ahmed *et al.* 2016; Chen *et al.* 2022; Matusso *et al.* 2013).

Fresh and dry weight of plant

Table 2 shows that there was a crucial impact on plant fresh and dry weight with a statistically significant difference having the highest fresh weight plant^{-1} (73.8 g) and dry weight plant^{-1} (6.9 g) in the sole radish leafy vegetable. The cauliflower with radish leafy vegetable intercropping (1:1) yielded the highest fresh weight plant^{-1} (68.2 g) and dry weight plant^{-1} (5.8 g) in the intercrop while cauliflower with red amaranth and radish leafy vegetable intercropping (1:2:1) produced the lowest fresh weight plant^{-1} (59.7 g) and dry weight plant^{-1} (4.6 g). These findings revealed that intercropping with appropriate crops had a positive effect on the increase in plant fresh weight and dry weight (Ahmed *et al.* 2020; Bhuiyan *et al.* 2021; Chimonyo *et al.* 2023).

Yield traits

Both under a solo cropping system and an intercropping system, the plot and overall yield of radish leafy vegetable differed considerably presented in Table 3. In the sole cropping system for radish leafy vegetable had the highest yield plot^{-1} (8.4 g) and total yield (18.6 tha^{-1}). The results showed that intercropping cauliflower with radish leafy vegetable (1:1) reduces both the plot and overall yield. In the intercropping scheme, cauliflower with radish leafy vegetable intercropping (1:1) yielded the highest plot yield (5.6 g) and total yield (12.5 tha^{-1}) whereas the lowest plot yield (4.0 g) and total yield (9.8 tha^{-1}) were found in the intercropping of cauliflower with red amaranth and radish leafy vegetable pattern (1:2:1). Han *et al.* (2023), Iqbal *et al.* (2019) and Soleimanpour *et al.* (2019) reported that the most significant advantage of intercropping systems over monoculture systems is the increase in production per unit of area.

Productivity and economic return analysis

Investment determines whether production potential per unit of space and time is realized. When assessing economic returns, market prices take precedence over the quantity of crops grown in a given region and time. Based on cost benefit analysis, the present study showed that a system of intercropping that consisted of cauliflower and red amaranth-radish leafy vegetable was the most economically important intercropping system.

Cauliflower equivalent yield

The intercropping systems of cauliflower with red amaranth and radish leafy vegetable had a substantial impact on cauliflower equivalent production (Table 4). The highest cauliflower equivalent yield (33.2 tha^{-1}) was obtained from the cauliflower-red amaranth-leafy radish intercropping than the sole crop (25.4 tha^{-}

Table 3: Yield and yield contributing characters of leafy vegetable radish

Treat-ment	Plant height (cm)	No. of leaves (plant^{-1})	Leaf breadth (cm)	Leaf length (cm)	Root length (cm)	Root diam-eter (cm)	Leaf fresh weight plant^{-1} (g)	Leaf dry weight plant^{-1} (g)	Fresh root weight plant^{-1} (g)	Dry root weight plant^{-1} (g)	Fresh weight plant^{-1} (g)	Dry weight plant^{-1} (g)	Yield (plot^{-1}) (g)	Yield (tha^{-1})
T_3	50.7	14.6	9.6	31.3	18.7	5.7	55.7	3.9	15.7	2.5	73.8	6.9	8.4	18.6
T_5	45.4	13.0	8.0	28.8	16.5	5.2	51.5	3.6	14.0	2.1	68.2	5.8	5.6	12.5
T_6	42.4	10.4	7.8	26.4	15.9	5.0	48.7	3.4	13.0	2.0	63.6	5.8	5.2	10.5
T_7	39.5	9.8	7.0	24.7	13.9	4.5	47.6	3.3	14.8	2.0	61.9	4.9	4.4	9.8
T_8	36.6	8.6	6.2	22.9	12.9	4.0	46.9	2.2	13.0	1.3	59.7	4.6	4.0	9.8
T_9	37.9	9.0	6.9	23.5	14.9	4.1	47.6	3.0	14.0	1.5	60.5	4.9	5.3	11.8
LSD0.01	3.2	3.0	3.2	3.9	2.7	1.6	3.7	1.4	2.0	1.0	4.3	1.5	1.6	2.1
Sig. lev-el	**	**	**	**	**	**	**	**	**	**	**	**	**	**
CV (%)	5.6	4.9	3.2	7.8	3.7	2.1	4.9	2.2	3.1	2.1	6.8	2.5	3.0	8.8

** = Significant at 1% level of probability, NS= non-significant

T_3 = Sole radish leafy vegetable, T_5= cauliflower–radish leafy vegetable intercropping (1:1), T_6=cauliflower-red amaranth-radish inter-cropping (1:1:1), T_7=cauliflower-red amaranth-radish intercropping (2:1:1), T_8=cauliflower-red amaranth-radish intercropping (1:2:1), T_9=cauliflower-red amaranth-radish intercropping (1:1:2)

[1]). The cost of red amaranth leafy vegetable was higher, which contributed to the highest equivalent yield. When cauliflower and red amaranth-leafy radish were intercropped, cauliflower equivalent yield increased. Kabiraj *et al.* (2017) reported about the similar results on intercropping with legumes are always preferred to yield cauliflower with a promising quality. Turan *et al.* (2022) and Tempesta *et al.* (2019) also reported the cauliflower equivalent yield when intercrop with other vegetables.

Land equivalent ratio (LER)

The LER of several crop combinations ranged from 1.3 to 2.0 are presented in the Table 4. The intercropping system of cauliflower with red amaranth and leafy radish (1:1:1) had the highest land equivalent ratio (2.0), followed by cauliflower with red amaranth and leafy radish intercropping (1:2:1). The intercropped cauliflower and radish leafy vegetable intercropping (1:1) combination obtained the lowest LER (1.3) of any combination. The average LER (greater than one) values across all intercropping treatments showed that intercropping was a more effective use of the land than solitary cropping of cauliflower. Regmi *et al.* (2019) also found similar results in intercropping of okra and cowpea while Khan *et al.* (2018) found higher LER value (1.56) in maize and garden pea inter cropping.

Gross return (Tk ha^{-1})

The gross return in the intercropping of cauliflower with red amaranth and radish leafy vegetable is given in the Table 5. It was discovered that intercropping treatments consistently produced higher gross returns than solitary crops. Therefore, it was evident that the intercropping treatments produced a higher gross return than the sole cropping techniques. The intercropping of cauliflower with red amaranth and leafy radish (1:1:1) produced the highest gross return (997102 Tk ha^{-1}) followed by cauliflower with red amaranth and leafy radish intercropping (1:2:1) of 900900 Tk ha^{-1} gross return. The results of higher productivity and returns were in line with past reports of crop mixtures having a yield advantage over monoculture (Ali *et al.* 2022; Khanal *et al.* 2021; Soleimanpour *et al.* 2019).

Table 4: Cauliflower equivalent yield and land equivalent ratio (LER) under cauliflower-red amaranth-radish intercropping systems

Cropping systems	Yield (tha^{-1})			Total yield (tha^{-1})	Cauliflower equivalent yield (tha^{-1})	LER
	Cauliflower	Red amaranth	Leafy radish			
T_1	25.4	-	-	25.4	-	1.0
T_2	-	13.5	-	13.5	-	1.0
T_3	-	-	18.6	18.6	-	1.0
T_4	17.6	11.1	-	28.7	26.8	1.5
T_5	16.4	-	12.5	29.0	24.8	1.3
T_6	18.6	9.2	10.5	38.3	33.2	2.0
T_7	17.4	7.0	9.8	34.2	29.8	1.7
T_8	16.5	8.4	9.8	34.7	30.0	1.8
T_9	15.6	6.7	11.8	34.1	29.0	1.7

T_1 = Sole cauliflower cropping, T_2 = Sole red amaranth cropping, T_3 = Sole radish leafy vegetable, T_4= cauliflower-red amaranth intercropping (1:1), T_5= cauliflower–radish leafy vegetable intercropping (1:1), T_6=cauliflower-red amaranth-radish intercropping (1:1:1), T_7=cauliflower-red amaranth-radish intercropping (2:1:1), T_8=cauliflower-red amaranth-radish intercropping (1:2:1), T_9=cauliflower-red amaranth-radish intercropping (1:1:2)

Net return (Tk ha^{-1})

The intercropping systems showed positive net return over variable costs. Out of the six intercropped system, cauliflower with red amaranth and leafy radish (1:1:1) had the highest net return (512102 Tk/ha) followed by closely related systems of cauliflower with red amaranth and leafy radish intercropping (1:2:1) of 435900 Tk ha^{-1} net return. These were mostly caused by increased cauliflower yield and red amaranth market price (Table 5). According to Ahmad *et al.* (2020) and Raseduzzaman and Jensen (2017), all intercropping systems have a higher chance of producing a profit than a pure stand.

Benefit-cost ratio (BCR)

The intercropping of green vegetables with cauliflower was found to boost overall production and economic return compared to cauliflower alone. Examining the benefit-cost ratio of each intercropping system, it was discovered that cauliflower with red amaranth and leafy radish (1:1:1) had the highest benefit-cost ratio (2.1). A single crop of red amaranth had the lowest benefit-cost ratio (1.6), as well as the lowest net return (Table 5). Because the component crops used growth resources efficiently, the intercropping system had a greater yield than the monocropping system (Daryanto *et al.* 2020; Iqbal *et al.* 2019; Mrnka *et al.* 2023). The present findings are corroborated with the findings of Khan *et al.* (2018) who stated that garden pea and maize intercropping increased gross return and gross margin compared to solitary crop.

CONCLUSION

This present finding demonstrated that intercropping systems between cauliflower with red amaranth and radish leafy vegetable had a significant impact on cauliflower output. Sole cauliflower produced the most grain at 25.4 tha^{-1}, which was the greatest yield. In cauliflower rows, red amaranth and leafy radish production gradually declined. In an intercropping system, cauliflower with red amaranth and leafy radish (1:1:1) produced the best yield (33.2 tha^{-1}). When cauliflower with red amaranth and leafy radish was grown together, the total individual yield was decreased but

Table-5: Economic analysis of different cropping systems

Cropping systems	Grain Yield (tha^{-1})			Gross return (Tk ha^{-1})			Total (Tk ha^{-1})	Total cost of Production (Tk ha^{-1})	Net return (Tk)	BCR
	Cauliflower tha^{-1}	Red amaranth tha^{-1}	Leafy radish tha^{-1}	Cauliflower	Red amaranth	Leafy radish				
T_1	25.4			760500			760500	440000	320500	1.7
T_2		13.5			337250		337250	216000	121250	1.6
T_3			18.6			372000	372000	215000	157000	1.7
T_4	17.6	11.1		527400	276750		804150	460000	344150	1.8
T_5	16.4		12.5	493200		250200	743400	435000	308400	1.7
T_6	18.6	9.2	10.5	557400	229500	210200	997102	485000	512102	2.1
T_7	17.4	7.0	9.8	521400	175500	196800	893700	480000	413700	1.9
T_8	16.5	8.4	9.8	495300	210000	195600	900900	465000	435900	1.9
T_9	15.6	6.7	11.8	468000	167750	235200	870950	455000	415950	1.9

Price: Cauliflower@30Tk kg^{-1} and Red amaranth @ 25 Tk kg^{-1}, Leafy radish@ 20 Tk kg^{-1}.

in gross and net return was increased. The intercropping of cauliflower with red amaranth and leafy radish (1:1:1) produced the highest gross return (997102 Tk ha^{-1}) and net return (512102 Tk ha^{-1}) using the highest land equivalent ratio (2.0). In overall result of the present study concluded that intercropping of leafy vegetables (red amaranth and leafy radish) and cauliflower, as opposed to sole cauliflower, increased overall production and economic return.

AUTHOR CONTRIBUTION

MHM performed the experiments, analyzed and interpreted data. MHM and MRM conceptualized and designed the study. MHM, SH, JA, and MSH performed the statistical analysis and drafted the manuscript.

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