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CORRELATIONS FOR PREDICTING DRYING RATES OF AGRICULTURAL PRODUCTS

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ABSTRACT:

The present work develops several empirical equations for estimating the drying rate of both grains and green plants, that grow in Egypt when dried with and without making use of direct radiation. The developed equations were based on the measurements of free moisture content over the period of 1992-1993. Lydersen model [1] for describing the drying rate process of dried materials was used as a basis in the present work. The empirical equations were presented for peanuts, soya beans and sorghum grains besides their green plants. Additional samples of barseem green plants were also dried and the accuracy of proposed equations was discussed. These equations were obtained for each individual product, in a generalized form and as a ratio between the two different modes of drying. The drying rates predicted by the proposed equations were in a satisfactory agreement with the observed values. The introduction of the drying rate of agricultural products dried under various conditions may be useful for the design of suitable drying units for countries like Egypt.

1. INTRODUCTION:

Drying or dehydration of material means removal of moisture from the interior of the material to the surface and then the removal of this moisture from the surface to the ambient air. In natural sun drying where the product is directly exposed to sun rays in open air, the necessary heat required for moisture removal is supplied from the direct radiation and a little from the ambient air, the wind and the natural convection disperse water vapor. This method of drying differs from the convection type of drying where a stream of solar energy preheated air supplemented by an auxiliary energy is allowed to pass over the product. It then supplies the necessary heat for moisture removal from inside to outside and also to carry away the evaporated moisture from the surface of the material.

The rate of moisture movement from inside product to the air outside differs from one product to another. The prediction of the drying rates of agricultural products are very important in the design of drying systems. This parameter is usually used as the most fundamental datum during the design stages and in optimization of a drying unit. Several general models have been proposed to describe the thin layer drying process of agricultural products. These models can be classified as follows: (a) the development of semi-empirical or empirical equations, (b) the development of theoretical equations. The main purpose of the empirical equations is to satisfy the experimental data. The theoretical approach concerns with either the diffusion equation or the heat and mass transfer equations. The empirical approach is often used to describe the drying rate of products. A number of researches [2-6] are available in which empirical drying rate expressions have been developed. Most of those authors assumed that the moisture movement within wet material could be represented by a diffusion-type equation. However, another models, that explained the transport of moisture in the solid materials, are based on the pressure driving force-type of equation. The researches carried out by Lewis [2] suggested that the rate of drying of solid material is proportional to the difference between the average moisture content in the material M and the equilibrium moisture content, Me. Lewis [2] suggested an equation, analogous to Newton's law of cooling, to describe grains drying rate of the form:

$$dM/dt = - K (M - Me) \tag{1}$$

where K is a constant.

Chen and Johnson [3] suggested that Lewis's equation might be generalized to describe all the drying periods. They proposed a power function as a modified form of equation (1):

$$dM/dt = - K (M - Me)^n \tag{2}$$

where K and n are empirical constants.

Zaman and Bala [4] presented the dependence of K on both the humidity H and the saturated humidity Hs for rough rice grains by introducing an expression of the form:

$$dM/dt = - (Hs - H) (M - Me)^n \tag{3}$$

Bruce [5] used a exponential fit to model wheat drying investigating the dependence of K on air temperature in the form:

$$dM/dt = - A \, EXP [(-b/Ta) (M - Me)] \tag{4}$$

in which A and b are constants.

Zaman and Bala [4] used also the same exponential function for thin layer natural flow solar drying of rough rice. A comparison between these two equations (3) and (4) with Lewis's model (1) as indicated by [4] shows that the best representation of data was obtained with Lewis's equation and the worst fitting was for equation (4). Equation (3) gives moderately good fitting.

Shomo [6] extended Chen and Johnson equation (2) to yield an expression for the average drying rate of vegetables dried in a humid environment. The proposed equation was in the form:

$$\mathrm{Log}[-d(M - Me)]/dt = \mathrm{Log}\, K + n\, \mathrm{Log}(M - Me) \qquad (5)$$

Recently, the linear regression equation of Lewis has been used in [7] to predict the drying rate of agricultural crops; grains and green plants. This study showed that the constant K differed from one product to another and depended on the mode of drying and the drying conditions. Additional models for estimating the drying rate of agricultural crops were listed in [8, 9].

The purpose of the present study is to provide one exponential correlation for estimating a thin layer drying rate of both grains and green plants dried by making use of the two modes of solar energy: with and without using direct radiation. The proposed empirical equations depend mainly on the free moisture content measurements for various types of products grown in Egypt that carried out over the period of 1992-1993. These products include peanuts, soya beans and sorghum grains besides their green plants. In addition, samples of barseem green plants were also used. Simple empirical equations of each individual crop for a given drying mode of direct or indirect radiation and in a generalized form were proposed. Furthermore, the ratio between the two different modes of drying were presented.

2. ANALYSIS:

Two approaches are available to determine drying rate of agricultural products. The first one is used to determine the rate of drying (dM/dt) depending on the measurements of the moisture content only during the drying time. The drying rate according to this approach decreases till the moisture content becomes zero. The second approach is suitable mainly for the estimation of the drying rate of the hygroscopic materials. This is done by determining the rate of drying (dw/dt) based on the minimum moisture content to which the material could be dried under a given set of drying conditions; i. e., the equilibrium moisture content. It is usually expressed in terms of the free moisture content. This approach was developed by Lydersen [1] and is adopted in the present study.

A large number of studies on agricultural products drying process have been devoted to predict the rate of drying using the first approach. However, hygroscopic materials and their drying rate predictions have been scarcely studied. Empirical equations including the external variables affecting the drying process are required for the design of suitable drying systems.

The general proposed expression of exponential function for predicting drying rate is presented as follows:

$$dw/dt = - a \, EXP \, [z \, (M-Me)/Ta] \tag{6}$$

Where dw/dt is the drying rate based on the free moisture content, a is the amplitude of the exponential function which specifies the amount of the drying rate oscillation about its average value, z is the empirical constant, M is the moisture content, Me is the equilibrium moisture content and Ta is the air temperature.

The ratio [z (M-Me)/Ta] represents the angular frequency which characterizes how often the drying rate function occurs. The constant z is considered as a measure of the drying process. The speed and efficiency of the drying process depend on the humidity of the drying air [8]. The coefficient "a" can be expressed in terms of the difference between the saturation humidity Hs and the humidity H as follows: a = c (Hs-H). The values of the constants c and z were determined using a least square technique and the results of the proposed function were found to fit the data satisfactorily. The function of the form (6) was fitted to 16 sets of experimental data on solar drying for various types of products grains and green plants with and without making use of direct radiation.

The prediction of drying rate using the proposed expression in equation (6) has the advantage that it exposes the drying behavior of the products in which there is no constant rate period as indicated by Parry [8] and as shown by the present results. In addition, this equation takes into consideration the influence of external parameters that have direct effect on the drying process. It merely requires the measurement of the free moisture content and the air temperature.

The equilibrium moisture content is obtained when the sample weight does not change with time and it is given by the following equation [1]:

$$Me = (Ge - Wd)/Wd \tag{7}$$

Where Ge is the constant weight at the end of the test and Wd is the dry weight of the material.

The free moisture content Mr can be calculated as follows:

$$Mr = (Gt - Wd)/Wd - Me \tag{8}$$

Where Gt is the weight of humid material observed at different drying times.

The variation in moisture content with time is given by:

$$\Delta Mr/\Delta t = -(Mr_{n+1} - Mr_n)/(t_{n+1} - t_n) \qquad (9)$$

where $[t_{n+1} - t_n]$ is the time interval.

The corresponding drying rate was calculated based on the free moisture content as follows:

$$dw/dt = -\Delta Mr/A\,\Delta t \qquad (10)$$

Where A is the heat and mass transfer area.

The average moisture content and the average temperatures were calculated as following:

$$M_{av} = (M_n + M_{n+1})/2 \qquad (11)$$

$$T_{av} = (T_n + T_{n+1})/2 \qquad (12)$$

The humidity of air was calculated from the following relationship:

$$H = 0.622\ Pv/(P - Pv) \qquad (13)$$

The vapor pressure Pv can be obtained from the ambient relative humidity ϕ as follows:

$$\phi = [Pv/Ps] \qquad (14)$$

The saturated vapor pressure Ps at dry bulb temperature Td in absolute scale is given by the equation [1]:

$$Ps = EXP\ [\ 23.7093 - 4111/Td\ ] \qquad (15)$$

3. EXPERIMENTS:

There are many categories of agricultural crops that grow in Egypt. Among these crops three various types of materials, namely: peanuts, soya bean and sorghum grains besides their green plants, were chosen to be dried. Additional samples of barseem green plants were used in the experiments. Because of the differences between sowing time, only one month, and consequently harvesting times of these materials, the process of sowing were carried out such that the complete plants growth and hence the harvested timing could be achieved during the same period. This means that the solar drying experiments could be simultaneously performed under the same conditions.

The agricultural products used in these experiments were obtained from ZELN farm, Shiben EL- Kom, Egypt. Two different modes of drying were used. The first one was achieved by exposing the samples to direct radiation. The second was performed by putting other samples under a covered shed. The products were dried simultaneously in November 1992 using the two drying modes. Additional samples of barseem green plants were dried in June of 1993. Each sample weighs 5 Kg. The drying test of products were carried out in an insulated tray made of plastic material. The samples were put in the sunshine to receive direct radiation during the daytime. At the same time, other samples were put under a covered shed where direct radiation was not available. All the samples were covered with a plastic material during night time to protect them from rewetting. To ensure that each particle receives the same amount of solar energy, the samples were distributed in the form of a thin layer. All the required measurements including samples weight, ambient dry bulb and wet bulb temperatures were taken at a regular time intervals of 24 hours. Table 1 presents the different types of the used products, the drying mode and the drying date during the process of drying. A pendulum balance of 20 Kg. capacity and 25 gm. sensitivity was used to weigh the samples. A laboratory psychrometer was used to measure dry bulb and wet bulb temperatures of the surrounding air. Over its range of 0-100 °C, the instrument is accurate to ± 1 °C.

4. RESULTS AND DISCUSSION:

The drying rate resulted from the experimental measurements (dw/dt) is fitted and is given in the following general form:

$$dw/dt = - c\ (Hs - H)\ EXP\ [\ z\ (M - Me)/Ta\ ] \qquad (16)$$

The values of the coefficients c and z are listed in table (1). The proposed empirical equation in the form of equation (16) is fitted according to three different cases:

1. By treating the experimental data of each individual product for each mode of drying.

2. By treating the experimental data as a whole and, hence, a generalized empirical equation for each sort of product can be expressed.

3. By treating the experimental data such that a generalized equation for the drying rate ratio can be introduced. Here, the drying rate ratio is defined as the ratio between the drying rate for samples exposed to direct radiation to that receiving no direct radiation (using covered shed).

4.1 Drying rate equations for each individual product:

A series of 16 experiments (188 runs) were performed to cover all the dried materials and the range of the governing parameters. The drying rate values for each experiment were computed using equation (16) with the aid of the corresponding values of the constants c and z listed in Table 1. The predicted drying rates [(dw/dt)pred] were compared with the measured values [(dw/dt)meas] for each run. Table 1 also shows the correlation coefficient r for each equation.

The following tests were determined to verify the accuracy of the proposed equations:

1. The residual values; $R = [(dw/dt)_{pred} - (dw/dt)_{meas}]$

2. The percentage error;

$$E=[(dw/dt)_{pred}-(dw/dt)_{meas}]/(dw/dt)_{meas}$$

3. The overall mean error;

$$E_{av} = 1/n \left[\sum_{i=1}^{n} \{ (dw/dt)_{pred}-(dw/dt)_{meas} \} / (dw/dt)_{meas} \right]$$

5. The variance; $\sigma^2 = \sum_{i=1}^{n} [(dw/dt)_{pred} - (dw/dt)_{meas}]^2 / (n-1)$

Where n is the number of experiments.

5. The standard deviation; $S = (\sigma^2)^{0.5}$

6. The assurance factor; $F = (dw/dt)_{pred}/(dw/dt)_{meas}$

Table 1, Values of the constants c and z of equation (16) and the correlation coefficient r for each equation.

EX	Product	Type	Drying mode	Drying date	$\frac{dw}{dt}=-c(Hs-H)\ EXP\ z(M-Me)/Ta$			Eq no
					c	z	r	
1	barseem	green plants	dir.	November 1992	0.091	1520.396	0.997	17
2			cov.		0.169	410.423	0.620	18
3			dir.	June 1993	0.418	850.010	1.000	19
4			cov.		0.495	625.500	0.9997	20
5	peanuts	grains	dir.	November 1992	0.370	2727.330	0.833	21
6			cov.		0.324	2024.582	0.804	22
7		green plants	dir.	November 1992	0.416	1320.500	0.955	23
8			cov.		0.106	1795.352	0.935	24
9	soya beans	grains	dir.	November 1992	0.177	3463.830	0.851	25
10			cov.		0.156	2235.916	0.714	26
11		green plants	dir.	November 1992	0.034	2608.400	0.999	27
12			cov.		0.033	979.571	0.814	28
13	sorghum	grains	dir.	November 1992	1.208	2935.530	0.997	29
14			cov.		0.140	3348.182	0.815	30
15		green plants	dir.	November 1992	0.030	1618.926	0.768	31
16			cov.		0.029	1476.722	0.511	32

Where: dir. - samples exposed to direct radiation, cov. - samples put under a covered shed.

The results of the present tests are listed in Table 2. A comparison between measured and predicted drying rates for grain and green plant samples are shown in Figs. 1 and 2, respectively. The ratio of the predicted drying rates [(dw/dt)pred] to the measured values [(dw/dt)meas] is presented as a function of the ratio [(M-Me)/Ta] for all cases. It can be seen that the proposed equations can be divided into four groups as follows:

1. The best fitting was obtained for equations (19), (20) and (29). The overall mean error is less than 2%.

2. Satisfactory fitting was found for equations (21), (22), (23), (24) and (27). The overall mean error ranges between 15.42 and 28.24 %.

3. Relatively poor fitting was found for equations (17), (18), (28) and (30). The overall mean error ranges between 32.7 and 35.7 %.

4. The worst fitting was for equations (25), (26), (31) and (32). The overall mean error reached 53.78 %.

The discrepancy observed between the predicted and measured drying rate values are due to the variations in the solar radiation and air drying conditions during the drying time. It was observed that the discrepancy was maximum in the case of sorghum green plants put under a covered shed where the drying time reached 16 days. On contrary, the discrepancy was minimum and the accuracy of equation was very high for sorghum grains exposed to direct radiation where the process of drying took only two days.

A Comparison between coefficients c and z for the experiments carried out throughout the seasons of 1992 and 1993 shows the following features:

1. The values of coefficients c and z depend strongly on the type of dried material, the mode of drying and the conditions of drying air.

2. The range of the coefficient z was varied between 3463.83 and 410.423 . These values belong to soya beans grains exposed to direct radiation and barseem green plants put under a covered shed, respectively. The coefficient c ranges between 1.208 and 0.029 which correspond to the sorghum grains exposed to direct radiation and green plants put under a covered shed, respectively.

3. The coefficient z for samples exposed to direct radiation is always higher than the corresponding values for samples put under a covered shed except for the case of peanuts green plants and sorghum grains.

4. The coefficient z for the samples of barseem green plants dried under average climatic conditions of 24 $^{\circ}$C dbt and 18 $^{\circ}$C wbt (dried in November 1992) is higher than that for the samples

Table 2, Values of the parameters S, σ^2, Fav and Eav of equation (16).

EX	Product	Type	Drying mode	S	σ^2	Fav	Eav %	EQ no
1	barseem	green plants	dir.	1.849×10^{-3}	3.420×10^{-6}	1.075	33.53	17
2			cov.	1.046×10^{-3}	1.049×10^{-6}	1.061	32.70	18
3			dir.	6.010×10^{-6}	3.61×10^{-11}	1.0002	0.030	19
4			cov.	1.217×10^{-6}	1.48×10^{-12}	0.9999	0.009	20
5	peanuts	grains	dir.	6.138×10^{-3}	3.768×10^{-5}	1.112	20.75	21
6			cov.	3.772×10^{-3}	1.423×10^{-5}	1.089	17.09	22
7		green plants	dir.	1.726×10^{-3}	2.981×10^{-6}	1.017	15.42	23
8			cov.	2.782×10^{-3}	7.740×10^{-6}	0.883	28.24	24
9	soya beans	grains	dir.	4.050×10^{-3}	1.638×10^{-5}	1.176	50.23	25
10			cov.	4.014×10^{-3}	1.611×10^{-5}	1.303	53.78	26
11		green plants	dir.	1.297×10^{-3}	1.681×10^{-6}	1.043	25.10	27
12			cov.	1.389×10^{-3}	1.930×10^{-6}	1.047	34.46	28
13	sorghum	grains	dir.	1.431×10^{-5}	2.046×10^{-6}	1.019	1.88	29
14			cov.	2.950×10^{-3}	8.720×10^{-6}	1.074	35.74	30
15		green plants	dir.	2.722×10^{-3}	7.412×10^{-6}	1.376	41.8	31
16			cov.	1.188×10^{-3}	1.411×10^{-6}	1.264	39.31	32

dried under conditions of 31 °C dbt and 21.7 °C wbt (dried in June 1993) regardless of the mode of drying.

5. The coefficient z for grains is always higher than that for green plants regardless of the mode of drying.

The drying rate results demonstrate the following features:

1. The drying rate for the samples exposed to direct radiation is higher than that put under a covered shed regardless of the type and the weight of dried material and the drying conditions.
2. The drying rate of green plants during the period of June 1993 is higher than that during the period of November 1992 regardless of the mode of drying.
3. The drying rate for grains is higher than that for green plants regardless of the mode of drying except for the case of peanuts.
4. The highest drying rate was obtained for sorghum grains exposed to direct radiation, while the lowest drying rate was observed for soya bean green plants put under a covered shed.

The differences in drying rates between different products may be attributed to the following: (1) the reduction in the surface vapor pressure as a result of increasing the viscosity of the material interior medium because of the existence of sugar and minerals of water which reduces the moisture evaporation, (2) the difference in the thermal conductivity of materials which permits changing in heat transfer on its surface and from particle to particle and (3) the change in transport properties of the product surface which differs from one product to another.

Comparison between the present equations and Lewis's model:

Similar empirical equations for estimating the drying rate of agricultural products have not been found in the available literatures. Only, the average drying rate expression based on the free moisture content for big pods of okra dried in humid environment was obtained by Shomo [6]. The Lewis's model represented by equation (1) was chosen for the purpose of comparison with the present proposed equations. This equation has been widely used as a basis for modeling the drying rate in crops drying. The free moisture content was used in the Lewis's model instead of the moisture content to obtain the values of drying rate. Table 3 presents two cases for comparison between the two models for the samples of barseem green plants and peanuts grains exposed to direct radiation. It can be seen that the new proposed equations predict the experiments to some extent well compared with Lewis's model.

4.2 Generalized drying rate empirical equations:

The experimental data were treated as a whole using the least squares technique in order to obtain a generalized empirical form valid for each sort of products under identical drying conditions. Four different generalized equations were established as follows:

$$dw/dt = -\ 0.317\ (Hs - H)\ EXP\ [3209.65\ (M - Me)/Ta] \qquad (33)$$

For grains exposed to direct radiation,

$$dw/dt = -\ 0.192\ (Hs - H)\ EXP\ [2550.44\ (M - Me)/Ta] \qquad (34)$$

For grains put under a covered shed,

$$dw/dt = -\ 0.065\ (Hs - H)\ EXP\ [1384.34\ (M - Me)/Ta] \qquad (35)$$

For green plants exposed to direct radiation,

$$dw/dt = -\ 0.072\ (Hs - H)\ EXP\ [899.80\ (M - Me)/Ta] \qquad (36)$$

For green plants put under a covered shed.

Table 3, Comparison between drying rates predicted with proposed equation (16) and Lewis's equation.

Ex	Run	Product	Measured values	Predicted with equation (16)		Predicted with Lewis's equation	
			(dw/dt)meas	(dw/dt)pred	F	(dw/dt)pred	F
1	1	barseem green plants, dir.	10.250×10^{-3}	12.820×10^{-3}	1.251	9.065×10^{-3}	0.972
	2		4.270×10^{-3}	2.398×10^{-3}	0.562	3.880×10^{-3}	0.909
	3		1.708×10^{-3}	1.566×10^{-3}	0.917	1.373×10^{-3}	0.804
	4		6.405×10^{-4}	1.005×10^{-3}	1.569	3.884×10^{-3}	0.606
5	1	peanuts grains, dir.	33.300×10^{-3}	21.143×10^{-3}	0.635	26.040×10^{-3}	0.782
	2		4.157×10^{-3}	9.773×10^{-3}	2.351	14.930×10^{-3}	3.591
	3		8.334×10^{-3}	9.836×10^{-3}	1.180	11.230×10^{-3}	1.348
	4		8.334×10^{-3}	5.804×10^{-3}	0.697	6.293×10^{-3}	0.755
	5		4.157×10^{-3}	3.552×10^{-3}	0.854	2.591×10^{-3}	0.623
	6		4.157×10^{-3}	3.978×10^{-3}	0.957	7.404×10^{-5}	0.018

Figures 3 to 6 give a comparison between predicted and measured drying rates for the above cases. The parameters σ^2, S, r, Fav and Eav are listed in Table 4. The best fitting was obtained for equation (33) and the worst fitting was for equation (35). Satisfactory fitting was found for equations (34) and (36).

4.3 Drying rate ratio empirical equations:

Two different empirical equations for the drying rate ratio are proposed. The first is concerned with the ratio between the drying rate for grain samples exposed to direct radiation $[(dw/dt)_{dir}]$ and that put under a covered shed $[(dw/dt)_{cov}]$. The second equation states the drying rate ratio for green plant samples; i.e. $[(dw/dt)_{dir}/(dw/dt)_{cov}]$. These equations can be expressed as follows:

$$(dw/dt)_{dir}/(dw/dt)_{cov} = 98.55\ (Hs-H)\ EXP\ [1008.5(M-Me)/Ta] \quad (37)$$

For grain samples,

$$(dw/dt)_{dir}/(dw/dt)_{cov} = 56.23\ (Hs-H)\ EXP\ [798.2\ (M-Me)/Ta] \quad (38)$$

For green plant samples.

Table 5 presents the calculated values of σ^2, S, r, Fav and Eav. A comparison between drying rate ratio predictions $[(dw/dt)_{dir}/(dw/dt)_{cov}]$pred; i. e.; [(N)pred] and measured data $[(dw/dt)_{dir}/(dw/dt)_{cov}]$meas; i.e.; [(N)meas] are given in Figs. 7 and 8. It can be seen that a reasonable agreement is found between predicted and measured values of the drying rate ratios.

Table 4, Values of the parameters σ^2, S, r, Fav and Eav of equations (33), (34), (35) and (36).

Product	drying mode	σ^2	S	r	Fav	Eav %	Eq. no.
Grains	dir.	8.740×10^{-5}	$9,348\times10^{-3}$	0.732	1.167	29.72	33
	cov.	1.448×10^{-5}	3.810×10^{-3}	0.766	1.210	34.87	34
Plants	dir.	1.020×10^{-5}	3.192×10^{-3}	0.676	1.780	39.96	35
	cov.	6.902×10^{-6}	2.627×10^{-3}	0.639	1.169	33.90	36

Table 5, Values of the parameters σ^2, S, r, Fav and Eav of equations (37) and (38).

Product	σ^2	S	r	Fav	Eav %	Eq. no.
Grains	1.289	1.135	0.76	1.134	26.83	37
Plants	1.334	1.155	0.98	1.242	34.50	38

The proposed empirical equation was applied on materials that differ in surface characteristics, chemical compositions and physical structures and it gives good prediction. Detailed information on thermal properties of dried materials are required to obtain more accurate general models of the drying process.

5. CONCLUSIONS:

The present work provides new several empirical equations of the form:

$$dw/dt = - c\ (Hs - H)\ EXP\ [\ z\ (M - Me)/Ta\ ]$$

which best represent the measured drying rate data of various types of agricultural products that grow in Egypt with and without making use of direct radiation. These equations were obtained for each individual product; Eqs. (17) to (32), in a generalized form; Eqs. (33) to (36) and as a ratio between the two different modes of drying; Eqs. (37) and (38). The accuracy of the derived equations were tested against the measured data over the period of drying. The agreement between predicted values and measured data was found to be satisfactory. The coefficients c and z depend strongly on type of dried material, mode of drying and the drying conditions. The results showed that the best representation of the drying rate process can be obtained using the present equations compared with Lewis's model. The results of the present study can be used for design and development of suitable drying systems utilizing solar energy for countries like Egypt.

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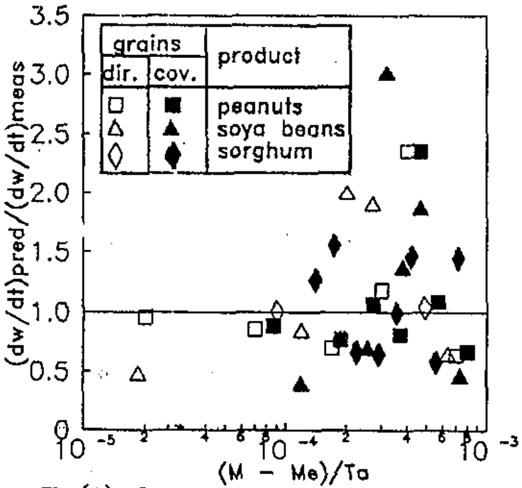

Fig.(1): Comparison of measured and predicted drying rate for grain samples.

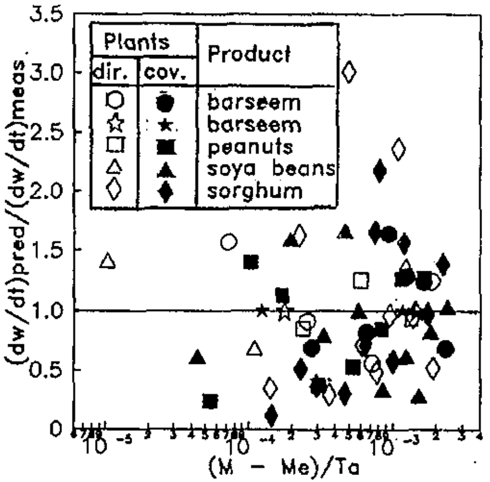

Fig.(2): Comparison of measured and predicted drying rate for green plant samples.

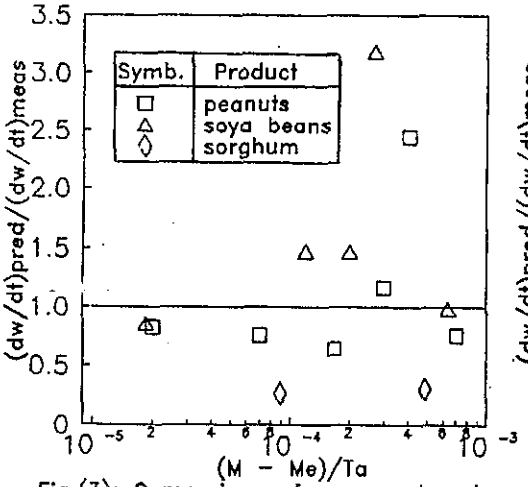

Fig.(3): Comparison of measured and predicted drying rate for grains exposed to direct radiation.

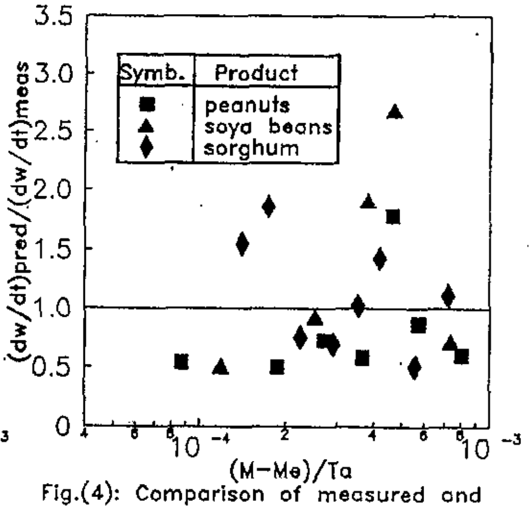

Fig.(4): Comparison of measured and predicted drying rate for grains put under a covered shed.

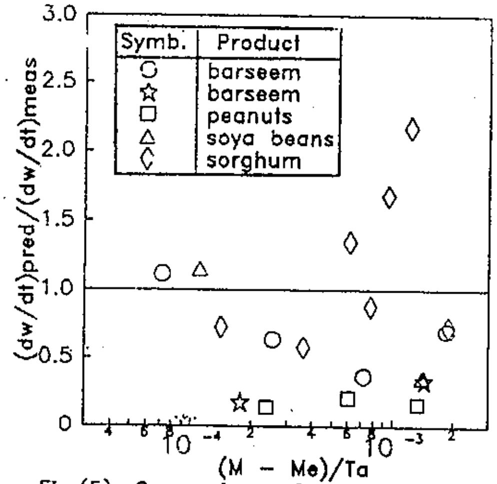

Fig.(5): Comparison of measured and predicted drying rate for green plants exposed to direct radiation.

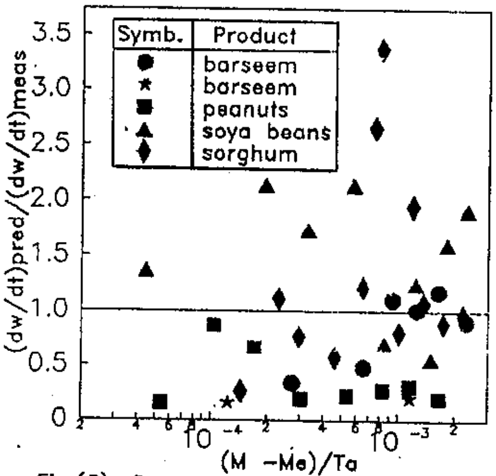

Fig.(6): Comparison of measured and predicted drying rate for green plants put under a covered shed.

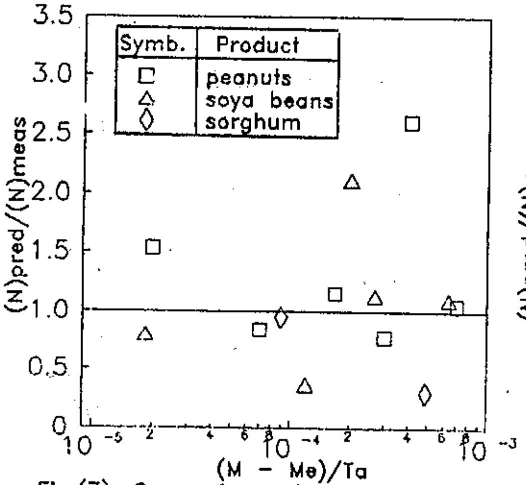

Fig.(7): Comparison of measured and predicted drying rates for grain samples.

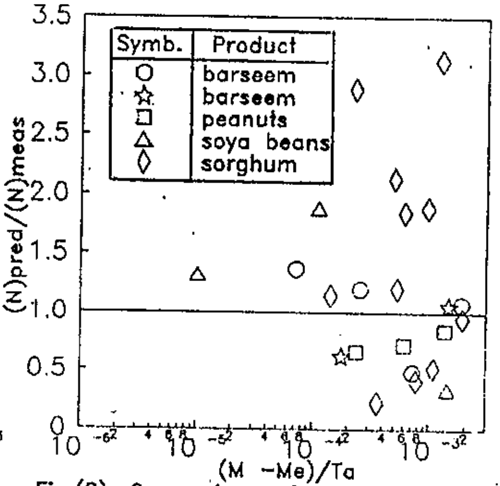

Fig.(8): Comparison of measured and predicted drying rates for green plant samples.

" معادلات تجريبية للتنبوء بمعدلات التجفيف للمنتجات الزراعية"

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الملخص :

يتناول البحث بالتطوير لعديد من المعادلات التجريبية لتقدير معدل التجفيف لكل من الحبوب والنباتات الخضراء التى تنمو فى مصر عندما تجفف باستخدام الاشعاع الشمسى المباشر أو بدونه . ولقد اختيرت المعادلات المتناولة بالتطوير على أساس قياس نسبة الرطوبة الحرة خلال فترة التجفيف فى عامى ١٩٩٢، ١٩٩٣ واستخدم موديل ليدرسون الذى يصف عمليةالتجفيف للمنتجات الزراعية كأساس للبحث الحالى وتناول البحث المعادلات التجريبية لجبوب الفول السودانى والفول الصويا والذرة بالاضافة الى المجموع الخضرى لكل منهم وكذلك عينات اضافية من نبات البرسيم واحتوى البحث أيضا على مناقشة لدقة المعادلات المقترحة .

ولقد تم الحصول على هذه المعادلات طبقا للحالات الآتية :

١ - لكل منتج على حدة.
٢ - فى شكل عام.
٣ - كنسبة بين الأسلوبين المختلفين للتجفيف.

وبمقارنة النتائج التى تم الحصول عليها من المعادلات المقترحة بالنتائج التجريبية الموجودة بالبحث لوحظ وجود تقارب مرضى بينهما .

وقد استخلص من هذا البحث أن تقديم معدل التجفيف للمنتجات الزراعية المجففة تحت ظروف جوية مختلفة مفيدا لتصميم وحدات تجفيف مناسبة فى دولة مثل مصر.