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A study of comparative quantitative performances of moisture-dependent models for microwave complex permittivity of soft red winter wheat

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ABSTRACT

In the present work, two models namely, quadratic and cubic, for the variation of relative permittivity and dielectric loss factor of soft red winter wheat (*Triticum aestivum L.*), with decimal moisture content at 2.45 GHz have been proposed by the authors. The resulting data for relative permittivity and loss factor have been derived from the works of Nelson. The models chosen for comparison with the present models are also due to Nelson. The evaluation of constants for the models has been done using the method of Least-Squares-Fit for nonlinear regression analysis. With the values of coefficients of determination (r^2) too close to unity (≈ 0.99), and lower average percentage errors ≈ 1 and 0.3 for relative permittivity and ≈ 8.7 and 4.1, respectively for both the present models compare them favorably with the established models.

KEYWORDS

Relative permittivity;
Dielectric loss factor;
Nonlinear regression;
Microwave frequency;
Wheat.

INTRODUCTION

The use of electrical properties of grains for moisture measurement has been one of the most prominent agricultural applications for dielectric properties data. The dielectric properties offer a potential means in making devices for sensing moisture content of grains which help in preventing the spoilage of large blended lots stored in elevators, ships or mills[1]. It is why, several efforts to model the dielectric properties of grains have been made[2,3,4]. The purpose of the present paper is to consider a more general approach towards modeling the dielectric properties of soft red winter wheat *(Triticum aestivum L.)* using the data of results for them at a fixed frequency of 2.45 GHz at 24^0C in order to present empirical expressions which allow predictions of permittivity and loss factor. The data of results for relative permittivity and dielectric loss factor have been taken from plots showing their variations as functions of percentage moisture content, wet basis (w.b), as contained in Nelson's Paper[5]. The values of bulk density at the five moisture contents ranging from 10.0 % to 20.0 % (w.b) were derived from the bulk density-moisture relationship for soft red winter wheat as presented by equation (1) of Nelson's paper[6]. Data for dielectric properties have been chosen at microwave frequency keeping in view the fact that the ionic conductivities and bound-water relaxation effects almost disappear in this range of frequency[7, 8, 9].

Thus, microwaves offer a non-destructive, sensi-

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tive and feasible method for determining the water content of grain samples.

2. Existing models, development of present models and evaluation of constants

The general quadratic and cubic models connecting dielectric constant, moisture content and frequency of operation were used for their comparison with the corresponding new models proposed in the present study. Two general forms of the equations are[2]:

$$\varepsilon' = [1+\{A_2 - B_2 \log f + (C_2 - D_2 \log f)M\}\rho]^2 \quad (1)$$

and

$$\varepsilon'' = [1+\{A_3 - B_3 \log f + (C_3 - D_3 \log f)M\}\rho]^3 \quad (2)$$

The only one equation for the dielectric loss factor available for comparison is of the form:

$$\varepsilon'' = 0.146\rho^2 + 0.004615\, M^2 \rho^2 [0.32 \log f + (1.743/\log f)-1] \quad (3)$$

where $\rho = \rho_b$ = bulk density of the material in gram/cm^3; M=100m = percentage moisture content; wet basis; f = frequency of operation in MHz.

The values of constant viz., A_2, B_2, C_2, D_2 and A_3, B_3, C_3, and D_3 of equation (1) and (2) for soft red winter wheat were taken from Table 6 of Nelson's paper[2].

Based on the observations of almost linear plots obtained from the dependence of relative permittivity of grains and cereals with moisture content, especially in the microwave range, it was proposed to give quadratic as well as cubic models for such variations. The proposed models are:

Quadratic

$$\varepsilon' = am^2 + bm + K_1 \quad 4(a)$$

and

$$\varepsilon'' = cm^2 + dm + K_2 \quad 4(b)$$

Cubic

$$\varepsilon' = am^3 + bm^2 + cm + K_1 \quad 5(a)$$

and

$$\varepsilon'' = dm^3 + em^2 + fm + K_2 \quad 5(b)$$

The values of bulk density corresponding to M=0 (ρ_0, say) as taken from equation (2) of Nelson's paper[6] is equal to 0.7744 in the present case. The value of the constant K_1 was taken as the average of the values of relative permittivity derived from equations (1) and (2) by putting M = 0, which in the present case comes out to be equal to 1.494. The value of K_2 was equal to the value of loss factor corresponding to M=0, which in the present case comes out to be equal to 0.0876.

The constants for the first part of each of the two sets of model as envisaged in equations 4(a) and 5(a) were evaluated using the method of least-squares-fit for non-linear regression. The same method was adopted for the second part of each of the two models given by equations 4(b) and 5(b) using the data of results for dielectric loss factor derived from the works of Nelson[5] as referred to earlier in the text.

RESULTS AND DISCUSSIONS

Data of results for relative permittivity, loss factor and bulk density of soft red winter wheat *(Triticum aestivum L.)* at 2.45 GHz and 24^{0}C and at five moisture contents are illustrated in TABLE 1 and the evaluated constants for different proposed models are listed in TABLE 2. Further, the quantitative comparative performances of the present models and those of Nelson are reported in TABLES 3(a) and 3(b).The coefficients of determination (r^2) and average percentage errors of prediction for each of the different models have also

TABLE 1: Data of results for relative permittivity, loss factor and bulk density of soft red winter wheat *(Triticum aestivum L.)* measured at 2.45 GHz and 24^{0}C at five moisture contents, wet basis

Moisture content (%,wet basis)	Bulk density in gram×cm^{-3}	Relative permittivity ε'	Dielectric loss factor ε''
10.0	0.771	2.65	0.26
12.5	0.761	2.88	0.41
15.0	0.740	3.06	0.57
17.5	0.712	3.28	0.64
20.0	0.681	3.57	0.71

TABLE 2: Constants for different proposed models connecting relative permittivity and dielectric loss factor with moisture content for soft red winter wheat *(Triticum aestivum L.)* at 2.45 GHz and 24^{0}C

Parameters and constants for the present models			
Models for relative permittivity		Models for dielectric loss factor	
QM[a]	CM[b]	QM	CM
a = -10.6353	a = 230.8584	c =9.5222	d = -282.9223
b = 12.3163	b = – 82.7858	d =1.3829	e = -97.9445
K_1= 1.4940	c = 17.6910	K_2= 0.0876	f = - 5.2040
	K_1 = 1.4940		K_2= 0.0876

[a]QM-Quadratic model; [b]CM-Cubic model

TABLE 3 : Quantitative comparative performances of present models and those of Nelson for moisture dependence of relative permittivity and loss factor of soft red winter wheat *(Triticum aestivum L.)* measured at 2.45 GHz and 24^{0}C

TABLE 3(a): Models for relative permittivity

Nelson's models				Present models			
QM[a]		CM[b]		QM		CM	
Predicted values	r^2/ % error	Predicted values	r^2/ % error	Predicted values	r^2/ % error	Predicted values	r^2/Average % error
2.72		2.74		2.62		2.67	
2.92		2.99		2.87		2.86	
3.16		3.17	0.9990/2.76	3.10		3.06	
3.35	0.9992/1.76	3.36		3.32	0.9999/1.02	3.29	0.9934/0.35
3.58		3.59		3.53		3.57	

[a]QM–Quadratic model; [b]CM–Cubic model

TABLE 3(b) : Models for dielectric loss factor

Nelson's models		Present models			
QM		QM		CM	
Predicted values	r2/Average % error	Predicted values	r2/Average % error	Predicted values	r2/Average % error
0.27		0.32		0.26	
0.35		0.41		0.41	
0.42	0.9994/16.71	0.51		0.56	0.9662/4.10
0.50		0.62	0.9999/8.62	0.66	
0.59		0.74		0.70	

a]QM – Quadratic model; b]CM– Cubic model

been reported.

Examination of data in TABLE 3 reveals that both quadratic and cubic models of Nelson relating relative permittivity to decimal moisture content generally predicted almost the same values, excepting a few instances where they differed by more than 5%. The average error of prediction over all moisture contents was 1.76% and 2.76% for quadratic and cubic models, respectively. The corresponding average errors of prediction for the present two models are 1.02% and 0.35%. The average percentage error of prediction in Nelson's solitary model for dielectric loss factor against moisture content is too high ≈16.71 %. The deviation in the newly proposed quadratic model is ≈8.67. On the contrary, the deviation is too small ≈4.10% with the newly proposed cubic model. The r^2-values for all the models for relative permittivity are ≈0.96 to 0.99. Thus, all the models show good fits with experimental data.

Thus, on the basis of the present study, it may be opined that the new cubic models proposed in the present study, provide better performance as compared with others in predicting moisture dependence of relative permittivity and dielectric loss factor at the chosen microwave frequency. However, the new quadratic models for relative permittivity as well as the loss factor provide higher r^2-values (≈0.9999) as compared to those for cubic ones.

CONCLUSIONS

The moisture dependence of relative permittivity and dielectric loss factor of soft red winter wheat *(Triticum aestivum L.)* over moisture range of 10 % to 20 % at 2.45 GHz and 24^{0}C can be accurately represented by second and third order polynomial trends equations, both dielectric parameters showing slowly increasing trends with the increase of moisture content. The results derived from the models are indicative of the fact that these equations should be generally useful for predictive purposes in most practical applications.

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