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Research article

Climatic change and its impact on tomato *(lycopersicum esculentum l.)* production in plain area of Nepal

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ABSTRACT

The present study attempts to assess the tomato productivity trend, potential diseases impacting tomato farming and attitudes and practices of tomato cultivators under the light of changing climate in Lalbandi, Sarlahi, Nepal. Meteorological data of the Lalbandi station was analyzed; 89 households out of 248 tomato growers in Lalbandi were surveyed and five key Informant's Interviews as well as one Focus Group Discussion were conducted to understand the perception of tomato cultivators. In the area, average summer temperature over the last 30 years increased by 0.02°C per annum and maximum annual winter temperature rose by 0.01°C, while minimum winter temperature dropped by 0.02°C per year. Likewise, annual precipitation and monsoon precipitation declined by about 31.5 mm and 25.3 mm each year respectively. The phenology of tomato has been shifted by approximately one month, being shifted from August/September to September/October as an impact of climate change. Tomato plants were observed to have suffered from various diseases such as late blight, leaf curl, and black spot which could be attributed to change in climatic conditions. Despite the increment in number of diseases, productivity, however, has slightly increased since 2003 due to the excessive use of chemical pesticides. It is expected that plastic house technology, use of hybrid varieties of tomato and application of organic pesticides and fertilizers could significantly yield more tomato in Lalbandi area.

1. Introduction

Tomato, which belongs to the Solanaceae family, is one of the highly consumed vegetables in the world with an annual production value of more than 90 billion USD (FAOSTAT, 2019). In many countries around the world, tomato has occupied second rank considering its importance after potato (Prajapati et al., 2014). Globally, the annual productivity of tomato has rose by about 300% since the last four decades (Costa and Heuvelink, 2007). *Lycopersicum esculentum* is one of the major commercial horticultural crops grown in Nepal (Ghimire et al., 2001), which still shares third ranking both in terms of total cultivated area and productivity (MoALD, 2020). Among the horticultural crops, the sector of vegetables has been emerging as one of the crucial sub sector and the contribution of horticultural crops to total Agricultural Gross Domestic Product (AGDP) is 17% (MoAD, 2015). Tomato farming in Nepal spans about 20,000 hectares, with an average production scale of 0.3 million metric tons i.e. 15 tons per ha in the fiscal year 2013/14 (MoAD, 2014) and has increased to 22,566 ha of cultivated area with productivity of 18 tons per ha in the year 2018/19 (MoALD, 2020). Tomato growers can earn net profit of Rs 85,400 per year (around 700 USD) from the plastic house per ropani of land i.e. 1400$ per ha. This profit is 2-3 times more as compared to the open field tomato farming (Budhathoki, 2006).

The global average surface temperature of the earth has increased by approximately 1°C (likely between 0.8°C and 1.2°C) above the pre-industrial level in 2017, which have plethora of ecological, economic and societal impacts (IPCC, 2018). Climate change has affected the precipitation, for instance in the Marche region of Central Italy, the annual average precipitation has decreased, while the summer season has experienced the fluctuating trend with a peak precipitation in the thirty years' time period between 1961 and 1990 (Gentilucci et al., 2019). Farmers, in sub- Saharan Africa have faced climate shocks such as droughts, flooding, hailstorms, pests and diseases manifestation, while not all the farmers have applied adaptation strategies with regard to climate change (Rahut et al., 2021). Agriculture, specifically rain fed agriculture, is extremely sensitive and highly vulnerable to climate change and probably will be affected (Al-Bakri et al., 2011). It was predicted that the global agricultural productivity will decline between 3 to 16% by 2080 because of climate change, and this estimation may vary as per the geographical location (Cline, 2008). Nepal resides at the ninth position in terms of country highly impacted by climatic extremities from 1999 to 2018 with 0.4% losses per unit GDP (Eckstein et al., 2018). Global warming is more likely to shift patterns of monsoon rainfall which will pose serious threat to the Nepal's vulnerable subsistence agriculture, infrastructure, biodiversity, and water resources, specifically in

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the mountain region where physical restriction of the species migration is prevalent (Paudyal & Regmi, 2009).

Agriculture is central to the livelihood of Nepalese people that contributes around 35% of the country's GDP (MOF, 2014), and employs about 66% of its labor force (MoAD, 2015). Thus, without accounting agriculture sector in the progressive path, sustainable development goals may not be achieved. In Nepal, present climate variability and extremities are already causing major impacts and economic costs estimated to be equivalent to the yearly cost of 1.5 to 2% of GDP and by 2070s, the net agricultural losses in Nepal are estimated to be around 0.8% of current GDP per year (IDS-Nepal, 2014). Climatic extremities occurring at the different time interval in the crop cycle reduce the productivity higher than the normal yield loss (Beilloiin et al., 2020). Changing temperatures have direct impact on the growth of insects and pests, with higher temperature the growth rate of insects increase. Continuous rise in temperature can cause more damage to the crops from fungi, bacteria and insects (Johkan et al.,2011). The frequency of new pests introduction, pests outbreaks, and high risks of pesticides residues in food are observed as an impact of climate change (Dhanush et al., 2015). Duruing the period of flowering, higher temperature results in abscission of flowers, very poor flowering and low fruit quality, pollen sterility and low color development in tomato (Johkan et al., 2011). Increasing temperature in the South Florida has reduced fruit numbers and yield of tomatoes, with low pollen viability and fruit set and the continuous rise in temperature could further reduce the productivity (Ayankojo and Morgan, 2020).

The intense precipitation and high relative humidity are destructive to tomato plants, as the proliferation of leaf diseases is higher during the period of humid conditions (Kalibbala, 2011). The ranges of late blight diseases in tomato and potato inducing low yields in Egypt have expanded since the early 1990s, which could be attributed to climate change (Fahim et al., 2007). It was insisted that higher level of humidity indicated by the low vapor pressure deficit reduces the growth of tomato crop, further in the extreme cases it might cause death of the apical region of tomato plants (Acock et al., 1976). Yield of tomatoes may be reduced significantly when tomato is exposed to low humidity along with low calcium supply or excess salinity which causes increment in the blossom-end rot incidence (Bradfield and Gurrridge 1984; Ehret and Ho, 1986).

Analysis of historical weather data of South west Italy showed that, the transplanting month of tomato is getting hotter and drier and the rise in temperature has induced a shortening of the phenology (Cammarano et al., 2020). Tomatoes can grow under a wide range of climatic conditions. However, they are largely sensitive to hot and cold growing conditions, basically to the weather that exists in the summer season such as in Bangladesh (Ahmed, 2002). Tomato plants in Lalbandi have been suffering from drastic variations of climatic conditions and several diseases have been observed since some years which are in accelerating trend. Local people have directly perceived the change in climate as being largely responsible for altering the tomato productivity due to the frequent outbreak of diseases and insects manifestation. A very small figure of researches dealing with climate change has been conducted in the study area and a very few specific studies on the impact of climatic change on tomato have been conducted in the country before in an open field condition. So, it was felt imperative to understand if there was the impact of climatic change on tomato production in the study area. The objective of this research was to assess the trend of precipitation, temperature and relative humidity and to analyze the trend on yield of tomato under varying climatic phenomena in Lalbandi. Moreover, diseases impacting tomato cultivation due to altering temperature and relative humidity was to be identified.

Various techniques for increasing tomato productivity have been applied in different parts of the country. Farmers in the eastern high hills of Nepal have been adopting the plastic house technology which is earning great popularity these days due to the fact that bulk amount of fungicides is to be sprayed otherwise, which is not environmental friendly and has significant health impact (Chapagain et al., 2010). However, tomato growers in the study have been practicing cultivation in an open field condition that might affect the production because of climatic factors and diseases. So, the study was deemed necessary to analyze the trend of production under varying climatic conditions and the potential diseases impacting tomato farming in an open field conditions. Typically, this research would assist farmers and decision makers to enhance their understanding on the trend of tomato production and diseases outbreak in light of changing climate, so that appropriate measures can be adopted in the future. Furthermore, this research might be helpful for other researchers willing to conduct research work on the related field.

2. Methodology

2.1. Study area

The study was conducted in Lalbandi: Lalbandi 8, a plain area of Nepal (Fig. 1). Lalbandi is a Municipality in Sarlahi District in the Janakpur Zone of south-eastern Nepal which lies North-South to the East-West Mahendra Highway. It is situated at 27O4′30" North and 85O39′12" East with area of 64.9 square kilometer. About 45.5% of the total land area in the study area is cultivated. Soil in the study area is sandy loam with more cobbles and pebbles. It has tropical to sub-tropical type of climate.

2.2. Data and methods

The primary methods of data collection were Direct Field Observation, Household Questionnaire Survey, five Key Informants Interview (KII) and a Focus Group Discussion (FGD) which were conducted between the period of initial seedlings and harvesting (September/October to February/March), while the secondary sources include data collected from Department of Hydrology and Meteorology (data on minimum and maximum temperature, precipitation and relative humidity from 1988 to 2017), Lalbandi Market Development Committee (production data from 2003 to 2017), District Agriculture Development office, published government reports (MoAD, 2015; MoAD, 2014). The meteorological data on temperature, relative humidity and rainfall was analyzed in Ms excel 2010 and SPSS version 20 through trend lines and regression analysis.

Based on the preliminary survey conducted during July/August 2018, the place where the maximum tomato farming was done was purposively selected in Lalbandi. The Lalbandi ward number eight was further selected for the household questionnaire survey where all most all of the households were involved in tomato farming either for their own consumption or for the commercial point of view. Based on the Cohron's formula (Cochron, 1977) for determining sample size, 89 households were determined as the standard sample size out of 248 tomato growers in the study area. The survey with tomato growers was conducted in between initial seedlings and harvesting period. Five Key Informants Interviews were conducted in the study area, where the Key Informants were agriculture officer, Horticulture Conservation Officer, 92 years old tomato farmer, president of Lalbandi ward number 8, and a pesticides seller of the local agrovet. A comprehensive in depth responses regarding their perceptions on climate change, tomato productivity and diseases impacting tomato were recorded from KII. A Focus Group Discussion (FGD) was conducted with the mothers groups, who were engaged in tomato farming from several years in the study area. Periodic field observation on tomato farming from initial seedlings to the final harvesting was performed to record and analyze the climatic disturbance seen in tomato cultivation in the study area. Thus gathered information form the household survey was analyzed comprehensively by determining the respondent's % to a particular case, while the qualitative information was analyzed qualitatively.

The analysis of temperature, relative humidity and tomato production were done by using the correlation test and the linear regression

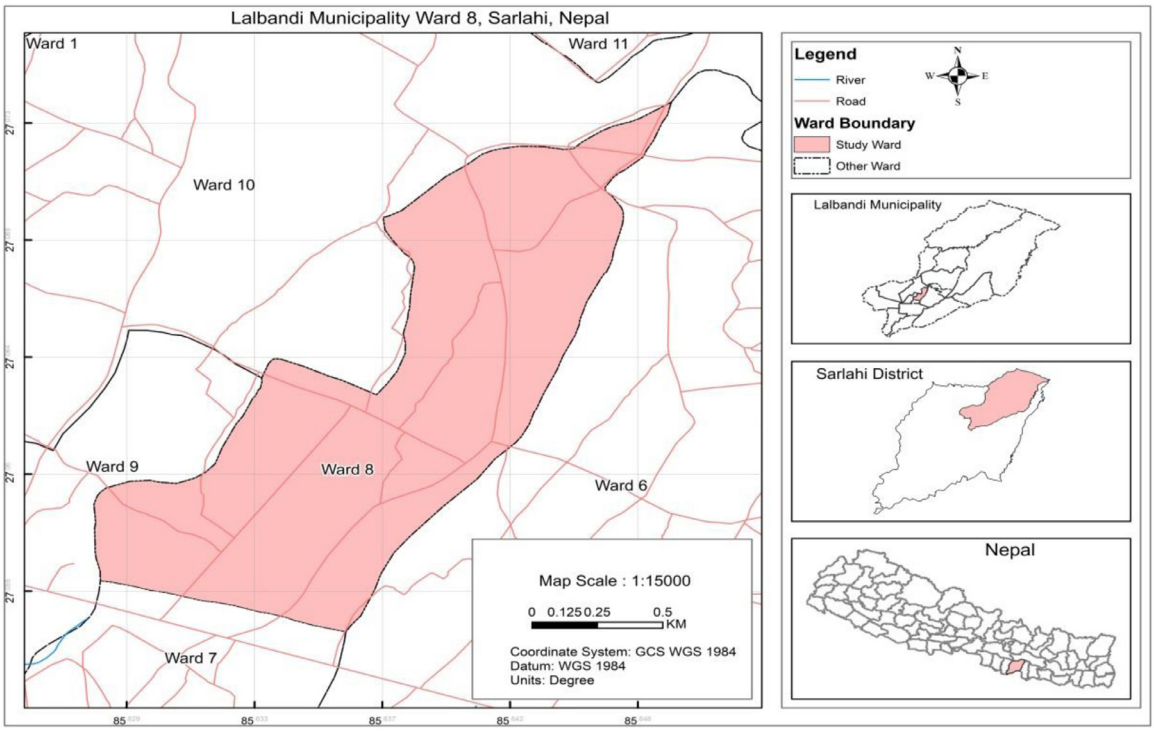

Fig. 1. Location map of the study area.

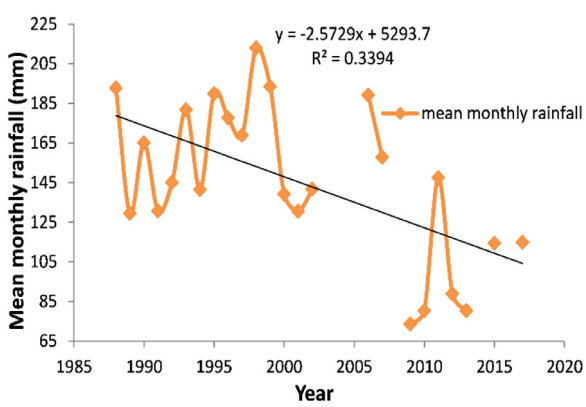

Fig. 2. Mean monthly rainfall (1988-2017).

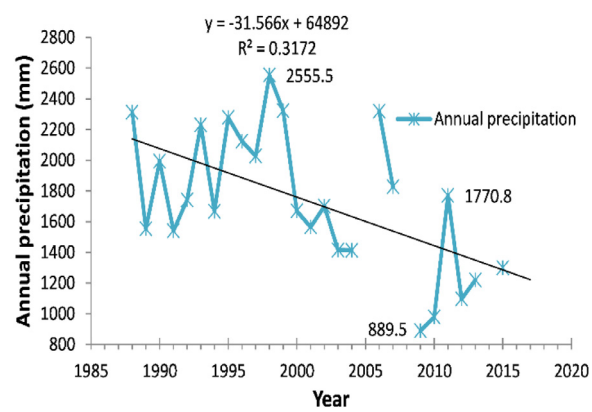

Fig. 3. . Annual precipitation (1988 -2017).

analysis, where the trend line, R square value, P value and standard error were calculated and interpreted. The necessary numerical analyses were illustrated using bar diagram, trend lines and various graphs.

3. Results

The trends of various meteorological parameters such as minimum and maximum temperature, precipitation and relative humidity of the study area were analyzed and necessary interpretations were done in a comprehensive way.

3.1. Precipitation

Precipitation has been declining steadily since the past thirty years. Mean monthly precipitation declined by 2.57 mm per year while annual precipitation dropped by 31.5 mm per year as in Figs. 2 and 3. The drastic variation in the precipitation can be observed in some years that can have impact to the various sectors. Similarly, pre- monsoon precipitation, monsoon precipitation, post monsoon precipitation, and winter precipitation declined by 0.76 mm, 25.2 mm, 1mm, and 0.85 mm respectively.

3.2. Temperature

Temperature data of the study area showed the change in temperature with years. As in Figs. 4 and 5, annual average summer maximum temperature accelerated by 0.03°C a year, while average annual minimum winter temperature decreased by 0.02°C a year.

Likewise, annual average maximum temperature, annual average Tmin, average pre-monsoon Tmax, average pre-monsoon Tmin, average post-monsoon Tmax and average post-monsoon Tmin dropped by 0038°C, 0.036°C, 0.0054°C, 0.017°C, 0.021°C and 0.0013°C per annum respectively. Moreover, Relative Humidity showed simultaneous increasing trend. The thirty years of analyzed temperature of Aug/Sept for the phenological study showed the positive trend in Tmax, Tmin and T average with increasing rate of 0.041°C, 0.0069°C and 0.024°C per annum respectively. Average Relative humidity for the phenological study

Table 1
Phenological shift of tomato in the past versus present.

Phenology	Time period	Bhadra(Aug/Sep)	Ashoj(Sep/Oct)	Kartik(Oct/Nov)	Mangsir(Nov/Dec)	Poush (Dec/Jan)	Magh (Jan/Feb)	Falgun (Feb/March)	Chaitra (March)
Spreading seeds in field	Past(30 years back)								
	Present								
Transplanting /displacing seedlings	Past(30 years back)								
	Present								
Flowering and fruiting	Past(30 years back)								
	present								
Harvesting	Past(30 years back)								
	Present								

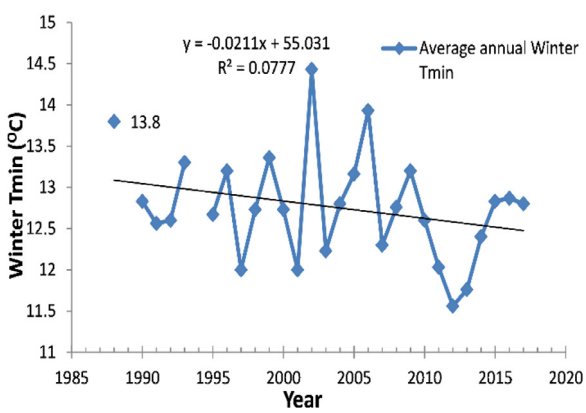

Fig. 4. Annual average minimum winter temperature (1988 - 2017).

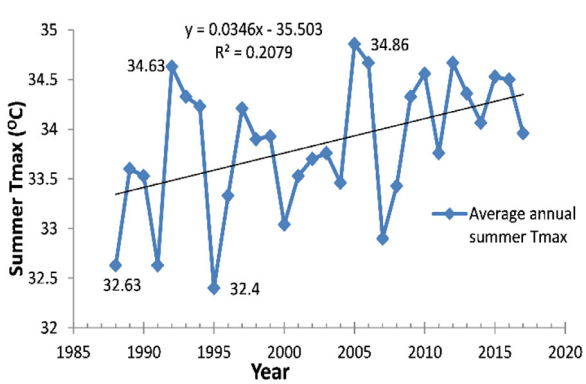

Fig. 5. Annual average maximum summer temperature (1988 - 2017).

showed positive trend during August /September with the rate of 0.2% per annum between 1988 and 2017. Therefore, the following shift in phenology was taken place.

Table 2
Summary table for the various statistical results.

Parameters	R square	Standard error	P value
Tmax, Tmin and production	0.16	4.02	0.34
Taverage, RH average and production	0.208	4.09	0.27
mean monthly rainall,	0.34	32.85	0.03
Annual precipitation	0.32	385.81	0.03
Winter Tmin	0.078	0.63	0.15
Summer Tmax	0.208	0.60	0.01
Taverage and production	0.15	3.88	0.14

3.3. Phenological shift of tomato in the past versus present

The Table 1. describes the details on phonological shift of tomato from the past thirty/ forty years to present. In the past tomato seeds were cultivated during August/ September, but at present, it has reached to September/ October. Likewise, all the stages of tomato phenology have been shifted by one month. In the past 30/40 years back, harvesting of tomato used to be between November/ December to mid-February, while at present, it is during December/January to March. It was supported by the analysis of temperature and relative humidity of the past 30 years (1988-2017) which showed the continuous increasing trend during August/ September.

3.4. Production, temperature and relative humidity

While analyzing production of tomato against Tmax and Tmin from initial seedlings to harvesting, considerable variation in production was obtained as in Fig. 6. The production level increased by approximately 0.28 metric tons per ha per annum, while the maximum temperature accelerated by 0.047 °C and minimum temperature declined by 0.044 °C per year. When the maximum temperature exceeded 28 °C and reached to 28.26 °C in 2006, the production actually fell dramatically to just around 0.32 tons per ha. At this point, minimum temperature was 15 °C. Likewise, other relationships are shown in the Fig. 6 in detail. Regression analysis test was conducted for identifying the impact of Tmax and Tmin on production, where the P value was 0.34. It indicated that there was no significant impact of changing temperature on the produc-

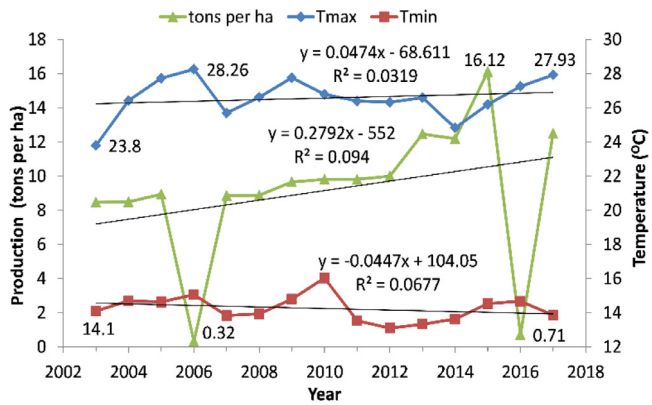

Fig. 6. Tmax, Tmin versus production level (2003 - 2017).

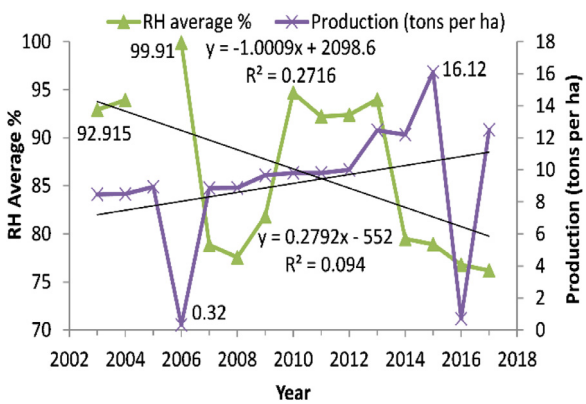

Fig. 7. RH versus production level (2003 to 2017).

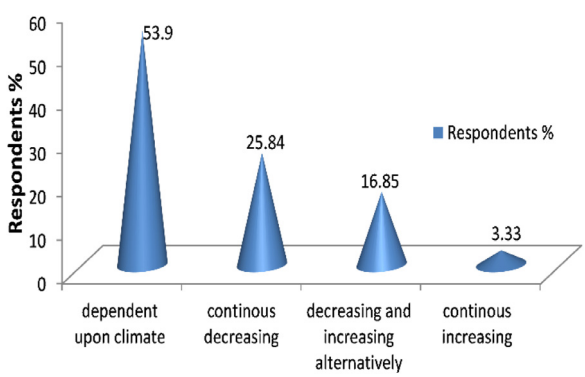

Fig. 8. Trend on yield of tomato by respondents.

tivity of tomato. In this case, the R square value was just 0.16 which shows that there is no significant correlation between temperature and productivity (Table 2).

From Fig. 7, Relative humidity dropped by almost 1% per annum, while on the other hand, productivity increased by 0.28 tons per ha per year. The production was accelerated when RH was between 75% and nearly 95%. However, sharp increase in productivity was observed between RH 75% and 85%. The productivity of tomato declined unpredictably in the year 2006 where the RH was highest with approximately 100 %. It hindered the production of tomato in entire open field. The regression analysis test for the impact of average relative humidity and average temperature showed the P value 0.27 with the standard error and R square value of 4.09 and 0.20 respectively. This suggests that there was no significant impact of humidity and temperature on the final yield of tomato.

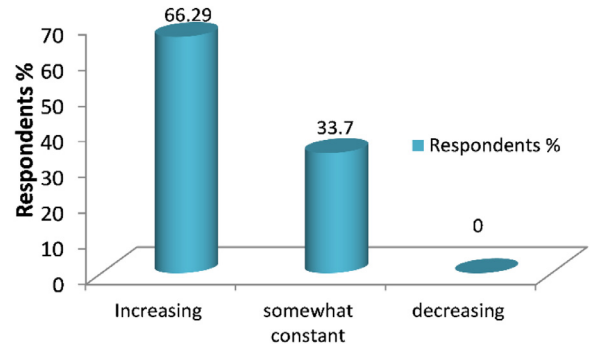

Fig. 9. Summer temperature as per respondents.

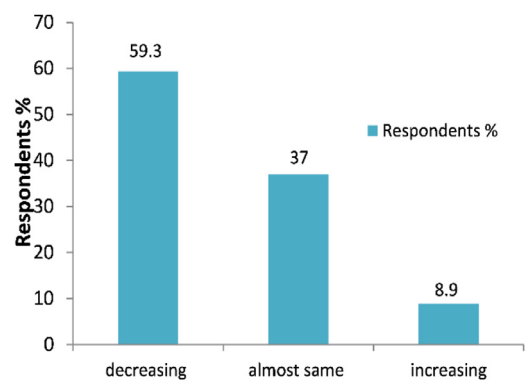

Fig. 10. . Winter temperature perceived by respondent.

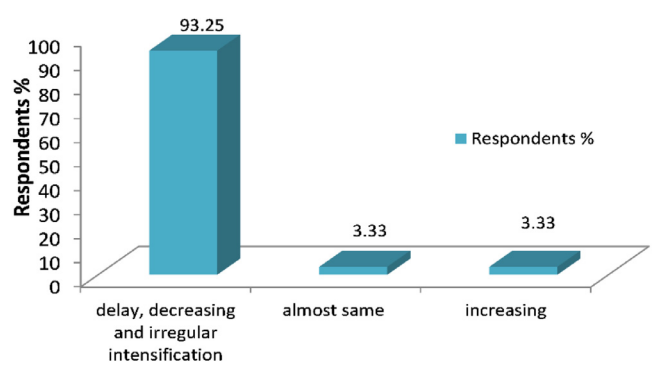

Fig. 11. Responses on monsoon rainfall.

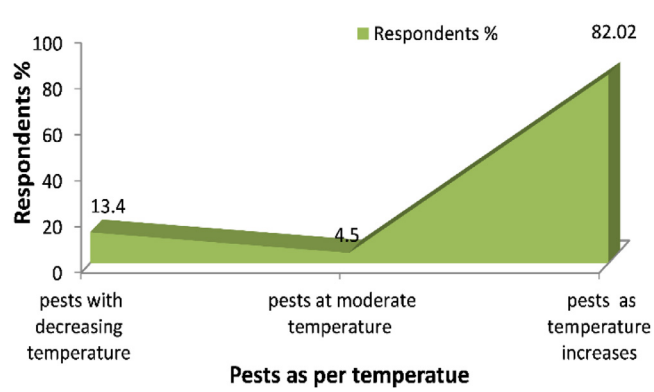

Fig. 12. Increment of pests as per temperature.

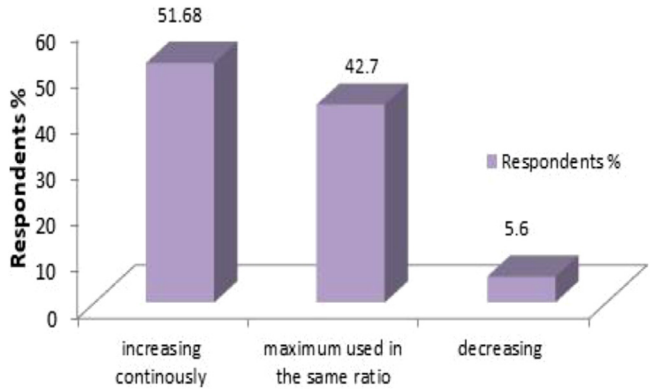

Fig. 13. Trend of using pesticides/chemicals.

3.5. Results of household questionnaire survey, KII, FGD and field observation

In the questionnaire survey, approximately 54% of the local respondents observed that the production of tomato entirely dependent upon climate (Fig. 8). Since the last 20 years, 25.84% reported continuous declining trend of tomato farming while 3.33% found increasing trend and 16.85% respondents said alternative increasing and decreasing trend in productivity. Nearly 67% has perceived increasing summer temperature these years than it used to be in the past. About 33.7% respondents have felt similar temperature in summer than in the past (Fig. 9).

Nearly 54% of the total respondents has perceived decreasing winter temperature during winter while 37% of the respondents has felt somewhat constant temperature since the past (Fig. 10). About 93.25% of the respondents have felt delay, decreasing and irregular intensification of rainfall (Fig. 11). Almost 82% of the respondents surveyed reported increment of pests as temperature increases.

About 13.4 % respondents observed increment of pests in tomato as temperature decreases, while 4.5% claimed that pests could be observed at the moderate temperature (Fig. 12). About 51.68 % found simultaneous increasing trend of pesticides use in tomato field (Fig. 13). Also, 42.7% of the famers have observed the maximum use of chemicals in the same ratio. Nearly, 38.2 % of the respondents sprayed pesticides in their tomato field mostly during flowering, fruiting's and harvesting. Approximately 31.5 % local farmers sprayed pesticides thrice a week while 17.97 % sprayed pesticides once a week and 6.74%once a fortnight.

Five Key Informants Interview with various experts, representatives and old aged tomato growers of the study area and a Focus Group Discussion with mothers group were conducted which insisted that climate has been changing, whose impacts are clearly evident in agriculture and are largely responsible for the declining tomato productivity which therefore demanded excess use of chemical pesticides and fertilizers. They observed the incidences of diseases in tomato are increasing than the past and extended cold winter at present and very warm temperature have declined the productivity and the attractions of the farmers in tomato farming. KII and FGD insisted that fungal infestations are more in the cold winter that sometimes spread throughout the tomato field and the trend of fungal manifestations are more than in the past. This has decreased the yield, so that farmers tend to spray fungicides more frequently during winter and when pest's manifestation during warm days increases, they also use more pesticides to control the pests and increase the yield. From the information obtained from the FGD, KII and household survey, it was found that the phenology of tomato has been shifted by approximately one month, being shifted from Aug/Sep to Sep/Oct. They have also observed high yield (about 2 times) of tomato in the plastic house technology than in an open field conditions as the incidences of diseases in the controlled conditions are low. Also, when using diseases resistant hybrid varieties of tomato seeds are distributed to the farmers from the Government of Nepal, they observed the incidence of leaf curl and black spot low.

Late blight, Kopre (leaf curl), black spot, and burning of plant were observed in the field from the flowering period to final harvesting due to cold winter and extremely hot summer. Late blight due to fungal infestation in the field was recognized as brownish blotches in leaves, stem and fruits with rapid proliferation throughout the field in just 3-4 days when severe winter and frost persisted during that time. Under high relative humidity, white powdery growth appeared on the infected plant. Burning of leaves and stem was detected when daytime temperature exceeded 33°C. When the warming days increased (with temperature more than 28°C) black spots in fruits were observed. Leaf curl diseases appeared in the field mostly during winter.

4. Discussion

Analysis of rainfall of Nepal between 1971 and 2005 showed the change in annual and seasonal rainfall pattern with overall increase in mean monthly rainfall by 2.08 mm (K.C, 2017). However, the analysis of rainfall data from 1988-2017 in Lalbandi found that the mean monthly rainfall declined by 2.57 mm per year with overall declined in various seasonal precipitation. Monsoon season in Nepal has been delayed because of the climate change and has directly affected thousands of hectares of productive agriculture land. Insufficient water supply has declined yield of agriculture to the greater extent (Regmi and Adhikari, 2007). This study was quite similar to the trend in monsoon rainfall and corresponding perception of the local people which they have been perceived as delay, decreasing and irregular intensification. The average temperature rise across Mountain and Himalayas is 0.08°C and Terai is 0.04°C (Gautam and Pokhrel, 2010). However, Lalbandi being a place of Terai showed negligible decreasing trend of annual average temperature. In the study area, maximum annual winter temperature rose by 0.015°C per year while minimum annual winter temperature dropped by 0.02°C per year. The average temperature of summer accelerated by 0.024°C per year.

Tomatoes in Terai has been interrupted by high temperature (Pandey et al., 2006).While analyzing the thirty years average temperature from initial seedlings period to final harvesting, it was found to be increased by 0.011°C per year. However, with increase in temperature, production of tomato was observed to be increasing provided that the chemical fertilizers and pesticides were applied abundantly. Though, the increasing temperature and relative humidity tended to interrupt tomato production in the study area, the application of excessive chemicals on the other hand nullify the consequences of climate change. As the significant effect was observed mainly from the time of initial seedlings to final harvesting, the separate analysis of climatic parameters were performed. The positive relationship between temperature and production was obtained where average temperature increased by just 0.0013°C per year and production by almost 0.28 tons per ha per annum which could be considered as negligible effect on the total yield. The P value in this case was 0.14 which illustrates that the change in temperature in the study area had no significant impact on the production. The optimum temperature required for the favorable growth of tomato is generally in between 21°C to 24°C and above this range the yield will decrease (Attoh et al., 2014). The production in the study area was found to be increased when maximum temperature ranged between 23.8°C-27.7°C and minimum temperature between 13°C-16°C. Yield of tomato rose when the average temperature was between 19°C and 21.4°C. Low RH (20-40%) reduced spore germination, reduces growth, and elevates death of host tissue as well as reduced disease progress (Guzman-Plazola et al., 2003). High RH (70%-90%) analyzed in the study area favored the growth of tomato with germination of spores while the incidence of diseases also increased accordingly after long term exposure to that level. So, farmers in Lalbandi tended to spray more pesticides in order to increase the productivity by eradicating diseases. Relative Humidity above 90% declined the productiv-

ity and numbers of diseases started appearing in larger ratio. Diseases and insects in tomatoes plant of Nepal were regularly observed where the percentage leaf damage by late blight (*Phytophthora infestans*) disease and leaf miner flies (*Bedellia somnulentella Zeller*) were recorded highly (Chapagain et al.,2012). Low temperature, high rainfall during flowering stage and blight diseases and other fungal infestations limit the growth of tomato in an open field in high hill region (Pandey and Chaudhary, 2004).

Nelson (2008) found the cosmopolitan distribution of late blight, but the epidemics occur majorly in the areas with frequent cool and moist weather and is characterized by brownish-black lesions on the leaf, stems and fruits and in humid weather white moldy growth occurs in the plant and eventually lead to the curling and death of plants. In Hawaii, late blight is a common disease infecting tomato at higher elevation where the weather pattern is predominantly cool and moist during winter months. However, Fahim et al. (2010) observed the increment in late blight diseases in tomato under the climate change projection scenario. Also, it was projected to occur from 10-15 days earlier and was lengthened by 10-20 days with increase in warmer conditions. In contrast, the study conducted in Lalbandi was different, where the incidences of late blight diseases increased with increasing in the number of cold days with decreasing temperature. According to the tomato growers also, the manifestation of fungus was reported in the field mostly during winter that have also declined production of tomato to the point of complete destruction. Fungal infestation by late blight is the major and the most devastating disease in tomato and potato and can destroy these crops at any time period of their ontogeny (Nowicki et al.,2013). High dose of fungicide is required to control and protect crops from late blight; as for instance higher than 2000 tons of fungicide was applied in the potato field in the USA in 2001 to control this fungal infestation (Anonymous, 2004). Similarly, farmers in the study area sprayed fungicides so frequently that it did not allow the complete destruction of tomato. The spraying of fungicides has helped to raise productivity.

During the winter season (November- March), the incidences of tomato leaf curl was higher than that in the rainy season (Singh et al., 2015). In the study area, similar kind of observation was made, where the curl of leaves accelerated as the severe winter extended for some days. Ventrella et al. (2012) studied climate change adaptation strategies for various crops including tomato in Italy and observed that rising temperature may alter the phenology of tomato by 2050 and can reduce the production of tomato. In the study area, the phenology of tomato has already been shifted by approximately one month being shifted from August/September to September/ October which was obtained from the tomato growers, KII and FGD and was also supported by the analysis of temperature and relative humidity of past 30 years (1988-2017) during August/ September. In the year of 2009/10 total area and production of tomato in Nepal was estimated to be 15,609 ha and 242,018 tons, respectively with an average productivity of 15.5 tons/ha (VDD, 2010) and in the year 2013/14 was 15 tons/ha (MoAD, 2014). The average productivity of tomato in the study area from 2003-2017 was about 9 tons/ha which is lower than the average tomato productivity of Nepal. The low yield of tomato in the study area could be attributed to the change in climate that has induced several diseases in the field with increment in diseases and pests manifestation.

5. Conclusion

Climate change had detrimental effect on tomato cultivation in the study area. However, the overall scenario of yield was found increasing since 2002/2003 excluding some years where the production fall dramatically because of climatic extremities. Due to the compound effect of climatic change, the incidence of diseases has been increased, while on the other hand, the application of pesticides on tomato field has also increased accordingly in order to cope with the effect of pests and cold winter. Massive dose of pesticides, if were not sprayed, the production would have declined steadily due to various climate induced diseases such as late blight by fungal manifestation, black spot, leaf curl, burning (yellowing) of plant, increasing insects and so on. The dose of pesticides has been increased while on the other hand, they can have serious impact on human health and soil. The cultivation time of tomato has already been shifted by approximately one month in the past thirty years being shifted from Aug/Sep to Sep/Oct due to which tomato crop these days experienced early winter, such that late blight and leaf curl incidences have been increased. In order to cope with the changing climate in the study area, farming practices in the plastic house technology, applications of organic pesticides/ fungicides, use of diseases resistant varieties of tomato seeds might be the alternative solutions that can increase the productivity by reducing the probability of the occurrance of dieases.

Declaration of Competing Interest

The authors declare that they have no competing interests.

Data availability

The data used to support the findings of this study are included within the article. In any case, if the data used to support the findings of this study are required by anybody, they are available from the corresponding author upon request.

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References

Acock, B., Charles-Edwards, D.A., Hand, D.W., 1976. An analysis of some effects of humidity on photosynthesis by a tomato canopy under winter light conditions and a range of carbon dioxide concentrations. J. Exp. Bot. 27, 933–941. doi:10.1093/jxb/27.5.933, https://doi.org/.

Ahmad, S., 2002. Genetics of Fruit Set and Related Traits in Tomato Under Hot-Humid Conditions. BSMRAU, pp. 44–180.

Al-Bakri, J., Suleiman, A., Abdulla, F., Ayad, J., 2011. Potential impact of climate change on rainfed agriculture of a semi-arid basin in Jordan. Phys. Chem. Earth. 36, 125–134. doi:10.1016/j.pce.2010.06.001, https://doi.org/.

Anonymous., 2004. Potatoes- fall fungicide use. NSF Center for Integrated Pest management, 2001. National Agricultural Statistics Service.

Attoh, C., Martey, E., Kwadzo, G.T.M., Etwire, P.M., Wiredu, A.N., 2014. Can farmers receive their expected tomato price in Ghana? A probit regression analysis. Sus. Agri. Research. 3 (2), 16–23. 10.22004/ag.econ.230519.

Ayankojo, I.T., Morgan, K.T., 2020. Increasing air temperatures and its effects on growth and productivity of tomato in South Florida. Plants (Basel, Switzerland) 9 (9), 1245. doi:10.3390/plants9091245, https://doi.org/.

Beillouin, D., Schauberger, B., Bastos, A., Ciais, P., Makowski, D., 2020. Impact of extreme weather conditions on European crop production in 2018. Phil. Trans. R. Soc.B. 375. doi:10.1098/rstb.2019.0510, http://dx.doi.org/.

Bradfield, E.G., Gurrridge, C.G., 1984. Effects of night-time humidity and nutrient solution concentration on the calcium content of tomato fruit. Scient. Hortic. 22, 207–217.

Budhathoki, K., 2006. Market oriented, organic and off-season vegetable production technology (Nepali). Shrimati Basanti Budhathoki Lalitpur, Nepal.

Chapagain, TR., Piya, S., Mandal, J.L., Chaudhary, B.P., 2010. Up-scaling of polyhouse tomato production technology in mid hills of eastern Nepal. In: Paudel, MN, Barakoti, TP, Ghimire, YN (Eds.), Proceedings of Ninth National Outreach Research Workshop, Kathmandu, Nepal, pp. 116–120.

Chapagain, T., Khatri, B., Mandal, J., 2012. Performance of tomato varieties during rainy season under plastic house conditions. Nepal J. Sci. Tech. 12, 17–22. doi:10.3126/njst.v12i0.6473, https://doi.org/.

Cline, W.R., 2008. Global Warming and Agriculture. Impact Estimates by Country, Washington DC.

Cochran, W.G., 1977. Sampling technique, 3rd Ed. Wiley, New York.

Cammarano, D., Ronga, D., Di Mola, I., Mori, M., Parisi, M., 2020. Impact of climate change on water and nitrogen use efficiencies of processing tomato cultivated in Italy. J. Agri. Water Manag. 241 https://EconPapers.repec.org/RePEc:eee:agiwat:v:241:y:2020:i:c:s0378377420305199.

Costa, M., Heuvelink, E., 2007. Today's worldwide tomato production. In: Fruit and Veg Tech: International Magazine for Production, Marketing and Technology of Fruits and Vegetables Worldwide, pp. 14–16 Amsterdam.

Dhanush, D., Bett, B., Boone, R., Grace, D., Kinyangi, J., Lindahl, J., Mohan, C.V., Ramirez-Villegas, J., Robinson, T., Rosenstock, T.S., 2015. Impact of Climate Change on African Agriculture: Focus on Pests and Diseases Copenhagen, Denmark.

Eckstein, D., Künzel, V., Schäfer, L., Winges, M., 2018. Global Climate Risk Index 2020. Who Suffers Most from Extreme Weather Events? Weather-Related Loss Events in 2018 and 1999 to 2018.

Ehret, D.L., Ho, L.C., 1986. Translocation of calcium in relation to tomato fruit growth. Ann. Bot. 58, 679–688. doi:10.1093/oxfordjournals.aob.a087230, https://doi.org/.

Fahim, M.A., Medany, M.A., Aly, H.A., Fahim, M.M., 2007. Effect of the Climate Change on the Widespread and Epidemics of Potato and Tomato Late Blight Disease Under the Egyptian Conditions. Cairo Univ., Egypt, p. 177.

Fahim, M., Hassanein, M., Abou Hadid, A., Kadah, M., 2010. Impacts of climate change on the widespread and epidemics of some tomato diseases during the last decade in Egypt. Acta. Hortic. 914, 317–320. doi:10.17660/ActaHortic.2011.914.57, https://doi.org/.

FAOSTAT., 2019. Food and Agriculture Organization of the United Nations http://fao.org/faostat/en.

Gautam, A.K., Pokhrel, S., 2010. Climate Change Effects on Agricultural Crops in Nepal and Adaptation Measures. Paper presented at TWG (agriculture and food security) meeting.

Gentilucci, M., Barbieri, M., Lee, H.S., Zardi, D., 2019. Analysis of Rainfall Trends and Extreme Precipitation in the Middle Adriatic Side, 11. Marche Region (Central Italy). Water. 1948.

Ghimire, S.R., Subedi, R.P., Green, S.K., 2001. Status of tomato yellow leaf curl virus in tomato in the western hills of Nepal. Nepal Agri. Research J. 5, 1–4. doi:10.3126/narj.v4i0.4856, https://doi.org/.

Guzman-Plazola, R.A., Davis, R.M., Marois, J.J., 2003. Effects of relative humidityand high temperature on spore germination and development of tomato powdery mildew (Leveillula taurica). Crop Protection 22 (10), 1157–1168.

IDS-Nepal, PAC and GCAP., 2014. Economic Impact Assessment of Climate Change in Key Sectors in Nepal https://cdkn.org/wp-content/uploads/2014/05/EIA-summary_sharing_final-low-resolution.pdf.

IPCC., 2018. Global Warming of 1.5°C.An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J.B.R. Matthews, Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M., Waterfield, T. (eds.)]. https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

Johkan, M., Oda, M., Maruo, T., Shinohara, Y., 2011. Crop production and global warming. In: Casegno, S. (Ed.), Global Warming Impacts-Case Studies on the Economy, Human Health, and on Urban and Natural Environments, pp. 139–152 Rijeka: In Tech..

Kalibbala, J.M., 2011. The influence of organic manure on tomato growth in Rakai District Uganda. A Research Report Submitted to the Department of Zoology, in Partial Fulfillment of the requirement for the degree of Bachelor of Science. Makerere University.

K.C, A., 2017. Climate change and its impact on tourism in Nepal. J. Touri. Hospit. 7, 25–38. doi:10.3126/jthe.v7i0.17688, https://doi.org/.

MoALD., 2020. Statistical information on Nepalese agriculture I 2018/2019. Ministry of agriculture and livestock development. Planning and Development Cooperation Coordination Division. Statistics Analysis section. Singha durbar Kathmandu, Nepal http://www.doanepal.gov.np/downloadfile/Statistical%20information%20on%20Nepalese%20agriculture_1601976502.pdf .

MoAD., 2015. Statistical information on Nepalese agriculture 2014/2015. Government of Nepal. Ministry of Agricultural Development (MoAD), Agri-Business Promotion and Statistics Division, Statistics Section Singha Durbar, Kathmandu, Nepal.

MoAD, 2014. Statistical information on Nepalese agriculture (2013/14). Government of Nepal, Ministry of Agricultural Development (MoAD), Agri-Business Promotion and Statistics Division, Statistics Section Singha Durbar, Kathmandu, Nepal.

MoF., 2014. Economic survey, Fiscal year 2013/14: Government of Nepal. Ministry of Finance, Singhadurbar, Kathmandu, Nepal.

Nelson, S.C., 2008. Late Blight of Tomato (Phytophthora infestans). University of Hawaii, Honolulu, HI (Plant Disease; PD-45) http://hdl.handle.net/10125/12406.

Nowicki, M., Kozik, E.U., Foolad, M.R., 2013. Late blight of tomato. In: Varshney, RK, Tuberosa, R (Eds.), Translational genomics for crop breeding. John Wiley and Sons Ltd, pp. 241–265.

Pandey, Y.R., Chaudhary, B.N., 2004. Evaluation of tomato varieties and their planting dates for commercial production under Jumla agro-ecological condition. In: Proceedings of the Fourth National Horticultural Research Workshop. Horticulture Research Division, Nepal Agriculture Research Council, Khumaltar, pp. 380–385 *(Khatri, B.B., Sharma, B.P., Khatiwada, P.P., Pudyal, K.P., Regmi, H.N, eds)*.

Pandey, Y.R., Pun, A.B., Upadhyay, K.P., 2006. Participatory varietal evaluation of rainy season tomato under plastic house condition. Nepal Agri. Res. J. 7, 11–15.

Paudyal, A., Regmi, B., 2009. Climate Change and Agrobiodiversity in Nepal: Opportunities to Include Agrobiodiversity Maintenance to Support Nepal's National Adaptation Programme of Action (NAPA) Enter Title www.agrobiodiversityplatform.org/blog?getfile=3537.

Prajapati, H.N., Panchal, R.K., Patel, S.T., 2014. Efficacy of bioagents and biological interaction of Alternaria solani with phylloplane mycoflora of tomato. J. Mycopathol. 52, 81–86.

Rahut, D.B., Aryal, J.P., Marenya, P., 2021. Ex-ante adaptation strategies for climate challenges in sub-Saharan Africa: macro and micro perspectives. J. Environ. Chall. 3. doi:10.1016/j.envc.2021.100035, https://doi.org/.

Regmi, B.R., Adhikari, A., 2007. Human Development Report 2007/2008- Fighting Climate Change: Human Solidarity in A Dividend World-Country Case Study -Nepal. Human Development Report Office, Occasional paper no. 57 http://hdr.undp.org/sites/default/files/regmi_bimal_and_adhikari_anu_nepal.pdf.

Singh, R.K., Rai, N., Singh, M., Singh, R., Kumar, P., 2015. Effect of Climate change on tomato leaf curl virus (ToLCV) disease in tomato. Ind. J. Agri. Sci. 85, 290–292.

, 2010. Annual progress report (2009/2010). In: Vegetable Development Directorate, Agriculture Department. Ministry of Agriculture and Coperative, Nepal, p. 89.

Ventrella, D., Charfeddine, M., Moriondo, M., Rinaldi, M., Bindi, M., 2012. Agronomic adaptation strategies under climate change for winter durum wheat and tomato in southern Italy: irrigation and nitrogen fertilization. Reg. Environ. Chang. 12, 407–419.