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Comparing models for temporal progress of zonate leaf spot (*Gloeocercospora sorghi*) disease in sorghum (*Sorghum bicolor*)

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ABSTRACT

Field studies were conducted during 2004–06 rainy *(kharif)* seasons to analyze the temporal progress of zonate leaf spot (*Gloecercospora sorghi.* Bain & Edgerton) . Two growth models (Gompertz & logistic) were used to fit empirically derived disease progress curves. The Gompertz transformation effectively linearized the disease progress for all the 3 seasons. A close agreement was observed between the predicted and observed disease level in case of Gompertz model which accounted for > 90% of disease severity ($P < 0.01$) along with low root mean square error (0.053 to 0.061) as compared to logistic model ($R^{*2} > 80\%$, RMSE* =0.063 to 0.105) over the years. The Gompertz model was found to be best fit over the years for describing zonate leaf spot disease progression in a natural inoculum population of *G. sorghi* on sorghum (*Sorghum bicolor* L.).

Key words: Disease progress, *Gloeocercospora sorghi*, Gompertz and logistic model, Sorghum temporal development, Zonate leaf spot

Sorghum [*Sorghum bicolor* (L.) Moench] is an important dual-purpose crop and in India. It occupies about 30% of world acreage (Rana *et al.* 1998). Zonate leaf spot caused by fungus *Gloeocercospora sorghi* Bain & Edgerton ex Deighton is an important foliar disease (Odvody and Hepperly 1992) of sorghum, which is prevalent in hot and humid climatic conditions. Generally, it appears in a severe form during the rainy (*kharif*) season in north India. The disease spreads through spores produced in sporodochia. Black sclerotia are formed in necrotic lesions, which play a major role in the survival and initial spread of the pathogen. The secondary infection is caused by conidia. Being a polycyclic disease, the disease severity is proportional to the amount of initial inoculum present as well as the rate of secondary spread.

Disease development with time is a dynamic process and quantification of disease progress with time is desirable for many reasons (Madden 1980). Various growth models are used to quantify and compare effects of different disease management practices. A variety of growth curves, especially Gompertz, logistic and monomolecular correspond to the Richard function. Various growth models (Vanderplank 1963, SubbaRao *et al.* 1990, Ngugi *et al.* 2000) have been used to characterize the progress of disease in time. The sigmoidal progress curves of a polycyclic disease need to be linearized (Nagarajan and Muralidharan 1995) to aid in interpretation and to effectively utilize the least square analysis. Hau and Kranz (1977) used the Gompertz and other models to linearize the disease progress curves. Berger (1981) emphasised the superiority of Gompertz model over the logistic model for describing 113 plant disease epidemics in nine foliar pathosystems. Gompertz transformation was also found to be superior in linearizing the disease progress curves in pathosystems including leaf rust of wheat (Hau and Kranz 1977), apple scab (Analytis 1979) and groundnut rust (Bulbule *et al.* 1996). The logistic equation has also been used frequently to characterize disease progress. In Kenya, the logistic model provided a good fit for 72 sorghum anthracnose and 108 leaf blight disease progress curves (Ngugi *et al.* 2000).

An important aspect of the temporal analysis of epidemics is the selection of an appropriate model for describing the disease progress data to avoid inaccurate estimates of the epidemic parameters (Berger 1981). The aim of the present study was to identify and compare growth models that best describe temporal disease progress of zonate leaf spot on sorghum.

MATERIALS AND METHODS

A field experiment was conducted during the rainy (*kharif*)

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seasons of 2004–06 at Central Research Farm of Indian Grassland and Fodder Research Institute, Jhansi (25° 27′ N, 78° 35′ E, 271 m amsl). The region receives (Singh *et al.* 2005) an annual rainfall of 906.5 mm with 781 mm during *kharif* and 52 mm during winter *(rabi)* season and experiences annual potential evapotranspiration of 1 512 mm. The soils was clay loam, neutral in reaction (*p*H 7.56) and non-saline (EC_2 0.148 dS/m) in nature. The status of organic carbon (0.29%), available N (233.1 kg/ha) and available P (16.1 kg P/ha) in the soil was low, whereas available K content of the soil was in the medium range (219.4 kg/ha). 'MP-chari' forage sorghum susceptible to zonate leaf spot was sown on 21, 20, 25 July during 2004, 05 and 06, respectively in plot size of 4 m × 6 m having 4 replications. A basal fertilizer dose of 40 kg N + 40 kg P_2O_5 + 40 kg K_2O was applied at the sowing time and the crop was top-dressed with 30 kg N/ha after 30 days of sowing. Standard crop management practices except spraying were followed.

Each year the experiment relied entirely on the natural inoculum for disease development. Plants were assessed at 7 days interval from sowing to harvesting (50% flowering stage). Estimates of the disease severity were obtained through non- destructive systematic sampling of 10 plants from each plot. Top 5 leaves of each plant were visually scored for% leaf area affected by disease and severity was recorded on 0–9 scale (Mayee and Datar 1986). In all there were 10 disease assessments during 2004 and 9 each during 2005 and 2006.

Two most common models, i e logistic and Gompertz were used to fit empirically derived disease progress curves. Equations with linear parameters from each of these 2 models of the Richards family of growth curves represented predicted equations which were compared statistically with the linearly transformed empirical data. The transformation equations for logistic and Gompertz models, respectively, were as under:

$$\text{(i) } Z = \ln(y/(1-y)) \quad \text{(ii) } Z = -\ln(-\ln(y))$$

in which y = disease proportion in the range: $0 < y < 1$.

The linearly transformed data of both the models was plotted against the passage of time in the epidemic to determine whether the transformed data forms a straight line. After linear regression, goodness-of-fit (Campbell and Madden 1990, Madden *et al.* 2008) of the model was determined by examining the co-efficient of determination (R^2), root mean square error (RMSE) and the graph of the standardized residuals vs the predicted value. Models with R^2 e" 80% were considered and in the residuals, random scatters of the points were examined for appropriateness of the model under study. Further to compare R^2 and RMSE values precisely, the predicted linearly transformed disease progress data was back transformed to the original (untransformed) scale and regression analysis was done for predicted disease values on the observed values. The back transformation for logistic and Gompertz model was made using (Hau and Kranz 1990) following functional relationships

$$y = 1/(1+e^{-z}) \text{ and } y = \exp(-e^{-z})$$

Finally, the predictive capability of the 2 models in describing the temporal progress of zonate leaf spot was compared. The recalculated value of R^2 (R^{*2}) and RMSE (RMSE*) indicates the best fit among the chosen models.

RESULTS AND DISCUSSION

The characteristic symptom of disease initiation under field condition were observed as small reddish-brown (Fig 1 a) and water-soaked spots. Later on, the lesions enlarged (Fig 1 b) becoming circular with alternating bands of dark purple or red colour giving a zonate appearance (Fig 1 c, d). Zonate leaf spot started appearing at 10–11 days after sowing coinciding with first week of August in all the years. Initially, the disease showed low severity values (0.4 to 2.6%) but from the last week of August, the disease developed rapidly achieving maximum level during first fortnight of September for all the years. The disease progress curves are illustrated in Fig 2. Inspection of the disease progress curves shows a clear leveling off of the disease severity (y) values at higher days after sowing. Besides that,

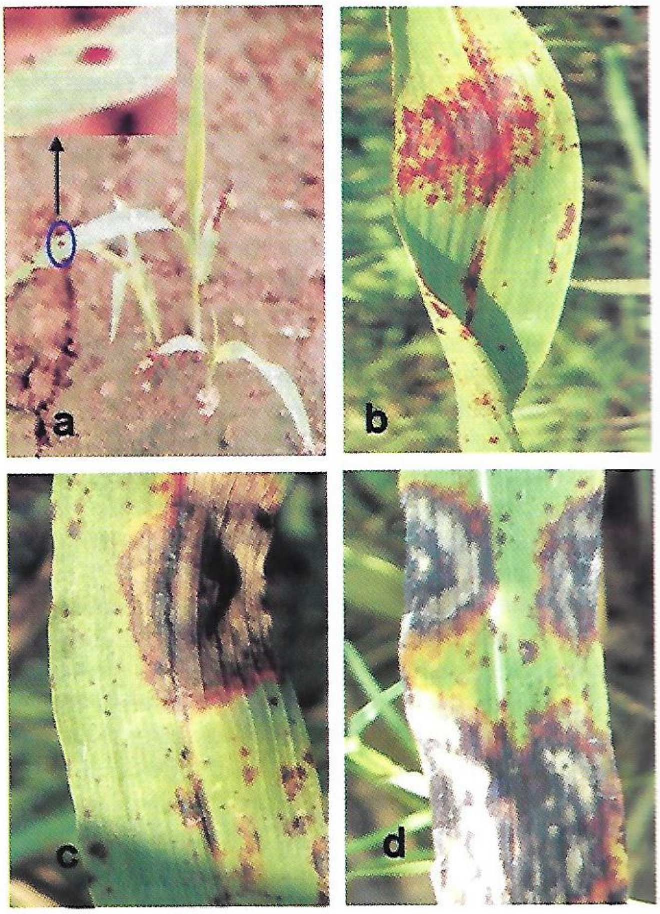

Fig 1 Development of zonate leaf spot (*a*) initiation; (*b*) spot enlargement; (*c & d*) developed symptom on sorghum

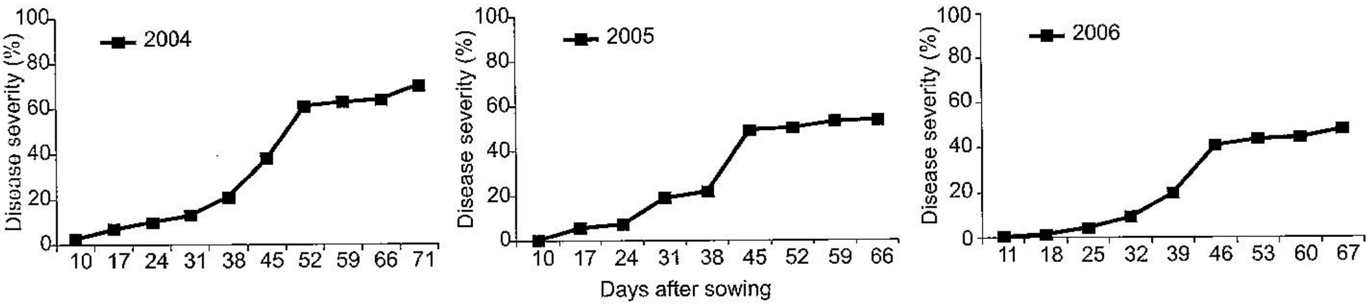

Fig 2 Progression of zonate leaf spot disease during different years on sorghum

the curves follow an approximate S-shape, therefore, fitting of an exponential and monomolecular model would not be appropriate in the present study. Hence, the linearized forms of the logistic and Gompertz models were fitted to the entire set of disease progress data individually. Equations with parameters transformed linearly were used to fit empirically derived disease progress curves statistically using linear equations. Of special mention is the fact that the linearized measure of disease is not the quantity of disease that exists on plants. In fact, the transformation of y to obtain a linear model is an artificial quantity that is calculated primarily for convenience. The plotting of transformed disease severity vs. time for both the models in all the three years is shown in Fig 3. It was observed that in general, the transformed disease severity forms a straight line. The linear regression statistics and the goodness of fit of the 2 models are presented in Table 1. The Gompertz model showed R^2 values ($P< 0.01$) in the range of 0.93 to 0.96 over the years, indicating low variability about the predicted line. The R^2 for logistic model ranged between 0.85 to 0.96 (Table 1) with a low value during 2005. Both these ranges of R^2 are acceptable. Therefore, both the models are capable of explaining >80% variability in disease severity during different years. The RMSE displayed by Gompertz model varied between 0.186 and 0.227, whereas it was 0.333 to 0.765 for the logistic model during the three crop seasons. The above reported values of R^2 or RMSE of the 2 models under study cannot be compared directly because different transformations of severity were used. The plots of the standardized residuals versus predicted values for each year of the 2 models are given in Fig 4. The residuals generally had a random pattern and normally distributed about e=0 and no undesirable pattern was present in case of Gompertz model, for all 3 seasons, indicating the appropriateness of Gompertz transformation in linearizing the disease progress data.

To compare the 2 models, the predicted (linearly transformed) disease progress data was back transformed to the original (untransformed) scale and regression analysis was done between the disease severity predicted and actually observed. The resulting recalculated values of R^2 (R^{*2}) and RMSE (RMSE*) for Gompertz and logistic models for individual years are depicted in Table 1. This recalculated value provides direct comparison (Campbell and Madden 1990) of the 2 models for best fit and appropriateness of the model to the observed data. Plots of fitted Gompertz model closely resembled the observed disease data over the 3 years. The model accounted for close to > 90%(R^{*2}; *P*< 0.01) of the variation in disease severity, thereby providing an excellent description of disease progress data in all the 3 years. In case of the logistic model, a close agreement was observed during 2004 only and not during 2005 and 2006 (Table 1) as compared to Gompertz model. Further, Gompertz model displayed a low RMSE* in the range of 0.053 to 0.061, whereas, the logistic model was in the range of 0.063 to 0.105

Table 1 Summary of linear regression statistics used in evaluation of 2 growth models for appropriateness for describing disease progress of sorghum zonate leaf spot

Model	Intercept	Slope	R^2	P	RMSE	Recalculated R^2 (R^{*2})	Recalculated RMSE(RMSE*)
				2004			
Gompertz	–1.771**	0.041**	0.959	<.01	0.186	0.960	0.053
Logistic	–4.027**	0.074**	0.960	<.01	0.333	0.944	0.063
				2005			
Gompertz	–1.834**	0.040**	0.928	<.01	0.227	0.917	0.061
Logistic	–4.815**	0.088**	0.849	<.01	0.765	0.839	0.101
				2006			
Gompertz	–2.078**	0.040**	0.947	<.01	0.192	0.911	0.061
Logistic	–5.718**	0.097**	0.913	<.01	0.615	0.808	0.105

** *P*= 0.01

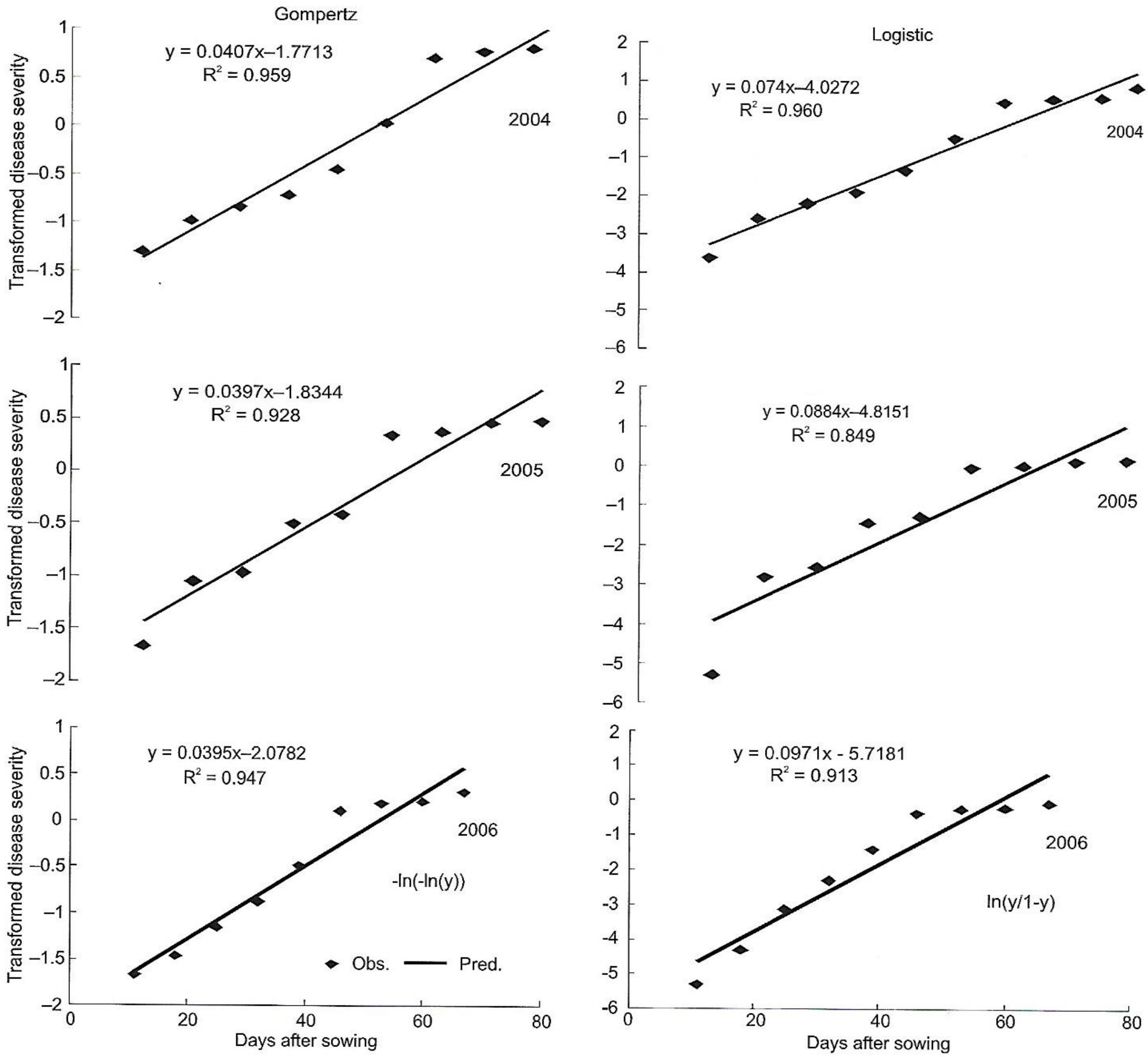

Fig 3 Gompertz and logistic transformation for zonate leaf spot disease of sorghum

(Table 1), indicating higher unexplained variability. The low RMSE* value of Gompertz model further supports the accuracy of the model in predicting the zonate leaf spot severity in a natural pathogen population. This clearly demonstrates that over the years, the Gompertz model with high R^{*2} and low RMSE* performed very well in explaining the data on year-to-year variation in the disease level and progression. Superiority of the Gompertz model in describing disease progress data was also highlighted by some other reports (Berger 1981, Hau and Kranz 1977, Analytis 1979, Bulbule *et al.* 1996). Therefore, the Gompertz model was the best fit over the years for describing the progression of the disease in the sorghum - zonate leaf spot pathosystem under natural field conditions.

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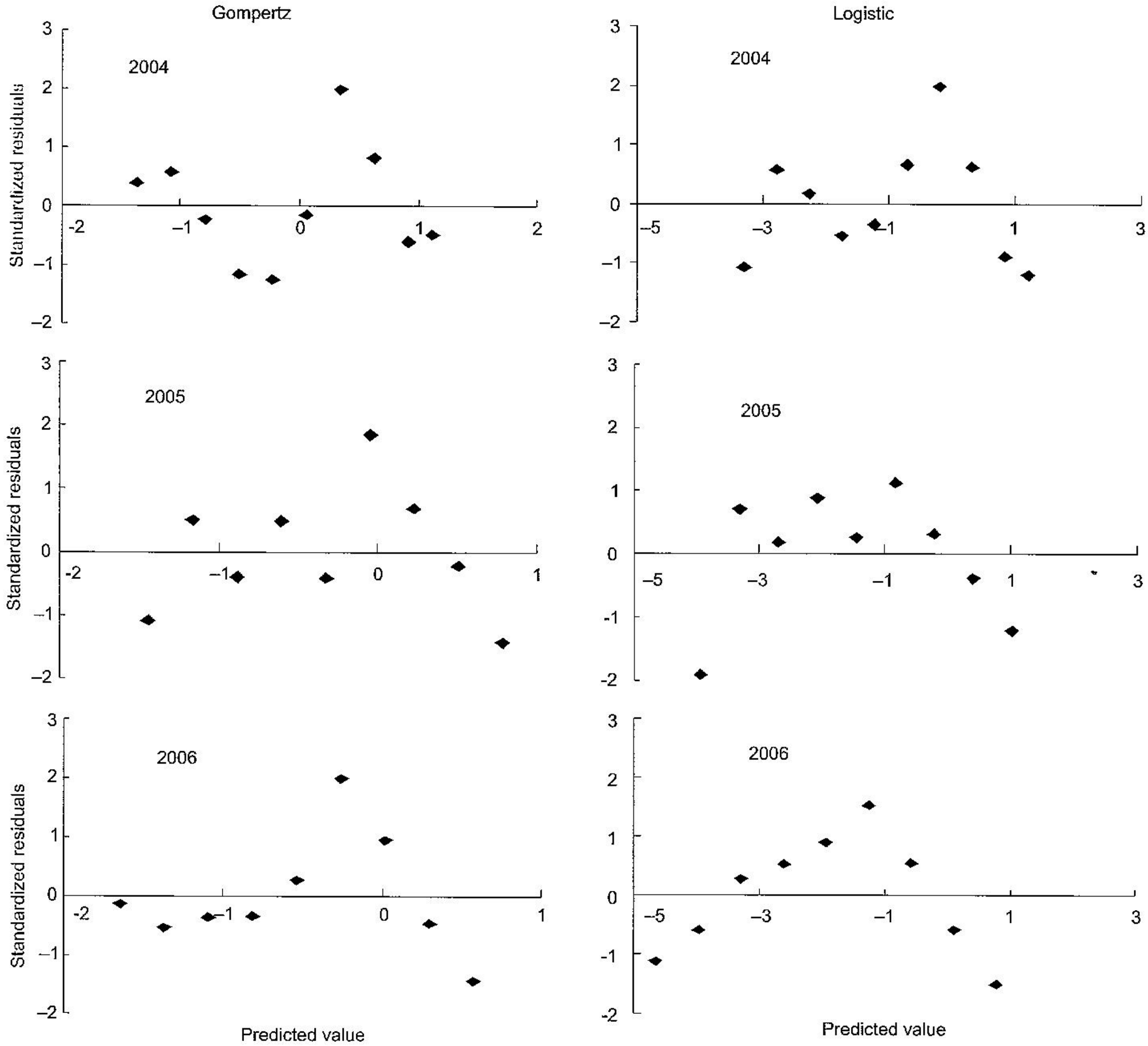

Fig 4 Standardized residuals plotted against predicted value for logistic and Gompertz models for describing epidemics of zonate leaf spot of sorghum

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