Discover Food

Research

Status of postharvest papaya anthracnose (*Colletotrichum gloeosporioides*) in Assosa Zone, Western Ethiopia

Muluken Getnet[1] · Kumlachew Alemu[1] · Binyam Tsedaley[1]

Received: 4 December 2023 / Accepted: 26 April 2024
Published online: 02 May 2024

Abstract
Papaya is among the most economically important fruit crops cultivated in Ethiopia supporting the livelihood of thousands of people. Anthracnose of papaya caused by *Colletotrichum gloeosporioides* is the major limitation that threatens the production and consumption of papaya fruit worldwide. This investigation was initiated to determine the current status of papaya anthracnose and identify factors influencing postharvest loss of papaya fruit in Assosa Zone, western Ethiopia. Field and market assessments were conducted in three major papaya-producing districts of Assosa Zone namely Assosa, Bambasi, and Homosha. Data on the disease intensity of anthracnose was recorded both in the field and in the market. Furthermore, factors associated with postharvest disease development were recorded through administration of a pretested semi-structured questionnaire to randomly selected papaya producers, wholesalers, and retailers. The results revealed that anthracnose of papaya was prevalent in all assessed localities, nevertheless, there was a significant ($p < 0.05$) difference between districts and peasant association in intensity of disease. At the orchard level, the disease incidence and severity ranged between 21.30–33.87% and 10.90–20.83%, respectively. Similarly, postharvest anthracnose incidence and severity ranged between 47.04–60.85% and 28.84–47.95%, respectively. Morphological and pathological identification of pure cultures from symptomatic fruits revealed that *C. gloeosporioides* was the causal agent of postharvest anthracnose of papaya in the Assosa Zone. Moreover, poor postharvest practices such as wrong methods of harvesting, improper handling of produce, and poor or improper transportation facilities are some factors that significantly influence postharvest disease development. This empirical evidence revealed that anthracnose is the major challenge to papaya production and utilization in Assosa, Western Ethiopia.

Keywords Incidence · Severity · Disease development · Postharvest loss · Environment

1 Introduction

Papaya (*Carica papaya* L.) is one of the most economically important fruit crops grown throughout the tropical and subtropical regions of the globe. It is ranked as the fourth most popular tropical fruit, behind banana, mango, and pineapple and global papaya production has grown significantly in recent years [1]. Koul et al. [2] reported India, Brazil, Mexico, Indonesia, and Nigeria as leading papaya producers. Papaya serves as a good source of different vitamins including ascorbic acid, carotene, riboflavin B-6, and vitamin K [3]. The fruit also contains several minerals and micronutrients. Moreover, each papaya fruit part has been reported to have pharmacological properties like anthelmintic, anti-protozoan, and anti-fertility, and also help prevent very important diseases including cancer [4–6].

✉ Kumlachew Alemu, kum.alemu@gmail.com | [1]College of Agriculture and Natural Resource, Department of Plant Science, Assosa University, P.O.Box 18, Assosa, Benishangul Gumuz Region, Ethiopia.

In Ethiopia, papaya is among the economically important fruits cultivated in different parts of the country [7, 8]. It is cultivated in backyard gardens, semi-commercial and commercial levels for home consumption of fresh fruit and domestic markets in the country [9]. The total land area converges in Ethiopia in 2020/2021 was 5,096.09 hectares, with an estimated annual production of 72,007.77 metric tons; with an average yield of 14.13 tons/hectare [10]. Currently, Ethiopia is exporting a considerable amount of papaya fruits to different African countries [11].

Despite the potential and economic importance, numerous biotic and abiotic factors affect papaya production, quality, and utilization in Ethiopia. Pre- and postharvest disease have been reported to be the major constraint for papaya production [12]. Postharvest losses of papaya fruit due to fungal diseases can reach from 50 up to 100% [13, 14]. Diseases such as anthracnose, stem-end rot Phytophthora, powdery mildew, and black spot severely affect papaya production [15, 16]. Among these Anthracnose is by far the most severe disease of papaya [13].

Papaya anthracnose caused by the fungus *Colletotrichum gloeosporioides* (teleomorph *Glomerella cingulata*) is the major limitation that threatens the production and consumption of papaya fruit worldwide [17–20]. The disease significantly reduces the quality and shelf-life of papaya fruit [21]. Although papaya anthracnose symptoms may occur both in fruits and leaves, *Colletotrichum* infection is usually more severe in fruits [22]. Fruit quality decreases due to the reduction of aesthetic value because of dark necrotic and sunken salmon-colored lesions present on its surface [23]. Papaya anthracnose can cause significant damage and reduce the market value of the fruit because blemished fruit does not meet the standards for the market [24, 25].

Postharvest papaya fruit losses can result from immature harvest, and poor handling practices during the transportation and storage process including loss due to mechanical injury and over-ripeness [26, 27]. There is a higher postharvest loss of fruits and vegetables in developing than in developed countries [28]. Postharvest loss in developing countries is higher due to the lack of capital and technology for fruit transportation storage, processing, and distribution [29]. Moreover, papaya fruits have a limited postharvest shelf life because of factors such as weight losses, rapid softening of the pulp, and lower market quality [30]. Despite this fact, there is limited research on postharvest anthracnose of papaya in Ethiopia, mainly because of limited attention given to postharvest losses of fruits [31]. So far there has been no document report on papaya anthracnose in the Benishangul Gumuz Regional State. Disease assessment is one of the key aspects in understanding distributions, frequency, and intensity of disease in the area of actual and potential occurrence forecast epidemics, and classifies zones according to disease risk. Thus, disease assessment data will help to get an accurate picture of a disease which helps to prioritize the research agenda and serve as baseline data to develop strategies for disease management [32]. Therefore, this study was conducted to assess the current status and importance of papaya anthracnose and identify factors influencing postharvest loss of papaya fruit in Assosa administration Zone of Benishangul Gumuz Region, Western, Ethiopia.

2 Materials and methods

2.1 Description of the study area

The survey was conducted in Assosa Zone, Benishangul Gumuz Regional State in three selected districts namely Assosa, Bambasi, and Homosha indicated in (Fig. 1). Districts were selected purposively due to their potential for papaya production, marketing, and occurrences of anthracnose disease, which was observed on random assessments made before the actual survey. Assosa district is one of the districts of Assosa zone in the Benishangul-Gumuz Regional State, 664 km away from Addis Ababa, Ethiopia. It is located at 10°04′ N, 34°31′ E, and an altitude of 1570 m above sea level. The area receives an average annual rainfall of 1293 mm and the annual ambient temperature varies between 16 and 25 °C. Bambasi district is situated between 9°45′ latitude and 34°45′ longitude. It is located between 1100 and 1450 m above sea level. The average annual rainfall is between 1350 and 1450 mm and the annual ambient temperature varies between 21 and 35 °C. Homosha is located between 1250 and 1552 m.a.s.l average annual rainfall is between 127 and 148 mm and the annual ambient temperature varies between 19 and 27 °C.

2.2 Sampling method

The study was carried out in three selected districts of the Assosa Zone, namely Assosa, Bambasi, and Homosha. The districts were selected purposively based on their potential for the production and marketing of papaya. From each district,

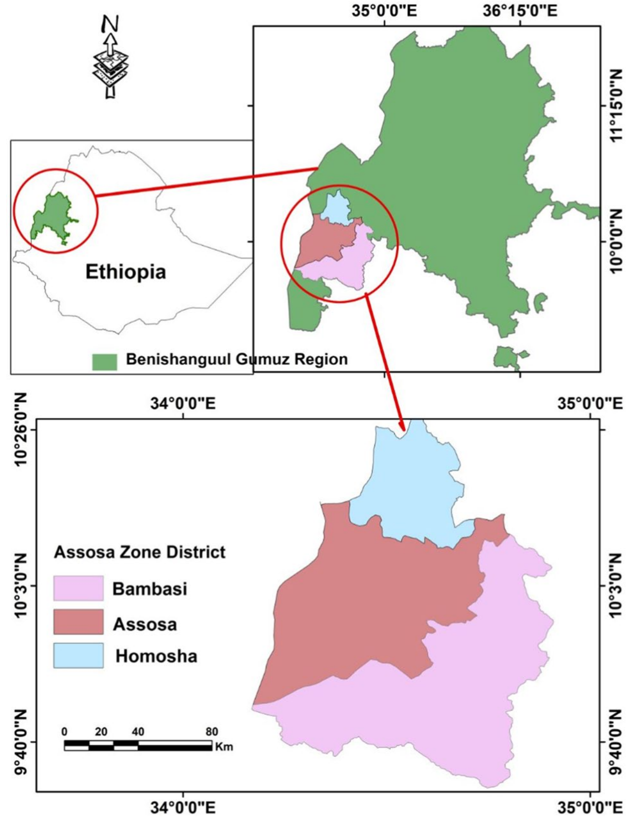

Fig. 1 Geographical map of the selected sample area for assessment of papaya anthracnose disease in Assosa, Western Ethiopia

three peasant associations (Kebeles), and from each Kebeles 10 householders and sellers were selected randomly for disease assessment. Pretested semi-structured questionnaires were administered to growers, wholesalers, and retailers to identify factors influencing postharvest anthracnose of papaya fruit. A total of 90 Households (papaya orchards) and sellers (retailers and wholesalers) were selected and considered for data collection.

2.3 Data collected

2.3.1 Disease assessment

A total of 45 papaya orchards from the three districts were visited to determine the prevalence, disease incidence, and severity of pre-harvest papaya anthracnose in the Assosa zone during the 2021 main cropping season. Disease prevalence was assessed as the proportion of farmer's fields (papaya orchards) with symptoms of papaya anthracnose disease to the total number of fields evaluated in each district using the following formula.

$$\text{Prevalence} = \frac{\text{Number of farms with papaya anthracnose}}{\text{Total number of assessed papaya farms}} \times 100$$

The incidence of anthracnose at field condition was assessed on 10 randomly selected papaya trees from each orchard using the following formula.

$$\text{Incidence} = \frac{\text{Number of papaya tree showing symptoms of anthracnose}}{\text{Total number of papaya tree assessed}} \times 100$$

Disease severity: on leaves or fruit was estimated based on a percentage of the area covered by lesions of the disease following the method employed by Bautista-Baños et al. [33] using a 1–5 rating scale. Where, 1 = 0% of fruit area affected, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%.

Similarly, postharvest anthracnose disease assessment was conducted from 45 randomly selected sellers (retailers and wholesalers) representing the three districts. The incidence and severity of anthracnose were assessed from 10 randomly selected papaya fruits from the fruit lots. Accordingly, data on disease incidence and severity were measured following a standard procedure employed by Bautista-Baños et al. [33]. Disease incidence was determined as the proportion of infected papaya fruits showing anthracnose disease symptoms using the following formula:

$$\text{Incidence} = \frac{\text{Number of papaya fruit showing symptom of anthracnose}}{\text{Total number of papaya fruit survey}} \times 100$$

Disease severity (%) on papaya fruits was measured following the method employed by Bautista-Banos et al. [33] using a 1–5 rating scale. Where, 1 = 0% of fruit area affected, 2 = 1–25%, 3 = 26–50%, 4 = 51–75%, and 5 = 76–100%. The percent severity index of fungal infection was then estimated from the numerical ratings of the total samples using the following formula.

$$\text{Percent severity index} = \frac{\text{Sum of numerical ratings}}{\text{Total number of fruit examined*maximum grade}} \times 100$$

2.3.2 Data on fruits handling practices

A pretested semi-structured questionnaire where administered to randomly selected 45 wholesalers and retailers to collect data on postharvest fruit handling practices and factors affecting postharvest loss of papaya. Yamane [34] sample size determination formula was used to determine the samples. Data on harvesting methods, packaging practices, and transportation systems were collected.

2.3.3 Isolation and identification of the causal pathogen

Isolation of the pathogen was done to identify the causative agent responsible for anthracnose disease in papaya. The targeted pathogen was isolated from symptomatic papaya fruit using the tissue plating method [35]. Isolation was done by the tissue cutting into several small Sections 3–5 mm from the margin of the infected lesion. They were surface sterilized in sodium hypochlorite (NaOCl) for 1–2 min and contained both diseased and healthy-looking tissue of papaya fruit. Then the tissue pieces were taken out aseptically washed in three changes of sterile distilled water and were blotted dry on clean sterile paper towels. The tissue was then placed on a Petri plate with freshly prepared potato dextrose agar (PDA) medium and incubated at 25 °C ± 2 °C for 3 days. The growth of the fungi was observed periodically. The culture obtained was further purified by hyphal isolation. Pure colonies were developed from the mycelia that were transferred to the PDA slant. The causal pathogen was identified based on morphological and cultural characteristics following the method employed by Rampersad [36] and Torres-Calzada et al. [37]. Moreover, a pathogenicity test was conducted to confirm whether or not the identified pathogen is pathogenic or not following Koch rules.

2.3.4 Pathogenicity test

For this purpose, apparently healthy-looking, undamaged, unripe, and physiologically matured papaya fruits were used. A pathogenicity test of *C. gloeosporioides* was conducted on harvested papaya fruits. The conidia suspension was prepared by suspending mycelial scraps from a 7-day-old culture of *C. gloeosporioides* washed in sterile distilled water and spore harvested by a glass rod. The resulting spore suspension was filtered through a double layer of cheesecloth. The concentration of conidia suspension was determined and adjusted to $1*10^6$ CFU/m^3 using the hemocytometer.

Inoculation of the pathogen was conducted following the standard method [38]. The fruit was surface sterilized by dipping in a 1% sodium hypochlorite solution (NaOCl) for 2 min before being repeatedly rinsed thoroughly in sterile distilled water and air dried. Then the fruit was pierced with a sterilized needle in three places. Then after, 0.02 ml spore suspension with $1*10^6$ CFU/m^3 was dropped on the pierced portion of the fruit using a pipette, sealed in a moist plastic box with filter paper sprayed with sterilized distilled water to maintain at least 95% relative humidity, and incubated at 25°Cfor 2 h. Control fruit was inoculated with sterile distilled water. After 7 days, the reaction of each of the isolates was recorded as positive (+) showing the sign of lesions, and negative (–) showing no reaction.

2.3.4.1 Re-isolation The causative organism in the diseased part was re-isolated on potato dextrose agar medium as described above. The morphological and cultural characteristics of the re-isolated pathogen were compared with the original isolate.

2.4 Data analysis

Survey data on incidence and severity of postharvest anthracnose of papaya were analyzed using nested design with the following random effect model:-

$$Y_{ijkl} = \mu + \alpha_j + \beta(\alpha)_{ij} + \gamma(\alpha * \beta)_{ijk} + \varepsilon_{ijkl}$$

.

Where:-$Y_{ijkl=}$ Disease intensity was households *k* nested within Kebele *j* nested within District *i* = μ overall mean; α_j = the effect District; $\beta(\alpha)_{ij}$ = the effect of Kebele *j* nested within farmer field.

$\gamma(\alpha^* \beta)_{ijk}$ = the effect of farmer field k nested within District *i* and kebele *j*; $\varepsilon_{ijkl=}$ the error term.

Analysis of variance (ANOVA) was performed using SAS V 9.2 software package [39]. Means were separated using Tukey test at a 5% probability level. Data on factors influencing postharvest anthracnose disease such as postharvest handling practices, packaging, and transportation systems were analyzed using IBM SPSS software version 25 [40]. The associations of disease intensity and weather data were computed using simple correlation analysis to establish their relationships using the following formula

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \overline{x})(y_i - \overline{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \overline{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \overline{y})^2}}$$

where: xy = correlation coefficient between x and y; x = values of the x-variable in a sample.

$\overline{x}$ = mean of the values of the x-variable, y = values of the y-variable in a sample; $\bar{y}$ = mean of the values of the y-variable.

3 Results and discussion

3.1 Intensity of field and postharvest papaya anthracnose disease in Assosa zone

3.1.1 Intensity of papaya anthracnose in the field

The survey results revealed that anthracnose of papaya was prevalent (100%) in all assessed farmer fields, however, there was a significant ($p < 0.05$) difference among the assessed districts and peasant association (Kebeles) in incidence and severity of papaya anthracnose disease (Table 1 and Fig. 2). At the district level, the highest anthracnose incidence (29.5%) and severity (17.2%) were recorded in the Bambasi districts followed by Assosa and Homosha districts, with no statistical difference from each other (Fig. 2). The study also revealed a significant difference ($P < 0.05$) in anthracnose disease intensity at the peasant association (Kebeles) level. The highest disease incidence (33.87%) and severity (20.83%) were recorded at Amba-16 followed by Mender-46 with a mean incidence and severity value of 30.79% and 19.90%, respectively with no significant difference with the former Kebele. While, the lowest anthracnose incidence and severity was observed in Tumet, Tsore, Sherkole, Amba-6, Mengele-35, and Abrhamo with a mean value ranging between 21.30% -22.70% and 10.90%-14.13%, respectively (Table 1).

Anthracnose of papaya commonly caused by *C. gloeosporioides* is a serious and economically important disease in papaya production areas across the globe. The anthracnose spots symptoms on green fruits are dark brown to black with a pale margin and ventricular in shape [37]. These increased in size and became sunken and coalesced to form large spots. The incidence and severity are severe in areas where relative humidity and rainfall are highest, which is conducive to fungal development. The present study also revealed that anthracnose was prevalent in all assessed areas. However, the extent of occurrence and damage levels varied among farmer's orchards, peasant assoc,iations and district levels. The variation among the districts may be attributed to the difference in weather conditions.

Table 1 Assessment of intensity of papaya anthracnose disease at an orchard in districts of Assosa zone, Benishangul Gumuz Region, Ethiopia during the 2021 cropping season

Districts	Kebele	Disease Incidence	Disease Severity
Assosa	Abrhamo	22.65[c*]	13.81 [cd*]
	Amba-6	25.15[bc]	13.95 [cd]
	Mengele-35	22.70[c]	14.13 [cd]
Bambasi	Amba-16	33.87[a]	20.83[a]
	Kebele-02	23.71[c]	10.90[d]
	Mender-46	30.79[ab]	19.90[ab]
Homosha	Sherkole	22.44[c]	16.41[bc]
	Tsore	22.34[c]	13.25 [cd]
	Tumet	21.30[c]	12.24[d]
Mean		24.99	15.05
SE		1.33	0.76
CV (%)		11.92	11.31

a, b, c, d indicates the statistical difference among the kebeles in disease incidence and severity magnitued

SE: Standard error CV: Coefficient of variation

*Values with the same letter(s) within the column are not significantly different according to the Tukey test at $P < 0.05$.

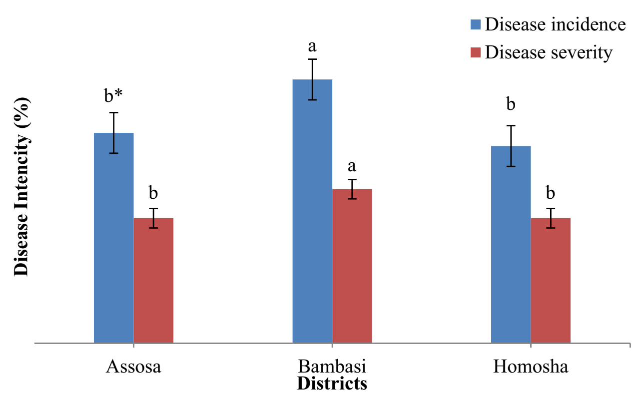

Fig. 2 Mean disease intensity of papaya anthracnose disease across the surveyed districts in Assosa zone, Benishangul Gumuz Region, Ethiopia during the 2021 crop season. *Bars with the same letter (s) are not significantly different according to the Tukey test at $P < 0.05$

The growth of postharvest fungi and anthracnose disease development depends on environmental factors such as rainfall, water activity, relative environmental humidity, and temperature [41]. The highest disease intensity in Bambasi districts is associated with low temperatures and high rainfall prevails in the study area. The correlation analysis also indicates that there is a significant positive correlation between rainfall and disease incidence ($r = 0.59$) and severity ($r = 0.43$). Mekonnen et al. [12] also indicated that the low incidence and severity of papaya anthracnose were associated with low rainfall.

Similar to the present study Chala et al. [2014] found a significant positive correlation between disease intensity and rainfall. Rainfall is very important for the germination spore, and release of conidia from acervuli and are important means for local dispersal of conidia from infected plants [32, 42]. It has been established that *C. gloeosporioides* spores must have free water or relative humidity (RH) above 95% for germination and appressorium formation. On the other hand, a significant negative correlation between temperature and disease incidence ($r = -0.71$) and disease severity ($r = -0.83$) was also recorded for the study areas. The result was in agreement with the previous findings of Sandoval-Contreras et al. [41] who indicated a negative correlation between temperature and fungal development. It was also reported that the severity of the disease depends on the weather, and the fungus is relatively inactive in dry weather. Sunlight, low humidity and temperature extremes (below 18 °C or greater than 25 °C) rapidly inactivate spores [42].

3.1.2 Intensity of postharvest papaya anthracnose

The study showed that there was a significant ($p < 0.05$) difference between peasant association in disease incidence and severity of postharvest papaya anthracnose assessed from wholesalers and retailers in the market (Table 2). The highest disease incidence (60.85%) was recorded in Tsore followed Assosa-Kebele 01, Mender 46, Amba 16, Sherkole, Abrehamo, and Assosa-Kebele 02, with a mean incidence ranging between 52.36% and 56.19%, with no statistical difference with the former PA's. Whereas, Tumet and Bambasi-Kebele-2 recorded comparatively the lowest disease incidence with a mean value of 47.04% and 48.37%, respectively.

On the other hand, the higher postharvest anthracnose severity was recorded in Tsore, Mender 46, Amba 16, and Assosa Kebele-01 with a mean severity of 47.95%, 41.68%, 41.57%, and 39.10%, respectively. While1, lower disease severity (28.84%) was recorded in sherkole kebele. Some of the symptomatic fruits assessed during the survey are indicated below in (Fig. 3).

Among, the district highest postharvest anthracnose intensity was recorded in Bambasi followed by Assosa district. The highest postharvest disease intensity recorded in the Bambasi district is associated with higher pre-harvest infection of the fruits. Previous research results also suggest that preharvest infection can significantly affect the intensity of postharvest anthracnose diseases in papaya [43]. Yahia et al. [44] also suggest that preharvest infections of the fruit with microorganisms can deteriorate the postharvest quality of fruits. Aside from this the poor postharvest handling practices, such as harvesting method, loading, packaging, and transportation system significantly influences postharvest anthracnose intensity [45–48]. Moreover, in the present study, none of the farmers, wholesalers, and retailer applies any preharvest and postharvest disease management practices. Thus, there is a need to implement safe and effective preharvest and postharvest disease management measures in the area to minimize the loss due to this disease.

3.2 Isolation of the causal pathogen

Out of 90 samples a total of 12 different *C. gloeosporioides* isolates were recovered from symptomatic papaya fruits On the upper side of the potato dextrose agar plates, the majority of the isolates showed white, light grey, and grey colony colors, whereas on the reverse side of the plates displayed a variety of colors, including greenish grey and dark grey. Orange conidial masses have been observed in some cultures in the center or dispersed in concentric circles throughout the colony, which is in agreement with the description of Rampersad [36] and Torres-Calzada et al. [37].

Mycelial growth rate varied among the isolates and an average mycelial growth rate up to 10.7 mm/day was recorded from the isolate implying a fast colony growth rate. Weir et al. [49] also indicated the growth rate is among the useful features used to differentiate Colletotrichum species. Rampersad [36] also indicated *C. gloeosporioide1s* can be differentiated from *C.*

Table 2 Assessment of intensity of postharvest papaya anthracnose disease in districts of Assosa zone, Benishangul Gumuz Region, Ethiopia during the 2021 cropping season

Districts	Peasant Association	Disease Incidence	Disease Severity
Assosa	Abrhamo	52.36^{ab*}	33.67^{bcd*}
	Kebele-01	56.19^{ab}	39.10^{abc}
	Kebele-02	51.11^{ab}	31.55^{bcd}
Bambasi	Amba-16	53.52^{ab}	41.57^{abc}
	Kebele-02	48.37^{b}	34.23^{bcd}
	Mender-46	54.86^{ab}	41.68^{ab}
Homosha	Sherkole	53.50^{ab}	28.84^{d}
	Tsore	60.85^{a}	47.95^{a}
	Tumet	47.04^{b}	30.55^{cd}
Mean		53.09	36.68
SE		02.69	02.24
CV (%)		11.08	13.64

a, b, c, d indicates the statistical difference among the kebeles in disease incidence and severity magnitued

SE: Standard error CV: Coefficient of variation

*Values with the same letter(s) within the column are not significantly different according to the Tukey test at $P < 0.05$

Fig. 3 Disease symptoms of papaya anthracnose observed upon disease assessment during 2021 cropping season at Assosa Zone, Western Ethiopia; where **a**–**d** harvested fruit showing anthracnose symptoms **e**–**f** ripened papaya fruit showing anthracnose symptoms still attached with the mother plant

acutatum by its significantly faster growth rate, and recorded a growth rate of 10.1–11.8 mm/day. Torres-Calzada et al. [37] also recorded 10.93–11.02 mm/day on *C. gloeosporioides* isolates associated with papaya anthracnose.

The study showed that all isolates exhibited cylindrical1 spore shape with one or both ends obtuse which is a typical feature of *C. gloeosporioides* conidia. Conidia of *C. gloeosporioides* are typically cylindrical with one or both ends obtuse that distinguish1 it from oblong to elliptical shape conidia of *C. acutatum* and falcate *conidia of C. truncatum* [36, 50]. Torres-Calzada et al. [37] also found cylindrical1, with both ends rounded conida11 of *C. gloeosporioides* that is distinctly different from falcate conidia with acute apex conidia of *C. capsici* isolates isolated from papaya fruit.

3.3 Pathogenicity tests

The isolated *C. gloeosporioides* showed a positive reaction to the inoculated papaya fruit (Fig. 4) proving that *C. gloeosporioides* were a causal pathogen of anthracnose disease on papaya. The site of inoculation of fruit initially showed water-soaked and sunken lesions and continued to develop a dark lesion and orange conidial masses throughout the fruit. Torres-Calzada et al. [37] have confirmed that pathogenicity towards physiologically mature fruit and the development of water-soaked, sunken, and contained orange conidial masses on papaya fruit is the most distinctive characteristic of the *C. gleosporioides*, which separates it from all other fungal species. Previously also reported that sunken lesions with salmon-to-pink-colored spore masses toward the center of the lesion were indicative of *C. gloeosporioides* infection [36]. Re-isolation of the inoculated culture from the diseased papaya fruit showed the typical colony of *C. gloeosporioides*. The results of cultural morphological and pathological characteristics revealed *C. gloeosporioides* the causative pathogen of papaya anthracnose in the study area.

Fig. 4 Pathogenicity of *Colletotrichum gloeosporioides* on artificially inoculated papaya fruits

3.4 Harvesting and postharvest factors that influence anthracnose development

3.4.1 Harvesting methods

The time and method of harvesting papaya fruit can significantly impact the quality and postharvest disease development. The present study showed that there was variation in harvesting methods of papaya fruits among papaya-growing farmers which might be a reason for the difference in intensity of anthracnose disease in the study area. All papaya-producing farmers harvest the fruit after it attains horticultural maturity (when the fruits become yellow and start dropping on the ground), which might ultimately shorten the shelf life of the fruit as disease pressure increases after harvest and affects final fruit quality. Thus, it is advisable to harvest papayas after the fruit attains physiological maturity when the skin color changes from dark green to light green because if the fruit remains in the field, it accumulates sugars during the final stage of development and becomes vulnerable to physical damage and microbial spoilage [51]. Harvesting at appropriate maturity is important for the development of good eating quality papaya fruit and better consumer preferences [52].

In addition to poor harvesting time management, most of the farmers (40%) are harvesting the fruit by hitting bamboo sticks, which might result in mechanical damage and injuries to the fruit as a result of dropping papaya fruits to the ground. These phenomena might give opportunities for inoculums found near the tree to cause infection. Furthermore, the mechanical injuries open the door for secondary opportunistic pests that ultimately spoil the fruit [45]. Al-Dairi et al. [48] also indicated that the mechanical damage that occurs upon harvesting of the fruits can predispose the fruit to anthracnose disease infection and secondary infections by other fungal pathogens. Thus, Papaya fruit should be manually harvested by hand to prevent bruising injury, in such a way as by twisting the fruit until the peduncle breaks free from the plant, or cutting the peduncle with a sharp knife and transfer into a collection basket. The farmers also harvest by handpicking through the ladder.

3.4.2 Packing material

The present study revealed the difference between papaya producer farmers and retailers in utilizing packaging materials used for the transportation of the fruits from the orchard to the local market. Nearly 88.9% of the interviewed farmers and retailers uses baskets where as 11.1% of the producers/retailers use plastic bags to store and transport papaya fruit from the orchard/home to the market (Fig. 5). The study indicates that the material used for the packaging of papaya fruit in the Assosa zone increases the chance of occurrence of anthracnose disease, as papaya fruit in the basket is susceptible to bruising injury and exposed to physical damage, and those papaya fruit packed in plastic sheet favors the outbreak of quiescent infection. It has been indicated previously that fruit packing material has a

Fig. 5 Farmers' papaya packaging and transportation material in Assosa Zone, western Ethiopia where **a** Papaya fruit packed in basket **b** Papaya fruit packed in Zembil [bag with handles woven from straw or thatch] **c** Papaya fruit packed in the sack **d** Ripen papaya packed in Zembil

significant impact on the postharvest quality and shelf life of papaya fruit [11, 46, 53]. Udomkun et al. [5] revealed that moisture content and water activity, degree of browning, 5-hydroxymethylfurfural antioxidant activities, and total phenolic and ascorbic acid contents were significantly affected by packaging materials. Similar to the present study Chiangsin et al. [54] indicated the impact of packing material on the development of anthracnose. the author revealed that bagging papaya fruit in a kraft paper bag with black-lined paper after harvest reduces anthracnose disease incidence by 69.5%. Chonhenchob and Singh [55] indicated that the best way of packaging to reduce damage, improve marketability, and extend the shelf life of papaya fruits was single-layer placement of the fruit at optimum maturity stage with cushion. Packaging materials used in fresh produce should also prevent mechanical injury resulting from the vibration force transferred from the transport truck to the product itself [48].

3.4.3 Transportation of fruit

The papaya fruit wholesaler and trailers transport the fruit from the orchard to the markets in unsafe ways. Most of the sellers usually use inappropriate packaging material and transportation. Mostly the farmer transports the fruit on open track, in which the fruits are exposed to direct sunlight, and the transport as well as road facilities are very poor which results in fruit vibrations, that ultimately increase the risk of microbial contamination and spoilage of the fruit due to mechanical damage. Baiyewu et al. [56] and Fadiji et al. [57] indicated that improper handling of fruits increased microbial infection and spoilage of the fruits. It was reported that more than 20% of losses in fresh produce incurred during transportation alone [48]. Opara et al. [28] also indicate that lack of adequate transportation facilities to deliver fresh products to the market causes enormous postharvest losses. Moreover, the fruits are loaded with other commodities, which increases the chance of bruising and mechanical damage in papaya fruits. Transportation has a significant impact on retaining the optimum organoleptic, nutritional, and functional quality attributes of the papaya fruit [51]. Bruising is one of the frequent mechanical damages to plant tissue in fresh produce that is initiated by external forces that results in physical changes to the firmness, color, and quality of the products [47, 48]. Generally, mechanical damages during transportation can significantly reduce the product's aesthetic value and reduce grower's and retailer's profit. Thus, care should be given while transporting of papaya from the product site to the market, so improving the cold storage system and, utilization of appropriate packaging is important to avoid damage to papaya fruit during transportation.

4 Conclusion

The study results revealed that anthracnose was predominant and major disease affecting the production and utilization of papaya in Assosa zone, western Ethiopia. The study also showed that *C.gloeosporioides* was recognized as the most important fungal pathogen responsible for anthracnose disease and postharvest loss of papaya fruit in the study area. Moreover, poor harvesting practices and method, and poor postharvest handling practices including packaging, storage, and transportation systems are among the factors contributing for the postharvest loss of papaya fruit. Thus, there should be a strong effort towards improving the harvesting and postharvest fruit handling practices in the study area. Furthermore, safe and effective papaya anthracnose disease management options should be explored in the future to reduce the loss due to this major disease.

From the present study, the following specific recommendations are forward.

1. Policymakers should give due attention to postharvest losses of papaya fruit and must formulate and implement policies related to postharvest management systems and fruit production. Moreover, the government should invest in research and infrastructure to enhance the production and marketing of the products.
2. The researcher should focuses on the development of an efficient, environmentally friendly, and cost effective integrated disease management strategy for minimizing the losses of papaya fruit due to anthracnose disease.
3. Extension workers should educate and empower farmers, wholesalers and retailers to adopt improved preharvest and postharvest papaya production technologies, which ultimately contribute to increased yields and higher quality produce.
4. Papaya-growing farmers have to adopt and implement appropriate preharvest and postharvest practices. Including the implementation of appropriate agronomic and crop husbandry practices, appropriate harvesting methods, grading, packing, and transportation methods to reduce postharvest losses, and improve the quality and marketability of their fruits.

Acknowledgements We appreciate Assosa University for financial assistance and for making available all the necessary laboratory resources to conduct the research.

Author contributions MG conceived and designed the study, collected the data, interpreted the data, and wrote the manuscript. KA conceived and designed the study, analyzed and interpreted the data, and wrote and edited the manuscript. BT conceived and designed the study, wrote, and edited the manuscript. All authors contributed as members of the research team, read, and approved the manuscript

Data availability The datasets used during this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Ethical clearance was obtained from Assosa University institutional research ethics review board in accordance with the University research ethics guidelines.

Competing interests The authors do not have a competing interests.

Informed consent Informed consent was obtained from all individual participants included in the study.

References

1. Koul B, Pudhuvai B, Sharma C, Kumar A, Sharma V, Yadav D, Jin JO. Carica papaya L. a tropical fruit with benefits beyond the tropics. Diversity. 2022;14(8):683.

2. Xu Y, Xu H, Wall MM, Yang J. Roles of transcription factor SQUAMOSA promoter binding protein-like gene family in papaya (*Carica papaya*) development and ripening. Genomics. 2020;112(4):2734–47.
3. Saran PL, Choudhary R. Drug bioavailability and traditional medicaments of commercially available papaya: a review. Afr J Agric Res. 2013;8(25):3216–23.
4. Hewitt H, Whittle S, Lopez S, Bailey E, Weaver S. Topical use of papaya in chronic skin ulcer therapy in Jamaica. West Indian Med J. 2000;49(1):32–3.
5. Udomkun P, Nagle M, Argyropoulos D, Mahayothee B, Latif S, Müller J. Compositional and functional dynamics of dried papaya as affected by storage time and packaging material. Food Chem. 2016;196:12–719.
6. Alara OR, Abdurahman NH, Alara JA. *Carica papaya*: comprehensive overview of the nutritional values, phytochemicals and pharmacological activities. Adv Tradit Med. 2020. https://doi.org/10.1007/s13596-020-00481-3.
7. Fuentes G, Santamaría JM. Papaya (Carica papaya L.): origin, domestication, and production. In: Ming R, Moore PH, editors. Genetics and genomics of papaya. New York: Springer; 2020. p. 3–15. https://doi.org/10.1007/978-1-4614-8087-7_1
8. Assefa W, Etissa E, Dagnew A, Ayele L, Kebede G, Damtew M, Ayalew M. Genetic variability and association of characters of hermaphrodite papaya genotypes. Adv Biosci Bioeng. 2016;4(2):10–5.
9. Shafi T, Zemedu L, Geta E. Market chain analysis of papaya (*Carioca papaya*): the case of Dugda District, Eastern Shewa Zone, Oromia National Regional State of Ethiopia. Acad Res J. 2014;3(8):120–30.
10. CSA (Central Statistic Authority), Agricultural sample survey. Report on area and production of major crops (private peasant holdings, meher season) statistical bulletin Vol. 1. Addis Ababa, Ethiopia. 2021.
11. Azene M, Workneh TS, Woldetsadik K. Effect of packaging materials and storage environment on postharvest quality of papaya fruit. J Food Sci Technol. 2014;51(6):1041–55.
12. Mekonnen Y, Chala A, Alemayehu S. Prevalence of Colletotrichum spp. infecting fruits in Southern Ethiopia. World J Agric Sci. 2015;11(1):34–41.
13. Bautista-Baños S, Sivakumar D, Bello-Pérez A, Villanueva-Arce R, Hernández-López M. A review of the management alternatives for controlling fungi on papaya fruit during the postharvest supply chain. Crop Prot. 2013;49:8–20.
14. Demartelaere AC, Nascimento LC, Guimarães GH, Silva JA, Luna RG. Elicitors on the control of anthracnose and post-harvest quality in papaya fruits. Pesquisa Agropecuária Tropical. 2017;47:211–7. https://doi.org/10.1590/1983-40632016v4745093.
15. Gabrekiristos E, Dagnew A. A newly emerging disease of papaya in Ethiopia: black spot (Asperisporium caricae) Disease and Management Options. J Plant Pathol Microbiol. 2020;11:488. https://doi.org/10.35248/2157-7471.20.11.488.
16. Tan GH, Ali A, Siddiqui Y. Current strategies, perspectives and challenges in management and control of postharvest diseases of papaya. Sci Hortic. 2022;301:111139.
17. Cia P, Pascholati SF, Benato EA, Camili EC, Santos CA. Effects of gamma and UV-C irradiation on the postharvest control of papaya anthracnose. Postharvest Biol Technol. 2007;43(3):366–73.
18. López-Velázquez JG, Delgado-Vargas F, Ayón-Reyna LE, López-Angulo G, Bautista-Baños S, Uriarte-Gastelum YG, López-López ME, Vega-García MO. Postharvest application of partitioned plant extracts from Sinaloa, Mexico for controlling papaya pathogenic fungus Colletotrichum gloeosporioides. J Plant Pathol. 2021;103:831–42.
19. Kugui K, Mwamburi LA, Kiprop EK. Efficacy of plant extracts and extracting agents against Colletotrichum gloeosporoides of pawpaw fruits. Afr Crop Sci J. 2020;28(4):567–84.
20. Kebede M, Bamud K. Assessment of major fruit diseases and insect pests in silte, Gurage and Yem special Woreda, southern Ethiopia. Ukr J Ecol. 2023;13(3):20–6.
21. Maringgal B, Hashim N, Tawakkal IS, Mohamed MT, Hamzah MH, Shukor NI. The causal agent of anthracnose in papaya fruit and control by three different Malaysian stingless bee honeys, and the chemical profile. Sci Hortic. 2019;257:108590.
22. Zakaria L. Diversity of Colletotrichum species associated with anthracnose disease in tropical fruit crops—a review. Agriculture. 2021;11(4):297.
23. Vilaplana R, Chicaiza G, Vaca C, Valencia-Chamorro S. Combination of hot water treatment and chitosan coating to control anthracnose in papaya (Carica papaya L.) during the postharvest period. Crop Protect. 2020;128:105007.
24. Hamim I, Alam MZ, Ali MA, Ashrafuzzaman M. Incidence of post-harvest fungal diseases of ripe papaya in Mymensingh. J Bangladesh Agric Univ. 2014;12(1):25–8.
25. Ayón-Reyna LE, González-Robles A, Rendón-Maldonado JG, Báez-Flores ME, López-López ME, Vega-García MO. Application of a hydrothermal-calcium chloride treatment to inhibit postharvest anthracnose development in papaya. Postharvest Biol Technol. 2017;124:85–90.
26. Paull RE, Nishijima W, Reyes M, Cavaletto C. Postharvest handling and losses during marketing of papaya (Carica papaya L.). Postharvest Biol Technol. 1997;11(3):165–79.
27. Vyas PB, Gol NB, Rao TR. Postharvest quality maintenance of papaya fruit using polysaccharide-based edible coatings. Int J Fruit Sci. 2014;14(1):81–94.
28. Opara IK, Fawole OA, Kelly C, Opara UL. Quantification of on-farm pomegranate fruit postharvest losses and waste, and implications on sustainability indicators: South African case study. Sustainability. 2021;13(9):5168.
29. Kader AA. Increasing food availability by reducing postharvest losses of fresh produce. InV Int Postharvest Symposium. 2004;682:2169–76.
30. Waghmare RB, Annapure US. Combined effect of chemical treatment and/or modified atmosphere packaging (MAP) on quality of fresh-cut papaya. Postharvest Biol Technol. 2013;85:147–53.
31. Debebe S. Post-harvest losses of crops and its determinants in Ethiopia: tobit model analysis. Agric Food Secur. 2022;11(1):1–8.
32. Chala A, Getahun M, Alemayehu S, Tadesse M. Survey of mango anthracnose in southern Ethiopia and in-vitro screening of some essential oils against Colletotrichum gloeosporioides. I J Fruit Sci. 2014;14(2):157–73.
33. Bautista-Baños S, Hernández-López M, Bosquez-Molina E, Wilson CL. Effects of chitosan and plant extracts on growth of *Colletotrichum gloeosporioides*, anthracnose levels and quality of papaya fruit. Crop Prot. 2003;22(9):1087–92.
34. Yamane T. Statistics: An introductory analysis (No. HA29 Y2 1967). 1967.
35. Sivakumar D, Sultanbawa Y, Ranasingh N, Kumara P, Wijesundera R. Effect of the combined application of chitosan and carbonate salts on the incidence of anthracnose and on the quality of papaya during storage. J Hortic Sci Biotechnol. 2005;80(4):447–52.

36. Rampersad SN. Molecular and phenotypic characterization of Colletotrichum species associated with anthracnose disease of papaya in Trinidad. Plant Dis. 2011;95(10):1244–54.
37. Torres-Calzada C, Tapia-Tussell R, Higuera-Ciapara I, Perez-Brito D. Morphological, pathological and genetic diversity of Colletotrichum species responsible for anthracnose in papaya (Carica papaya L.). Eur J Plant Pathol. 2013;135:67–79.
38. Zhang Y, Sun W, Ning P, Guo T, Huang S, Tang L, Li Q, Mo J. First report of anthracnose of papaya (Carica papaya) caused by *Colletotrichum siamense* in China. Plant Dis. 2021;105(8):2252.
39. SAS. SAS user's guide (version 9.4). Cary: SAS Inst; 2015.
40. IBM Corp N. IBM SPSS statistics for windows. Version 25.0. 2017.
41. Sandoval-Contreras T, Iñiguez-Moreno M, Garrido-Sánchez L, Ragazzo-Sánchez JA, Narvaez-Zapata JA, Ascencio F, Calderón-Santoyo M. Predictive model for the effect of environmental conditions on the postharvest development of Colletotrichum gloeosporioides strains isolated from papaya (Carica papaya L.). J Food Protect. 2020;83(9):1495–504.
42. Siddiqui Y, Ali A. Colletotrichum gloeosporioides (Anthracnose). Postharvest Decay. Cambridge: Academic Press; 2014. p. 337–71.
43. Madani B, Mohamed MT, Biggs AR, Kadir J, Awang Y, Tayebimeigooni A, Shojaei TR. Effect of pre-harvest calcium chloride applications on fruit calcium level and post-harvest anthracnose disease of papaya. Crop Prot. 2014;55:55–60.
44. Yahia EM, Gardea-Béjar A, de Jesús O-PJ, Maya-Meraz IO, Rodríguez-Roque MJ, Rios-Velasco C, Ornelas-Paz J, Salas-Marina MA. Preharvest factors affecting postharvest quality. Postharvest technology of perishable horticultural commodities. Sawston: Woodhead Publishing; 2019. p. 99–128.
45. Coates L, Johnson G. Postharvest diseases of fruit and vegetables. In: Brown JF, Ogle HJ (eds) Plant Pathogens Plant Dis. Rockvale publications, Armidale, Australia. 1997;533–48.
46. Parven A, Sarker MR, Megharaj M, Meftaul IM. Prolonging the shelf life of Papaya (Carica papaya L.) using Aloe vera gel at ambient temperature. Sci Hortic. 2020;265:109228.
47. Hussein Z, Fawole OA, Opara UL. Harvest and postharvest factors affecting bruise damage of fresh fruits. Hortic Plant J. 2020;6(1):1–3.
48. Al-Dairi M, Pathare PB, Al-Yahyai R, Opara UL. Mechanical damage of fresh produce in postharvest transportation: current status and future prospects. Trends Food Sci Technol. 2022;124:195–207.
49. Weir BS, Johnston PR, Damm U. The *Colletotrichum gloeosporioides* species complex. Stud Mycol. 2012;73:115–80.
50. Alemu K, Adugna G, Lemessa F, Muleta D. Variation among Colletotrichum isolates associated with coffee berry disease in Ethiopia. Cogent Biol. 2020;6(1):1740537.
51. Sivakumar D, Wall MM. Papaya fruit quality management during the postharvest supply chain. Food Rev Intl. 2013;29(1):24–48.
52. Singh SP, Rao DS. Papaya (Carica papaya L.) Postharvest biology and technology of tropical and subtropical fruits. Amsterdam: Elsevier; 2011.
53. Chávez-Sánchez I, Carrillo-López A, Vega-García M, Yahia EM. The effect of antifungal hot-water treatments on papaya postharvest quality and activity of pectinmethylesterase and polygalacturonase. J Food Sci Technol. 2013;50:101–7. https://doi.org/10.1007/s13197-011-0228-0.
54. Chiangsin R, Wanichkul K, Guest DI, Sangchote S. Reduction of anthracnose on ripened mango fruits by chemicals, fruit bagging, and postharvest treatments. Australas Plant Pathol. 2016;45:629–35.
55. Chonhenchob V, Singh SP. Packaging performance comparison for distribution and export of papaya fruit. Packag Technol Sci Int J. 2005;18(3):125–31.
56. Baiyewu RA, Amusa NA, Ayoola OA, Babalola OO. Survey of the postharvest diseases and aflatoxin contamination of marketed Pawpaw fruit (Carica papaya L.) in South Western Nigeria. African J Agric Res. 2007;2(4):178–81.
57. Fadiji T, Coetzee C, Chen L, Chukwu O, Opara UL. Susceptibility of apples to bruising inside ventilated corrugated paperboard packages during simulated transport damage. Postharvest Biol Technol. 2016;118:111–9.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.