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Climate Change and Nam Dok Mai Mango Yield: A Process Management

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Abstract

Climate change affects plants and animals which need to adapt themselves to environmental changes. Nam Dok Mai mango (science name as *Mangifera indica Linn*) is one of the important economic crops in Thailand and it is also affected by climate change. In this research, the relationship in terms of *correlation* between climate and Nam Dok Mai mango yield was explored. The cultivation areas of Nam Dok Mai Mango in the eastern, northeastern, and northern regions were studied. Climate and diseases in the growers' orchards in these three areas were measured and collected in three phases: (1) flowering to fruit setting, (2) fruit setting to bagging, and (3) bagging to harvesting. Mango yields and qualities were measured and collected in the harvesting phase. The study results reveal that climate in the off-season crops has a great effect on mango yields and mango qualities than the on-season crops. The obtained findings were expected to benefit improvement in the production process management to reduce side effects from climate change and increase mango yields with good qualities.

Keywords*:* *Nam Dok Mai mango yield, climate change, correlation coefficient, production process management*

1. Introduction

Mangoes are one of the important economic crops of Thailand. The Office of Agricultural Economics (Kidsang, 2019) reported that Thailand has planted nearly 320,000 hectares of mangoes since 2016. The top five mango cultivation provinces are Phitsanulok, Chiang Mai, Prachuap Khiri Khan, Suphan Buri, and Phetchabun. Mangoes can be produced all year round and there are mango yields to the market throughout the year. However, the month with the highest yield is April. The strength of mango production in Thailand is that the production can be off season, but the crops are affected in quality from diseases.

Nam Dok Mai Mango is a major export crop currently exposed to climate change. Most of the effects stemmed from elevated temperatures, drought, dry spells, too much rain, and humidity fluctuation at the start and the end of the season (Boonpradub, 2015). These aspects affect mango growth, yield, and quality, as seen in a rapid increase in pests and diseases. In addition, high temperature and severe drought accelerate flowering to occur faster than usual. As a result, the blooming period of mango flowers does not correspond with the pollination period of insects—leading to less fruiting.

In this research, the impact of climate on growers' production process management was investigated by finding the correlation coefficient between climate and mango yields to identify factors affecting mango yields and their qualities. The study results will be used to adjust the management process of Nam Dok Mai Mango production to reduce the effects of climate change. The study also aimed to identify the best practice of the management process that can avoid or reduce the damage on mango yield caused by climate change in the case of Nam Dok Mai mango as well as the other mango types.

2. Literature Review

The effect of climate change on mango production was studied by Worasathit et al. (2020). The researchers investigated the area of mango cultivation in Khon Kaen Province which is in the northeast region of Thailand. The results of the study pointed to climate change affecting the flowering and fruit development phases of mangoes in the crop season. The research covered development of mango flowering in 2014 and 2015 with temperatures below 20 degrees Celsius from 15 September to 25 November 2014, and 6 December 2014 to 15 February 2015. However, rainfall in February and March 2015 caused the development of peduncles into leaves. High temperature and rain caused the flowers and inflorescences to drop. The researchers also found that climate change had impacts on insect infestations. Although growers tried to maintain and prevent diseases and insects, they were not able to protect mangoes against pests and insects in arid environments. Growers adapted their cultivations to climate change by producing mango off season instead. The off-season crops mean more profits (Sukiam et al., 2020) and they have to adjust production as an innovation in changing their management process (Sriboonnark, 2020). Therefore, the pruning phase was postponed to February to allow the flowering period to correspond with the cold weather. However, this caused mango trees to encounter the hot weather in April. Growers solved this problem by using nets to shade mango trees. The net was found to help ease up the fruit setting phase.

In this study, the researchers explored the relationship between climate and Nam Dok Mai Mango yields by values of correlation coefficient. Taylor (1990) put Equation 1 for analyzing the relationship between two or more variables to find whether they are related or not.

$$\text{Correlation coefficient } (r) = \frac{\sum xy - n\overline{x}\overline{y}}{\sqrt{\left(\sum xi^2 - n\overline{x}^2\right)}\sqrt{\left(\sum yi^2 - ny^2\right)}} \quad (1)$$

where n = number of samples, $\overline{x}$ = average of x variable, $\overline{y}$ = average of y variable.

The interpretation of correlation coefficient r is as follows:

- If r is a positive number, it means x and y have direct relationship. If value of x variable increases, then value of y variable will also increase.
- If r is a negative number, it means x and y have inverse relationship. If value of x variable increases, then value of y variable will decrease.
- If r is zero, it means x and y are not associated.
- If absolute of r or $|r|$ is closer to one, then x and y are closely related.
- If $|r|$ is closer to zero, then x and y are less correlated.

3. Research Objective

The research objective of this study was to use correlation coefficients to find the degrees of relationship between climate and Nam Dok Mai mango yields and qualities.

4. Research Methodology

This research examined the correlation coefficient between climate and Nam Dok Mai Mango yields as crops on season and off season. The cultivated areas in the study were divided into two sets. The first area consisted of mango orchards in two provinces--Sa Kaeo, Chachoengsao, and Nakhon Ratchasima. Growers in the first area produced mangoes both on season and off season. The on-season crop of the first area was from November to May and the off-season crop from June to November. The second area covered mango orchards in four provinces--Phichit, Phitsanulok, Phetchabun, and Chiang Mai. Growers in the second area produced mangoes only on season from October to May.

The research was conducted in three stages:

(1) Collecting data on climate and diseases,

(2) Gathering data on mango yields and mango qualities, and

(3) Finding correlation coefficients between climate and mango yields.

4.1 Collecting Data on Climate and Diseases

Factors affecting mango yields were studied and collected as follows: temperature, relative humidity, and disease. These factor data were divided into two sets: on-season and off-season crops. Data of each season were divided into 3 phases: (1) flowering to fruit setting, (2) fruit setting to bagging, and (3) bagging to harvesting.

For each mango orchard, diseases were collected for the whole season and the average percent of diseases for all mango trees in each orchard was computed. Temperature and relative humidity were measured and collected every day for each phase and the following data were computed:

(1) Daily temperature and relative humidity values were averaged.
(2) Maximum daily temperature and relative humidity values were averaged.
(3) Minimum daily temperature and relative humidity values were averaged.
(4) Different maximum and minimum for daily temperature and relative humidity values were averaged.

The climate and disease data for on-season and off-season crops are displayed in Tables 1 and 2, respectively.

4.2 Gathering Data on Mango Yields and Product Qualities

Mango yields and mango qualities were collected by the end of the third phase. The product qualities were divided into 6 variables: (1) grade A, (2) grade B, (3) weight, (4) specific gravity, (5) Total Soluble Solid (TSS), and (6) Titratable Acidity (TA).

Mango grades are defined by the Office of Agricultural Economics (2021) as follows:

(1) Mangoes classified as grade A must have weight between 300 and 600 gram and their skin must not have blemish by insects.
(2) Mangoes classified as grade B must have weight between 200 and 299 grams and their skin must not have blemish by insects.

According to Wongkhot, Rattanapanone, & Chanasut (2012), the specific gravity is used to measure starch in fruit. The specific gravity of fruit depends on its species including maintenance during planting. If a fruit has a high specific gravity, it shows that there is a large amount of starch. This will result in the fruit being very sweet. The relationship between TSS and TA is also used to measure fruit sweetness. If TSS value is large and TA is small, it indicates that a fruit is very sweet.

The mango yields and qualities for both on-season and off-season crops are presented in Table 3.

4.3 Finding Correlation Coefficients between Climate and Mango Yields

Python programming language was used to find correlation coefficients between climate, diseases, mango yields, and mango qualities. The function named data_corr() in pandas library (The Pandas Development Team, 2021) was used to calculate correlation coefficients. The formula in Equation 1 is used in the data_corr() function to find the correlation coefficients. The results were later generated in the form of graphs. The numpy (The NumPy Community, 2021) and matplotlib (Matplotlib Development Team, 2021) libraries were used to generate graphs of correlation coefficient results. The Python codes are displayed in Figure 1 as described below:

(1) Steps 1-3: Import pandas, numpy, and matplotlib libraries.
(2) Step 4: Define user function named find_corr(in_file), where in_file is an input parameter of the function. The in_file is a file name containing data with CSV file format to find correlation coefficient.
(3) Step 5: Read data stored in the in_file to keep in the variable named "data."
(4) Step 6: Call function named data_corr() to calculate correlation coefficient and stored results in a variable named corr.
(5) Step 7-17: Convert correlation coefficient results stored in the variable named corr into a graph.
(6) Step 18-23: Each step is used to call the function named find_corr(in_file) to execute. The find_corr(in_file) function generates correlation coefficient graph of following CSV input file:

a. The on_season_yields_phase1.csv stores climate and mango yield data of the first phase of on-season crop.
b. The on_season_yields_phase2.csv stores climate and mango yield data of the second phase of on-season crop.
c. The on_season_yields_phase3.csv stores climate and mango yield data of the third phase in of on-season crop.
d. The off_season_yields_phase1.csv stores climate and mango yield data of the first phase of off-season crop.
e. The off_season_yields_phase2.csv stores climate and mango yield data of the second phase of off-season crop.
f. The off_season_yields_phase3.csv stores climate and mango yield data of the third phase of off-season crop.

Table 1: Climate and Disease Data for the On-season Crop

	T AVG (C)	**T MAX (C)**	**T MIN (C)**	**T (MAX-MIN) (C)**	**RH AVG (%)**	**RH MAX (%)**	**RH MIN (%)**	**RH (MAX-MIN) (%)**	**Disease (%)**
On-season: the 1st Phase of Flowering to Fruit Setting									
1	27.81	32.04	22.03	10.01	51.82	58.34	38.22	20.12	3.13
2	27.81	32.04	22.03	10.01	51.82	58.34	38.22	20.12	3.23
3	27.81	32.04	22.03	10.01	51.82	58.34	38.22	20.12	6.45
4	26.83	27.87	25.10	2.77	74.97	81.95	69.95	12.00	0.00
5	26.83	27.87	25.10	2.77	74.97	81.95	69.95	12.00	6.45
6	26.83	27.87	25.10	2.77	74.97	81.95	69.95	12.00	6.45
7	27.03	30.15	20.95	9.20	71.24	82.32	43.98	38.34	6.67
8	27.88	24.05	19.33	4.72	57.41	63.55	51.68	11.87	0.00
9	27.88	24.05	19.33	4.72	57.41	63.55	51.68	11.87	0.00
10	27.88	24.05	19.33	4.72	57.41	63.55	51.68	11.87	6.06
11	29.31	24.21	18.39	5.82	59.82	68.02	52.04	15.98	0.00
12	29.31	24.21	18.39	5.82	59.82	68.02	52.04	15.98	3.33
13	29.31	24.21	18.39	5.82	59.82	68.02	52.04	15.98	0.00

On-season: the 2nd Phase of Fruit Setting to Bagging									
1	29.68	35.56	27.83	7.73	57.28	61.61	41.75	19.86	3.13
2	29.68	35.56	27.83	7.73	57.28	61.61	41.75	19.86	3.23
3	29.68	35.56	27.83	7.73	57.28	61.61	41.75	19.86	6.45
4	28.69	32.38	24.13	8.25	73.41	93.15	44.07	49.08	0.00
5	28.69	32.38	24.13	8.25	73.41	93.15	44.07	49.08	6.45
6	25.69	30.15	19.61	10.54	71.96	82.32	43.98	38.34	6.45
7	26.42	28.25	21.49	6.76	66.83	82.29	51.61	30.68	6.67
8	24.22	26.41	21.51	4.90	51.75	60.35	43.94	16.41	0.00
9	24.22	26.41	21.51	4.90	51.75	60.35	43.94	16.41	0.00
10	24.22	26.41	21.51	4.90	51.75	60.35	43.94	16.41	6.06
11	24.40	27.18	21.98	5.20	54.59	62.30	43.87	18.43	0.00
12	24.40	27.18	21.98	5.20	54.59	62.30	43.87	18.43	3.33
13	24.40	27.18	21.98	5.20	54.59	62.30	43.87	18.43	0.00
On-season: the 3rd Phase of Bagging to Harvesting									
1	29.50	32.82	25.98	6.84	53.14	61.94	48.71	13.23	3.13
2	29.50	32.82	25.98	6.84	53.14	61.94	48.71	13.23	3.23
3	29.50	32.82	25.98	6.84	53.14	61.94	48.71	13.23	6.45
4	34.14	37.75	28.04	9.71	65.83	79.63	51.93	27.70	0.00
5	34.14	37.75	28.04	9.71	65.83	79.63	51.93	27.70	6.45
6	27.40	30.23	23.98	6.25	57.62	65.42	46.79	18.63	6.45
7	27.42	32.23	23.98	8.25	55.93	65.42	46.79	18.63	6.67
8	28.78	32.65	25.30	7.35	44.63	77.08	33.36	43.72	0.00
9	28.78	32.65	25.30	7.35	44.63	77.08	33.36	43.72	0.00
10	28.78	32.65	25.30	7.35	44.63	77.08	33.36	43.72	6.06
11	28.11	31.64	25.11	6.53	50.70	80.25	38.18	42.07	0.00
12	28.11	31.64	25.11	6.53	50.70	80.25	38.18	42.07	3.33
13	28.11	31.64	25.11	6.53	50.70	80.25	38.18	42.07	0.00

T = Temperature, C = Celsius, AVG = Average, RH = Relative Humidity

Table 2: Climate and Disease Data for the Off-season Crop

	T AVG (C)	**T MAX (C)**	**T MIN (C)**	**T (MAX-MIN) (C)**	**RH AVG (%)**	**RH MAX (%)**	**RH MIN (%)**	**RH (MAX-MIN) (%)**	**Dis-ease (%)**
Off-season: the 1st Phase of Flowering to Fruit Setting									
1	27.77	28.88	26.13	2.75	94.27	97.86	89.73	8.13	15.09
2	27.77	28.88	26.13	2.75	94.27	97.86	89.73	8.13	16.00
3	35.49	37.37	32.24	5.13	87.09	99.33	76.36	22.97	18.00
4	26.99	29.59	24.34	5.25	70.33	83.86	61.95	21.91	21.62
5	22.20	24.22	19.93	4.29	94.61	99.79	88.74	11.05	5.88

	T AVG (C)	T MAX (C)	T MIN (C)	T (MAX-MIN) (C)	RH AVG (%)	RH MAX (%)	RH MIN (%)	RH (MAX-MIN) (%)	Dis-ease (%)
Off-season: the 2nd Phase of Fruit Setting to Bagging									
1	28.40	29.94	26.42	3.52	89.28	98.07	81.65	16.42	15.09
2	28.40	29.94	26.42	3.52	89.28	98.07	81.65	16.42	16.00
3	36.36	44.13	29.38	14.75	82.94	99.90	32.07	67.83	18.00
4	25.68	29.47	21.09	8.38	61.16	66.65	46.99	19.66	21.62
5	21.24	25.71	15.66	10.05	90.16	96.73	77.92	18.81	5.88
Off-season: the 3rd Phase of Bagging to Harvesting									
1	26.04	29.47	21.09	8.38	62.50	76.14	46.99	29.15	15.09
2	26.04	29.47	21.09	8.38	62.50	76.14	46.99	29.15	16.00
3	34.08	37.18	27.54	9.64	80.01	99.86	66.35	33.51	18.00
4	30.10	33.30	27.87	5.43	72.59	91.78	47.90	43.88	21.62
5	24.08	28.00	15.87	12.13	88.35	95.31	83.02	12.29	5.88

T = Temperature, C = Celsius, AVG = Average, RH = Relative Humidity, SG = Specific Gravity.

Table 3: Nam Dok Mai Mango Yields and Qualities for both On-season and Off-season Crops

	Grade A (%)	Grade B (%)	Weight (g)	SG	TSS (%Brix)	TA (%)		Grade A (%)	Grade B (%)	Weight (g)	SG	TSS (%Brix)	TA (%)
On-season								**Off-season**					
1	78.13	21.88	356.11	1.03	21.36	0.42	1	64.15	35.85	312.45	1.02	17.48	0.87
2	87.10	12.90	417.50	1.03	22.61	0.42	2	53.33	46.67	376.26	1.01	17.03	0.96
3	64.52	35.48	337.91	1.02	18.88	0.36	3	88.00	12.00	298.34	1.04	18.88	0.55
4	84.38	15.63	327.88	1.30	16.61	0.49	4	72.97	27.03	352.24	1.02	21.56	0.45
5	83.87	16.13	350.95	1.02	17.99	0.54	5	79.41	20.59	215.19	1.04	20.27	0.66
6	87.10	12.90	307.62	1.02	17.06	0.48							
7	83.33	16.67	352.69	1.03	20.21	0.67							
8	36.36	63.64	356.32	1.02	19.01	0.53							
9	74.29	25.71	309.22	1.03	17.84	0.35							
10	84.85	15.15	429.32	1.02	16.22	0.24							
11	97.14	2.86	292.95	1.01	16.96	0.22							
12	93.33	6.67	358.08	1.01	16.93	0.19							
13	73.68	26.32	277.06	1.01	16.50	0.27							

g = gram, SG = Specific Gravity

Figure 1: Python Codes for Computing Correlation Coefficients

```
import pandas as pd                                                   #1
import numpy as np                                                    #2
import matplotlib.pyplot as plt                                       #3

def find_corr(in_file):                                               #4

    data = pd.read_csv(in_file, index_col=0)                          #5
    corr = data.corr()                                                #6

    fig = plt.figure()                                                #7
    ax = fig.add_subplot(111)                                         #8
    cax = ax.matshow(corr,cmap='binary', vmin=-1, vmax=1)             #9
    fig.colorbar(cax)                                                 #10
    ticks = np.arange(0,len(data.columns),1)                          #11
    ax.set_xticks(ticks)                                              #12
    plt.xticks(rotation=90)                                           #13
    ax.set_yticks(ticks)                                              #14
    ax.set_xticklabels(data.columns)                                  #15
    ax.set_yticklabels(data.columns)                                  #16
    plt.show()                                                        #17


find_corr('on_season_yields_phase1.csv')                              #18
find_corr('on_season_yields_phase2.csv')                              #19
find_corr('on_season_yields_phase3.csv')                              #20

find_corr('off_season_yields_phase1.csv')                             #21
find_corr('off_season_yields_phase2.csv')                             #22
find_corr('off_season_yields_phase3.csv')                             #23
```

5. Experimental Results

The Python code in Figure 1 was executed and the results are displayed in Figures 2 to 7.

Figures 2 and 3 show the results of correlation coefficients of the flowering to fruit setting phase in the on-season and off-season crops, respectively. The results indicate that:

(1) Difference in temperature and relative humidity in the off-season crop have a greater effect on Grade A yield than the on-season crop, but opposite with grade B yield.

(2) Average temperature, maximum temperature, and minimum temperature in the off-season crop has greater effect on mango weight than the on-season crop.

Figure 4 and 5 show the results of correlation coefficients of the fruit setting to bagging phase in the on-season and off-season crops, respectively. The results indicate that:

(1) Average temperature, difference in temperature and relative humidity in the off-season crop have a greater effect on Grade A yield than the on-season crop.

Minimum relative humidity in the off-season crop has a great effect on Grade B yield.

(2) Average temperature and minimum temperature have a great effect on mango weight in the off-season crop.

Figure 6 and 7 show the results of correlation coefficients of the fruit bagging to harvesting phase in the on-season and off-season crops, respectively. The results indicate that:

(1) Climate has little effect on mango weight, and grade A and grade B yields in the on-season crop. Average temperature, maximum temperature, average relative humidity, maximum relative humidity, and minimum relative humidity have a great effect on grade A yield in the off-season crop, but opposite with grade B yield.

(2) Average temperature, maximum temperature, and minimum temperature have an effect on mango weight in the off-season crop.

Temperature in the off-season crop has a greater effect on diseases than the on-season crop. High temperature and relative humidity in both on-season and off-season crops have a great effect on sweetness of mangoes.

(1) Temperature and humidity have less effect on grade A yield, grade B yield, and mango weight in the on-season crop. Temperature and humidity have a great effect on grade A yield in the off-season crop, but opposite with grade B yield.

(2) Average temperature, maximum temperature, and minimum temperature have a great effect on mango weight in the off-season crop.

(3) High temperature, low humidity and difference of humidity have an effect on disease in the off-season crop.

(4) High temperature and high relative humidity in the off-season crop results in increased starch.

Figure 2: Correlation Coefficients between Climate and Nam Dok Mai Mango Yields of the Flowering to Fruit Setting Phase in the On-season Crop

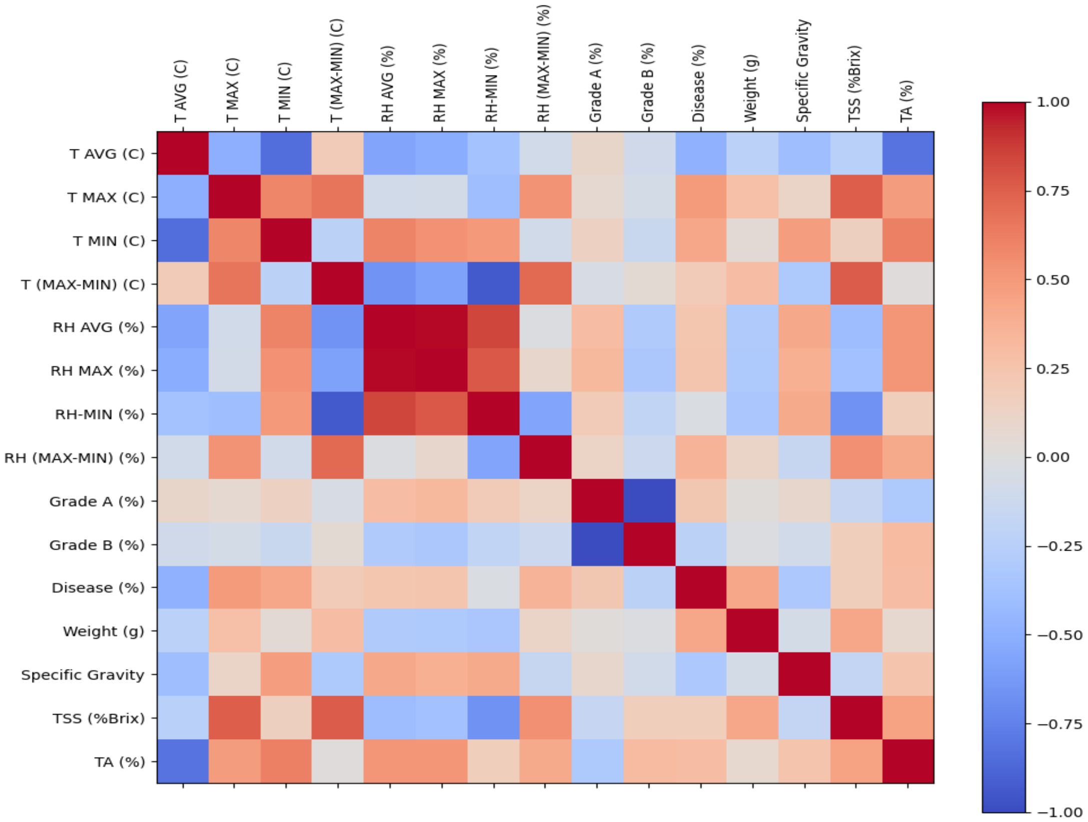


Figure 3: Correlation Coefficients between Climate and Nam Dok Mai mango Yields of the Flowering to Fruit Setting Phase in the Off-season Crop

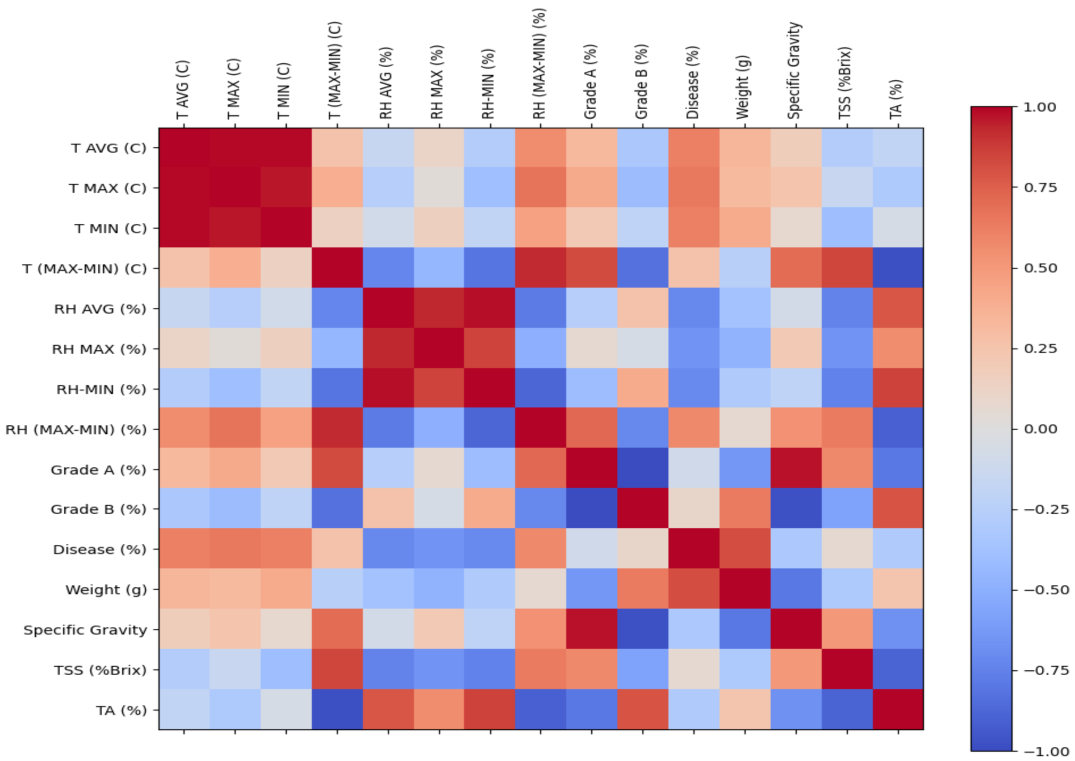


Figure 4: Correlation Coefficients between Climate and Nam Dok Mai Mango Yields of the Fruit Setting to Bagging Phase in the On-season Crop

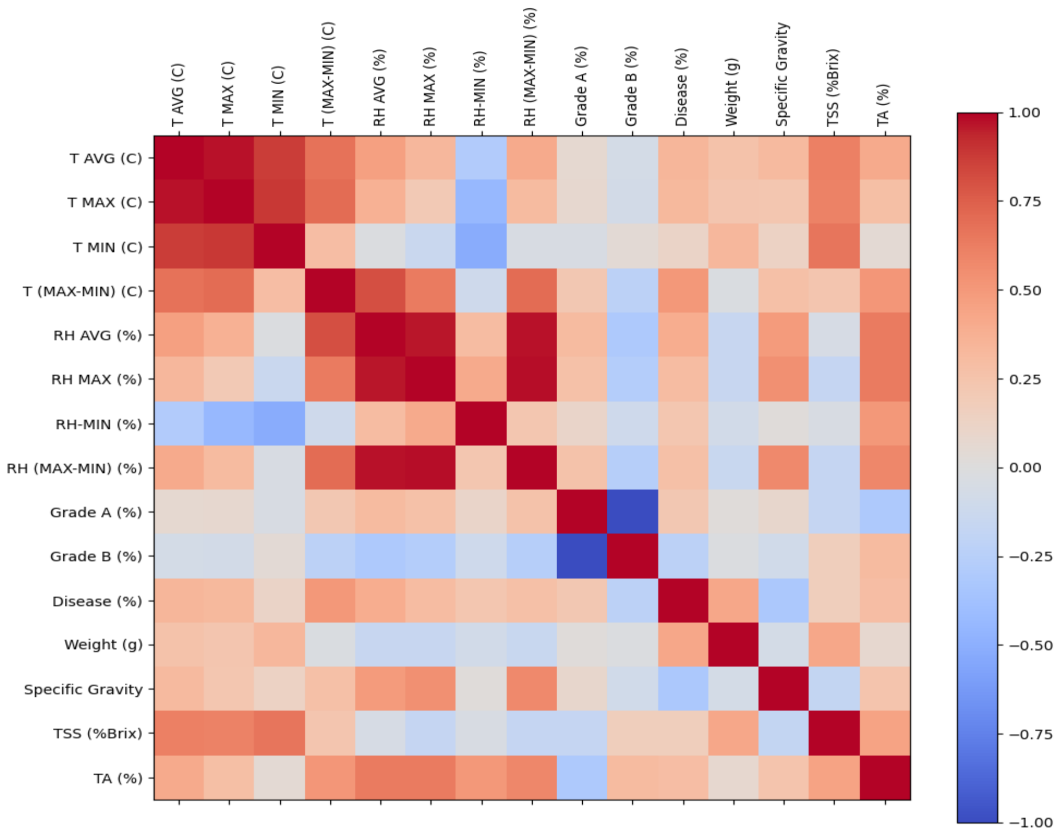


Figure 5: Correlation Coefficient between Climate and Nam Dok Mai Mango Yields of the Fruit Setting to Bagging Phase in the Off-season Crop

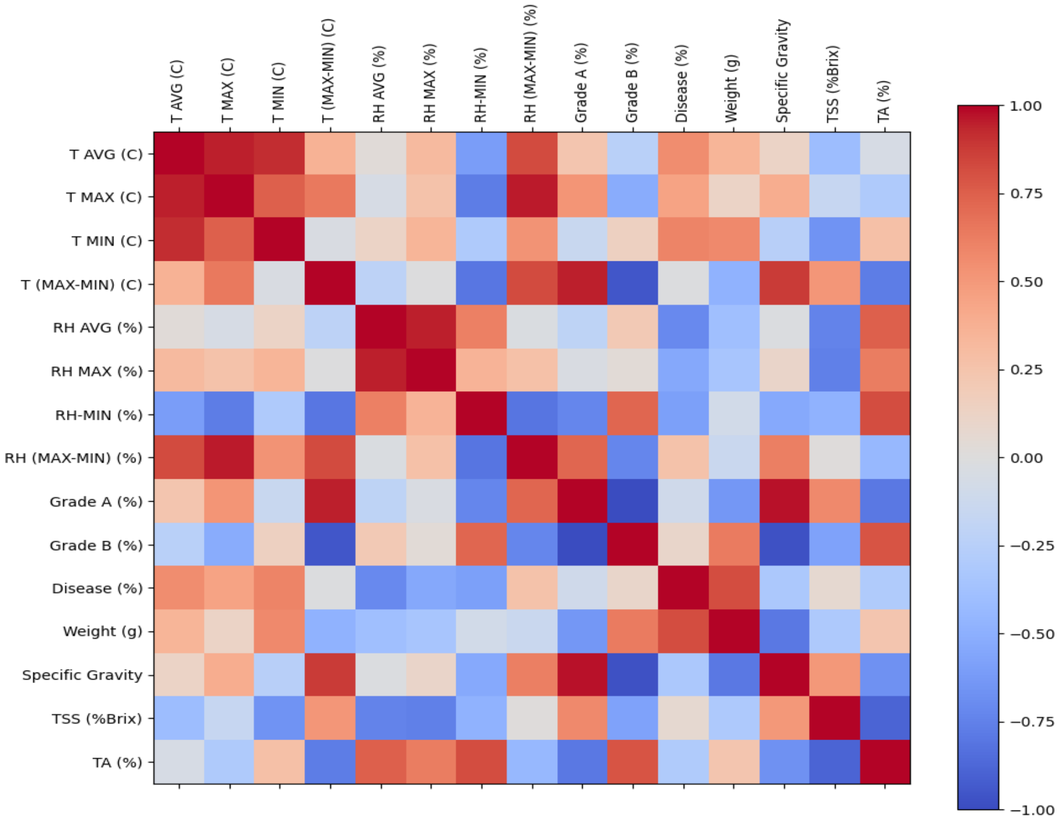


Figure 6: Correlation Coefficients between Climate and Nam Dok Mai Mango Yields of the Bagging to Harvesting Phase in the On-season Crop

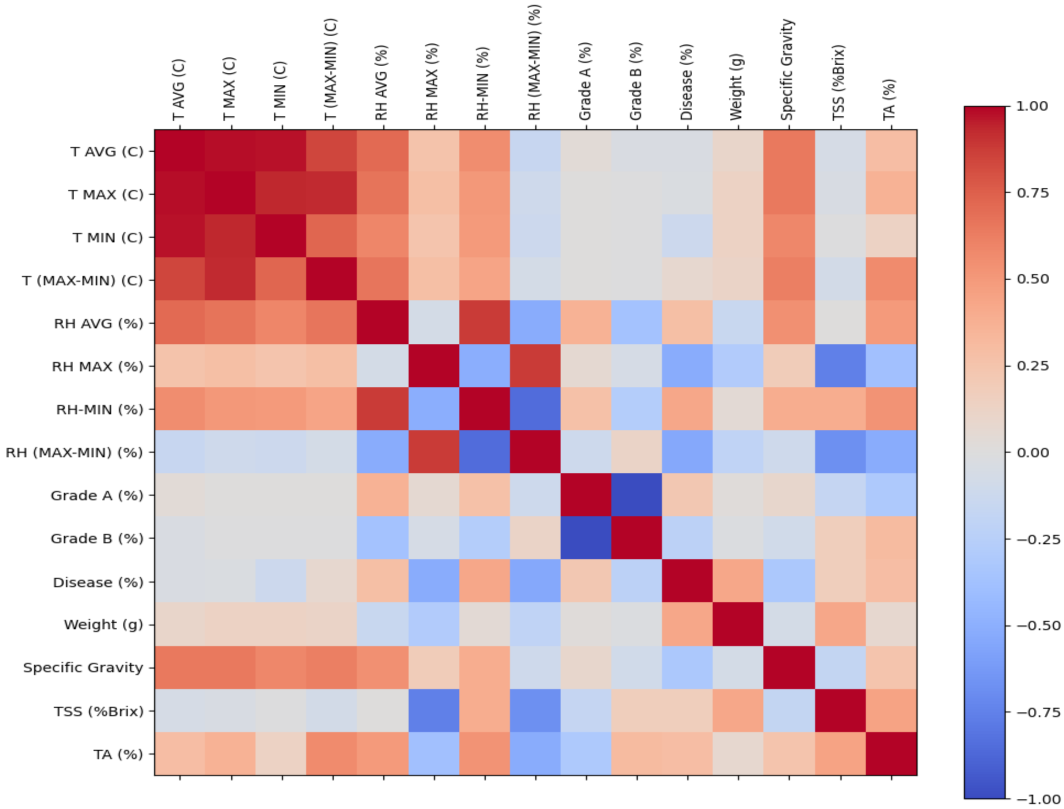
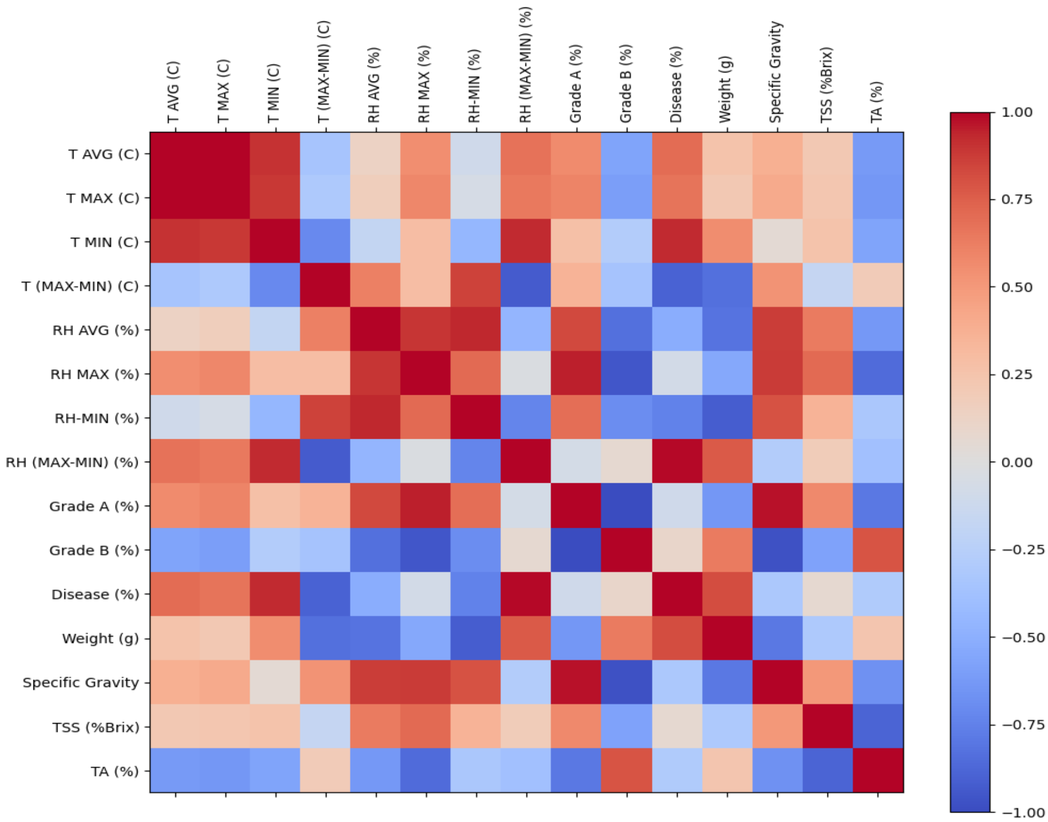


Figure 7: Correlation Coefficients between Climate and Nam Dok Mai Mango Yields of the Bagging to Harvesting Phase in the Off-season Crop



6. Discussion and Conclusion

The correlation coefficient was applied to find relationship between climate, diseases, mango yields, and mango qualities in both the on-season and off-season crops. The climate and mango yields were measured and collected from the selected mango orchards in three regions with differences in climate: eastern, northeastern, and northern. The results revealed that mango yields and their qualities produced off season are highly correlated with temperature and relative humidity than those on season. Temperature off season has a greater effect on diseases than that on season. High temperature and relative humidity both on season and off season have a great effect on mango starch.

The results of the studies are vitally important to the production process management of off-season mango yields. The correlation coefficient results can be used to manipulate mango orchards in the production process to increase mango yields and improve mango qualities. The researchers have planned to conduct a further study in the following year to identify the side effects of climate change to be avoided or reduced in two cases: (1) If the production phase needs low temperature at the time of very high temperature, to what extent should the growers use shading nets to cover mango trees to reduce temperature? And (2) If the production process requires relatively high humidity amidst drought, to what extent should the growers use sprinklers for a required relative humidity? The results to be obtained from further studies are expected to generate a useful guideline for Nam Dok Mai Mango growers to increase efficiency in their off-season production process management in terms of yield and quality.

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