



Evaluation of cabbage varieties for resistance to clubroot pathogens, *Plasmodiophora brassicae* woronin in Dhankuta, Nepal

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Abstract

A field experiment was conducted to evaluate the varietal resistance of cabbage against club root disease, *Plasmodiophora brassicae* Woronin, in a naturally infested field in Sidhuwa, Dhankuta. It was conducted in a randomized complete block design (RCBD) of three replications and seven treatments, viz., T1: Green Coronet, T2: Nepa Green 777, T3: Big Sun 171, T4: Yr Honam, T5: Big Sun 111, T6: Super Green, and T7: Nepa Star. The plant height was comparatively greater in Green Coronet and Super Green in 60 DAT. In contrast, there was no significant difference in the number of leaves. Big Sun 111 and Yr Honam did not show any signs of galling or clubroot, indicating a significantly higher resistance. Despite not being afflicted by clubroot, Nepa star produced less than satisfying results due to black rot and early head decay. The maximum average head weight and marketable cabbage yield were recorded as being highest in Big Sun 111 (2.56 kg) and Yr Honam (2.24 kg). Furthermore, the yield from Big Sun 171 (1.93 kg) and Nepa Green 777 (1.84 kg) was satisfactory, despite the higher PDI (percentage disease index) (40.33%) and (61.04%), respectively. Disease incidence was zero in Big Sun 111, Yr Honam, and Nepa Star. In terms of productivity and disease resistance, Big Sun 111 (160.13 Mt/ha) and Yr Honam (140.51 Mt/ha) provide the best results, which may be beneficial to farmers who face costly and lengthy disease control practices.

Keywords – disease incidence – productivity – resistant varieties

Introduction

Cabbage (*Brassica oleracea* L. var. *capitata*) is one of the most significant vegetables farmed worldwide which is a member of the Cruciferae family that includes *Brussels sprouts*, broccoli, cauliflower, and kale. Cabbage is a cool-season crop with short roots that is farmed for its enormous leaves head (Singh et al. 2006). The origin of cabbage is the Mediterranean. It is believed to have initially been domesticated in Western Europe and has subsequently played a significant role in cuisines around the world (Moreb et al. 2020). According to the evidence, the Ancient Greeks, Romans, Indians, and Chinese all highly appreciated and utilized them (Balliu 2014).

The head, which is made up of dense layers of leaves in a variety of sizes, colors, and textures, is the part that may be eaten. Red, white, and savoy cabbage cultivars are among those that

can be cooked, shredded, steamed, pickled, fermented, boiled, or eaten raw (Moreb et al. 2020). In numerous epidemiological studies and interventional trials, this cruciferous vegetable has been shown to reduce the risk of multiple cancer types as well as chronic ailments like cardiovascular disease, cataracts, Alzheimer's disease, and diabetes (Moreb et al. 2020).

In crucifer crops, especially cabbage and closely related crops, clubroot is possibly the most serious disease. It is caused by a soil-borne parasitic phytopathogen *Plasmodiophora brassicae* Woronin, which has already made an economic impact in many regions of the world (Dixon 2009). Infected plants display flagging leaves, untidy growth, and even premature death. A root uprooted from the ground shows characteristic symptoms of hypertrophied club-shaped roots (Gahatraj et al. 2019). The disease has been reported in more than 60 countries and can result in total yield loss in heavily infested fields (Dixon 2009). Plasmodiophorids share some characteristics, such as zoospores with whiplash flagella of unequal length, long-lived resting spores, and multinucleated plasmodia (Braselton 1995). Brassica crops are almost impossible to grow profitably in the disease-appeared field as the plant is often lost totally in the diseased field (Dixon 2009). Throughout the world, clubroot contributes to 50-100% yield loss in cabbage (Karling 1968).

Plasmodiophora brassicae has three stages in its life cycle: survival in the soil as a resting spore, root hair infection, and cortical infection (Tommerup & Ingram 1971). As some reports suggest, clubroot spores can survive up to 20 years, but most likely will die within five to seven years due to thick-walled, long-lived resting spores (Wallenhammar 1996). Hence, the pathogen is difficult to be eradicated once established in a field. There are a variety of pest control options, including cultural, biological, selected chemicals, and other innovative IPM measures that can be used in combination or alone to overcome this problem (Timila & Neupane 2008). One of the easiest and most economical ways to control soil-borne pathogen clubroot is to grow resistant varieties, which don't require any changes to the grower's farming methods. Additionally, a lack of available land or a strong year-round demand for brassica crops, gives the farmer the most flexibility regarding when and where to sow brassica crops (Heinrich et al. 2016). Furthermore, purchasing resistant seed is far less expensive than soil pH management with liming, which can cost hundreds of dollars per acre (Heinrich et al. 2016). The main objective of the study is to evaluate the resistivity of different cabbage varieties against the clubroot pathogen and evaluate the performance of different varieties on the vegetative characteristics of cabbage. Also, to evaluate the disease incidence and disease severity of different cabbage varieties. The major rationale of this study is to increase production and productivity, which is stuck by the disease thereby causing the greatest yield loss by following the fundamental step i.e. use of resistant variety. And, encourage farmers to grow resistant varieties which is one of the easiest and most economical strategies to manage the soil-borne pathogen clubroot.

Materials & methods

Geographical location of the experimental site

The study was conducted in the farmer's field at Sindhuwa, Dhankuta from February to June 2022. It is located at 27°04'37" N latitude and 87°23'19" E longitude with an elevation of 2148 m above sea level (Mapcarta 2022). The sample was analyzed in the soil test camp, organized by the Prime Minister Agriculture Modernization Project, Vegetable Zone, Sidhuwa. Nitrogen content was medium, phosphorus and potassium content were low and pH was 6. Among these, Yr Honam, Super Green, Nepa Star, Big Sun -171 and Nepal Green 777 are registered varieties; whereas, Big Sun 111 is yet to be registered in Nepal.

The samples of seeds of cabbage namely Nepa Green 777, Big Sun 171, and Big Sun 111 were obtained from Karma Group of Companies, Nepal; genotypes were imported from Chia Tai Co. Ltd., Thailand. Likewise, Green Coronet, Yr Honam, Super Green, and Nepa Star were obtained from Nepal Seed Company.

Experimental design and details of the treatment used

The experiment was carried out in Randomized Complete Block Design (RCBD) with seven treatments viz. T1: Green Coronet, T2: Nepa Green 777, T3: Big Sun 171, T4: Yr Honam, T5: Big Sun 111, T6: Super Green and T7: Nepa Star with three replications. The total experimental area was 180 m² (18 m × 10 m) and the space between replication and treatment was 0.5 m and 1m respectively. The individual plot size was 2 m × 2 m i.e. 4 m². The row-to-row distance was 40 cm and plant to plant distance was 40 cm. There were altogether 25 plants in each plot and the inner 4 sample plants were randomly selected to record the data required for the experiment.

Pathogen isolation and identification

The research was conducted in a naturally occurring pathogen field by natural inoculation. Four out of seven varieties showed swollen and distorted roots forming clubs which is one of the close symptoms of the clubroot pathogen. Two samples of root tissue from each of the seven varieties were collected from the field. The collected samples from the research field were taken to the pathology laboratory of the Nepal Agriculture Research Council, Pakhribas, Dhankuta. They were washed with running water to remove soil particles, and surface sterilized by soaking in 70% ethanol for 1 minute. After removing excess ethanol with distilled water, they were soaked in distilled water for 2 hours (Zhou et al. 2014). They were macerated by using a homogenizer (13,500 rpm/5 min) in distilled water (Heo et al. 2009). The resting spores were extracted by filtering the slurries through four layers of nylon cloth (Zhou et al. 2014). The oval to spherical, thick-walled, uninucleate resting spores were observed under a compound microscope which confirms the infection of *P. brassicae* (Bulman et al. 2011). This test was done only to confirm whether the club-like structure formed was due to *P. brassicae* and the pathogen was observed under a compound microscope in Super Green, Nepa Green 777, Green Coronet, and Big Sun 171. Whereas, the varieties Yr Honam, Big Sun 111, and Nepa Star did not show any pathogen under observation.

General cultural practices

Nursery preparation (Seedling production)

Seven varieties of cabbage, including Big Sun 111, Nepa Star, Green Coronet, Yr Honam, Super Green, Nepa Green 777, and Big Sun 171, were raised under a high-tech plastic tunnel using plug mix as a growing medium to prevent early seedling infection by clubroot pathogen. To prevent seedlings from drying out, they were irrigated almost every day based on their moisture content. Charge (Humic acid 15%) was applied twice to seedling leaves at an interval of 1 week after 15 DAS at a concentration of 2 mL/L with a sprayer. It increases root and seedling growth, uptake of nutrients, crop production, soil fertility, and microorganism activity, and improves soil fertility.

Land Preparation and seedling transplantation

The experimental field was prepared by complete removal of crop residues and weeding was done before ploughing. To bring soil to good tilth before transplanting seedlings, deep ploughing was done twice. The field layout was done according to the design and laid out with 21 experimental units for arranging seven treatments with three replications. The fertilizers such as organic amendment (poultry manure), Nitrogen, Phosphorus, and Potassium were applied at the recommended rate of 120 kg, 100 kg, and 120 kg per ha in the form of Urea, DAP, and MOP. Half the dose of N and the entire amount of P and K were given at the time of transplanting. The balance N was given six weeks after transplanting at the time of earthing up by side placement. Seedlings were transplanted 30 days after sowing. The seed tray was irrigated with water 2 hours before transplanting for easy uprooting and to prevent damage to the root ball.

Irrigation

First irrigation was given just after transplanting of seedlings and subsequent irrigations were

given at an interval of 5-10 days depending upon the moisture conditions in the soil. Proper care was given to avoid water stress from the time of head formation to the head maturity period.

Intercultural operations

After transplanting, two hand weeding and earthing up were done in 30 days after transplanting to keep crops free of weeds. At the time of earthing up the plants are supported with soil to avoid toppling of the plant during head formation.

Harvesting

Cabbage was ready for harvest 90 days after planting. Cabbage was harvested promptly when the heads were firm and mature. The head was harvested by bending it to one side and cutting it with a knife.

Observations recorded

The observations were taken from plants and plant roots from randomly selected four plants of each experimental plot. The following parameters were taken during the time of data collection.

Biometric Parameters

Four plants from each treatment plot were selected at random and tagged for recording the observations on the following parameters. The observations were recorded at 15 DAT, 30 DAT, 60 DAT, 90 DAT.

Plant height (cm)

Plant height was measured from the ground level to the growing point in four randomly tagged plants at the tallest part and expressed in centimeters.

Number of leaves per plant

The total number of leaves attached to the plant at the time of data collection was counted from sample plants. Dried and senescence leaves were excluded from counting in each observation.

Plant spreading

Plant spreading was recorded by measuring the length covered by the plant at the widest side of the ground in crisscross and then averages from two values were recorded in centimeters as plant spreading.

Yield parameters

Average Head Weight (kg per plant)

The average head weight was recorded by measuring the individual head weight of all four tagged sample plants and taking their average. The head weight was recorded weighing the marketable head and excluding the biomass.

Marketable yield (Metric ton per hectare)

The marketable yield was measured by converting the average head weight to yield in Mt/ha. to determine the productivity of the production.

Disease assessment parameters

Disease scoring

The severity of club root was assessed by visually estimating the degree of gall development on the lateral and main root systems using the 0-3 disease scale given by (Kuginuki et al. 1999). The disease scoring scale is presented in the table.

Table 1 Disease scoring scale used to score club root on cabbage.

S.N.	Score	Severity
1	0	No symptoms of galling
2	1	A few small clubs (small galls on <1/3 of roots)
3	2	Moderate clubs (small to medium galls on 1/3-2/3 of roots)
4	3	Severe clubs (medium to large galls on > 2/3 of roots)

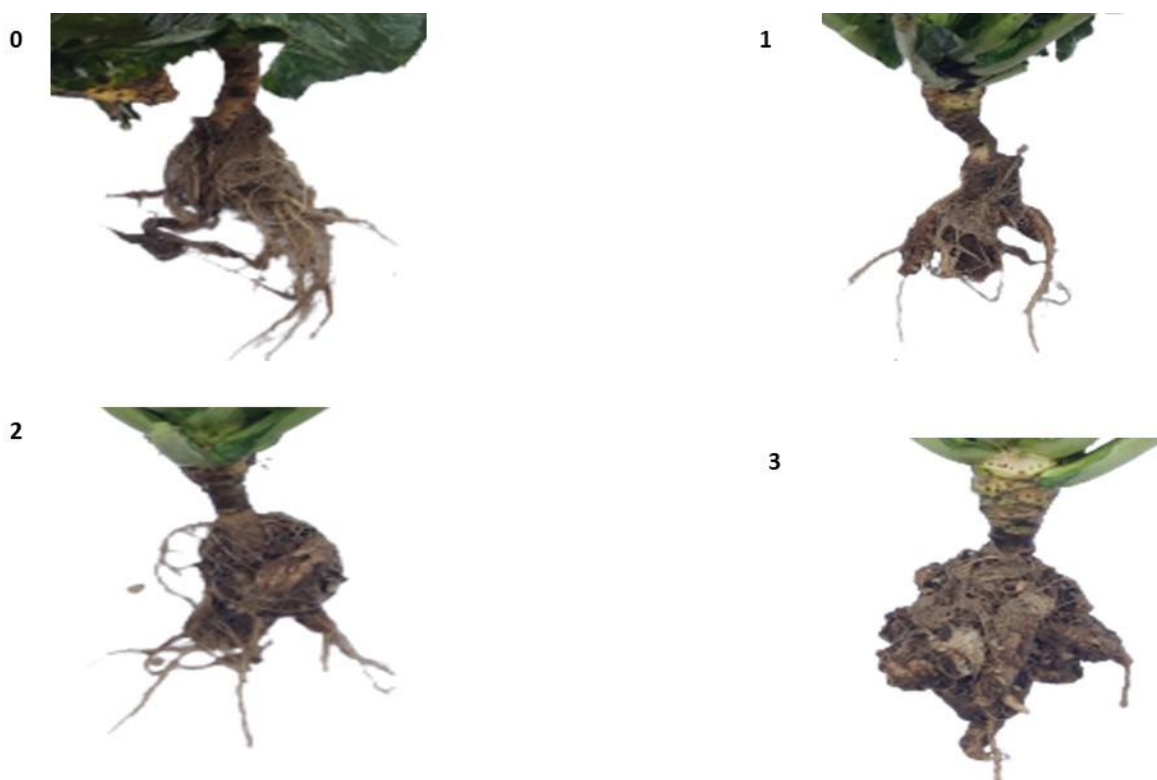


Fig. 1 – Disease scoring of infected roots based on 0-3 scale. (Kuginuki et al. 1999)

Disease assessment

Six sampled per plot were uprooted and scored on a 0-3 scale (Kuginuki et al. 1999) by visual observation of gall formation of each plant's roots. Club root severity of each plant was assessed.

Percentage Disease Index (PDI) or Disease Severity Index (DSI)

Individual scores were used to calculate an index of disease according to the formula:

$$DSI(\%) = \sum \frac{(Total\ number\ of\ rating)}{(Total\ rating \times maximum\ rating)} \times 100$$

Disease Incidence

$$DI(\%) = \frac{Number\ of\ plants\ infected}{Total\ no.\ of\ plants\ observed}$$

Statistical analysis

All data were presented as mean \pm SEM. Statistical analysis was done by using the R-Studio edition. Data were subjected to one-way analysis of variance (ANOVA) and means were compared by Duncan's Multiple Range Test (DMRT) to compare treatment means at (P = 0.05). The effectiveness of treatments was studied based on above mentioned parameter.

Result & Discussion

Plant height (cm)

The analyzed data (Table 2) revealed that the plant height of cabbage was significantly influenced by the different varieties at 15 DAT, 30 DAT, 60 DAT, and 90 DAT. At 15 DAT, the highest plant height was recorded in Yr Honam (11.58 cm) which was statistically similar to Big Sun 111 (11.42 cm) and Nepa Green 777 (11.37 cm) followed by Green Coronet (10.50 cm) and Super Green (9.87 cm). While lowest plant height was recorded in Big Sun 171 (8.00 cm) almost similar to Nepa Star (7.96 cm).

At 30 DAT, the highest plant height was recorded in Yr Honam (21.83 cm). Whereas, Nepa Green 777 (20.50 cm) was the second highest and is statically similar to Big Sun 111 (19.92 cm) and Big Sun (19.00 cm) followed by Green Coronet (18.25 cm) and Super Green (18.16 cm). While the lowest plant height was recorded in Nepa Star (15.00 cm).

At 60 DAT, the highest plant height was recorded in Supper Green (49.16 cm) which was statically similar to Green Coronet (46.00 cm) followed by Big Sun 111 (43.67 cm), Big Sun 171 (41.25 cm) and Yr Honam (40.7 cm). The plant height in Nepa Green was recorded (39.83 cm). While the lowest plant height was recorded in Nepa Star (33.58 cm).

At 90 DAT, the highest plant height was recorded in Green Coronet (42.75 cm) which was statically similar to Super Green (41.67 cm) followed by Big Sun 111 (37.58 cm), Yr Honam (34.33 cm), Nepa Green 777 (32.50 cm) and Big Sun 171 (32.25 cm). While the lowest plant height was recorded in Nepa Star (28.08 cm).

Table 2 Effect of different varieties of cabbage on plant height (cm) at 15, 30, 60, and 90 DAT.

Treatments	Plant height (cm)			
	15 DAT	30 DAT	60 DAT	90 DAT
Green Coronet	10.50 ^b	18.25 ^d	46.00 ^{ab}	42.75 ^a
Nepa Green 777	11.37 ^a	20.50 ^b	39.83 ^c	32.50 ^{bc}
Big Sun 171	8.00 ^d	19.00 ^{cd}	41.25 ^{bc}	32.25 ^{bc}
Yr Honam	11.58 ^a	21.83 ^a	40.75 ^{bc}	34.33 ^{bc}
Big Sun 111	11.42 ^a	19.92 ^{bc}	43.67 ^{abc}	37.58 ^{ab}
Super Green	9.87 ^c	18.16 ^d	49.16 ^a	41.67 ^a
Nepa Star	7.96 ^d	15.00 ^e	33.58 ^d	28.08 ^c
LSD (0.05)	0.587	1.312	5.628483	6.475633
SE _m (±)	0.072045	0.16095	0.690410	0.794325
F – Probability	***	***	**	**
CV, %	3.268	3.89	7.52	10.22
Grand mean	10.10119	18.95238	42.03571	35.59524

[Note: The common letters (s) within the column indicate non-significant differences based on the Duncan Multiple Range Test (DMRT) at 0.05 level of significance. SE_m(±) = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation, Ns = Non-significant and DAT = Days after transplanting]

Number of leaves per plant

The analyzed data (Table 3) revealed that the plant height of cabbage was significantly influenced by the different varieties at 15 DAT but no significant difference at 30 DAT, 60 DAT, and 90 DAT. At 15 DAT, the highest number of leaves was recorded in Yr Honam (5.66 cm) followed by Nepa Green 777, Nepa Star, Green Coronet, Big Sun 111, Super Green. While lowest number of leaves was recorded in Big Sun 171 (4.25 cm).

Table 3 Effect of different varieties of cabbage on number of leaves at 15, 30, 60, 90 DAT.

Treatments	Number of Leaves			
	15 DAT	30 DAT	60 DAT	90 DAT
Green Coronet	5.08 ^{ab}	10.16 ^a	12.75 ^b	8.33 ^{ab}
Nepa Green 777	5.50 ^{ab}	9.75 ^{ab}	15.16 ^{ab}	7.83 ^b
Big Sun 171	4.25 ^d	9.00 ^b	13.75 ^{ab}	8.75 ^{ab}
Yr Honam	5.66 ^a	9.66 ^{ab}	14.66 ^{ab}	9.16 ^{ab}
Big Sun 111	5.08 ^{ab}	9.75 ^{ab}	15.41 ^a	9.25 ^{ab}
Super Green	5.00 ^b	9.41 ^{ab}	15.91 ^a	8.41 ^{ab}
Nepa Star	5.33 ^{ab}	9.08 ^b	16.25 ^a	9.41 ^a
LSD _(0.05)	0.5742595	0.8003493	2.268478	1.405292
SE _m (±)	0.0704407	0.0981738	0.278259	0.1723783
F – Probability	**	Ns	ns	Ns
CV, %	6.291	4.712	8.58	9.040
Grand mean	5.130952	9.547619	14.84524	8.738095

[Note: The common letters (s) within the column indicate non-significant differences based on the Duncan Multiple Range Test (DMRT) at 0.05 level of significance. SE_m(±) = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation, Ns = Non-significant and DAT = Days after transplanting]

Plant spread (in cm)

The analyzed data (Table 4) revealed that the plant spread of cabbage was significantly influenced by the different varieties at 15 DAT, 60 DAT, 90 DAT, and non-significant at 30 DAT. At 15 DAT, the highest plant spread was recorded in Nepa Green 777 (19.96 cm) which was statically similar to Yr Honam (19.08 cm) followed by Nepa Star, Green Coronet, Super Green, and Big Sun 111. Whereas, the lowest plant spread was recorded in Big Sun 171 (13.87 cm).

At 30 DAT, there is no significant difference, yet Yr Honam (41.62 cm) showed the highest plant spread which is statically similar to Big S un 111, Nepa Green 777, and Green Coronet. The varieties, Super Green and Nepal stars were at par. While the lowest plant spread is of Big Sun 171 (32.62 cm).

At 60 DAT, the highest plant spread was recorded in Super Green (71.04 cm) which was statically similar to Big Sun 111 (70.08 cm), followed by Big Sun 171, Yr Honam, Green Coronet (at par) with Nepa Green 777. The lowest plant spread was recorded in Nepa Star (61.33 cm).

At 90 DAT, the highest plant spread was shown by Super Green (67.20 cm), statically similar at par with Green Coronet, Big Sun 111, Yr Honam, Big Sun 171, and Nepa Green 777. While the least plant spread was recorded by Nepa Star (53.08 cm). Results are presented in Table 4.

Table 4 Effect of different varieties of cabbage on plant spread(cm) at 15, 30, 60, 90 DAT.

Treatments	Plant spread 15 days (cm)			
	15 DAT	30 DAT	60 DAT	90 DAT
Green Coronet	16.70 ^{bc}	38.66 ^a	66.79 ^{ab}	62.54 ^{ab}
Nepa Green 777	19.96 ^a	40.04 ^a	63.70 ^{bc}	58.50 ^{bc}
Big Sun 171	13.87 ^d	32.62 ^b	67.95 ^{ab}	56.08 ^{bc}
Yr Honam	19.08 ^a	41.62 ^a	67.58 ^{ab}	58.87 ^{bc}
Big Sun 111	16.12 ^c	40.83 ^a	70.08 ^a	62.12 ^{ab}

Table 4 Continued.

Treatments	Plant spread 15 days (cm)			
	15 DAT	30 DAT	60 DAT	90 DAT
Super Green	16.70 ^{bc}	36.20 ^{ab}	71.04 ^a	67.20 ^a
Nepa Star	18.70 ^{ab}	36.45 ^{ab}	61.33 ^c	53.08 ^c
LSD (0.05)	2.169351	5.798263	4.93971	6.419183
SE _m (±)	0.266101	0.711236	0.605923	0.7874
F – Probability	***	ns	*	**
CV, %	7.044	8.562	4.148	6.03
Grand mean	17.30952	38.06548	66.92857	59.77381

[Note: The common letters (s) within the column indicate non-significant differences based on the Duncan Multiple Range Test (DMRT) at 0.05 level of significance. SE_m (±) = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation, Ns = Non-significant and DAT = Days after transplanting]

Average Head Weight (kg/plant)

The data observed revealed that the average head weight of cabbage was significantly influenced by varieties at 90 DAT or at the time of harvest. The highest average head weight of cabbage was recorded in variety Big Sun 111 (2.56 kg) which was almost similar to Yr Honam (2.24 kg) followed by Big Sun 171 (1.93 kg), Nepa Green 777(1.84 kg) and Nepa Star (1.46 kg). The lowest head weight was Super Green (1.17 kg) statically similar to Green Coronet (1.20 kg). Results are presented in Table 5.

Table 5 Effect of different varieties of cabbage on Average Head Weight (kg/plant) of cabbage at 90 DAT.

Treatments	Average Head Weight 90days (kg/plant)
Green Coronet	1.20 ^d
Nepa Green 777	1.84 ^{bc}
Big Sun 171	1.93 ^{bc}
Yr Honam	2.24 ^{ab}
Big Sun 111	2.56 ^a
Super Green	1.17 ^d
Nepa Star	1.46 ^{cd}
LSD (0.05)	0.5143721
SE _m (±)	0.063094789
F – Probability	***
CV, %	16.29
Grand mean	1.710119

[Note: The common letters (s) within the column indicate non-significant differences based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance. SE_m (±) = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation and Ns = non-significant]

Marketable Yield (ton/ha)

The data analyzed showed that the market yield of cabbage was significantly influenced by

cabbage variety. The highest marketable yield was recorded in variety Big Sun 111 (160.13 ton/ha) which is statically similar to Yr Honam (140.51 ton/ha) followed by Big Sun 171 (120.56 ton/ha), Nepa Green 777 (115.10 ton/ha) and Nepa Star (91.72 ton/ha). While the lowest marketable yield was recorded in Super Green (73.12 ton/ha). The results are presented in Table 6 below.

Table 6 Effect of different varieties of cabbage on Marketable Yield (Mt/ha) of cabbage at 90 DAT.

Treatments	Marketable Yield 90 days (Mt/ha)
Green Coronet	75.24 ^d
Nepa Green 777	115.10 ^{bc}
Big Sun 171	120.56 ^{bc}
Yr Honam	140.51 ^{ab}
Big Sun 111	160.13 ^a
Super Green	73.12 ^d
Nepa Star	91.72 ^{cd}
LSD (0.05)	32.16979
SE _m (±)	3.946064948
F – Probability	***
CV, %	16.30
Grand mean	110.9159

[Note: The common letters (s) within the column indicate non-significant differences based on Duncan Multiple Range Test (DMRT) at 0.05 level of significance. SE_m (±) = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation and Ns = non-significant.]

Disease Incidence (%)

The analyzed data Table 7 revealed that the clubroot disease incidence in cabbage was found to be significantly influenced by the varieties used. The highest disease incidence (64.00%) was recorded in the Super Green variety which was statically similar to Green Coronet (56.00%) followed by Nepa Green 777 (42.33%). Whereas, the least disease incidence was recorded in Big Sun 171 (26.66%). And there was no disease incidence (0%) observed in Big Sun 111, Yr Honam, and Nepa Star.

Table 7 Effect of different varieties of cabbage on Disease Incidence (%) of cabbage at 90 DAT.

Treatments	Disease Incidence (%) at 90 DAT
Green Coronet	56.00 ^a
Nepa Green 777	42.33 ^b
Big Sun 171	26.66 ^c
Yr Honam	0.00 ^d
Big Sun 111	0.00 ^d
Super Green	64.00 ^a
Nepa Star	0.00 ^d
LSD (0.05)	10.46435
SE _m (±)	1.283596

Table 7 Continued.

Treatments	Disease Incidence (%) at 90 DAT
F – Probability	***
CV, %	21.785
Grand mean	27

[Note: The common letters (s) within the column indicate non-significant differences based on the Duncan Multiple Range Test (DMRT) at 0.05 level of significance. $SE_m (\pm)$ = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation and Ns = non-significant.]

The above finding shows that the Big Sun 111, Yr. Honam and Nepal Star are the highly resistant varieties against clubroot disease.

Percentage Disease Index/Disease Severity Index (%)

The percent disease index or disease severity of club root disease on cabbage was found to be significantly influenced by the cabbage varieties as treatments. It was calculated based on a rating scale (0-3) given by (Kuginuki et al. 1999). Comparing all the treatments, Super Green showed the highest PDI (79.53%) followed by Green Coronet (66.65%) statically similar to Nepa Green 777 (61.04%). The least PDI was recorded in Big Sun 171 (40.33%). The treatments (varieties) Big Sun 111, Yr Honam, and Nepal Star were untouched with clubroot as no PDI i.e., (0%) was observed in these varieties. The results are presented in Table 8.

Table 8 Effect of different varieties of cabbage on Percentage Disease Index/Disease Severity Index (%) of cabbage at 90 DAT.

Treatments	Percentage Disease Index/Disease Severity Index (%) 90days
Green Coronet	66.65 ^b
Nepa Green 777	61.04 ^b
Big Sun 171	40.33 ^c
Yr Honam	0.00 ^d
Big S un 111	0.00 ^d
Super Green	79.53 ^a
Nepa Star	0.00 ^d
LSD (0.05)	7.754452
$SE_m(\pm)$	0.951189
F – Probability	***
CV, %	12.325
Grand mean	35.36524

[Note: The common letters (s) within the column indicate non-significant differences based on the Duncan Multiple Range Test (DMRT) at 0.05 level of significance. $SE_m (\pm)$ = Standard Error of Mean, *** = significant at 0.001, ** = significant at 0.01, * = significant at 0.05 level, CV = Coefficient of Variation and Ns = non-significant]

Discussion

Plant height was observed at 42.75 cm, almost double the finding of Moniruzzaman (2011), which was 25.63 cm in Green Coronet at harvest. This may be due to the spacing, which was 60 × 45 cm. The number of leaves was observed at 11.3 in Green Coronet during the cabbage harvest

(Moniruzzaman 2011). Nepa Green 777 (1.84 kg), which was comparatively more than the finding of Ghimire & Shrestha (2019). i.e., (1.175 kg). The average head weight was observed 1.674 kg in Green Coronet at harvest (Shrestha 2019). Likewise, the average head weight was observed at 1.10 kg in the Green Coronet variety at harvest (Stoner & Shelton 1998). The average head weight was observed at 1.175 kg in Nepa Green 777 (Ghimire & Shrestha 2019). The lowest marketable yield was recorded in Super Green (73.12 ton/ha), which is statically similar to Green Coronet (75.25 ton/ha). Pun & Pandey (2021) reported that the Green Coronet variety is good for the late season. Shrestha (2019) reported a 78.40 t/ha head yield while Moniruzzaman (2011) observed a 51.30 t/ha head yield in Green Coronet. The disease incidence was recorded highest in Nepa Green 777 (93.17%), whereas it was 75% by Trichoderma application (Ghimire & Shrestha 2019). The percent disease index, or disease severity, of club root disease on cabbage was found to be significantly influenced by the cabbage varieties used as treatments. It was calculated based on a rating scale (0-3) given by Kuginuki et al. (1999). Comparing all the treatments, Super Green showed the highest PDI (79.53%), followed by Green Coronet (66.65%), which was statistically similar to Nepa Green 777 (61.04%). The DSI of Nepa Green 777 was close enough to the finding of (Ghimire & Shrestha 2019) i.e. (64.58 %), whereas the lowest PDI was recorded in Big Sun 171 (40.33%). PDI was observed at 76.30 % in Green Coronet by Khatiwada et al. (2011) at harvest. The author further explained that the result was obtained at 62.22% using the recommended dose of fertilizer (FYM). The PDI was recorded at (64.58%) in Nepa Green 777 (Ghimire & Shrestha 2019).

Conclusion

As a result of evaluating the disease resistance of different cabbage varieties, significant differences were found in growth, yield, and disease parameters, which helped distinguish resistant from susceptible varieties. This study has highlighted resistant varieties and farming practices that could be easily adopted by farmers to enhance clubroot control in the field. It was estimated that Big Sun 111 and Yr Honam produced more than twice the average head weight and marketable yield compared to highly susceptible varieties Green Coronet and Super Green. PDI (Percentage Disease Index) or Disease Severity Index (DSI) was zero in Big Sun 111, Yr Honam, and Nepa Star. I advise farmers to use Big Sun 111 and Yr Honam as they are excellent varieties for yield and disease resistance. Green coronet and Super Green are both highly susceptible varieties.

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Appendix

Different varieties of cabbage showing clubroot infection in root



Fig. 1 – Green Coronet.



Fig. 2 – Big Sun 171.



Fig. 3 – Super Green.



Fig. 4 – Nepa Green.

Different varieties of cabbage without any clubroot infection



Fig. 5 – Nepa Star.



Fig. 6 – Yr Honam.



Fig. 7 – Big Sun 111.