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Effects of Temperature and Moisture on Growth of Common Bean and Its Resistance Reaction against Common Bacterial Blight (*Xanthomonas axonopodis* pv. *phaseoli* strains)

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Abstract

Common bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *phaseoli* Smith (*Xap*) and *Xanthomonas axonopodis* pv. phaseoli var. *fuscan* Burkholder (*Xapf*) is the most serious biotic constraint of common bean (*Phaseolus vulgaris* L.) production. Variables temperature and moisture are dominant climate factors that affect common bean growth as well as the development of CBB epidemics. Two sets of experiments were conducted in the Plant Pathology Laboratory of Haramaya University) to assess the effect of temperature and moisture on the resistance level of common bean in 2014 and 2015. In the first experiment, two common bean varieties (Gofta and Mexican 142) were inoculated with two bacterial strains (*Xap* and *Xapf*) and a control were incubated at four temperature levels (28°C, 30°C, 32°C and 34°C) in growth chambers. In the second experiment, three-soil moisture levels (100%, 75% and 50%) were employed to that of experiment one. The treatment combinations were arranged in factorial completely randomized design (CRD) in the growth chambers for both series of experiments. The disease rating was significantly ($P<0.05$) affected by common bean varieties and temperature levels at 17 days after inoculation (DAI). Higher disease rating was recorded on the variety Mexican 142 than on Gofta. The highest (1.75) mean disease rating was recorded at 28°C and the lowest (1.44) at 34°C. The mean disease ratings differed significantly among the moisture levels. The highest (2.01) mean disease rating was recorded from 75% moisture content, while the lowest (1.80) disease rating was obtained from 50% moisture content. The results of these series of experiments indicated that climate change effects above optimum level would not be favorable for CBB development in the arid and semi-arid agro ecologies unless new bacterial strains adapted to the drought tolerant common beans in the area.

Keywords: Common blight; Disease rating; Moisture; *Phaseolus vulgaris*

Introduction

Common bean (*Phaseolus vulgaris* L.*)* is the most widely produced and consumed legume worldwide [1] and occupies an important place in human nutrition. It belongs to the genus *Phaseolus,* with pinnately compound trifoliate large leaves [2]. The dietary fibre part of the carbohydrate reduces cholesterol and prevents colon cancer [3], while 18% to 30% dry weight of common beans is protein [4]. It also contains vitamin B and minerals (namely calcium, copper, magnesium, and zinc) and sometimes referred to as a near perfect food [4-6].

Common bean production is limited due to different biotic and abiotic factors. Among the abiotic constraints are inadequate total rainfall, erratic rainfall distribution, periodic water stress, extended dry spells during the crop critical growth as a result of climate change [2,7,8]. Low soil fertility, shortage or excess of mineral salts and extreme lower pH of soil are also the abiotic factors that limit common bean production [9-11]. The major disease of common bean in east Africa, especially in Ethiopia, that is targeted for the management is common bacterial blight (CBB), caused by *Xanthomonas axonopodis* pv. *phaseoloi* (Smith) and *Xanthomonas axonopodis* pv. *phaseoloi* var. *fuscans* (Burkholder) [12-16].

Depending on susceptibility of common bean varieties and environmental conditions, CBB may cause yield losses ranging between 10% and 40%, [17-20]. Because common bacterial blight is a warm weather and higher humidity disease, it can cause the greatest damage at warm temperature of 28°C to 32°C [21-23]. The bacteria survive at the temperature ranges of 25°C to 35°C in the field on infected seed and plant debris [24-27].

The global surface temperature is projected to increase from 1.8°C lower scenario to 4°C maximum scenario in 2050s [28]. In arid and semi-arid agro-ecologies, the temperature is expected to be increased with the maximum scenario. When temperature is increasing at an alarming rate, water loss occurs through evapo-transpiration and results in reduction of soil moisture content with increase in relative humidity. Increasing temperature until the optimum level for bacterial strains, and increasing relative humidity creates suitable condition for the development of CBB epidemics in susceptible common bean varieties [26]. However, at higher temperature, above the optimum level for bacterial blight development, especially above 30°C, the heat tolerant, disease resistant and drought resistant varieties adapt to high temperature and lower soil water content [29-31]. The drought resistant and disease resistant common bean varieties develop several adaptation mechanisms that allow the plant survival during hot and dry conditions [7,32].

The high temperature causes water deficit due to excessive transpiration that could adversely affect the development and function

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of its reproductive organs [30]. In drought resistant varieties, tissue water content is kept high by restricting excessive vegetative growth and a large reduction in water potential. The reduction in leaf water potential due to water stress is linearly correlated with reductions in shoot extension rate and leaf water content [7,32]. The reduction in shoot growth due to stress contributes to a build-up of water-economizing traits, such as specific leaf weight and succulence index [32].

Drought stresses induce genotypic variation of shoot biomass accumulation, pod, seed number, and biomass partitioning index. In general, drought resistance mechanisms can include drought escape; drought avoidance; and drought tolerance [7,32]. Drought escape allows plants to accelerate their cell cycle with an early flowering and maturity, and rapidly relocates metabolites to seed production [8,30] and away from leaves and shoot tissues [33,34]. Drought avoidance is the capability to keep high tissue water potential through increased rooting depth, hydraulic conductance reduction, and radiation absorption reduction in leaves, water-loss area reduction, reduced absorption of radiation by leaf movement, and reduced surface evaporation [7,30,35].

During higher temperature and lower moisture, the disease resistant varieties will reduce disease development due to mobilization of resources into host resistance through various mechanisms, such as reduced stomata density and conductance [30]. Common beans adapt stress conditions of climate change variables through production of greater accumulation of carbohydrates such as waxes, extra layers of epidermal cells, increased fiber content and pH change in their cell cytoplasm [33,34]. Sallam [35] reported that the resistance might be increased by change of pH of plant cell cytoplasm, due to the increase in phenolic acid content, resulting in inhibition of pathogen development. Hence, the accumulation of phenolic compounds at infection site restricts the development of common bacterial blight causing bacterial strains since such compounds are toxic to bacterial strains [35].

Changes in climate, such as increasing temperature and reducing soil moisture, can potentially affect disease development and crop production [21,36,37]. Crop production in Ethiopia is dependent on rainfed agriculture, largely at a subsistence level. Hence, change in weather patterns, particularly rainfall amounts and distribution as well as temperature could be favourable to CBB development and can devastate common bean production. The response of CBB development to increased temperature and reduced moisture needs *in vivo* investigation at different temperature and moisture levels [36,38]. Knowing the effect of temperature and moisture content on disease development and resistance expression of common bean varieties enable to setup resilience strategies of climate change for the management of bacterial blight of common bean in the ever-changing climate in the field conditions.

The objective of this study, therefore, was to assess the effects of temperature and moisture on disease development and on resistance of common beans against common bacterial blight.

Materials and Methods

Description of the study area

Isolation, characterization, and identification of bacterial strains as well as pathogenicity test were conducted in the Plant Pathology Laboratory of Haramaya University during 2014 and 2015 from February to June each year**.** Symptomatic leaves were collected from the field experiments of Babile and Haramaya research stations of Haramaya University during 2014 cropping season. Then the two sets of experiments were conducted in thermoregulated growth chambers.

Pathogen isolation and culturing: Leaves with typical CBB symptoms (irregular necrotic lesions with yellow borders and water-soaked spots) were collected from the experimental fields and dried between paper towels. For some sorts of leaf samples, tissues (0.16 mm^2) were excised from the lesion margin, placed in a drop of distilled water on Petri dish and macerated with sterilized mortar and pestle. Loopfuls of macerates were streaked onto nutrient agar (NA) and plates were incubated at 28°C for 24 h. Yellow, mucoid, xanthomonad-like colonies were selected from each leaf sample and subcultured on NA [20,36].

Loopfuls of subcultured samples from purified colonies were streaked onto plates of Milk Tween (MT), a semi-selective media [36] and of *Xanthomonas axonopodis* pv *phaseoli* (*Xcp1*) medium [39]. The sample plates were visually assessed for the presence of typical colonies of *Xap* and *Xapf.* The purified bacterial strains were inoculated to YDC medium in the form of broth media and plate media. Parts of purified culture were preserved for future use and part of it was inoculated to the common bean seedlings to demonstrate for fulfilling the Koch's postulate.

Effect of temperature on resistance reactions of common bean

Experimental materials and procedures: Two common bean varieties Mexican 142 (G11239) and Gofta (G2816) were used in the growth chamber experiment. Mexican 142 is susceptible to CBB, while Gofta is moderately resistant to CBB [40]. Seeds of the two common bean varieties were disinfected with 2% sodium hypochlorite for five minutes and rinsed with three changes of distilled water. Three disinfected seeds were planted to germinate in 10 to 13 cm diameter plastic pots containing normal soils of clay, sand, and loam (1: 1: 2 v/v), respectively [41]. The soil types were mixed, air dried, sterilized and filled into the pots. The seedlings were thinned to one plant per pot after emergence in the growth chamber (Fitotron SANYO LE115XG, UK). The growth chamber temperatures were maintained at 4 levels: 28°C, 30°C, 32°C and 34°C with 12 h light alternating with 12 h darkness by modifying the methods used by Mkandawire et al. [41] since the day and night duration is about 12 h for each.

Inoculation and incubation: The purified cell concentrations were adjusted with a spectrophotometer to an optical density of 0.05 (600 nm), which corresponds to 10^7 cfu/ml using distilled sterile water [41,42]. When the trifoliate leaves of common beans were fully expanded (12 days old), 2 ml of bacterial suspension per plant was sprayed onto the aerial parts of the emerged seedling leaves after rubbing them with carborandom. The inoculated seedlings were covered with transparent polyethylene bags for 18 to 48 h after inoculation to maintain the required moisture disease development [36]. Inoculated seedlings were arranged at room temperature with a photoperiod of 12 h of visible light and 12 h of darkness and relative humidity of 95% [41,43].

After 48 h of inoculation, seedlings were arranged at 28°C, 30°C, 32°C and 34°C in a growth chamber at different times. Next morning, they were uncovered, sprayed with a fine mist of water once every 3 h and then covered again in the evening to maintain high humidity until the appearance of typical CBB symptoms. Disease reactions (ratings) were recorded 5 to 17 days after inoculation (DAI) employed based on 1-4 disease scale by following the procedures of Lopez et al. [42] and Popovic et al. [44].

Treatments and experimental design: The experiment was conducted on two common bean varieties (Gofta and Mexican 142) against two strains of bacteria (*Xap, Xap)* and a control at four temperature levels (28°C, 30°C, 32°C and 34°C). The control seedlings were inoculated with 0.1% of saline solution. Twenty-four experimental

treatment combinations were arranged in a factorial completely randomized design (CRD), replicated three times, and repeated.

Effect of temperature and moisture on resistance of common bean

Treatments and experimental design: The experiment was conducted on two common bean varieties (Gofta, Mexican 142), two bacterial strains (*Xap, Xapf)* and a control. The control seedlings were inoculated with 0.1% of saline solution. Four temperature levels (28°C, 30°C, 32°C and 34°C) and three moisture levels (100%, 75% and 50% of field capacity), following the method of Emam et al. [21] were applied in a factorial completely randomized design. Four factor factorial combinations of strains (3 levels), varieties (2 levels), temperature (4 levels) and moisture (3 levels), totally 72 treatment combinations were used. Each treatment combination was replicated three times and repeated once. The three different moisture levels (100%, 75% and 50%) were obtained from the field capacity (FC) of the soil used in the experiment following the procedure described by Emam et al. [21] and Abd El-Aal et al. [11]. The soil used in the experiment had the field capacity of soil of 40.9% on a volume basis.

Data collection

Disease, plant height and dry weight data: The disease rating was recorded from the first appearance of aerial symptoms four times at four days intervals (5, 9, 13 and 17) days after inoculation (DAI). The reactions of common bean varieties to *Xap* strains were assessed as diseased leaf area [41]. Disease rating and determination of resistance reaction was evaluated based on a 1-4 scale (41). 1=no visual symptoms or slight marginal necrosis; 2=water-soaking, chlorosis, or necrosis (blight) in <25% of the inoculated area; 3=25 to 50% blight; and 4 ≥ 50% blight. Above soil level plant heights were measured with ruler in centimeters. Dry weights in grams (g) were measured after the sample plants were uprooted at 29 days after planting (DAP) and oven-dried (48 h in 75°C of temperature) on the methods described by Eman et al. [21].

Data analysis

Disease ratings at different DAI, plant height (cm) and dry weight (g) data were subjected to analysis of variance using the PROC GLM procedure of SAS version 9.1 [45]. Homogeneity of variances was tested using the procedure described by Gomez and Gomez [46] and as the test showed homogeneity of variances, combined analysis of the two-season data was performed. Differences among treatment means were compared using the Fisher's Least Significant Difference (LSD) test at 5% level of significance.

Results

Effect of temperature on resistance expression of common bean

The evaluation of common bean varieties showed various levels of resistance against the two bacterial strains of common bean blight. The disease rating was highly significantly (P<0.001) affected by bacterial strains at 9, 13 and 17 days after inoculation (DAI). Relatively higher disease rating was recorded in fuscous blight strain than in common blight strain at 13 and 17 DAI. During the entire disease recording dates, the disease caused by common blight bacterial strain was more or less similar with the disease caused by fuscous blight strain although both bacterial strains had significantly higher disease rating than uninoculated controls.

The disease rating was highly significantly (P<0.01) affected by common bean varieties at 13 and 17 DAI. Higher disease rating was obtained on variety Mexican 142 than on Gofta. At 17 DAI, the mean disease rating was lower by 12.6% on the Gofta than on Mexican 142 (Table 1). Disease rating was significantly (P<0.05) affected by temperature at 13 DAI and (P<0.01) at 17 DAI. Significantly, higher mean disease ratings were recorded at 28°C and lower at 34°C at 13 and 17 DAI. There was no interaction effect between strains of bacteria, variety of common bean and among temperature levels.

Effect of temperature and moisture on resistance reaction of common bean

The analysis of variance (ANOVA) revealed that disease rating of CBB of common bean during 5-17 DAI responded significantly to the main effects of strain, variety, moisture and temperature. Disease rating was also affected by interaction effect of strain and variety at 13 and 17 DAI, strain, and temperature at 17 DAI and strain and moisture at 13 DAI.

Effect of CBB bacterial strains: The disease rating was highly significantly (P<0.001) affected by the main effect of bacterial strain during all disease recording dates. At 5 DAI, the value of disease rating caused by both bacterial strains was not significantly different, while both bacterial strains caused significantly higher disease rating than the uninoculated control. During 9-17 DAI, common bean varieties had higher mean disease ratings caused by common blight strain than fuscous blight strain. The mean disease ratings caused by bacterial strains had similar trend of progress during 9-17 DAI.

Effect of common bean varieties, moisture and temperature on CBB development: The mean disease rating of CBB was significantly (P<0.001) affected by the main effect of common bean varieties during 9-17 DAI. The variety Mexican 142 had significantly higher mean disease rating than the variety Gofta. At 5 DAI, the mean disease rating of both common bean varieties had no significant difference even if the disease rate on Mexican 142 was higher than on Gofta (Table 2). The mean disease rating recorded on the variety Mexican 142 was higher by 17.3% than on variety Gofta at 17 DAI.

The mean disease ratings differed significantly among the moisture

Strain[a]	Days after inoculation			
	5	9	13	17
Xap	1.19[a]	1.46[a]	1.62[a]	1.81[a]
Xapf	1.21[a]	1.46[a]	1.65[a]	1.83[a]
Control	1.00[a]	1.00[b]	1.00[b]	1.04[b]
LSD (0.05)	0.14	0.21	0.18	0.2
Variety				
Gofta	1.10[a]	1.26[a]	1.33[b]	1.46[b]
Mexican	1.17[a]	1.35[a]	1.51[a]	1.67[a]
LSD (0.05)	0.112	0.168	0.145	0.16
Temperature(°C)				
28	1.139[a]	1.361[a]	1.56[a]	1.75[a]
30	1.194[a]	1.361[a]	1.42[ab]	1.53[ab]
32	1.111[a]	1.306[a]	1.44[ab]	1.53[ab]
34	1.083[a]	1.194[a]	1.28[b]	1.44[b]
LSD (0.05)	0.16	0.24	0.21	0.23
CV (%)	9.82	12.99	10.52	10.67

[a]Xap is *Xanthomonas axonopodis* pv. *phaseoli, Xapf* is *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscan,* LSD is least significant difference, CV is coefficient of variation.

Table 1: Disease ratings of CBB caused (*Xap, Xapf*) on Gofta and Mexican 142 varieties at four temperature levels and during 5 to 17 days after inoculation.

contents. On the average, 75% of soil moisture content showed significantly higher disease rating than 100 and 50% moisture level during the entire disease recording dates. Relatively, higher mean disease ratings were recorded from 100% moisture level than 50% and a similar trend was exhibited during the entire experimental duration. The mean disease ratings were in the order of 75%, 100% and 50% of soil moisture level from the highest to the lowest (Table 2).

The mean disease rating was highly significantly (P<0.001) affected by temperature during 13-17 DAI and significantly (P<0.01) differed at 17 DAP. Significantly, the highest mean disease rating was recorded at 30°C and the lowest at 34°C during the entire disease recording dates. Disease rating had similar trend in all temperature levels in the order of 30°C, 28°C, 32°C, and 34°C from the highest to the lowest, respectively (Table 2). The resistance level of the common bean varieties increased with increase in temperature and decrease in moisture.

Variety	1-4 disease rating scale			
	5	9	13	17
Mexican	1.29[a]	1.57[a]	1.76[a]	2.03[a]
Gofta	1.26[a]	1.35[b]	1.52[b]	1.73[b]
LSD(0.05)	0.08	0.09	0.1	0.09
Moisture (%)				
100	1.25[b]	1.43[b]	1.56[b]	1.82[b]
75	1.39[a]	1.54[a]	1.81[a]	2.01[a]
50	1.19[b]	1.41[b]	1.56[b]	1.80[b]
LSD (0.05)	0.1	0.11	0.12	0.12
Temperature (°C)				
28	1.33[a]	1.56[a]	1.72[a]	1.98[a]
30	1.39[a]	1.59[a]	1.85[a]	2.08[a]
32	1.21[b]	1.40[b]	1.56[b]	1.80[b]
34	1.17[b]	1.30[b]	1.43[b]	1.66[b]
LSD (0.05)	0.11	0.12	0.14	0.14
CV (%)	9.82	12.99	10.52	10.68

LSD is least significant difference, and CV is coefficient of variation. Means followed by the same letter for each factor are not significantly different at 5% level of significance.

Table 2: Main effects of common bean variety, moisture content and temperature levels on disease development of common bacterial blight of common beans (1-4 disease rating scale) during 5-17 days after inoculation (DAI).

Moisture (%)	1-4 disease rating scales by bacterial strains		
	[a]*Xap*	[b]*Xapf*	Control
100	1.9c	1.7d	1.1e
75	2.3a	2.1b	1.1e
50	1.8d	1.8d	1.1e
LSD (0.05)	0.12		
CV (%)	21.14		

[a]*Xap* is *Xanthomonas axonopodis* pv. *phaseoli,* [b]*Xapf* is *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscan,* LSD is least significant difference, and CV is coefficient of variation. Means followed by the same letter for each factor are not significantly different at 5% level of significance.

Table 3: Interaction effects of moisture content and bacterial strain on disease development of common bacterial blight of common beans at 13 days after inoculation (DAI).

Variety	13 days after inoculation			17 days after inoculation		
	Xap	*Xapf*	Control	*Xap*	*Xapf*	Control
Gofta	1.8c	1.7c	1.1d	2.1c	2.0c	1.1d
Mexican 142	2.2a	2.0b	1.1d	2.6a	2.4b	1.1d
LSD (0.05)	0.11			0.1		
CV (%)	21.14			17.12		

Xap is *Xanthomonas axonopodis* pv. *phaseoli, Xapf* is *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscan,* LSD is least significant difference, and CV is coefficient of variation.

Table 4: Interaction effects of common bean varieties and bacterial strains on disease development of common bacterial blight (1-4 rating scale) of common beans at 13 and 17 DAI.

Temperature (°C)	1-4 scale disease ratings caused by bacterial strains		
	Xap	***Xapf***	**Control**
28	2.5a	2.3a	1.1d
30	2.6a	2.5a	1.2d
32	2.2b	2.1b	1.1d
34	2.0b	1.9c	1.0d
LSD (0.05)	0.2173		
CV (%)	17.72		

Xap is *Xanthomonas axonopodis* pv. *phaseoli, Xapf* is *Xanthomonas axonopodis* pv. *phaseoli* var. *fuscan,* LSD is least significant difference, and CV is coefficient of variation. Means followed by the same letter for each factor are not significantly different at 5% level of significance.

Table 5: Interaction effects of temperature and bacterial strain on disease development of common bacterial blight of common beans 17 days after inoculation (DAI).

Interaction effect of strain and temperature: The analysis of variance revealed that the disease rating of CBB of common bean was significantly affected by the interaction effects of strain with variety at 13 and 17 DAI, strain with moisture at 13 DAI and strain with temperature at 17 DAI. The highest CBB disease rate (2.3) was recorded in response to combined effect of the medium moisture content (75%) with common blight strain at 13 DAI. At each moisture content level, the highest disease rating was caused by common blight strain, followed by fuscous blight strain and lowest disease rating was from the control plants (Table 3).

The highest CBB rate at 13 and 17 DAI was recorded in response to interaction effect of the common bean variety Mexican 142 with common blight bacterial strain, followed by interaction effect of variety Mexican 142 with fuscous blight strain. The lowest CBB rating occurred in response to interaction effect of uninoculated control plants of both varieties (Table 4). At each variety level, the highest disease was caused by common blight strain, followed by fuscous blight strain and lowest disease rate was from control plants (Table 4). At each strain level, higher disease rate was recorded from the variety Mexican 142 than variety Gofta during 13 and 17 DAI.

The highest (2.6) CBB disease rating at 17 DAI was recorded in response to interaction effect of the temperature level of 30°C with common blight strain, while the lowest (1) CBB rating was occurred in response to the interaction effect of uninoculated control plants with the highest temperature level (Table 5). At each temperature level, the higher disease rating was caused by common blight strain, followed by fuscous blight strain and the lowest disease rating was from control plants. At each strain level, the highest (2.6) disease rating was recorded from temperature level of 30°C by common blight strain and the lowest (1.9) disease rating from highest temperature level (34°C) by fuscous blight strain.

Discussion

Growth chamber evaluation of the susceptibility of common bean varieties showed that the variety Gofta was less susceptible to *Xap* strains than the variety Mexican 142 although disease-rating values of both bacterial strains were very similar in both varieties. The results of this study showed that the variety Gofta was less susceptible at all temperature levels, with its mean disease rating value of 1.46, while the variety Mexican 142 was more susceptible at all temperature levels with disease rating value of 1.67 at 17 DAI in temperature effect experiment. At higher temperature levels, the variety Gofta had more spiny structures

on the stems and on the underside of leaves that might have contributed to the less susceptibility of Gofta than variety Mexican 142. Fininsa and Tefera [40] found a similar result in earlier investigation of susceptibility of some bean varieties to *Xap* under field conditions where the variety Gofta was found resistant and the variety Mexican 142 was susceptible. It can be concluded that the disease development is dependent on the resistance level of common bean varieties, temperature and moisture levels vis-à-vis all environmental conditions are constant.

The results of the present study showed 10% reduction in the average dry weight of the two common bean varieties under the rapid warming scenario (30°C to 34°C) and dry weight reduction by 2.5% under lower case warming scenario (30°C to 32°C). The relationship between temperature levels and crop yields was used to assess the effects of changes in average weather on crop yields. The dry weight reduction may have a similar trend to the findings of Schlenker and Roberts [37] who found important impacts under climate change for soybeans that imply a 33% reduction in yields under the slower warming scenario. The disease resistance and drought resistance levels of the common bean varieties increased with increase in temperature and decrease in soil moisture content. Particularly, increase in temperature and decrease in moisture content reduced disease development due to mobilization of resources into the host resistance through various mechanisms, such as reduced stomata density and conductance in disease resistant and drought tolerant varieties. The result of current study is in agreement with the reports of Beebe et al. [7] who reported that common beans adapt stress conditions due to climate change variables through production and accumulation of carbohydrates, such as waxes, extra layers of epidermal cells, increased fiber content and pH change in their cell cytoplasm. Beebe et al. [8] also defined drought tolerance as the capability of plants to resist the stress by adjusting cell osmosis, cell plasticity, and cell size. Sallam [35] reported that the host resistance might be increased by change in pH of plant cell cytoplasm, due to the increase in phenolic acid content, resulting in inhibition of pathogen development. Hence, the accumulation of phenolic compounds at infection site has been correlated with restriction of *Xap* development since such compounds are toxic to *Xap* [35].

The results of the experiment indicated that the higher case scenario climate change events above optimum level would not be favorable for common bacterial blight development in common bean growing agro-ecologies unless the adaptation of the pathogen to the stress adapted common beans. There might be risk of common bacterial blight epidemic development during temperature increase due to climate change at middle altitudes and highlands since higher scenario of climate change events warm highland areas in the future. However, common bacterial blight epidemic development could be minimized by using drought tolerant and disease resistant common bean varieties. In addition, eco-friendly integrated disease management strategies have to be developed and implemented.

Conclusion

When bacterial strains were inoculated into fresh culture media, there was no immediate increase in cell number until the inoculated cells synthesized new cell components in the lag phase of bacterial growth. During the exponential growth phase, common blight strain grew at a faster rate than fuscan blight strain at regular intervals at the same temperature. A wider variation in growth of bacterial strains was observed at different temperature ranges during earlier exponential phase and narrower variation in growth during stationary phase due to depletion of essential nutrients and accumulation of wastes.

Growth chamber evaluation of the susceptibility of common bean varieties showed that the variety Gofta was less susceptible to *Xap* strains than the variety Mexican 142. At higher temperature levels, the variety Gofta had more spiny structures on the stems and on the underside of leaves that might have contributed to the less susceptibility of Gofta than variety Mexican 142. The disease resistance and drought resistance levels of the common bean varieties increased with increase in temperature and decrease in soil moisture content. Particularly, increase in temperature and decrease in moisture content reduced disease development due to mobilization of resources into the host resistance through various mechanisms, such as reduced stomata density and conductance in disease resistant and drought tolerant varieties.

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