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Effects of sorghum ergot on grain sorghum production: a preliminary climatic analysis

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Abstract. Until 1996 the disease 'sorghum ergot' (*Claviceps africana* and *Claviceps sorghi*) was unknown in Australia. Following an outbreak near Gatton, the disease was found throughout most of the sorghum-producing areas in Queensland within 4 weeks. A climatic risk analysis was conducted to assess the likely timing and frequencies of further outbreaks of the disease across the main sorghum-producing regions of Australia. Based on the information available, likely conditions that could lead to a disease outbreak were formulated and a computer program developed to interrogate an existing database of long-term, daily weather records. Case studies were conducted for 10 key sorghum-producing locations, ranging from Narromine in central New South Wales to Mareeba in far North Queensland and Kununurra in Western Australia.

For grain sorghum production, crops flowering in January and February are unlikely to be affected, regardless of location. However, in up to 30% of years, late-sown grain sorghum crops and crops flowering before January could be affected, depending on climatic conditions prior to and around anthesis. The frequency and timing of these events differed strongly temporally and spatially and appeared highest in high rainfall years and in regions with relatively cooler temperatures and more frequent autumn rains. Hybrid seed production (i.e. breeding programs) and forage sorghum production are likely to be more affected due to their inherently low pollen generation, again with strong regional variation. Further applications of the methodology, such as the development of an early warning system, based on phases of the Southern Oscillation Index, are discussed.

Additional keywords: climatic risk, model, Southern Oscillation Index (SOI).

Introduction

In late April 1996, an outbreak of the exotic disease 'sorghum ergot' (caused by the fungi *Claviceps africana* and *Claviceps sorghi*) occurred near Gatton in southern Queensland, Australia (Ryley *et al.* 1996). Within a few weeks the disease was found over an area of approximately 50 000 km^2 throughout southern Queensland, and within 4 months was identified at several locations along the Queensland coast and on the Atherton Tableland in far North Queensland. The disease occurs in India (Bandyopadhyay 1992), southern and eastern Africa (Mantle and Haradi 1994), and South America (Reis *et al.* 1996). Little is known about the climatic conditions that favour a disease outbreak in Australia. However, some South African studies allowed the development of basic climatic indicators that can be used to analyse historic climate records to assess frequencies of potential outbreaks for the various production regions (McLaren and Wehner 1990, 1992).

Infection of sorghum plants by *C. africana* and *C. sorghi* occurs at anthesis when conidia of the fungus germinate on stigmas and the hyphae grow down the styles into the developing ovaries (Bandyopadhyay *et al.* 1990; Frederickson *et al.* 1991). Bandyopadhyay (1992) found that pollen usually germinates earlier than ergot conidia and thus reaches the developing ovary

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faster than hyphae from the conidia. Once the ovary is fertilised, infection by ergot spores can no longer occur (Willingdale *et al.* 1986). However, if infection occurs, ovaries are completely colonised and converted into sphacelia, and within 10 days after infection, honeydew (containing thin-walled macroconidia) exudes from the florets (Frederickson *et al.* 1991). Macroconidia near the surface of the honeydew germinate to produce secondary conidia, which are believed to be the major method of dispersal of both species (Bandyopadhyay *et al.* 1990; Frederickson *et al.* 1993). Sphacelia gradually harden into sclerotia, reaching maturity 4–6 weeks after infection (Frederickson *et al.* 1991).

Environmental conditions influence infection and disease development by their direct effects on the pathogen and through their effects on pollen production and pollination. Generally, high humidity and low temperatures (Sangitrao and Bade 1979; McLaren and Wehner 1990) favour infection. Cool, wet, and cloudy weather also favours secondary sporulation (Bandyopadhyay *et al.* 1990) and the rapid spread of the disease (Sundaram 1970).

Sorghum genotypes with low pollen production, low pollen viability, or poor pollination, male sterile lines in seed production blocks and breeders' nurseries, and some forage sorghum genotypes are highly susceptible to infection. Modern grain sorghum cultivars only suffer from low pollen production if crops are exposed to low minimum temperatures 2–3 weeks before anthesis. This temperature threshold is not well defined and is likely to be a function of cultivar, length and severity of the cold spell, and general environmental conditions. McLaren and Wehner (1992) reported a considerable decrease in the ratio of normal to sterile pollen at minimum temperatures below 13°C 2–3 weeks before anthesis. Downes and Marshall (1971) reported the same threshold value. In addition to low temperatures affecting pollen production, high daytime temperatures, low night-time temperatures, heavy rainfall, and cloudy weather (Quinby 1958) can also adversely affect pollination at anthesis.

Options for management of sorghum ergot are limited because there is no physiological resistance to the disease, fungicides are only practical for seed production and parent seed blocks, and the pathogens can spread long distances, making quarantine and sanitation ineffective. Sowing sorghum at a time that corresponds with low risk of infection has been used to minimise damage from ergot. In India, a male sterile sorghum line sown before mid July was not affected by ergot (Desai *et al.* 1979). McLaren (1996) developed a crop risk analysis for infection for various production areas in South Africa, based on the temperature criteria, reduced pollen production before flowering, and interrogation of long- and medium-term weather data.

The study presented here is an attempt to define the climatic conditions that are conducive for a serious outbreak of the disease in Australia. As part of this study, a methodology was developed that allows a quantification of timing and frequency of such events, based on historic climate records. Once the key climatic indicators leading to disease development are better defined, this framework will allow a fast and thorough comparative assessment of the likelihood of timing and frequency of ergot outbreaks for any location for which long-term, daily weather records are available.

Methods

Based on the information available from the literature, combined with daily weather records from Gatton, Qld (recorded prior to and during the first ergot outbreak in Australia), we developed a rule-based system that allows the interrogation of long-term, daily weather records (i.e. rainfall, maximum and minimum temperature). This provides estimates of how frequently conditions occur that would be conducive to a disease outbreak at various times of the year and at a range of locations.

The rules to interrogate historic climate data

The following conditions had to be met before it was deemed likely that a disease outbreak could occur in a grain sorghum crop.

Condition 1

Minimum daily temperatures <14°C for at least 3 consecutive days 2–3 weeks prior to anthesis (Downes and Marshall 1971; McLaren and Wehner 1992) would have to occur. Under such conditions, pollen viability is adversely affected.

Condition 2

Maximum daily temperatures <27°C for at least 2 consecutive days at anthesis, combined with at least 5 mm of rain during that period, would have to occur. McLaren and Wehner (1992) showed that infection is higher under high humidity and when maximum temperatures are below 27°C during fertilisation.

Condition 3

A minimum of 380 thermal units (TU, accumulated daily average temperature) and a maximum of 510 TU would have to separate the time that pollen viability was sensitive to low temperatures from anthesis (Hammer and Muchow 1994).

Condition 4

Anthesis would have to occur after 15 October and before 1 May, except for Kununurra where an anthesis window from 1 June to 15 September was considered. This time period covers all commercial grain sorghum crops and was developed in consultation with the industry. Forage sorghum crops flowering outside this window will always be at risk if the humidity is high during anthesis.

To assess frequency of likely disease outbreaks for hybrid seed and forage sorghum production, low minimum temperatures prior to anthesis are not a necessary condition because pollen production is always low. Hence, only conditions 2 and 4 were used to estimate frequencies of events in such systems.

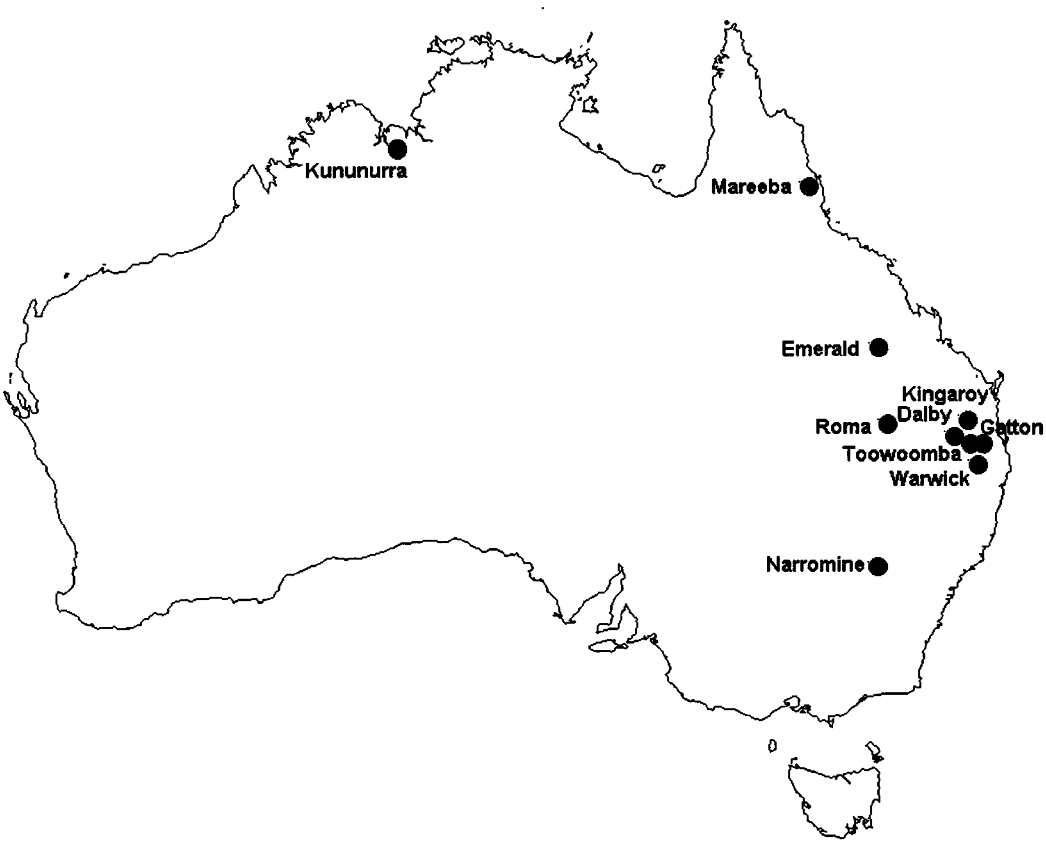

Fig. 1. Map of locations considered in this study.

Using these rules, weather data from 10 locations throughout the Australian sorghum-producing regions were checked for a 30-year period (1960–1990) to establish the timing and frequency of possible disease outbreaks. A 30-year period was chosen to overcome the variable record length of historical weather data at the various locations, hence making results comparable across locations. The locations considered in this analysis were: Kununurra, Mareeba, Emerald, Kingaroy, Roma, Dalby, Toowoomba, Warwick, Gatton, and Narromine (Fig. 1). Weather data were analysed by applying either (*a*) all 4 conditions to assess the impact for grain sorghum production or (*b*) only conditions 2 and 4, which are relevant for hybrid seed and forage sorghum production. To analyse frequency distribution and timing of potential outbreaks ('events'), the anthesis window was split into 10-day intervals and the number of 'events' within each 10-day interval was accumulated over the 30-year period.

Results and discussion

Figure 2 shows the number of 'events' that could have triggered a sorghum ergot outbreak in grain sorghum crops during the 30-year period from 1960 to 1990 for 10 key locations throughout Australia. Likewise, Fig. 3 shows the corresponding analysis for either hybrid seed or forage sorghum production. Anthesis dates that correspond with a high number of events in Figs 2 and 3 are the ones most likely to be at risk by the disease.

Grain sorghum production

For grain sorghum, a bi-modal distribution is apparent at most locations, showing a higher probability of such events occurring at the beginning and end of the growing season (Fig. 2). In October 1996, ergot was found on grain sorghum regrowth in central Queensland, in line with this climatic analysis for the region. The disease has also been recorded on tillers in central Queensland throughout the 1996–97 season, but at very low levels (<5%). Infection of primary heads has occurred only in central and southern Queensland in crops that flowered in late April–May 1997. Although the disease mostly affects late-grown crops with anthesis dates in autumn (McLaren and Wehner 1990), we are also concerned about early flowering crops in northern NSW and southern Queensland. It appears likely that crops flowering before mid December might be at risk, particularly when conditions remain cool and wet.

A geographical north–south as well as a west–east gradient is apparent whereby the number of events late in the season increases for locations further south and further east (Figs 1 and 2). This is related to lower temperatures further south and more frequent rainfall events further east. At several locations (Kununurra,

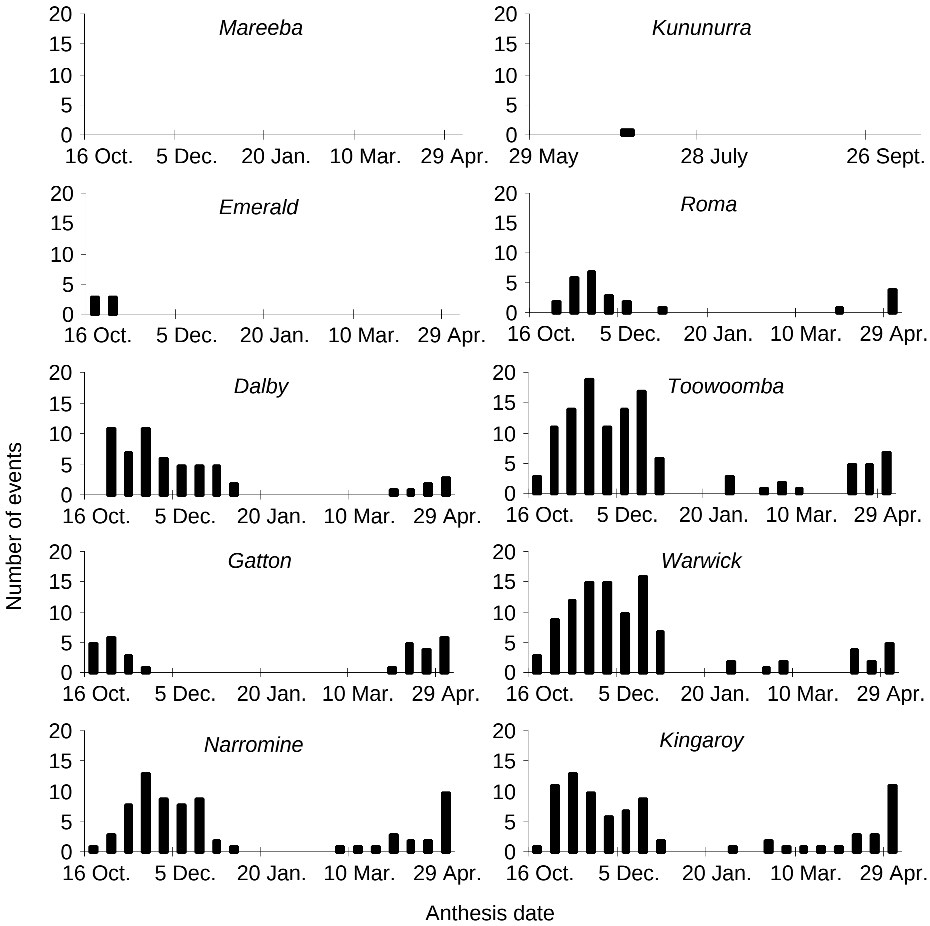

Fig. 2. Frequency of occurrence of conditions that are likely to be conducive to an outbreak of the ergot disease ('events') in grain sorghum crops at a range of locations. Possible anthesis dates were grouped into 10-day intervals. Using a rule-based system (see text), the number of 'events' occurring in each 10-day interval is shown, based on historic climate records from 1960 to 1990.

Mareeba, Emerald, and Roma) the analysis indicates little or no risk of the disease affecting grain production significantly. However, higher elevation is associated with lower temperatures and, hence, increases the number of 'events'. Kingaroy, for instance, showed the highest number of 'events' occurring, whereby the critical period for anthesis starts at the beginning of February. At Dalby, the critical anthesis time starts at the end of March with the frequency of 'events' increasing in April. Toowoomba and Warwick appear to be more variable, with the risk period starting at the end of February. Due to the generally higher temperatures at Gatton, significant disease outbreaks are unlikely before early April. Finally, at the most southern location (Narromine) the critical period starts at the beginning of March.

The number of 'events' in any year also differed strongly, depending on season type. At Toowoomba, Warwick, and Narromine, for instance, 11–12 'events' occurred in 1971, but only 2–3 'events' occurred in 1982. The 1971 season was typified by mainly consistently positive Southern Oscillation Index (SOI) phases which correlate with above-average rainfall for many regions in Australia (Stone *et al.* 1996). Conversely, 1982 was a year dominated by severe El Niño conditions resulting in consistently negative SOI phases for most of the year, associated with substantially below-average rainfall. This indicates that there could be considerable scope to incorporate recent advances in long-range rainfall forecasting based on phases of the SOI to develop an early warning system for the industry (Stone *et al.* 1996). Meinke and Hammer (1995, 1997) developed a similar system to forecast regional peanut yields affected by possible harvest losses due to rain.

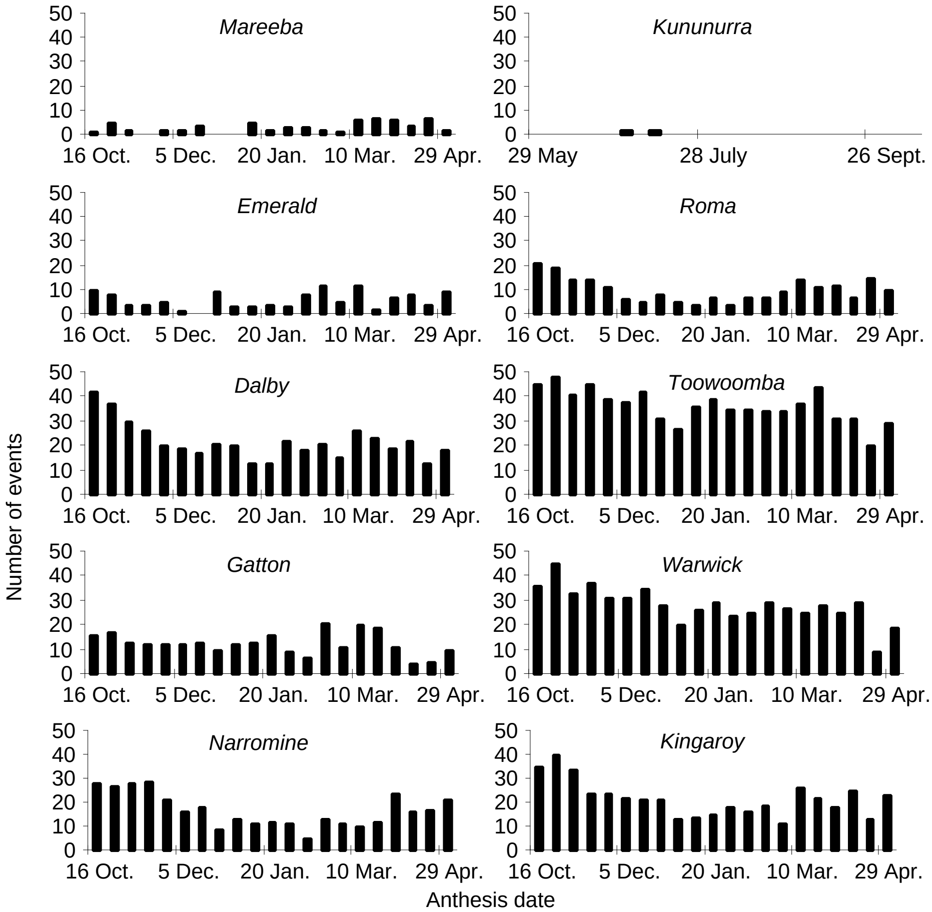

Fig. 3. Frequency of occurrence of conditions that are likely to be conducive to an outbreak of the ergot disease ('events') in hybrid seed or forage sorghum crops at a range of locations. Possible anthesis dates were grouped into 10-day intervals. Using a rule-based system (see text), the number of 'events' occurring in each 10-day interval is shown, based on historic climate records from 1960 to 1990.

Hybrid seed production and forage sorghum

The number of 'events' for hybrid seed or forage sorghum production is considerably higher than for grain production, due to the inherently low pollen generation in these crops (Fig. 3). Although this is of considerable concern to the seed industry, the direct impact on forage sorghum might be low, because the fungus is non-toxic to stock and does not impair feed quality (M. Ryley, unpublished data). However, infected forage sorghum crops will act as refuges for the pathogen between crops and as inoculum sources early and late in growing seasons. As for grain sorghum, disease likelihood appears lowest for crops flowering in January (at Kununurra only 4 events over 30 years were identified for a June anthesis date). For conventional anthesis dates, the relative risks of disease outbreak could be classified as low (Mareeba, Emerald, and Roma), intermediate (Dalby, Gatton, and Narromine), or as high (Toowoomba, Warwick, and Kingaroy; Fig. 3). Ergot was recorded in male sterile A-lines in breeders' nurseries near Gatton in December 1996 and again in May 1997, near Toowoomba in February 1997, and in seed production blocks near Narromine in February 1997, in line with results of this analysis. The disease has been observed in the Gatton district on forage sorghum regrowth since late October 1996 and in central Queensland and other areas of southern Queensland since April 1997.

Conclusions

Inevitably, the disease sorghum ergot will become a feature of Australian sorghum production. However, disease risk appears to vary strongly with season type, location, and the timing of anthesis. The analysis indicates that there is scope for grain sorghum producers to minimise their exposure to the disease by avoiding either early or late plantings. Hybrid seed production appears to be more threatened by the disease and the industry might have to re-evaluate location of production areas.

Although the analysis successfully pin-pointed outbreaks in most instances, the occurrence of the disease on grain sorghum tillers in central Queensland during the summer of 1997 was not foreseen, but likely to be related to low pollen production of these tillers. This is a preliminary study. Many of the parameter values used in the analysis are not very well defined and it is therefore paramount to monitor closely the situation over the next few seasons. Such monitoring will provide the necessary benchmark data to enable a better quantification of the disease risk. In addition, environmental factors, such as high temperatures at flowering, which adversely affect pollination, need to be included as parameters. A more thorough analysis should be conducted using dynamic simulation models (e.g. Hammer and Muchow 1994) combined with a rule-based system as outlined in this study. This would integrate our physiological understanding of sorghum growth and development, disease outbreak, and local environmental conditions. Meinke and Hammer (1995, 1997) used a similar approach to quantify possible yield losses due to rain at harvest for the peanut industry. Further, a simulation approach would allow the integration of recent advances in long-range weather forecasting (Stone *et al.* 1996) to develop a probabilistic forecasting system with a minimum lead-time of 3 months or more (Meinke *et al.* 1996; Meinke and Hammer 1997). This would give the industry and producers an indication of likely production risks either prior to, or shortly after, sowing a crop, thus allowing strategic adjustments to their operations. The methodology outlined could also be used to predict the likely distribution (and hence impact) of other exotic diseases, such as karnal bunt of wheat, which is favoured by similar climatic conditions (Murray *et al.* 1996).

Acknowledgments

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