



Original Article

Agronomic performance and biochemical evaluation of gamma-irradiated tomato varieties (*Solanum lycopersicum* L) for resistance to early blight pathogen (*Alternaria solani*)

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ABSTRACT

Leaf blight is one of the major foliar diseases of tomatoes caused by *Alternaria solani*, resulting in yield loss. Thus, there is an urgent need for effective and environmentally friendly alternatives to control the pathogen, given the risks of chemical fungicides. On these premises, gamma-irradiated tomato varieties were assessed for agromorphological performance and resistance to the early blight pathogen. Seeds of two tomato varieties, namely EKA and UC82B, were exposed to gamma rays of 100, 150, 200, and 250 Gy at the Centre for Energy and Research Training in Zaria, Nigeria. The non-irradiated seeds served as control. The treated seeds were shown in experimental pots and arranged in a Randomised Complete Block Design (RCBD) with three replicates. Germinated seedlings were spray-inoculated two weeks after transplanting (WAT) with *Alternaria solani* inoculum. Data were taken on disease incidence and severity, as well as some morphological and yield parameters. The results showed that 100 Gy significantly reduced disease incidence (12.00% at 2 weeks after inoculation) and maintained low severity (2.71 at 8 weeks after inoculation). At the same dose, it produced superior plant height (79.70 cm) and fruit number (12). A dose of 150 Gy resulted in the highest leaf area (28.28 cm²) at 12 WAT. The EKA variety had the highest mean fruit weight (17.86 g) and the number of fruits per plant (11), In contrast, UC82B demonstrated stronger biochemical defense, with higher catalase (81.09 μ/mg), superoxide dismutase (204.30 μ/mg) and peroxidase (2975.83 μ/mg) activities. These findings demonstrate that low to moderate gamma irradiation can induce beneficial variability in tomatoes by simultaneously improving morphological performance, yield potential, and biochemical resistance. The tolerance observed in EKA at 100 Gy underscores its suitability for mutation breeding strategies aimed at developing early blight-resistant cultivars. Advancing EKA at 100 Gy for further mutation breeding programs, coupled with molecular characterization, is recommended to validate the genetic basis of its resistance.

Keywords: *Alternaria solani*, Enzymatic activity, Gamma irradiation, Tomato

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INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is a key vegetable crop valued for its nutritional content, particularly lycopene, vitamins A and C, and antioxidants [1, 2]. Nigeria ranks as Africa's second-largest producer, with 3.6 million tons in 2021 [3], however production is severely threatened by early blight caused by *Alternaria solani*, leading to yield losses of 35 - 78% [4]. Although fungicides are commonly used, they also pose environmental and health risks as well as contribute to resistant pathogen strains [5, 6]. Resistant cultivars offer a sustainable alternative, but current varieties provide only moderate protection [7]. Hence, there is an urgent need for more effective and environmentally friendly alternatives. Mutagenesis is a valuable tool for inducing genetic variations that enhance agronomic traits in crops [8]. It is one of the promising approaches for resistance breeding, particularly using gamma irradiation. Hence, this study is distinct in simultaneously evaluating both agronomic and biochemical responses of gamma-irradiated tomato varieties under early blight stress. By integrating yield performance with antioxidant defense mechanisms, the work provides novel insights into developing disease-resistant tomato cultivars while reducing reliance on chemical control measures.

MATERIALS AND METHODS

Source of Pathogen, Seed and Irradiation

An identified fungal isolate obtained from infected tomato leaves with early blight symptoms was collected from the Department of Plant Biology, Mycology Unit laboratory, and sub-cultured for a pathogenicity test using the method adopted by [9-11].

Two tomato varieties, UC82B hybrid were obtained from Royal Agro Bakers Ltd, Kano, Nigeria and a Local variety (EKA) were purchased from an agrochemical store in Kure Ultra-Modern Market, Minna, Niger State. Tomato seeds were irradiated with gamma doses of 0 Gy (control), 100 Gy, 150 Gy, 200 Gy, and 250 Gy using Caesium-137 at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria.

Experiment Design and Seed Sowing

A factorial experiment consists of two tomato varieties, five irradiation doses and two inoculants of an experimental combination of 20 pots (2 × 5 × 2) was carried out at the Botanical Garden (6° 33' E 9° 37'N) Department of Plant Biology, Federal University of Technology Minna, Niger State. An initial nursery planting was done before the setup for each dose and control. Two seedlings were transplanted for each treatment to an experimental pot filled with 30g of sandy-loamy soil two weeks after emergence (WAE). The plants were watered once a day with equal volume, and all cultural practices were carried out when necessary. The experiment was replicated three times for a total of 60 experimental pots arranged in a Randomised Complete Block Design (RCBD).

Nursery screening of irradiated Tomato for Early Blight Resistance

The transplanted irradiated tomato seedlings (EKA and UC82B varieties) were inoculated with *Alternaria solani* conidial suspension (1×10^4 conidia/mL) at 2 weeks after transplanting. Inoculated plants were incubated and maintained under high humidity. Data were collected on the disease incidence and severity.

Data Collection

Disease incidence, expressed as a percentage, was collected and calculated using the formula below at 14 and 21 days after inoculation (DAI), while severity was scored on a 0 -5 scale adopted by [12-13] at 21, 28, and 35 DAI.

$$\text{PDI} = \frac{\text{number of infected plants}}{\text{total number of plants}} \times 100$$

The agro morphological parameters, including plant height, number of leaves, fruit weight, and number of fruits per plant, were recorded using the methods described by [14-15].

Biochemical Characterisation of Irradiated Tomato Infected with *Alternaria solani* Superoxide Dismutase (SOD) Activity

SOD enzymatic activity was assayed as described by [16]. The reaction mixture contained 2 μM riboflavin, 50 μM potassium phosphate buffer (pH 7.8), 100 μM EDTA, 13 μM DL-methionine, 75 μM nitrobuterazolium (NBT), and 50 μL enzyme extract, producing a total reaction mixture of 1 mL. The reaction mixture was incubated for 15 minutes at 25°C under fluorescent light (400 $\mu\text{mol}/\text{m}^2\text{s}^{-1}$). Absorbance was measured using UV-VIS spectroscopy at a wavelength of 560 nm. One unit of SOD activity was defined as the amount of enzyme required to inhibit the reduction of NBT to formazan by 50% at 25°C under the specified conditions, expressed as $\mu\text{mol mg}^{-1}\text{min}^{-1}$.

Peroxidase (POD) Activity

Tomato leaves were homogenized in a solution containing 50 mM potassium phosphate buffer (pH 7.0), 0.1 mM EDTA, and 1 mM DTT to determine POD activity. The activity of POD was assessed using the method of [17] with some modification. For measurement of POD

activity, the assay solution contained distilled water (545 μL), 200 mM phosphate buffer (pH 7.0), 200 mM guaiacol, 400mM H_2O_2 , and 15 μL enzyme extract. The reaction was initiated after adding the enzyme extract. Every 20 seconds to a minute, the absorbance of the reaction solution at 470 nm (UV-VIS spectrophotometer U-2800) increased. One unit of POD activity was defined as an absorbance change of 0.01 min^{-1} . Enzyme activity was expressed on the leaf weight basis.

Catalase (CAT) Activity

CAT was estimated by homogenizing tomato leaves in a solution containing 50 mM potassium phosphate buffer (pH 7.0) and 1 mM dithiothreitol (DTT) by following the method [17]. For measurement of CAT activity, the assay solution contained 50 mM phosphate buffer (pH 7.0), 59 mM H_2O_2 , and 100 μL enzyme extract. The decrease in absorbance of the reaction solution was recorded at 240 nm after every 20 s to a minute by UV-VIS spectrophotometer (U-2800). An absorbance change of 0.01 min^{-1} was defined as 1 U of CAT activity. Enzyme activity was expressed on leaf weight basis.

Data analysis

The data collected were subjected to a two way analysis of variance (ANOVA) using SPSS version 20 and Duncan's Multiple Range Test (DMRT) was used to separate the means where there were significant differences. All data analysis was carried out using the Statistical Package for the Social Sciences (SPSS) version 20 at 5% level of significance.

RESULTS

Disease Incidence and Severity: All tomato plants inoculated with fungi exhibited foliar symptoms, including dark lesions and yellowing leaves, at varying degrees. Disease incidence

varied among gamma-irradiated plants, with 100 Gy showing the lowest incidence (12% at 2 WAI and 21.72% at 3 WAI) and 250 Gy having the highest incidence at 3 WAI (63.42%) (Table 1). The variety EKA had a lower incidence (18.42% and 35.86% at 2 and 3 weeks after inoculation, respectively) compared to UC82B (32.51% and 65.7%

at 2 and 3 weeks after inoculation, respectively). Disease severity increased over time, with the highest severity at 8WAI, particularly in 250Gy (4.89), while 100Gy had the lowest severity (2.32-2.71) (Table 1). Inoculated plants had a significantly higher incidence and severity of disease than non-inoculated plants.

Table 1: Incidence and Severity of *Alternaria solani* Inoculated in Gamma irradiated Tomato Varieties

Treatments	Incidence (%)		Severity			
	2 WAI	3WAI	3 WAI	6 WAI	7 WAI	8 WAI
Factor						
Doses						
Control	29.31 ^b	58.60 ^{bc}	2.63 ^{ab}	3.06 ^{ab}	3.42 ^b	3.73 ^b
100	12.00 ^a	21.72 ^a	2.32 ^a	2.40 ^a	2.56 ^a	2.71 ^a
150	19.36 ^{ab}	51.76 ^b	3.21 ^b	3.72 ^b	4.17 ^c	4.69 ^c
200	21.08 ^{ab}	37.40 ^b	2.42 ^a	2.68 ^a	2.94 ^{ab}	3.00 ^a
250	26.08 ^b	63.42 ^c	3.52 ^b	4.22 ^c	4.40 ^c	4.89 ^c
±SEM	3.4	3.9	0.22	0.26	0.16	0.18
Varieties						
EKA	18.42 ^a	35.86 ^a	2.62 ^a	3.21 ^a	4.39 ^a	4.62 ^a
UC82B	32.51 ^b	65.7 ^{ab}	3.58 ^b	3.96 ^b	4.84 ^a	4.86 ^a
±SEM	3.8	4.3	0.2	0.2	0.1	0.1
Inoculation rate						
Inoculated	28.32 ^b	64.22 ^b	2.93 ^b	3.48 ^b	3.8 ^b	4.1 ^b
Non- Inoculated	0.00 ^a	0.00 ^b	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
±SEM	3.8	4.3	0.2	0.2	0.1	0.1
Doses * Varieties * Inoculation						
000*EKA*Inoculated	33.30 ^e	60.00 ^{de}	2.67 ^c	3.00 ^c	3.25 ^d	4.00 ^f
000*EKA*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
000*UC82B*Inoculated	41.70 ^f	66.74 ^e	3.73 ^e	4.00 ^d	5.00 ^g	5.00 ^h
000*UC82B*Non-Inoculated	0.00 ^a	2.400 ^a	1.00 ^a	1.25 ^a	1.00 ^a	1.00 ^a
100*EKA*Inoculated	11.70 ^b	26.72 ^b	1.82 ^{ab}	1.25 ^a	2.15 ^b	2.71 ^c
100*EKA*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
100*UC82B*Inoculated	30.0 ^b	40.00 ^c	2.32 ^b	3.30 ^{cd}	4.00 ^f	4.70 ^g
100*UC82B*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
150*EKA*Inoculated	13.50 ^b	31.33 ^b	2.00 ^b	3.00 ^c	3.00 ^c	3.30 ^d
150*EKA*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
150*UC82B*Inoculated	30.00 ^d	58.30 ^d	3.30 ^d	3.70 ^d	4.70 ^g	5.00 ^h
150*UC82B*Non-inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
200*EKA*Inoculated	12.45 ^b	45.40 ^c	1.25 ^a	2.00 ^b	3.70 ^e	3.70 ^e
200*EKA*Non-Inoculated	0.00 ^a	5.40 ^a	1.00 ^a	2.00 ^b	2.00 ^b	2.00 ^b
200*UC82B*Inoculated	20.0 ^c	46.71 ^c	2.70 ^c	3.30 ^c	3.70 ^a	3.70 ^e
200*UC82B*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
250*EKA*Inoculated	26.71 ^d	58.30 ^d	2.70 ^c	3.70 ^d	5.00 ^g	5.00 ^h
250*EKA*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
250*UC82B*Inoculated	20.00 ^b	58.3 ^a	3.70 ^e	4.70 ^e	4.70 ^g	5.00 ^h
250*UC82B*Non-Inoculated	0.00 ^a	0.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a	1.00 ^a
±SEM	6.52	8.70	0.32	0.42	0.30	0.26

Means with the same letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using DMRTs. WAI: Weeks after inoculation SEM = Standard Error of Means

Interactive effects of gamma irradiation doses on the plant height of infected tomato varieties

The interactive effects of gamma irradiation, varieties, and inoculation on plant height showed that the local tomato variety EKA consistently exhibited higher mean plant heights compared to the UC82B hybrid variety across different weeks (Table 2). Although not significantly different ($p > 0.05$), there was an increase in plant height of the irradiated plants compared to the control plants, with an increase in irradiation doses with 150 Gy being

optimum and subsequent decrease at 3 WAE. EKA variety had a mean height of 15.51 cm compared to UC82B's 12.01 cm at 3 WAE. At 6 WAE, EKA mean height was 60.06 cm compared to UC82B's 45.60 cm (Table 2). Similarly, at 9 and 12 WAE, EKA maintained higher mean heights of 75.79 cm and 87.65 cm, respectively, compared to UC82B 57.23 cm and 64.95 cm. Irradiation dose 100Gy resulted in the highest height at 9 and 12 WAE (67.87 cm and 79.70 cm, respectively), which was a significant difference at 12 WAE ($p < 0.05$) (Table 2).

Table 2: Interactive Effects of Gamma Irradiation on Plant Height of Early Blight Infected Tomato Varieties

Treatments	Plant Height(cm)			
	3WAE	6WAE	9WAE	12WAE
Factors				
Doses				
0.00	13.92 ^a	56.47 ^b	66.93 ^a	74.25 ^{ab}
100.00	13.95 ^a	53.33 ^{ab}	67.87 ^a	79.70 ^b
150.00	14.46 ^a	53.63 ^{ab}	64.48 ^a	75.21 ^{ab}
200.00	14.07 ^a	48.35 ^a	65.65 ^a	72.96 ^a
250.00	12.39 ^a	52.36 ^{ab}	67.61 ^a	79.39 ^b
±SEM	0.69	2.17	1.74	1.84
Varieties				
EKA	15.51 ^b	60.06 ^b	75.79 ^b	87.65 ^b
UC82B	12.01 ^a	45.60 ^a	57.23 ^a	64.95 ^a
±SEM	0.43	1.37	1.10	1.16
Inoculation rate				
Inoculated	13.96 ^a	52.59 ^a	68.55 ^a	78.09 ^a
Non-inoculated	13.55 ^a	53.06 ^a	64.47 ^a	74.51 ^a
±SEM	0.43	1.37	1.10	1.16
Doses * Varieties * Inoculation				
0.00*EKA*Inoculated	11.98 ^c	52.25 ^{cd}	70.45 ^f	80.72 ^{fg}
0.00*EKA*Non-Inoculated	17.05 ^f	63.52 ^{de}	75.93 ^g	83.53 ^g
0.00*UC82B*Inoculated	11.83 ^{bc}	53.57 ^d	62.40 ^d	69.20 ^d
0.00*UC82B*Non-Inoculated	13.85 ^{de}	48.12 ^c	53.83 ^b	63.55 ^{bc}
100*EKA*Inoculated	17.70 ^{fg}	60.67 ^{de}	75.52 ^g	90.98 ^h
100*EKA*Non-Inoculated	11.95 ^c	62.63 ^{de}	76.72 ^g	87.97 ^h
100*UC82B*Inoculated	14.18 ^{de}	49.88 ^{cd}	66.27 ^e	75.47 ^e
100*UC82B*Non-Inoculated	12.95 ^{cd}	48.53 ^c	57.40 ^c	64.37 ^{bc}
150*EKA*Inoculated	14.20 ^e	66.82 ^f	70.07 ^f	91.08 ^h
150*EKA*Non-Inoculated	18.68 ^g	53.05 ^{cd}	72.73 ^{fg}	86.67 ^{gh}
150*UC82B*Inoculated	12.00 ^c	46.52 ^{bc}	52.38 ^{ab}	61.95 ^{bc}
150*UC82B*Non-Inoculated	12.95 ^{cd}	48.12 ^c	50.25 ^a	61.13 ^b
200*EKA*Inoculated	17.77 ^{fg}	55.95 ^d	82.57 ^h	91.12 ^h
200*EKA*Non-Inoculated	16.27 ^f	66.37 ^{ef}	83.18 ^h	99.00 ⁱ
200*UC82B*Inoculated	14.10 ^e	32.43 ^a	64.85 ^{de}	69.03 ^d
200*UC82B*Non-Inoculated	8.13 ^a	38.67 ^b	52.08 ^{ab}	57.37 ^a
250*EKA*Inoculated	13.43 ^d	65.18 ^{d^{ef}}	75.25 ^g	86.23 ^{gh}
250*EKA*Non-Inoculated	15.12 ^e	56.48 ^d	75.45 ^g	79.20 ^f
250*UC82B*Inoculated	11.47 ^{abc}	42.67 ^b	57.80 ^c	65.10 ^c
250*UC82B*Non-Inoculated	9.55 ^{ab}	45.12 ^b	55.03 ^{bc}	62.33 ^b
±SEM	1.37	4.34	3.48	3.68

Means with the same superscript letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using Duncan Multiple Range Tests SEM = Standard Error of Means WAE = Weeks after emergence.

Interactive effects of gamma irradiation doses on the number of leaves of infected tomato varieties

At 3 weeks after emergence (WAE), the maximum mean number of leaves per plant (24) was recorded at the control (0Gy), while the lowest was recorded at 250Gy (16 per plant). These values showed a significant difference ($p < 0.05$) from one another and the value of all other irradiated plants (Table 3). However, there were no significant differences ($p > 0.05$) in the mean number of leaves per plant among plants irradiated the 200Gy, 150Gy and 100Gy doses with the value of 20, 19 and 19, respectively. Conversely, at 6 and 9 WAE, gamma irradiation had no significant effect ($p > 0.05$) on the number of leaves

per plant recorded among plants irradiated with different doses (Table 3). The number of leaves per plant showed that the local tomato variety EKA had a significantly higher mean number of leaves per plant (22, 64, 85, and 105) compared to the UC82B hybrid variety (18, 55, 78, and 96) at 3, 6, 9, and 12 WAE, respectively ($p < 0.05$). Inoculated fungi had no significant effect on the plants at 3 and 6 WAE ($p > 0.05$), with significantly higher mean numbers of leaves per plant at 9 and 12 WAE recorded in non-inoculated plants (85 and 105, respectively) compared to inoculated plants ($p < 0.05$) (Table 3).

Table 3: Effects of Gamma Irradiation on Number of Leaves per Plant in Early Blight Infected Tomato Varieties

Factors	Number of Leaves Per Plant			
	3WAE	6WAE	9WAE	12WAE
Doses				
0.00	24 ^b	59 ^a	78 ^a	92 ^a
100.00	19 ^{ab}	57 ^a	80 ^a	99 ^a
150.00	19 ^{ab}	63 ^a	83 ^a	98 ^a
200.00	20 ^{ab}	56 ^a	79 ^a	99 ^a
250.00	16 ^a	61 ^a	86 ^a	114 ^b
±SEM	2	3	4	4
Varieties				
EKA	22 ^b	64 ^b	85 ^b	105 ^b
UC82B	18 ^a	55 ^a	78 ^a	96 ^a
±SEM	1	2	3	2
Inoculation rate				
Inoculated	19 ^a	59 ^a	77 ^a	96 ^a
Non-Inoculated	20 ^a	59 ^a	85 ^b	105 ^b
±SEM	1	2	3	2
Doses * Varieties * Inoculation				
0.00*EKA*Inoculated	19 ^{bc}	64 ^c	79 ^b	91 ^b
0.00*EKA*Non-Inoculated	24 ^{cd}	61 ^c	71 ^a	99 ^c
0.00*UC82B*Inoculated	18 ^b	50 ^b	71 ^a	82 ^a
0.00*UC82B*Non-Inoculated	28 ^d	43 ^a	72 ^{ab}	91 ^b
100*EKA*Inoculated	21 ^c	65 ^c	90 ^{cd}	108 ^d
100*EKA*Non-Inoculated	27 ^d	78 ^d	97 ^d	104 ^{cd}
100*UC82B*Inoculated	19 ^{bc}	56 ^{bc}	81 ^{bc}	86 ^a
100*UC82B*Non-Inoculated	19 ^{bc}	47 ^{ab}	85 ^{bc}	102 ^{cd}
150*EKA*Inoculated	22 ^c	62 ^c	78 ^{ab}	91 ^b
150*EKA*Non-Inoculated	21 ^c	72 ^d	85 ^{bc}	94 ^{bc}

150*UC82B*Inoculated	17 ^b	55 ^{bc}	71 ^a	92 ^{bc}
150*UC82B*Non-Inoculated	19 ^{bc}	66 ^{cd}	83 ^{bc}	117 ^e
200*EKA*Inoculated	20 ^b	64 ^c	88 ^c	103 ^{cd}
200*EKA*Non-Inoculated	31 ^e	54 ^b	80 ^b	103 ^{cd}
200*UC82B*Inoculated	15 ^{ab}	54 ^b	70 ^a	93 ^{bc}
200*UC82B*Non-Inoculated	14 ^{ab}	54 ^b	80 ^b	98 ^{bc}
250*EKA*Inoculated	18 ^b	63 ^c	91 ^{cd}	115 ^{de}
250*EKA*Non-Inoculated	17 ^b	54 ^b	95 ^{cd}	140 ^f
250*UC82B*Inoculated	17 ^b	62 ^c	73 ^{ab}	96 ^{bc}
250*UC82B*Non-Inoculated	12 ^a	63 ^c	86 ^c	107 ^{cd}
±SEM	3	6	8	8

Means with the same superscript letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using Duncan Multiple Range Tests. SEM = Standard Error of Means; WAE = Weeks after emergence.

Interactive effects of gamma irradiation doses on the leaf area of infected tomato varieties

The interactive effects of gamma irradiation doses, varieties, and inoculation on leaf area showed no significant differences at 6 and 9 WAE ($p > 0.05$). However, at 12 WAE, the 150Gy irradiated plant had a significant ($p < 0.05$) highest leaf area of 28.28 cm²

while the control had the least of 21.57 cm² (Table 4). Varieties EKA and UC82B showed no significant differences ($p < 0.05$) in leaf area, although EKA had higher mean values. Similarly, inoculated fungi had no significant effect on the leaf area of the irradiated plant at 6 and 9 WAE ($p > 0.05$). Still, the non-inoculated plants had significantly higher leaf area (26.35 cm²) at 12 WAE compared to infected plants (23.45 cm²) (Table 4).

Table 4: Interactive Effects of Gamma Irradiation on Leaf Area of Early Blight Infected Tomato Varieties

Factors	Leaf Area(cm ²)		
	6WAE	9WAE	12WAE
Doses			
.00	9.26 ^a	14.63 ^a	21.57 ^a
100.00	10.86 ^a	16.53 ^a	24.53 ^{ab}
150.00	10.43 ^a	16.62 ^a	28.28 ^b
200.00	11.03 ^a	16.33 ^a	25.59 ^{ab}
250.00	10.81 ^a	14.99 ^a	24.53 ^{ab}
±SEM	0.78	0.97	1.52
Varieties			
EKA	10.62 ^a	16.13 ^a	25.66 ^a
UC82B	10.33 ^a	15.52 ^a	24.14 ^a
±SEM	0.49	0.61	0.96
Inoculation rate			
Inoculated	10.54 ^a	15.76 ^a	23.45 ^a
Non-inoculated	10.41 ^a	15.88 ^a	26.35 ^b
±SEM	0.49	0.61	0.96
Doses * Varieties * Inoculation			
0.00*EKA*Inoculated	9.53 ^{bc}	12.68 ^{ab}	20.68 ^{ab}
0.00*EKA*Non-Inoculated	8.81 ^{ab}	17.88 ^{cd}	21.14 ^{ab}
0.00*UC82B*Inoculated	11.14 ^c	18.28 ^d	21.57 ^{ab}

0.00*UC82B*Non-Inoculated	7.54 ^a	11.14 ^a	22.88 ^{ab}
100*EKA*Inoculated	11.81 ^c	17.60 ^{cd}	24.44 ^b
100*EKA*Non-Inoculated	10.87 ^{bc}	16.02 ^c	29.64 ^c
100*UC82B*Inoculated	11.40 ^{cd}	17.92 ^{cd}	29.87 ^{cd}
100*UC82B*Non-Inoculated	9.37 ^b	17.48 ^{cd}	26.28 ^{bc}
150*EKA*Inoculated	8.14 ^{ab}	12.59 ^{ab}	20.50 ^a
150*EKA*Non-Inoculated	11.33 ^c	21.08 ^e	22.55 ^{ab}
150*UC82B*Inoculated	8.34 ^a	11.49 ^{ab}	25.37 ^b
150*UC82B*Non-Inoculated	13.91 ^d	21.33 ^e	23.63 ^b
200*EKA*Inoculated	12.18 ^{cd}	19.21 ^{de}	23.79 ^b
200*EKA*Non-Inoculated	12.94 ^d	16.57 ^{cd}	37.59 ^e
200*UC82B*Inoculated	10.87 ^{bc}	14.60 ^{bc}	24.47 ^b
200*UC82B*Non-Inoculated	11.55 ^{cd}	15.29 ^{bc}	25.46 ^b
250*EKA*Inoculated	9.51 ^b	13.36 ^b	23.29 ^{ab}
250*EKA*Non-Inoculated	11.08 ^c	14.30 ^{bc}	32.92 ^d
250*UC82B*Inoculated	9.04 ^{ab}	13.83 ^b	20.52 ^a
250*UC82B*Non-Inoculated	10.18 ^{bc}	13.81 ^b	21.41 ^{ab}
±SEM	1.56	1.94	3.04

Means with the same superscript letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using Duncan Multiple Range Tests. SEM = Standard Error of Means WAE = Weeks after emergence.

Interactive Effects of Yield Evaluation

The effects of gamma irradiation doses, varieties, and inoculation on yield parameters showed significant ($p < 0.05$) variations in fruit length, diameter, weight, and number of fruits. Irradiation dose 200 Gy resulted in the highest fruit length (19.20 cm), diameter (4.73 cm), and weight (14.12 g), while 100 Gy had

the highest number of fruits per plant (12) (Table 5). The UC82B variety had higher fruit length (29.34 cm) and diameter (4.67 cm) while the EKA variety had higher fruit weight (17.86 g) and number of fruits per plant (11). Non-inoculated plants had significantly higher yield parameters compared to inoculated plants (Table 5).

Table 5: Yield Parameters of Gamma Irradiated Tomato Varieties Infected with Early Blight Pathogen

Factor	Yield Parameters			
	FL(cm)	FB(cm)	FW(g)	NF
Doses				
0	14.39 ^a	4.10 ^a	8.43 ^a	8 ^{abc}
100	16.84 ^{ab}	4.08 ^a	12.02 ^{cd}	12 ^c
150	17.33 ^{ab}	4.05 ^a	11.18 ^{bc}	7 ^a
200	19.20 ^b	4.73 ^b	14.12 ^d	11 ^{bc}
250	17.56 ^{ab}	4.13 ^a	9.36 ^{ab}	8 ^{ab}
±SEM	1.12	0.14	0.76	1
Varieties				
EKA	4.79 ^a	3.76 ^a	17.86 ^b	11 ^b
UC82B	29.34 ^b	4.67 ^b	4.19 ^a	7 ^a
±SEM	0.71	0.09	0.48	1
Inoculation rate				
Inoculated	14.60 ^a	3.96 ^a	9.26 ^a	7 ^a
Non-Inoculated	19.53 ^b	4.47 ^a	12.79 ^b	11 ^b
±SEM	0.71	0.09	0.48	1
Doses * Varieties * Inoculation				
0.00*EKA*Inoculated	2.50 ^a	2.70 ^a	10.33 ^b	5 ^a
0.00*EKA*Non-Inoculated	4.40 ^{ab}	3.70 ^{bc}	14.89 ^d	15 ^d

0.00*UC82B*Inoculated	19.40 ^d	4.90 ^f	4.20 ^a	6 ^{ab}
0.00*UC82B*Non-Inoculated	31.27 ^f	5.10 ^g	4.30 ^a	9 ^b
100*EKA*Inoculated	5.60 ^b	4.80 ^{ef}	24.95 ^h	16 ^{de}
100*EKA*Non-Inoculated	6.00 ^b	4.70 ^{ef}	27.94 ⁱ	18 ^e
100*UC82B*Inoculated	36.71 ^g	4.70 ^{ef}	4.20 ^a	8 ^b
100*UC82B*Non-Inoculated	40.97 ^h	4.70 ^{ef}	4.40 ^a	5 ^a
150*EKA*Inoculated	4.60 ^{ab}	2.80 ^a	10.68 ^b	10 ^{bc}
150*EKA*Non-Inoculated	6.70 ^b	4.30 ^d	19.95 ^f	10 ^{bc}
150*UC82B*Inoculated	26.62 ^e	4.60 ^e	4.50 ^a	15 ^d
150*UC82B*Non-Inoculated	31.40 ^f	4.50 ^{de}	4.60 ^a	5 ^a
200*EKA*Inoculated	4.50 ^{ab}	3.50 ^b	18.00 ^e	5 ^a
200*EKA*Non-Inoculated	5.80 ^b	4.30 ^d	22.66 ^g	15 ^d
200*UC82B*Inoculated	16.07 ^c	3.80 ^c	3.60 ^a	12 ^c
200*UC82B*Non-Inoculated	28.50 ^e	4.70 ^{ef}	3.80 ^a	5 ^a
250*EKA*Inoculated	2.70 ^a	2.90 ^a	13.11 ^c	5 ^a
250*EKA*Non-Inoculated	5.10 ^b	3.90 ^c	16.04 ^d	15 ^d
250*UC82B*Inoculated	35.52 ^f	4.90 ^f	4.00 ^a	6 ^a
250*UC82B*Non-Inoculated	26.94 ^e	4.80 ^e	4.30 ^a	5 ^a
±SEM	2.24	0.28	1.53	2

Means with the same superscript letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using Duncan Multiple Range Tests FL=Fruit Length, FB=Fruit Breadth, FW=Fruit Weight, NF=Number of fruits per plant

Biochemical Enzymatic Activities

The interaction between treatment factors significantly affected enzymatic activities (Catalase, SOD, and POD) in irradiated tomato plants. Significantly ($p < 0.05$), the highest catalase activity was recorded in the control (75.63µ/mg) and the lowest at 200 Gy (58.17µ/mg) (Table 6). Similarly, SOD activity was highest in control (191.45 u/mg) and lowest at 100 Gy (156.16µ/mg). The control plant had the significantly ($p < 0.05$) highest POD value (2975.74 µ/mg) and the lowest at 200 Gy (2013.00 µ/mg). Among the irradiated plants, a significant ($p < 0.05$) decrease in POD activity with respect to

dosage increase was observed, ranging from 2268.60 /mg (100Gy plant) to 2013.00 u/mg at the 200Gy plant (Table 6). However, there is no significant difference between the POD values of 2267.68 recorded at 250 Gy and that of 100 Gy (2268.60). Variety UC82B exhibited higher enzymatic activities, with catalase (81.09 µ/mg), SOD (204.30 µ/mg), and POD (2975.83 µ/mg). Inoculated plants had significantly lower enzymatic activities, with Catalase (57.71 µ/mg), SOD (146.39 µ/mg), and POD (2174.78 µ/mg), compared to non-infection rates (70.94, 185.25, and 2463.18) µ/mg (Table 6).

Table 6: Biochemical Responses of Gamma Irradiated Tomato Varieties Infected with Early Blight Pathogen (*Alternaria solani*)

Factors	Antioxidants (µ/mg)		
	Catalase	SOD	POD
Doses			
0.00	75.63 ^d	191.45 ^d	2975.74 ^d
100.00	62.63 ^b	156.16 ^a	2268.60 ^c
150.00	58.67 ^a	164.27 ^c	2069.89 ^b
200.00	58.17 ^a	159.31 ^b	2013.00 ^a
250.00	66.53 ^c	157.94 ^b	2267.68 ^c
±SEM	0.44	0.59	0.97
Varieties			
EKA	47.56 ^a	127.34 ^a	1662.13 ^a
UC82B	81.09 ^b	204.30 ^a	2975.83 ^b

±SEM	0.28	0.37	0.61
Inoculation rate			
Inoculated	57.71 ^a	146.39 ^a	2174.78 ^a
Non-inoculated	70.94 ^b	185.25 ^b	2463.18 ^b
±SEM	0.28	0.37	0.61
Doses * Varieties * Inoculation			
000*EKA*Inoculated	76.97 ⁱ	158.04 ^g	2696.19 ^j
000*EKA*Non-Inoculated	64.66 ^g	203.50 ^m	2767.60 ^k
000*UC82B*Inoculated	82.74 ^k	207.10 ⁿ	3562.63 ^q
000*UC82B*Non-Inoculated	78.17 ^j	197.17 ^l	2876.56 ^l
100*EKA*Inoculated	26.69 ^c	69.84 ^b	1762.55 ^e
100*EKA*Non-Inoculated	77.13 ^g	182.49 ^j	2544.86 ^h
100*UC82B*Inoculated	77.24 ⁱ	191.02 ^k	1893.31 ^g
100*UC82B*Non-Inoculated	69.45 ^h	181.29 ^j	2873.66 ^l
150*EKA*Inoculated	22.15 ^b	76.98 ^c	391.64 ^a
150*EKA*Non-Inoculated	41.60 ^e	115.36 ^e	1322.21 ^d
150*UC82B*Inoculated	80.90 ⁱ	219.13 ^o	3580.76 ^f
150*UC82B*Non-Inoculated	90.02 ^l	245.59 ^r	2984.93 ⁿ
200*EKA*Inoculated	6.49 ^a	45.43 ^a	467.13 ^b
200*EKA*Non-Inoculated	62.89 ^{fg}	170.18 ^j	1791.84 ^f
200*UC82B*Inoculated	77.53 ^j	190.17 ^k	2575.06 ⁱ
200*UC82B*Non-Inoculated	85.78 ^d	231.45 ^p	3217.98 ^o
250*EKA*Inoculated	61.85 ^f	159.08 ^h	1893.26 ^g
250*EKA*Non-Inoculated	35.21 ^d	92.53 ^d	984.06 ^c
250*UC82B*Inoculated	76.85 ⁱ	147.14 ^f	2925.28 ^m
250*UC82B*Non-Inoculated	92.21 ^m	233.00 ^q	3268.14 ^p
Standard Error Mean	0.88	0.88	1.94

Means with the same superscript letter(s) within a set of treatment column are not significantly different at $p \leq 0.05$ using Duncan Multiple Range Tests

SOD= superoxide dismutase POD= Peroxidase

DISCUSSION

Observation of fungal symptoms, such as dark brown necrotic lesions and defoliation, as described earlier by [18-19] indicates the susceptibility of the plants to early blight caused by *Alternaria solani*. This suggests that the presence of typical disease symptoms in all fungi-inoculated plants implies that none of them were immune to the pathogen. Similar to the findings of this research, [20] reported that climatic factors, such as hot conditions and fluctuating humidity, are likely contributing factors to disease development. The emergence of systemic symptoms in inoculated plants, progressing over time, aligns with [21] findings, which observed the growth of leaves exhibiting severe symptoms of inoculated disease in a shorter period.

The non-significant differences in treated plant height at the early stage may be attributed to a latent effect of the irradiation on plant development. The variation in plant height observed among the different irradiation doses treated plants compared to controls could be attributed to the interaction of fungi and irradiation stress effects on plant growth hormones and physiology. [22] found that high doses (400 Gy) inhibit leaf growth due to oxidative stress, while lower doses promote growth. The tallest plant height was recorded at 100 Gy by the end of the research, especially in the EKA variety, indicating better tolerance of the variety to radiation compared to UC82B. The variation in responses of the variety to different irradiation doses aligns with [23] who reported that growth inhibition at doses above 200 Gy

could be due to oxidative stress. EKA outperformed UC82B, suggesting induction of beneficial mutant traits. The variation in height among the varieties could be attributed to the differences in their genetic makeup. This conforms to the report of [24], which indicated that both genetic and environmental factors influence height.

Leaf number and area are important morphological attributes that influence yield and yield attributes due to their direct relationship with photosynthesis [25]. [26] reported that a decrease in the leaf area of infected plants would result in a reduction of the available leaf surface area for trapping light energy, with a consequent decrease in photosynthesis and yield of the plant. This assertion is similar to the results of this study, with the reduction in the number of leaves and leaf area of the infected treated plant. The increase in leaf count at 200 Gy at early (3–6 WAE) and later stages (9–12 WAE) could be the reflection of enhanced cell division and expansion caused by the irradiation dose. [27] reported similar stimulation of leaf growth at 200–300 Gy in various horticultural plants.

The significantly improved fruit number and weight in tomato varieties at 100 Gy indicate the effectiveness of lower irradiation in inducing functional genetic variation in the plants. These findings are consistent with previous studies on various crops, including *Digitaria exilis* [28] and Groundnut [29]. Similar yield improvements were reported in fonio [30] and maize [31]. The yield decline at higher doses (200–250 Gy) may be attributed to the deleterious effects of these doses however, 200 Gy maintained some parameters in UC82B. Also, in conformity with the result of this study, [32] reported variation in response of varieties to induced mutagenesis,

emphasising genotype selection and dose optimisation [33].

A dose-dependent reduction in catalase, superoxide dismutase, and peroxidase activities across the treatment with increasing irradiation doses confirmed that irradiation-induced oxidative stress in the plant, which impaired the antioxidant defense system. This observation is in agreement with previous studies that high irradiation doses disturbed plant physiology, biochemistry, and enzyme activity due to free radical generation and damage to macromolecules [34]. The decrease in SOD in the infected tomato plants suggests superoxide radical detoxification under irradiation-induced stress. This could be due to the complex interaction of the plant pathogen with reactive oxygen species generated by the irradiation. Contrary to the report by [35], which indicates that the concentration of peroxidase (POD) and superoxide dismutase (SOD) increases when exposed to gamma radiation. The differences in these results may be attributed to the absence of a pathogen in their study, which prevented reactive oxygen species from acting on the plant cells, leading to damage. The modest increase at 150 Gy indicates a possible stress adaptation mechanism, as previously suggested by [36-37], where SOD serves as a vital enzyme for redox balance during pathogen attacks and stress conditions. The exhibition of significantly higher CAT, SOD, and POD activities in UC82B could be due to variation in their genetic constitution and defense mechanism strength compared to EKA.

CONCLUSION

Gamma irradiation showed significant interactive effects with varieties and infection on growth, yield, and enzymatic responses in tomato. The EKA variety

consistently outperformed UC82B in plant height, leaf number, and yield traits. Moderate doses (100–200 Gy) enhanced the growth and productivity of the plant, indicating the effectiveness of the dosage in improving the plant. Reduction in the enzymatic antioxidant activity of the infected plants intensified further oxidative stress imposed on the plant.

Authors Contribution

OII, AA conceptualized the study. OII, AA, and AH, designed the study. OII, AA, AH and YZM. Participated in fieldwork and data collection. OII, AA, BIM DOAY performed the data analysis; OII, AA, AH, BIM, DOAY, interpreted the data. OII prepared the first draft of the manuscript, reviewed by AA, AH, BIM DOAY. All authors contributed to the development of the final manuscript and approved its submission.

Disclosure of Conflict of Interest

None

Ethics Approval and Informed Consent

This study did not use human or animal subjects. Therefore, ethical consideration was not applicable.

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