Description of climatic factors for informed Sesame (Sesamum indicum L.) cultivation in Kafta Humera District, North Ethiopia

Kahsay Tadesse Mawcha<sup>a</sup>, Michele Gebrekirstos Gebreslassie<sup>a,b</sup>, Hailu Molla Gebreyohannes<sup>a,c</sup> and Assefa Mewael Kirso<sup>a</sup>

*Department of Plant Sciences, Aksum University Shire Campus, Tigray, Ethiopia; <sup>b</sup>School of Water Resources and Irrigation Engineering, Aksum University Shire Campus, Tigray, Ethiopia; <sup>c</sup>Shire Agricultural College, Tigray, Ethiopia

**ABSTRACT**

Sesame is an important oil crop and is very well-known for its quality plant oil. The study was conducted in Kafta-Humera to assess the rainfall variability and distribution of the area at an annual, seasonal, and monthly and 10 days scales based on the daily rainfall; and to describe the summer based on the accumulated rainfall and dry spell durations. All the meteorological data were analysed using InStat statistical package software. The mean of the kiremt rainfall was 556 mm with 95% confidence for mean 479.8 to 633.43 mm and has high variability with a coefficient of variability about 0.24. The rainfall intensity during the Kiremt season in Humera showed that the seasonal rainfall varies from 307.1 mm to 777 mm in 4 months. March, April, and May were the hottest months, where all the years have at least 1 day with a maximum temperature of above 44°C and the mean seasonal rainfall was 556.61 mm. The variability of the mean temperatures of all the months were very less except for July, August, and October with very high mean monthly temperature variability (SD>4). Kiremt, the main rainy season onset is the first wet spell of the year at least 3 days totalling 20 mm or more, provided there were no sequences of 10 or more dry days in the subsequent 30 days. The start date of sowing at Kafta-Humera was 19 June with a 95% confidence interval of average 07 June to 01 July. It had high variability with a standard deviation of about 2 weeks. Hence, farmers should arrange their sowing time in between the summer onset ranges, i.e. 07 June to 01 July.

1. Introduction

Sesame accounts for over 90% of the values of oilseeds exports from Ethiopia to the world. Ethiopia is the second-largest sesame exporter in the world after India and sesame is the second most valuable crop next to coffee in Ethiopian foreign exchange earnings (Rutes et al., 2015; Wijnands et al., 2009; Zerihun, 2012). Ethiopia is also known globally for producing quality sesame seeds (Wijnands et al., 2009) and supply to the international market (Boutros-Ghali, 2010; Fiseha & Gebrelibanos, 2018; Gebremariam, 2015; Girmay, 2018; Rutes et al., 2015). In the last decade, sesame production and marketing have shown very significant growth (Boutros-Ghali, 2010; Fiseha & Gebrelibanos, 2018). Sesame contributes about 1.5% to Ethiopian National Gross Domestic Product (GDP) and shares about 14% of foreign export earnings (Food and Agriculture Organization of the United Nations, 2015). According to the annual report of the Ministry of Trade of the Federal Democratic Republic of Ethiopia (MoT), sesame is the second major source of income next to coffee. Kafta-Humera district, northern Ethiopia, has suitable agroecology for sesame production, and Humera-type sesame is also highly preferred in the international market. This is mainly due to its high-quality seed and strong aroma, and is most preferred for bakery and other products (Wijnands et al., 2009).

The major contributor of sesame to the Ethiopian market is the northern parts of Ethiopia (Boutros-Ghali, 2010; Niguse, 2015; Rutes et al., 2015; Wijnands et al., 2009). However, changes in rainfall and temperature patterns are observed in many semi-arid parts of the developing countries including Humera, northern Ethiopia (Niguse, 2015). Characterizing the climate of the area is very important for agricultural planning and sesame production.

Though total sesame production has increased enormously over the past 10 years, sesame yields per hectare have remained constant or have declined (Boutros-Ghali, 2010). The yield loss is attributed to many factors (Fiseha & Gebrelibanos, 2018; Rutes et al., 2015). According to the survey of the Aksum University...
(College of Agriculture) made in March 2017, the major reasons behind the declining yields are pest and diseases problem, weeds, atmospheric air variability and quality of seeds are hardly available (Babu, 2018; Fiseha & Gebrelibanos, 2018; Girmay, 2018; Wijnands et al., 2009). Poor extension and adoption are also other collateral problems (Fiseha & Gebrelibanos, 2018; Girmay, 2018). These major problems need innovative actions that can be immediately implemented. In this regard, producing quality sesame seed holds immense potential to tackle the problem (Babu, 2018; Niguse, 2015). Also, knowing the planting time and water requirements for sesame production can address the problem of yield reduction in the area.

However, comparing with other countries, sesame production and productivity in Ethiopia particularly in Kaffta-Humera is very low and highly dependent on weather conditions (Girmay, 2018). The reason for the low productivity is very often due to climate variability (Girmay, 2018; Kostka & Scharrer, 2011; Rutes et al., 2015) and sesame cultivation mainly depends on the main rain season (kiremt season) as the crop is highly sensitive to water stress especially during the flowering stage. During this stage, the crop needs more water or moist weather (Niguse, 2015). For good sesame cultivation 500–800 mm of rainfall is optimal (Boere et al., 2015; Fiseha & Gebrelibanos, 2018; Rutes et al., 2015) and it does not tolerate excess water as the crop is susceptible to waterlogging (Girmay, 2018; Ibrahim, 2015; Jan et al., 2018; Rutes et al., 2015; Wijnands et al., 2009), and it can therefore only thrive during moderate rainfall, or when irrigation supply is carefully controlled in drier regions (Jan et al., 2018). The crop has taproots and this helped it to become more resistant to drought (Boere et al., 2015; Rutes et al., 2015). Furthermore, sesame can also grow better in sandy soils than in heavy soils (Boutros-Ghali, 2010), because heavy soils hold more water (soil moisture) than sandy soils (Niguse, 2015).

Climatic variations such as averages of temperature, rainfall, and relative humidity influence the productivity of sesame (Ibrahim, 2015; Nath et al., 2001). Other climate variables including cloud cover, soil temperature (microclimate), and timing cycles of weather phenomena have also impacted on sesame cropping success (Saxena et al., 2017). Macro and microclimatic factors play a significant role in the arid and rain-fed areas to obtain optimum sesame yields (Saxena et al., 2017). Therefore, studying climatic factors is useful to enhance the production and productivity of sesame crops. Knowledge of the impact of the climatic factors would be very useful for sesame production in arid zone farming (Kostka & Scharrer, 2011; Saxena et al., 2017) like the Kaffta-Humer area of northern Ethiopia.

According to the findings of Niguse and Aleme (2015), the end-users knowledge to use the locally available climate information and the ability to interpret the climate forecast is insufficient. On the other hand, Ethiopian Meteorological Agency is providing useful climate forecast information but the users (local authorities, extension workers, and farmers) level of understanding of the terminologies used and also their ability to use this information to support the sesame farmers is very limited (Kostka & Scharrer, 2011). In many cases, the end-users will seek the information and use it when it will give a benefit. Therefore, designing an effective method that helps to communicate on useful climate information and explaining its meaning to farmers is very important (Kostka & Scharrer, 2011; Niguse & Aleme, 2015). According to Ezihe et al. (2017) recommendation, the availability of newspapers and radio/television broadcasts is very important to improve farmer’s awareness and to sustain sesame production during climate change. sustainable and resilient soil management, improved agricultural water management, and climate risk management are the key remedies to adapt the risk of climate change (Zougmoré et al., 2018).

Kiremt rainfall is one of the most determinant factors that leads to the reduction of sesame production due to its high spatial and temporal variability, and late start early cessation of the kiremt seasons (Niguse & Aleme, 2015). Insufficient information on the rainfall distribution and variability during the kiremt (main rain season) on-set in Kaffta-Humera, the major area for sesame production in northern Ethiopia. Hence, the current study is designed with the following objectives:

(I) To assess the rainfall variability and distribution of the area at an annual, seasonal, and monthly and 10 days (decade) time scales based on the daily data of the Humera meteorological station.

(II) To determine the main rain season/summer onset based on the accumulated rainfall and dry spell lengths so that it would help farmers for their decision on the start of sowing sesame

2. Methodological approach
2.1. Description of the study area

Kaffa-Humera is a district located in the northern part of Ethiopia in the northwest part of Tigray Regional State (Figure 1). It has an area of 632,318.6 hectares. The area is known for its potential for sesame production during the kiremt (main rainy) season (June to September). The annual average temperature is 28°C.
with an annual average rainfall total of 585 mm. The
dominant soil type of the study area is chromic black
vertisol and characterized by deep (150 cm) clay tex-
tured with 35.66% clay content, silt 35.66%, sand 38.66%
and electrical conductivity of 0.047 to 0.17 g mmohs/
cm, low organic matter content (<2%), and Cation
Exchange Capacity ranged from 37 to 77 meq/100 g of
soil (Ethiopian agricultural research organization, 2002;
Baraki and Berhe, 2019).

2.2. Data collection and analysis
All statistical properties of atmospheric variables of
more than 30 years were obtained from Tigray meteor-
ological agency Humera weather station. The atmo-
spheric data of the weather station were pooled with
average data and district level interpretation for the
study area was made.

The mean, standard deviation and coefficient of var-
ation of all atmospheric variables were calculated. For
statistical analysis of the computed data, InStat statisti-
cal package (version 3.37) was used.

3. Results and discussion
3.1. Annual rainfall totals at Humera
Sesame grows well in hot to warm semi-arid plains of the
Humera, Northern Ethiopia, ranging from 500 to
1600 m above sea level (Geremew et al., 2012). Sesame
has important agricultural attributes. It can grow in tropi-
cal and temperate conditions and grow well on stored soil
moisture with minimal irrigation or rainfall. It can produce
good yields under high temperatures, and its grain has
a high value in the market (Salvin et al., 2004). Sesame is
sensitive to weather hazards, particularly to ‘normal’ rain-
fall and temperature variances. Heavy rain and rising
humidity can damage the plant exposing the leaves and
pods to blight and other fungal diseases (Kostka &
Scharrer, 2011). Higher soil moisture can shorten the
germination and seedling stages but extends the rest of
the stages (Langham et al., 2008). The frequency of annual
rainfall at Kafita-Humera as illustrated in Figure 2, the
mean annual rainfall totals of Humera, is about 585 mm
with a 95% confidence interval (C95) for the mean from
512.6 to 655.62 mm. The annual rainfall total has high
variability with a coefficient of variability (CV) of about
0.24. This result indicates that there is high variability in
rainfall and its distribution within the rainy season of the
area. In order to respond for changing rainfall intensity,
farmers need to be aware of potential risks associated
with the rainfall changes. In order to make informed decisions,
farmers must have access to information on climatic con-
ditions and on potential adaptive measures to address the
constraints (Kostka & Scharrer, 2011).

Annual rainfall totals variability of Humera
Meteorological Station (1981-2013)
(1) Seasonal, Monthly, 10 days (Decade) Rainfall Totals and Kiremt Onset Distribution and Variability at Humera

In the study area, rainfall is characterized by low inter-annual and seasonal variability. Sesame production is related to the Kiremt rainfall as the crop is highly sensitive to water stress. Sesame needs a great attention in selecting the suitable sowing date to avoid the long dry spells during the flowering stage (Niguse & Aleme, 2015). Kiremt (June-September) season is the main rainy season in Kafa-Humera which contributes more than 95% of rainfall to the annual rainfall totals. The mean of kiremt rainfall 556 mm with 95% confidence for mean 479.8 to 633.43 mm and has high variability with a coefficient of variability about 0.24 as revealed in Figure 3. Humera is characterized by the monomodal type of rainfall distribution as indicated in Figures 4 and Figure 5. Kiremt (June to September), main rainy season onset is the first wet spell of the year at least 3 days totaling 20 mm or more, provided there were no sequences of 10 or more dry (<0.1 mm) days in the subsequent 30 days. Based on this definition, the average kiremt onset (start date of sowing) of Humera is 19 June with a 95% confidence interval of average 07 June to 01 July. It had high variability with a standard deviation of about 2 weeks as revealed in Figure 5.

According to the report on the nexus Humera case study, the mean of rainfall is inferred 540.6 and varies from 357.8 mm and 650 mm minimum and maximum, respectively. The median rainfall of the study area is reported about 549.5 mm annually and the coefficient of variation of the annual rainfall is reported about 16.7%. This indicates a limited variability of rainfall in the region. The average rainfall in the main kiremt season (June—September) contributes about 85% to the annual rainfall totals (Figure 6). Krishnakumar et al. (2009) also attempted to study temporal variation in monthly, seasonal and annual rainfall over Kerala, India, during the period from 1871 to 2005. However, to have good sesame production, rainfall in the range of 500–1000 mm is effective throughout the vegetation

**Figure 2.** Annual rainfall totals variability of Humera meteorological station (1981–2013).

**Figure 3.** Kiremt rainfall (June–September) totals variability (1981–2013).
period (Boere et al., 2015; Fiseha & Gebrelibanos, 2018; Rutes et al., 2015).

For example, the above figure (Figure 7) which gives the kiremt (June to September) rainfall of Humera, shows that the seasonal rainfall varies from 307.1 mm to 777 mm in 4 months. The mean seasonal rainfall is 556.61 mm, but that is an average, it does not mean that one can expect 556.61 mm during kiremt season.

As shown in Table 1, the lowest rainfall recorded in Humera in the recorded years period was 307.2 mm. Based on the trend, one can deduce that the rainfall during the coming season will be more than 307.2 mm as it was the lowest amount ever recorded. Note that all the kiremt seasons had at least 307.2 mm of total kiremt rainfall. The same is true for the wettest year. The highest amount of rainfall recorded in the recorded years
was 777 mm. The 90% of the years, the kiremt rainfall was below 761.7 mm. Interpreting this indicates that the chance (probability) of getting at least 761.7 mm is only 10%. In 50% of the years, the rainfall was below 518.3 mm. This further indicates that there is only a 50% chance of receiving 518.3 mm and above. Extension personnel and farmers understood the dynamics and regularly employ a range of drought preparedness strategies. Climate forecasts decrease the risk of drought impact only when the uncertainty associated with forecasts is communicated properly. Failure to communicate or understand the uncertainty of forecasts exposes users to excessive risk.

### 4. Temperature requirement for sesame production

Climate change has varying effects in rain-fed regions which may lead to large declines in yield during unfavorable years. Climate change can result in low grain yield production and consequently increment of price in the market channel. To mitigate such kind of climate risks, there must be an improved management practices to cope with the weather change. Sesame requires a long time of sunshine duration (Ibrahim, 2015). According to the report on the nexus Humera case study and Niguse and Aleme (2015), the mean minimum temperature ranges between 17.5°C and 22.2°C while, the mean maximum temperature varies between 33°C and 41.7°C. For optimum growth, sesame requires a high constant temperature in the range of 26°C–30°C. Sesame needs high temperature for germination and the soil temperatures should be above 25°C (Geremew et al., 2012; Rutes et al., 2015; Wijnands et al., 2009). The temperature profile at 30 days after emergence (DAE) within the crop canopy has a direct negative effect on yield, whereas the temperature profile at 50 DAE has a direct positive effect on yield (Nath et al., 2001). When the temperature rises above 40°C, pollination and the formation of capsules could be repressed (Jan et al., 2018). Due to high temperatures and long sunshine requirements for sesame production, the crop should be cultivated during the rainy season in tropical areas (Jan et al., 2018).

Temperature is a critical factor for sesame production, so it is vital to observe the average and extreme temperatures in the Kafa Humera district at monthly and annual time scale based on the daily data of the Humera meteorological station. Comprehending the suitability of temperature for sesame production during the kiremt (main rainy) and off seasons helps the farmers and decision-makers to produce sesame in the area with supplemental irrigation. Higher temperatures than the normal temperature shorten the vegetative and reproductive phases in sesame, while, cool night temperatures increase the ripening phase and full maturity stage (Langham et al., 2008). Sesame growers should consider the key actions at each growing stages. The temperature needed for sesame production is different from country to country, tropical to subtropical region. In Kafa Humera, the largest sesame producing region in Ethiopia, sesame requires a high constant temperature in the range of 26°C–30°C. Sesame needs high temperature for germination and the soil temperatures should be above 25°C.
(Geremew et al., 2012; Wijnands et al., 2009). Temperatures below an optimum level can affect sesame production. While in some countries, sesame yields more in very hot temperatures (48°C) with threshold temperature 16°C (Salvin et al., 2004). In Kafta Humera, sesame needs 25°C soil temperatures to plant. When the night temperatures go below the threshold, it takes longer time to grow (Langham et al., 2008).

4.1. Annual mean temperature variability

As shown in Figure 8, the annual mean temperature at Humera is 28°C with a 95% confidence interval for the mean from 27°C to 29°C. It has a very low variability with a coefficient of variability of about 0.07. However, the current result is in contrast to the findings of Robeson (2002) who reported from a different area that during summer, the coefficient of variation is at the higher side. A small change in temperature means results in a relatively high increase in the probability of temperature extremes (Folland et al., 1999; Ventura et al., 2002).

4.2. Monthly temperature extremes distribution

As shown in Figure 9, March, April, and May are the hottest months, when all the years have at least 1 day with a maximum temperature of above 44°C. August and September were the only months in the 17 years that never had a day with a maximum temperature above 40°C. All the days in all months had at least 32°C daily maximum temperature. In general, the maximum temperature at Humera increases starting from January till it reaches its peak in April, and then it decreases starting from June till it reaches its lowest point in August.

4.3. Monthly temperature average distribution at Humera

The maximum of the mean temperature of all the months in the 17 years as indicated in Figure 8 was between 24°C and 32°C and the average of the mean temperature of all the months was between 20°C and 28°C except for April above 28°C. The minimum of the mean temperature was above 16°C except for July and August below 16°C but above 10°C. The variability of mean temperatures of all the months was very low except for July, August, and October with very high mean monthly temperature variability (SD>4).

The maximum and minimum temperatures showed more or less similar variability over a study period. In kiremt (wet) season, mainly July and August the minimum temperature was found to be less compared to the maximum temperature (Figure 10 and 11). Similar findings were reported by Kaur et al. (2006) in Ludhiana with higher variability and asymmetrical distribution of temperature over time. An increase in temperature perhaps can cause extreme weather events such as drought, heavy rainfall, and storms (Balling and Idos, 1990; Bollen, 2014; Jan et al., 2018).

5. Conclusion

Generally, Ethiopia is considered as the center of origin for many crops including sesame, barley, sorghum, and faba-bean. The reason for this can be attributed to topographic diversity and a wide range of agroclimatic conditions. Better understanding and interpretation of the local weather variables such as temperature, relative humidity, and rainfall are essential features to support sesame growers to use locally climatic change information and weather forecasting information in drought-prone districts like the Kasfta-Humera in north Ethiopia, which requires additional considerations. Understanding the sowing time

Figure 8. Kiremti rainfall variability at Kafta-Humera.
Figure 9. Annual mean temperature variability at Kafta-Humera.

Figure 10. Monthly temperature extremes distribution at Kafta-Humera.

Figure 11. Monthly mean temperature distribution at Kafta-Humera.
is very important for sesame production, as late or early planting time affects the yield. Based on the present study, the average kiremt onset (start date of sowing) of Humera is 19 June with a 95% confidence interval of average 07 June to 01 July. Therefore, farmers should start sowing within these dates. Besides, the result indicated that there is high variability in rainfall and its distribution within the rainy season of the area. In order to respond to changing rainfall intensity, farmers need to be aware of potential risks associated with the rainfall changes.

Policy-makers are increasingly concerned about the impact of climate variability and change on the productivity of vulnerable crops like sesame. Relative humidity and some other weather factors such as the concentration of carbon dioxide in the air, sunshine duration, radiation intensity, and wind speed also influence the production of sesame. Hence, the effect and relationship of these factors need attention in future research.

**Acknowledgements**

This work was supported by Aksum University, Internal grant. The authors would like to express their gratitude to Tigray Agriculture Research Institute Humera Centre for the collaboration to use the meeting hall to provide on-farm training for district extension officers, model farmers, and crop production experts.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

**Funding**

The authors received no direct funding for this research.

**Notes on contributors**

**Kahsay Tadesse Mawcha** (Mr) is a PhD candidate and Assistant Professor of Plant pathology at the department of Plant sciences Aksum University Shire Campus. His research interest is on crop production and protection, and molecular plant pathology. He has designed and written this manuscript and approved the final paper.

**Michgaele Gebrekiros** (Mr) is a PhD candidate in Hydraulic engineering and has immense experiences on climate and weather forecasting. He has analyzed the weather data and approved the final draft.

**Molla GebreYohannes Hailu** (Mr) is a senior lecturer in crop production, and he works for Shire Agricultural college. He has reviewed drafts of the paper and approved the final draft.

**Mewael Kiros Assefa** (PhD) is a former academic staff of Aksum University Shire Campus department of Plant Sciences. He has reviewed drafts of the paper and approved the final.

**ORCID**

Kahsay Tadesse Mawcha [http://orcid.org/0000-0002-7310-8085](http://orcid.org/0000-0002-7310-8085)

**Competing Interests**

The authors declare no competing interests.

**PUBLIC INTEREST STATEMENT**

One of the most important fast-growing sectors in Ethiopia is the Oilseeds sector, both in terms of its foreign exchange earnings and as a main source of income for over 3 million people. It is the second largest source of foreign exchange earnings after coffee. In the last decade, sesame production and marketing have shown very significant growth. Between 2001 and 2011, the total area of production and the quantity of sesame produced have grown eightfold. The major contributor of this production achievement is the northwest of Ethiopia, particularly Humera. The reason for the low productivity is very often due to bad climate and sesame cultivation is mainly depends on the main rain season (kiremti season) as the crop is highly sensitive to water stress especially during the flowering stage. During this stage, the crop needs more water or moist weather.

**References**

Babu, M. (2018). A study on challenges and opportunities of sesame production (with reference to sesame farmers, Tigray regional state, Ethiopia). *International Journal of Academic Research and Development*, 3(2), 850–857.

Boere, A., Rutgers, T., Willems, D., Kidane, D., & Dolfen, W. (2015). *Business opportunities report: Oilseeds and pulses*. Ethiopian Netherlands business event 5-6 November 2015.

Bollen, K. (2014). *Structural equations with latent variables*. John Wiley & Sons.

Boutros-Ghali, B. (2010). Current challenges and future prospects. Recueil des Cours, Collected Courses, 7522(3), 362–379

Ezihe, J., Agbugba, I., Shaibu, G., & Bachev, H. (2017). Assessment of climate change on sesame cultivation in Makurdi local government area of Benue State, Nigeria. *Turkish Economic Review*, 4(2), 226–233.

Fiseha, B., & Gebrelibanos, G. (2018). Genotype environment interaction and stability of oil content of sesame (Sesamum indicum L.) genotypes in Northern Ethiopia. *Journal of Cereals and Oilseeds*, 9(3), 20–28. [https://doi.org/10.5897/JCO2018.0183](https://doi.org/10.5897/JCO2018.0183)

Food and Agriculture Organization of the United Nations. (2015). Analysis of price incentives for sesame seed in Ethiopia for the time period analysis of price incentives for sesame seed in Ethiopia. *Monitoring Anal. Food Agric. Policies*, 12, 47.
Gebremariam, G. (2015). Growth, yield and yield component of sesame (Sesamum indicum L.) as affected by timing of nitrogen application. *Growth*, 5, 5.

Geremew, T., Adugna, W., Muez, B., & Hagos, T. (2012). *Sesame production manual*. Ethiopian Institute of Agricultural Research, Embassy of the Kingdom of the Netherlands.

Girmay, A. (2018). Sesame production, challenges and opportunities in Ethiopia. *Agricultural Research and Technology, 15*(5), 1–6. doi: 10.5958/2229-4473.2018.00007.1

Ibrahim, A. (2015). The impact of rainfall on the yields of staple crops-sorghum and sesame in Sudan. *Journal of Plant Science & Research, 2*(2), 1–4.

Jan, A., Wageningen, V., Innovation, D., Deltares, E., Linden, N., Rozemeijer, N., Centre, W., & Verhagen, J. (2018). Report on the Nexus Humera case study in Ethiopia. *Energy Research Center of the Netherlands, 18*(23), 1–67.

Kaur, P., Singh, H., & Hundal, S. (2006). Annual and seasonal climatic variabilities at Ludhiana, Punjab. *Jour. Agric. Physics, 6*(1), 39–45. ResearchGate.

Kostka, G., & Sharrer, J. (2011). The contribution of different farming models to poverty alleviation, climate resilience and women’s s empowerment. *Oxfam Policy and Practice: Agriculture, Food and Land, 11*, 192–237. http://www.maketradefair.org/en/index.htm

Krishnakumar, K., Rao, G., & Gopakumar, C. (2009). Rainfall trends in twentieth century over Kerala, India. *Atmospheric Environment*, 43(11), 1940–1944. https://doi.org/10.1016/j.atmosenv.2008.12.053

Langham, R., Jerry, R., Glenn, S., & Terry, W. (2008). Sesame grower guide. www.sesaco.net.

Nath, R., Chakraborty, P., & Chakraborty, A. (2001). Effect of climatic variation on yield of Sesame (Sesamum indicum L.) at different dates of sowing. *Journal of Agronomy & Crop Science, 186*(2), 97–102. https://doi.org/10.1046/j.1439-037X.2001.00456.x

Niguse, A. (2015). Agro climatic characterization of the Western zone of Tigray region. *Humera*, 5(17), 24–30.

Niguse, A., & Aleme, A. (2015). Modeling the impact of climate change on production of Sesame in Western zone of Tigray, Northern Ethiopia. *Journal of Climatology & Weather Forecasting, 03*(3), 03. https://doi.org/10.4172/2332-2594.1000150

Robeson, S. (2002). Relationships between mean and standard deviation of air temperature: Implications for global warming. *Climate Research, 22*(3), 205–213. https://doi.org/10.3354/cr022205

Rutes, T., Boere, A., Willems, D., Dawit, K., & Dolfen, W. (2015). *Business opportunity report: Oilseeds and pulses*. Ethiopian Ministry of Agriculture.

Salvin, S., Bourke, M., & Byrne, T. (2004). *The new crop industries handbook*. Rural Industries Research and Development Corporation, No. 04/125.

Saxena, S., Godara, S., & Swami, P. (2017). Impact of micro-climatic factors on the growth stages of Sesame (Sesamum indicum L) agro-ecosystem for betterment of arid zone farming in the North-Western arid region of Rajasthan. Advances in Crop Science and Technology, 05(5), 1–6. https://doi.org/10.4172/2329-8863.1000308

Ventura, F., Pisa, P., & Ardizzoni, E. (2002). Temperature and precipitation trends in Bologna (Italy) from 1952 to 1999. *Atmospheric Research, 61*(3), 203–214. https://doi.org/10.1016/S0169-8095(01)00135-1

Wijnands, J., Biersteker, J., & Van Loo, E. (2009). *Oilseeds business opportunities in Ethiopia*. The Hague, 2009. https://www.researchgate.net/publication/40791372.

Zerihun, J. (2012). Sesame (Sesame indicum L.) crop production in Ethiopia: Trends, challenges and future prospects. *Science Technology, and Arts Research Journal, 1*(3), 1–7. www.starjournal.org

Zougmoré, R. B., Partey, S. T., Ouedraogo, M., Torquebiau, E., & Campbell, B. M. (2018). Facing climate variability in sub-Saharan Africa: Analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cahiers Agricultures, 27*(3), 34001. https://doi.org/10.1051/cagri/2018019