CHAPTER 2

LITERATURE REVIEW

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2.1 DISEASES IN CORN CROP

There are several diseases that affect the corn crop and they are responsible for reducing the grain yield and reducing the quality of grains and seeds. Losses due to diseases vary from year to year and their occurrence is strongly influenced by the environment. Some diseases may occur generally but do not cause much damage, while others may be potentially more harmful, depending on the disease, season and susceptibility of the genotypes (ROBERTSON et al., 2008).

2.1.1 Rust

According to Pinho et al. (1999), rust is one of the diseases that affect corn crop since these were observed in most producing regions, causing crop limitation, such as direct damage to the plant by reduction of the photosynthesizing area, which may lead to a reduction in grain yield of the crop.

Rust is caused by fungi, and the name of the disease is related to the ferruginous aspect presented by the mass of spores present in the central region of the pustules (REIS; CASA, 1996). In the corn crop, there are common rust, caused by *Puccinia sorghi* Schw, southern rust, caused by *Puccinia polysora* Underw, and tropical rust, caused by *Physopella zeae* (Mains) Cummins & Ramachar.

Rust can cause substantial losses in grain yield in corn crop (CHEN et al., 2004). Costa et al. (2010) reported that in 2009/2010 crop, southern rust was responsible for severe epidemics in many corn producing regions in the states of Paraná, Santa Catarina and Rio Grande do Sul, requiring the application of fungicides for their control. For Reis, Casa and Bresolin (2004) the losses data from common rust have not yet been quantified in isolation. As for tropical rust, there are also no reports in the literature of the economic impact caused by the incidence of this fungus in corn.

Many authors suggest that the use of hybrids or varieties with satisfactory levels of resistance to the pathogen as being the most efficient and least expensive control method to rust (MCGEE, 1988; PINTO; FERNANDES; OLIVEIRA, 1997; SHERF; MACNAB, 1986).

2.1.2 Gray leaf spot

The etiological agent of gray leaf spot is *Cercospora zeae-maydis* Tehon & E.Y. Daniels. This is the most important disease in corn crop (BRITO et al., 2007). In Brazil, the disease was first reported in 1953 (CHUPP, 1953), in São Paulo. It was reported for the first time in the 2000/2001 crop and since then has been occurring generically, causing significant reductions in corn crop (FANTIN, 2004). In other corn-producing states, gray leaf spots have also caused significant damage (FANTIN et al., 2001; PINTO; ANGELIS; HABE, 2004; REIS; SANTOS; BLUM, 2007).The symptoms of gray leaf spot appear first in the lower leaves around 2 or 3 weeks before tasseling. The lesions are rectangular in shape and are delimited in width by the main nerves of the leaf. The lesions present brown coloration and in high humidity conditions (90%), with temperatures ranging from moderate to high (22 a 32 °C) and cold nights with dew, dense sporulation occurs, making the leaves gray, characteristic of this disease (CASELA; FERREIRA, 2003; ROBERTSON et al. 2008).

According to Brito et al. (2007), the pathogen colonizes a large part of the leaf tissue, reducing the photosynthetic area, leading to early senescence and, consequently, to the reduction of grain yield. The same authors evaluated 12 commercial corn hybrids on the incidence of gray leaf spot, evidenced that the level of damage caused by the pathogen varies between planting dates and hybrids, that the reduction in grain yield mainly related to late planting date and that the use of resistant hybrids does not require chemical control of the disease. Munkvold et al. (2001), also suggest that the main strategy of control of gray leaf spot is the use of resistant hybrids.

2.1.3 Northern leaf blight

According to Reis and Casa (1996), three similar diseases are described in corn crop in Brazil: northern leaf blight, southern leaf blight and helminthosporium leaf spot. Northern leaf blights, the most frequent, is caused by *Exserohilum turcicum* (Pass.) Leonard & Suggs (sin. *Helminthosporium turcicum* Pass.). It is distributed in most of crop producing regions of Brazil, constituting one of the main phytosanitary problems of this crop, with losses in grain yield reaching 60% in susceptible genotypes (RAYMUNDO; HOOKER, 1981). Symptoms of the disease appear approximately one week after the onset of the infection, characterized by elliptical lesions of straw staining that measure from 2.5 to 15 cm in length, with well-defined edges that become dark because of the fruiting of the fungus (WORDELL FILHO; CASA, 2012). The development of northern leaf blight is favored by the temperature between 18º and 27ºC, with an optimum temperature of 20ºC and the presence of dew on the surface of the leaves (SABATO et al., 2013).

In Brazil, the disease occurs in greater intensity in the second crop causing the greatest damage when infecting plants during the flowering period. For Fernandes and Oliveira (2000) the development of *E. turcicum* is negatively correlated with photoperiod, light intensity and sugar concentration in corn plants. These conditions are more frequently observed in the second crop, which could explain the greater severity of this pathogen at that time.

Many authors described the mechanisms of genetic inheritance associated with northern leaf blight. The disease is mainly controlled by the use of resistant cultivars through quantitative (non-specific) and qualitative (race-specific) resistance. Qualitative and quantitative resistance sources have been described, however, qualitative resistance is easily breakable in the presence of a virulent lineage (WELZ; GEIGER, 2000). The quantitative resistance confers partial resistance, in the case of northern leaf blight, causing a reduction in the development of the disease and the percentage of affected leaf area that can result in the expression of several components, including the incubation period, latent period, sporulation intensity size, number and rate of lesion growth (CARSON; GOODMAN, 2006; HURNI et al., 2015; PARLEVLIET, 2002).

2.1.4 Physoderma brown spot

Physoderma brown spot is caused by the fungus *Physoderma maydis*, commonly occurring in regions with high temperatures and high precipitations, the first symptoms of the disease usually appear on leaf limbs and nerves with chlorotic spots (LEÓN, 1984). According to Robertson et al. (2008), the pathogen is dormant in infected tissues or soil and produces innumerable zoospores in the presence of water. Leaf infection occurs at whorl when water is present for an extended period of time, occurs in a day cycle and requires a combination of light, free water and temperature between 23.8 and 29.4ºC. According to Fernandes and Balmer (1990), the brown spot is more severe in late plantings, carried out in low areas. There are few reports in the literature regarding the quantification of this disease in corn worldwide.

2.1.5 Phaeosphaeria leaf spot

Phaeosphaeria leaf spot, whose etiological agent is *Phaeosphaeria maydis* (PINTO; FERNANDES; OLIVEIRA, 1997) in association with the bacteria *Pantoeae ananas* (PACCOLA-MEIRELLES et al., 2001), is a disease that affects the major corn producing regions in Brazil and worldwide. Many researchers have argued that the disease is caused only by a fungus (*Phaeosphaeria maydis*), or only by the bacteria (*Pantoeae ananas*). However, evidence suggests that the symptoms are related to the joint action of both the fungus and the bacteria.

The incidence of phaeosphaeria leaf spot increased significantly since 1990, causing damage mainly when planting occurs in rainy periods and mild temperatures. Losses are grain yields associated with this disease may reach 60% (WORDELL FILHO; CASA, 2012). The symptoms of this disease are related to the appearance of irregular green, dark-green leaf spots that appear on the lower leaves, passing to the higher leaves of the plant. Subsequently, the lesions become necrotic of straw coloration being able to coalesce. The symptoms may present in different severities depending on the corn genotype (PACCOLA-MEIRELLES et al., 2002; REIS; CASA; BRESOLIN, 2004). Sawazaki et al. (1997) suggest that under conditions of frequent and well-distributed rains, the pathogen can cause greater severity and drastically affect the grain yield.

Lopes et al. (2007) studied the control of resistance of phaeosphaeria leaf spot from the evaluation of the means of the generations originating from the crossing between two resistant and one susceptible inbred line. These authors concluded that the additive gene effects predominate in the resistance to the phaeosphaeria leaf spot and that the characteristic has high heritability, which facilitates the genetic improvement.

2.2 DISEASES EVALUATION

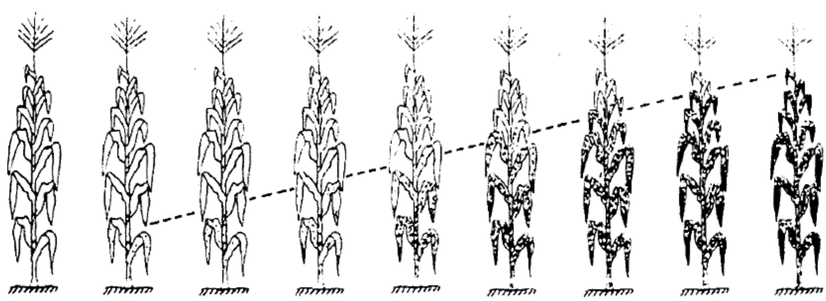
The quantification of plant diseases, known as plant pathophysiology, is necessary for the study of disease control measures, the determination of fungicide efficiency or the characterization of varietal resistance, as well as for epidemiology, in the construction of diseases progress curves and in estimating the damage caused by it (AMORIM, 1995).

The most common terms used in pathophysiology are incidence and severity, terms that are often misused. Incidence refers to the percentage (frequency) of diseased plants or parts of diseased plants in a sample or population. Severity is the percentage of area or volume of tissue covered by symptoms (BERGAMIN FILHO; AMORIM, 1996).

The severity parameter is the most appropriate to quantify foliar diseases in corn, the percentage of tissue area covered by symptoms represents the intensity of the disease better than the incidence. Several methods are described in the literature regarding the quantification of diseases in corn, with more frequent use of diagrammatic scales or scale of notes (AMORIM, 1995). The notes can be attributed to the entire crop, to an experimental plot or to an individualized plant. The best time to determine the resistance should be made at the phenological stages R3 or R4 (SABATO; PINTO; FERNANDES, 2013).

Diagrammatic scales are illustrated representations of a series of plants,parts of plants with symptoms at different levels of severity (Figure 1). These scales are the main tool for assessing the severity of many diseases (BERGAMIN FILHO; AMORIM, 1996).

Figure 1 - Diagrammatic scale for evaluating the incidence of foliar diseases in corn, according to Agroceres (1996).



Affected leaf area (%)								
0	1	10	20	30	40	60	80	> 80
Ratings								
1	2	3	4	5	6	7	8	9
Type of reaction								
HR	R	R	MR	MR/MS	MS	S	S	HS

HR – highly resistant. R – resistant. MR – moderately resistant. MR/MS – moderately resistant/moderately susceptible. S – susceptible. HS – highly susceptible.

Source: Agroceres (1996).

2.2.1 Disease progress curves

The disease progress curve is the best way to represent an epidemy, and it is usually expressed by disease versus time proportion. With the use of disease progress curves, it is possible to characterize the interactions between pathogen, host and environment, to define control strategies and to predict future levels of disease

(BERGAMIN FILHO; AMORIM, 1996). Disease progress curves can be constructed for any pathosystem, with the important parameters being the time of onset of the epidemy, the initial inoculum amount (x_0), the rate of disease increase (r), the shape of the progress curve of the disease, the area under this curve (AUDPC), the maximum (x_{max}) and final (x_f) amounts of disease and the duration of the epidemy (BERGAMIN FILHO, 1995).

The use of mathematical models to analyze disease behavior or progression over time is an important tool for phytopathologists. There are six mathematical models used for this purpose: the exponential model, logistic model, Gompertz model, monomolecular model, Richards model and the time-dependent model (BERGAMIN FILHO, 1995).

2.3 BREEDING FOR DISEASE RESISTANCE

Several studies report that large yield losses of corn are associated with the incidence of diseases (BRANDÃO et al., 2003; JULIATTI et al., 2004; SANTOS et al., 2011). The incidence and severity of the diseases that affect the corn crop have been attributed mainly to the planting of corn in the straw without the adoption of crop rotation and also due to crop overlap. The incidence and severity of the diseases depend on susceptibility of genotypes, the concentration of inoculum, the race or aggressiveness of the pathogen and favorable environmental conditions, provided by the climate, soil, cropping system or inadequate crop management. Under favorable conditions and susceptible genotypes, different diseases can occur in high severity (PINTO; OLIVEIRA; FERNANDES, 2007).

The most efficient control of diseases of the corn crop is the identification and introduction of resistance genes, aiming at the obtention of resistant hybrids and varieties. Many studies have been developed aiming at the identification and control of resistance mechanisms to many diseases (CHUNG et al., 2011; JINES et al., 2007; ZHANG et al., 2012). For Brito et al. (2012), one of the main causes of instability in the use of commercial hybrids in Brazil is the high disease severity, due to variations in the pathogen population, mainly caused by the planting of susceptible hybrids and changes in the production system.

Although the use of resistant cultivars is the most efficient and economical strategy for disease control, Yorinori and Kiihl (2001) consider that, for most diseases, the degree of resistance is insufficient to avoid losses to the level of economic damage and requiring the adoption complementary measures for its control. For diseases in which there is a source of resistance, this may be ephemeral, since the pathogen can develop new races or biotypes, before a new resistance gene. These same authors also suggest that it is fundamental to adopt integrated control strategies, where genetic resistance is one of the elements of the set of measures to be taken for maximum productivity, stability and profitability. In this context, the quantitative resistance, conferred by numerous loci of small effect, is also interesting, since it is more stable.

2.3.1 Interaction Genotypes x Environments

The interaction between genotypes x environments (G x E), can be defined as a change in the relative performance of one trait, of two or more genotypes, measured in two or more environments. This is because the effect of the environment, almost always, is different in each of the genotypes. Interaction may, therefore, cause changes in the order of classification of genotypes in each environment and changes in the absolute and relative magnitude of genetic, environmental and phenotypic variances between environments. (BOWMAN, 1972). This fact demands that the breeding is carried out under the conditions in which the genotype will be used. This interaction is characterized when the behavior of the races, inbred lines or cultivars are not consistent in the different environments, that is, the response of each genotype is specific and different from other genotypes to the changes that occur in the environments (RAMALHO et al., 2012). The effect of the interaction GxE describes the differential behavior of the genotypes in contrasting environments (COIMBRA et al., 2009). It is important to evaluate the magnitudes of the interactions GxE, since this knowledge guides the planning and the strategies of the improvement in the recommendation of cultivars, besides being determined in the phenotypic stability of cultivars, for a determined region (VENCOVSKY; BARRIGA, 1992). The use of phenotypic stability in the selection, in the early stages of breeding, is still rare, but it can be implemented in some cases where it is possible to evaluate a reasonable number of genotypes in several environments, which may even include different planting dates. For resistance to diseases this is still more valid because the potential of inoculum and conditions favorable to the various diseases vary throughout the year.

The analysis of the interaction GxE is important for breeding programs, because it provides the base for selection to broad or specific adaptation, to choose selection environments, to identify the level of stress in the selected environments and to indicate satisfactory levels of resistance (FOX; CROSSA; ROMAGOSA, 1997). Thus, the identification of genotypes with high adaptability and phenotypic stability is the most advantageous way to explore the interaction GxE (PEREIRA et al., 2009).

2.3.2 Adaptability and stability

Many authors describe the concepts of phenotypic adaptation and stability, as well evaluation methods. Mariotii et al. (1976) describe the adaptive term as a potential capacity to develop environmental performance assessment systems, and stability is considered as an ability to generate performance data in environmental assessment systems. Chaves (2001) suggest that most methods of adaptability and stability analysis, using regression techniques, measure the variation of the quantitative character in relation to an environmental index. The methods differ according to the type of regression model used and the way of determining the environmental index.

According to Cruz (2006), many methods have been proposed for the analysis of adaptability and stability, aiming to evaluate genotypes in different environments. These methods are based on G x E interaction and are distinguished from the concepts of stability and adaptability adopted and certain statistical principles selected. Among these are the methods based on analysis of variance (YATES; COCHRAN, 1938; PLAISTED; PETERSON, 1959; WRICKE, 1965; ANNICCHIARICO, 1992), linear regression (FINLAY; WILKINSON, 1963; EBERHART; RUSSELL, 1966; TAI, 1971), bissegmented regression (VERMA; CHAHAL; MURTY, 1978; SILVA; BARRETO, 1985; CRUZ; TORRES; VENCOVSKY, 1989), nonparametric analysis (HUEHN; NASSAR, 1990; LIN; BINNS, 1988), factor analysis (MURAKAMI; CRUZ, 2004) and main components (centroid and AMMI). The choice of the adaptability and stability analysis method depends on the experimental data, mainly related to the number of environments available, the precision required and the type of information desired (CRUZ; REGAZZI; CARNEIRO, 2012).

The analysis of adaptability and stability widely used by corn breeders is the methodology proposed by Eberhart and Russell (1966).

2.3.2.1 Method proposed by Eberhart and Russell

Finlay and Wilkinson (1963) proposed a methodology to evaluate the genotype performance for each genotype, adjusting a simple linear regression of the dependent variable in relation to the environmental index. Eberhart and Russell (1966) expanded the model proposed by Finlay and Wilkinson (1963), in that both the regression coefficients of phenotypic values of each genotype in relation to the environmental index and deviations from that regression would provide parameter estimates of stability and adaptability (CRUZ; REGAZZI; CARNEIRO, 2012).

Eberhart and Russell (1966) proposed a method of adaptability and stability study based on regression analysis. The parameters that express adaptability and stability are the average, the linear response to the environmental variation and the deviation of the regression of each genotype, obtained from the model:

$$Y_{ij} = \beta_{oi} + \beta_{1i} I_j + \delta_{ij} + \varepsilon_{ij} \quad (1)$$

Where:

β_{oi}: Overall average of genotype ***i*** (***i*** = 1, 2, .., g);

β_{1i}: Linear response of genotype ***i*** to environmental variation;

I_j: Environmental index (*j* = 1, 2, ..., a), being $I_j = \frac{Y_{.j}}{g} - \frac{Y_{..}}{ga}$;

δ_{ij}: Regression deviation;

ε_{ij}: Average experimental error.

According to this method, for disease symptoms analysis an ideal cultivar is one with an overall mean (β_o) around 1, a linear regression coefficient (β_1) lower than 1 and a variance of the regressions deviations (σ^2_{di}) equal to zero. Such a value of β_1<1 indicates that the genotype did not increase the symptoms of the disease with the improvement of the environment for disease. The variance of the regression deviations should be the smallest possible, close to zero, indicating that the cultivar modifies with the environmental variations in a predictable way, that is, following a perfect forecast line. With σ^2_{di} high, the behavior of the genotype will be unpredictable. If β_1 = 1 the genotype will be responsive to environmental improvement for disease, but in this case, for disease symptoms this is not interesting. Being β_1 > 1.0 the cultivar is less responsive and less demanding, being suitable for environments of inferior quality for disease, because the disease decreases quickly in these environments.

There are few reports in the literature using the Eberhart and Russell (1966) methodology for evaluating the resistance to disease (PINHO et al. 2001; BRITO et al., 2011). However, this methodology is widely used to evaluate stability and adaptability of grain yield in corn (CHANGIZI et al., 2014; KHALIL, 2013; BUSANELLO et al., 2015), sugarcane production (BARBOSA et al.,2015; FERRAUDO; PERECIN, 2014); soybean (SILVEIRA et al., 2016), wheat (HUANG et al., 2016) and peanuts (VASCONCELOS et al., 2015).

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