The genus *Botryosphaeria* identified in 1863 as saprophytes of dead tissue of woody plants have been described as pathogens of economically important plantation trees in agriculture and native forests. The genus is a species-rich, worldwide distributed occurring on diverse host ranges. Species of the *Botryosphaeria* are reported as the pathogens of many plantation trees, including species of *Acacia, Eucalyptus*, and *Pinus* causing canker and rapid dieback diseases which often end up in death. *Botryosphaeria* fungal pathogens have cross pathogenicity on different host tree species which enables them important and focus area of research. The taxonomy of *Botryosphaeria* spp. have been under research, identification of these fungi has generally been based on morphological features of the anamorph that usually seen under the microscope. Characters that are used to classify genera in the *Botryosphaeria* have mostly relied on the macroscopic features of the ascospores and the conidial features. Currently, molecular techniques such as DNA sequencing involving amplification of ITS region are important for exact identification of the genera to species level. Recent molecular, phylogenetic and morphological findings showed that order *Botryosphaeriales* is diverse consisting nine families and 33 genera with 23 genera only in the family *Botryosphaeriaceae*. *Botryosphaeria* spp. are naturally endophytes associated with tree plants known to cause monocyclic or polycyclic diseases resulting in polyetic epidemics. The factor that makes plants more prone to *Botryosphaeria* fungal species is assumed to be stress or wounding associated with the host plants. Global climate change driven drought is an important factor that initiate stress resulting in nutrient deficiencies. *Botryosphaeria* fungal tree diseases can be best managed by ensuring plants are in optimal health through appropriate integration of cultural, silvicultural and fungicidal applications to effectively prevent and control the diseases.
stressing environmental situations like drought, freezing, hot or cold winds, hail wounds or damage which expose to insects pests or other pathogens (Anderson et al., 2004; Slippers and Wingfield, 2007; Gonthier and Nicolotti, 2013; Moral et al., 2019). Research reports reveals that Botryosphaeria species are pathogens of many plantation trees, like Acacia, Eucalyptus and Pinus (Mohali et al., 2009). Gezahgne et al. (2004) also reported that Botryosphaeria species were among the fungi that cause the most damaging canker and dieback disease of Eucalyptus spp. in Ethiopia. Jami et al. (2014) showed that diverse ecological range and cryptic endophytic property leads these fungi prime for being spread with living material and infect both native and non-native trees. Recent research findings revealed that the species within the genus are now causing new disease outbreaks within the world (Phillips et al., 2013).

Several research findings also indicates increasing evidence of identified new species of the Botryosphaeriaceae related to global climate change (Desprez-Loustau et al., 2006; Slippers and Wingfield, 2007; Phillips, 2016). The increasing importance of Botryosphaeria due to pressure on plant communities as a result of climate change is a key motivation to focus on and compile existing knowledge about host, symptoms, taxonomy, diversity, distribution, pathogenicity and management options of this group of fungi for better widen awareness and future ease of identification, prevention and control of associated diseases.

**TAXONOMY OF BOTRYOSPHAERIA TREE FUNGAL PATHOGENS**

The family of Botryosphaeriaceae was reported being passed through sere of taxonomic revisions over the past years and now referred to as large family of filamentous fungi within the Ascomycota of which first members were described in the 1820s as species of Sphaeria (Phillips et al., 2013; Slippers et al., 2013). The genus Botryosphaeria was reported by Cesati and De Notaris in 1863 and Theissen and Sydow grouped the family Botryosphaeriaceae and therefore the genus Botryosphaeria as sub-class of the Dothideineae in 1918 (Slippers et al., 2009; Slippers et al., 2017). Taxonomy of Botryosphaeriaceae and Botryosphaeria are under several revisions to different family and subfamily up to now, but Schoch et al. (2006) introduced the order Botryosphaerales, containing single family, Botryosphaeriaceae and genera Botryosphaeria using multigene based phylogeny for the first time.

**IDENTIFICATION OF BOTRYOSPHAERIA SPECIES**

**Identification of Botryosphaeria spp. using morphological method**

Botryosphaeria spp. are often easily distinguished from the remainder of fungal groups by their macroscopic features like grey to black aerial mycelium and grey to indigo or grey to black pigment visible from the reverse side of cultures on the petri plates (Crous et al., 2006; Phillips et al., 2008). Asexual morphs are reported to be easily observed on cultures induced in Water Agar (WA), or pine needles and regularly used for identification because of minor differences across the taxon (Figure 1) while, sexual morphs have little taxonomic importance due to their variation in response to different substrate or growth conditions (Phillips et al., 2013). In recent years, identification of genus Botryosphaeria to species level is accurately done in combination of DNA sequence data with the morphological characteristics (Denman et al., 2003; Phillips et al., 2008).

**Identification of Botryosphaeria species using molecular methods**

In recent years, molecular techniques involving analysis of internally transcribed spacer (ITS) of the ribosomal RNA gene region (rRNA) is quicker and accurate identification method to differentiate between closely related Botryosphaeria species of overlapping features than traditional morphological methods (Phillips, 2002; Slippers et al., 2017). DNA sequence analysis of the ITS region are often more accurate and informative if it involves other explanatory gene regions: introns of protein-encoding genes, β-tubulin, actin, EF1-α and the RNA polymerase II (rpb2) to differentiate among very closely related genera to species of Botryosphaeria like B. dothidea and Neofusicoccum parvum (Phillips et al., 2013; Slippers et al., 2017). The minimal DNA sequence of the ITS region required for the identification of Botryosphaeria species is to be 200 base pairs (bp) sequence as reported by Vilas-Boas et al. (2007).
GENUS AND SPECIES OF \textit{BOTRYOSPHAERIA} SPECIES DESCRIBED SO FAR

Currently the taxonomy of \textit{Botryosphaeria} is reported under Fungi, Phylum \textit{Ascomycota}, Class \textit{Dothideomycetes}, order \textit{Botryosphaeriales}, family \textit{Botryosphaeriaceae} and genus \textit{Botryosphaeria} (Denman et al., 2003; Crous et al., 2006; Yang et al., 2017). Recent molecular, phylogenetic and morphological findings revealed that order \textit{Botryosphaeriales} generally consists 9 families and 33 genera of which 23 genera are within the family \textit{Botryosphaeriaceae} and genus \textit{Botryosphaeria} now encompassing, \textit{B. agaves}, \textit{B. corticis}, \textit{B. dothidea}, \textit{B. fabricerciana}, \textit{B. fusispora}, \textit{B. ramose}, \textit{B. eucalyptorum} and \textit{B. scharifii} (Ahumada, 2005; Abdollahzadeh et al., 2013; Phillips et al., 2013; Slippers et al., 2013).

BIOLOGY OF \textit{BOTRYOSPHAERIA} TREE FUNGAL PATHOGENS

\textit{Botryosphaeria} species were reported to survive frequently on bark and other parts like evergreen leaves as endophytes, latent or opportunists and overwinter as fruiting bodies on dead tissue, germinate epiphytically, penetrate and grow intercellularly and transmitted horizontally in plant tissues (Slippers et al., 2009). Gonthier and Nicolotti (2013) reported \textit{Botryosphaeria} fungi penetrate the trees using powerful enzymes actively or via the stomata, natural openings, wounds passively and absorb nutrients by producing an appressorium-like hyphal masses.

REPRODUCTION IN \textit{BOTRYOSPHAERIA} SPP.

Reproduction in \textit{Botryosphaeria} fungal species \textit{Botryosphaeria} spp. have clear sexual (teleomorph) and asexual (anamorph) stages that produce mass of spores from a central ostiole within the pycnidium or perithecium (Phillips et al., 2013). The sexual morphs are not intrinsically important for identification and classification since it varies within a species in several growth conditions (Phillips et al., 2013). Characters aid to differentiate between genera and species of \textit{Botryosphaeria} have largely relied on the morphological features of the anamorph like conidial shapes, pigmentation, wall thickness, and septation (Phillips et al., 2013). Conidia of the \textit{Botryosphaeria} are often distinguished by thin-walled, narrow and fusicoccum-like, and thick-walled, wider, diplodia-like conidia (Moral et al., 2019).

EPIDEMIOLOGY, LIFE CYCLE, PATHOGENICITY, AND SYMPTOMS OF \textit{BOTRYOSPHAERIA} TREE DISEASES

Species of the \textit{Botryosphaeria} survive adverse environmental conditions as pycnidia (small dark ‘pimple-like’ structure) often endophytically, on infected and/or pruned wood and barks while (Phillips et al., 2013; Slippers et al., 2013). The virulent nature of the fungi typically occurs when trees are subjected to stress (Jami et al., 2014). Mechanism of spread for \textit{Botryosphaeria} species from one plant species to another different is by conidia or ascospores dispersed via wind and rain splashes (Gonthier and Nicolotti, 2013). \textit{Botryosphaeria} spp. use appressorium, enzymes and toxins for active mechanical penetration and directly through natural openings like stomata and lenticels for colonization of host tissues (Mancero-Castillo et al., 2018). After active mechanical penetration fungal mycelium continually grow, advancing after arrival and rupture the leaf epidermis while in the case of wounds, openings like stomata and lenticels, the cell...
walls of xylem vessels and tracheids adjacent to the injuries are extensively lignified becoming necrotic ending up in canker development (Gonthier and Nicolotti, 2013; Moral et al., 2019).

**DISEASES AND SYMPTOMS**

*Botryosphaeria* being opportunistic pathogens trigger several pre-infection processes like adhesion, spore germination, and host recognition once land on susceptible tissues of as pycnidiospores or ascospores, (Slippers et al., 2009; Sammonds et al., 2015). Symptoms of the disease are usually die-back and canker on twigs, branches and trunks of trees, and more rarely cause diseases like seed-capssule abortion, leaf diseases, seedling diseases and root cankers, blight of shoots, gummosis, in severe cases (Pillay et al., 2013).

**HOST RANGES DISTRIBUTION AND CROSS PATHOGENICITY**

*Botryosphaeria* fungal species exists across all geographical and climatic areas of the planet, except the Polar Regions (Abdella, 2004; Slippers and Wingfield, 2007; Taylor et al., 2009). The fungal species are frequently introduced to new area via imported infected planting or nursery material and jump hosts to cause devastating diseases on native plant species (Slippers et al., 2005). *Botryosphaeria* spp. are reported to cause diseases on important forest tree species worldwide particularly on *Acacia* spp., *Pinus* spp., *Olea* spp., *Prunus* spp., *Syzygium* species and *Eucalyptus* spp. (Abdollahzadeh et al., 2013). Pavlic et al. (2007), Pillay et al. (2013), and Jami et al. (2014) reported the cross pathogenicity of *Botryosphaeria* spp. specially *Botryosphaeria dothidea*, among *Syzygium*, *Eucalyptus* spp. and *Acacia* spp. (Figure 2).

Figure 2. An illustrative example of typical disease symptoms, host associations, sporulation and cross pathogenicity of *Botryosphaeria dothidea* fungus on three hosts, including native (*Acacia* sp.) and non-native (*Eucalyptus* and *Malus* spp.) hosts (Marsberg et al., 2016).
FACTORS CONTRIBUTING TO DISEASES INITIATION AND SYMPTOM DEVELOPMENTS

Botryosphaeria spp. penetrate trees through wounds from mechanical damage or natural openings (Jami et al., 2014). Insects, animals, hail, windstorms and cultural practices can cause damage or wounds are prime infection sites for fungal species increasing the chance for the infection to develop and cause diseases in trees (Slippers and Wingfield, 2007; Abdella, 2004). Conidial dispersal of Botryosphaeria species and initiation of spore release were reported to be correlated with rainfall, fog, dew, overhead irrigation, as water dissolves the mucilage to free the conidia (Gonthier and Nicolotti, 2013). Early spring and summer, late summer and autumn are assumed ideal periods for primary and secondary infections respectively while the former the result of high relative humidity which initiate conidia release and germination (Úrbez-Torres et al., 2016). Increasing temperatures, droughts, floods, range expansions for pests and pathogens and pressure on mutualistic partners are stress aggravating factors on plant communities exposing to serious damaging diseases (Desprez-Loustau et al., 2006; Slippers and Wingfield, 2007). Marsberg et al. (2016), Gonthier and Nicolotti (2013), Slippers and Wingfield (2007) reported that various stresses are causing irreversible or reversible physical damage to tree physiology which enable Botryosphaeria spp., leading causes of diseases which usually manifests affecting both cuticle penetrability and therefore the persistence of the fungi in plant part.

DISEASES AND SYMPTOMS CAUSED BY BOTRYOSPHAERIA ON ECONOMICALLY IMPORTANT TREE SPECIES

Botryosphaeria dothidea causing diseases of Eucalyptus species

Botryosphaeria dothidea (Moug. ex Fr) Ces. & De Not, 1863, were considered as wound-infecting stress related pathogens and therefore the recent global climate change is predicted to be the main factor for the occurrence of the strain on many plant communities, including trees in the natural woody ecosystems, managed forests and agriculture offering opportunity for a pathogen to infect new hosts (Burgess et al., 2006). The present wide spread distribution of B. dothidea globally has most likely resulted from anthropogenic long-distance dispersal via the worldwide trade of plants and plant products and disease expression is typically attributed to a biotic stress like drought, physical damage, water logging, frost and unsuitable growing environments (Slippers and Wingfield, 2007). Botryosphaeria dothidea is among important quarantine fungi in many countries since it is often easily transported with plant tissues and seeds among countries and regions without showing any visible disease symptoms (Abdella, 2004; Pavlic et al., 2007). The limited host specificity nature of the fungal pathogen enables the fungi to be cross pathogenic once introduced into new area (Marsberg et al., 2016). Botryosphaeria were reported among the pathogens critically influencing Eucalyptus grown in plantations or woodlot causing cankers and dieback followed by production of kino, a dark-red tree sap, and in severe cases mortality of trees Figure 3 (Denman et al., 2000; Gezahgne et al., 2004; Slippers et al., 2009). These fungi also exist asymptotically with healthy Eucalyptus leaves, twigs and stems, typically causing disease when there are suitable environmental conditions (Gezahgne et al., 2004; Pérez et al., 2008).

MANAGEMENT OF TREE DISEASES CAUSED BY BOTRYOSPHAERIA FUNGAL PATHOGENS

There are no effective fungicide controls for Botryosphaeria diseases, the best management option is to keep plants in optimal health by providing the appropriate cultural management options such as silviculture, avoiding plant stress and injury, and employing appropriate sanitation measures (Slippers and Wingfield, 2007; Úrbez-Torres et al., 2016). Research findings showed that several strategies and their integration can help to effectively manage tree diseases.
caused by *Botryosphaeria* fungal species.

**Plant selection avoidance and exclusion**
Proper plant surveillance for signs of stress during purchase and planting trees at an appropriate landscape can help to minimize *Botryosphaeria* diseases (Gonthier and Nicolotti, 2013). In commercial forestry species-site matching, appropriate planting densities and spacing, soil treatment involving fumigation, soil solarization or sanitation to reduce inoculum can be used to minimize exposure of trees to *Botryosphaeria* diseases (Slippers et al., 2009; Little et al., 2003). Maintenance of soil fertility by addition of fertilizers or compost to avoid nutrient stress, and appropriate irrigation to avoid moisture stress, reducing humidity available for spore release, mycelial growth and infection can minimize host susceptibility and infection (Michailides et al., 2004). Coating wounds with a fungicidal paint may reduce infection by these and other pathogens (Epstein et al., 2008). Neighboring trees health is also important in nursery settings so that young plants may not get infected by inoculum from surrounding diseased plants (Stanosz et al., 2005).

**Resistance**
The use of clonal material with similar genetic features raises likelihood of disease outbreaks in large areas of the world (Pérez et al., 2008). Plant breeding using appropriate screening for resistance and tolerance to species of the *Botryosphaeria* in forestry and agriculture prior to commercialization and transplanting can be an effective management option against the diseases (Slippers et al., 2009). Research findings of Wingfield et al. (2001) show that breeding for resistance has reduced the impact of diseases such as *Cryptonectria* stem canker of *Eucalyptus* spp. to the extent of among the least threatening diseases.

**Integrated disease management**
In nurseries, strategies include sanitation, hygiene practices such as the disinfection of grafting shears and pruning tools, wound treatment with a fungicidal paint, pruning at an appropriate time and at a moderate level, and irrigation strategies that minimize exposure to the water or humidity that are available for spore release and mycelial growth can be best approaches to manage diseases due to *Botryosphaeria* spp. (Epstein et al., 2008; Cysne et al., 2010; Gonthier and Nicolotti, 2013).

**CONCLUSIONS**
- *Botryosphaeria* fungal spp. evolved from saprophytes to endophytes then to opportunistic pathogens of tree plants.
- Current global climate change is providing an opportunity for *Botryosphaeria* spp. to cause substantial losses on the plantation tree species in the world.
- Reliable identification of isolates to species level needs advanced molecular technology.
- The infection cycle and epidemiology of *Botryosphaeria* tree diseases needs further detailed research.
- There is limited information on management of *Botryosphaeria* tree plantation diseases using fungicides and biocontrol approaches.
- There is little information on mechanism for species overlap and gene flow between native and introduced *Eucalyptus* and other hosts.
- *Botryosphaeria* species are well suited to being accidentally moved internationally together with germplasm. The patterns and extent of such movements are not known for most of the species in the world.

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CONFLICT OF INTEREST
The authors declare that they have no conflicts of interest.

AUTHORS CONTRIBUTIONS
All the authors contributed equally to this work.

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