Volume and Surface Area Shrinkages of Some Hybrid Corn Varieties

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Abstract: Hybrid corn has been popular to Indonesian corn farmers in recent years. Nonetheless, physical properties of hybrid corn kernels, including their shrinkage behavior, are rarely investigated to support a more efficient post harvest handling. This research was designed to explore the shrinkage behavior of the kernels of five hybrid corn varieties (NK77, DK77, Pioneer, Makmur, and Bisi-2). The study was conducted in the Processing Laboratory of Agricultural Engineering Department, Hasanuddin University, Indonesia, in 2011. Five relatively homogenous kernels from each variety were selected and dried under a temperature of about 47^{o}C with drying air velocity of 1.0 m/s, using a tray dryer, Model EH-TD-300 Eunha Fluid Science. A caliper with an accuracy of 0.05 mm was used to measure the orthogonal dimensions of the kernels. Such dimensions were transformed into volume and surface area ratios. The behaviours of these ratios as a function of moisture contents, called shrinkage behaviors, were fitted to Rahman, Bala and Wood, Corrêa et al. and polynomial quadratic models. The results strongly suggested that there was no single model which was consistently more superior in estimating the shrinkage behaviors of both volume and surface area of the hybrid corn varieties of NK22, DK77, Pioneer, Makmur, and Bisi-2 than the other models. However, compared with the other two models, the Bala and Wood and the polynomial quadratic models consistently provided high R^2 values.

Keywords: Hybrid-corn; kernel; drying; shrinkage

1. Introduction

Corn is one of the major secondary food crops in Indonesia. This crop has become one of the main development focuses of some provincial governments, including the South Sulawesi Provincial Government. The BPS-Statistics of the South Sulawesi Province, Indonesia (2011) reported that corn production of this province in 2010 reached up to about 1.3 million tons with total harvested area of about 300 thousand hectares. The productivity level was about 4.43 tons per hectare. This high yield was mostly driven by the intensive use of hybrid varieties.

Hybrid corns are continuously developed across the world as part of the efforts to increase world corn production. In Indonesia, especially in South Sulawesi Province, there are at least five different corn hybrid varieties that are popular and commonly planted. Those are NK77, DK77, Pioneer, Makmur, and Bisi-2. Among others, their high yield is the main reason why these varieties are attractive to the farmers.

The physical and mechanical properties of the above hybrid varieties are not well characterized, including their volume and surface area shrinkages during the drying process. The knowledge of the physical and mechanical properties of the agricultural products, including the mentioned five corn varieties, is of fundamental importance for the correct storage procedure and for design, dimensioning, manufacturing and operating different equipments used in post harvesting main processing operations (Corrêa *et al*., 2007). It is also realized that crop varieties might affect these properties as indicated by Razavi *et al*. (2009). Based on these facts, this study was designed to examine the volume and surface area shrinkage behaviors of the corn kernel from several different hybrid corn varieties during the drying process. As conducted by Corrêa *et al*. (2004), this research was also intended to find the best mathematical model to represent the shrinkage behaviors as a function of moisture content.

The crop shrinkage was intensively studied by some researchers. Among others, Corrêa *et al*. (2004) observed coffee berry shrinkage. Matin *et al*. (2007) studied the impact of drying on dimensions of hybrid corn kernels of Bc-4982, Bc-462, Bc, Jumbo, Florencia, and Stefania varieties grown at different agrotechnological levels in Croatia. Abasi *et al*. (2009a) scrutinized the behavior of onion slice shrinkage during the thin layer drying process. Effect of drying time and temperature on moisture content, shrinkage, and rehydration of dried onion was also studied by Abasi *et al*. (2009b).

A similar approach was also applied by Seifi and Alimardani (2010) when examined the relationship of the corn porosity and moisture contents. Muhidong and Kartika (2011) characterized the best model to represent the volumetric-shrinkage of cocoa beans. Momenzadeh and Zomorodian (2011) studied the corn shrinkage by looking at the geometric mean diameter of corn during drying process in a microwave-assisted fluidized bed dryer. The research objective was to explore the shrinkage behavior of corn kernels, specipically for hybrid corn varieties of NK77, DK77, Pioneer, Makmur, and Bisi-2.

2. Materials and Method

2.1 Sample Preparation

Sample source in this study was corn hybrids of NK22, DK77, Pioneer, Makmur, and Bisi-2 varieties obtained from corn farmers in Takalar Regency, about 40 km to the South of Makassar City, South Sulawesi Province, Indonesia. Three mature unshelled corns for each variety were selected and harvested from the field in September 2011. The unshelled corns were put into plastic bags and taken to the Processing Laboratory of Agricultural Engineering Department of Hasanuddin University. About three rows of kernels from the middle cobs of each variety were shelled and mixed together. Five corn kernels which were relatively homogeneous from each variety were then selected as sample. Momenzadeh and Zomorodian

(2011) only used three kernels in their study. The five kernels of each variety were arranged in a 10 cm x 3 cm tray in such away the distance between two kernels was about 2 cm. The five loaded trays were then placed into a larger tray (25 cm x 13 cm). Since the number of varieties observed was five, the total number of sample was 25 kernels. Such sample size was relatively manageable throughout the experiment.

2.2 Main Equipment

Main equipment used was a tray dryer, Model EH-TD-300 Eunha Fluid Science. This dryer was equipped with a pair of dry and wet bulb thermometers. A digital anemometer (0.1 m/s accuracy) was used to calibrate drying air velocity. To measure sample weight across drying time, a digital balance with an accuracy of 0.001 g placed close to the dryer was utilized. Other instrument applied was a caliper with an accuracy of 0.05 mm to measure the orthogonal dimension (***L***: length, ***W***: width, and ***T***: thickness) of the corn kernel.

2.3 Experimental Procedure

The drying temperature and air velocity were stabilized at about 47 °C and 1.0 m/s, respectively, for about one hour prior to the drying process. This drying temperature was far below the ones used by Matin *et al*. (2007), namely 70°C, 90°C, 110°C, and 130°C. The use of low drying temperature in this research allowed the corn kernel moisture contents to gradually and smoothly decrease across elapsed drying time. The airflow rate used, however, was exactly the same, 1.0 m/s. Nonetheless, Momenzadeh and Zomorodian (2011) used 30°C, 40°C, 50°C, and 60°C air drying temperatures in their study.

Kernel weight and dimension were measured prior to the drying process. Each kernel weight and dimension from each corn variety were then observed for every hour elapsed drying time. With this approach, there were 25 data collected for kernel weight and 75 data for kernel orthogonal dimension (***L***, ***W***, and ***T***) every hour. The weighing and dimension measuring process were done as quickly as possible to prevent the dried kernels from absorbing a significant amount of moisture from their surrounding atmosphere. To have a consistent measurement, position of each kernel in the tray was maintained throughout the drying process. The drying process was terminated when the kernel weight was unchanged for about 3 to 4 hours. At this point time, the sample weight was assumed in an equilibrium stage. Finally, all dried kernels were oven-dried for about 72 hours under a constant temperature of 105°C to get their dry weight. Such dry weight would become a basis for moisture content determination.

2.4 Model Development

Volume and surface area of each kernel were calculated based on the observed kernel orthogonal dimension. Methods applied to figure out the volume (***V***) and surface area (***S***) of the kernel were shown below. These methods were also used by Kibar and Öztürk (2008), Zareiforoush *et al*. (2009) and Seifi and Alimardani (2010).

$$V = 0.25\,[\frac{\pi}{6}L(W+T)^2]$$

$$S = \frac{\pi B L^2}{2L - B} \qquad B = \sqrt{WT}$$

L, ***W***, and ***T*** were the corn kernel orthogonal dimensions. The volume shrinkage represented by volume ratio (V_f) was then calculated using Corrêa *et al*. approach (2004) as shown below:

$$V_f = \frac{V_m}{V_o}$$

Where V_m represented corn kernel volume corresponding to the moisture content after the elapsed drying time ***m***, and V_o was the initial volume of the corn kernel. This approach is relatively different from the one applied by Momenzadeh and Zomorodian (2011) where corn shrinkage behaviors were observed based on the ratio of the corn geometric mean diameter.

Similar models were applied to determine the reduction of the kernel surface area by replacing ***V*** with ***S***. In this regard, the surface area ratio, S_f, could be calculated as follows:

$$S_f = \frac{S_m}{S_o}$$

Where S_m was kernel surface area corresponding to the moisture content after the elapsed drying time ***m***, and S_o was the initial surface area of the corn kernel.

The relationship of the V_f and S_f values and the moisture content (dry basis, d.b.) of the kernels were then evaluated using the models presented in Table 1.

U_o and **U** were the initial moisture content (d.b.) and the moisture content (d.b.) at a certain elapsed drying time, respectively. The Microsoft Excel Solver was used to evaluate the performance of the equations. Muhidong *et al*. (2013) also used this approach. As Kingsly *et al*. (2007), Hii *et al*. (2008), Rafiee *et al*. (2009) and Triratanasirichai *et al*. (2011) approaches, the best fitted model would be chosen based on the magnitude of the R^2, Root Mean Squared Error (*RMSE*) and Chi-squared (χ^2) values. The R^2 value was caculated using RSQ function of the Microsoft Excel. The values of *RMSE* and χ^2 were determined using the following approaches:

$$X^2 = \frac{\sum (MR_{(observed)} - MR_{(predicted)})^2}{N - n}$$

$$RMSE = \frac{\sqrt{\sum (MR_{(observed)} - MR_{(predicted)})^2}}{N}$$

Where ***N*** symbolizes the number of observations and ***n*** is the number of parameters involved in the model.

Table 1. List of equations being evaluated to represent the corn kernel shrinkage behavior

Model Name	Mathematical Model	References
Rahman (1995)	$V_f = 1 - b.(U - U_o)$	Corrêa *et al.* (2004)
Adapted Bala and Wood (1984)	$V_f = 1 - a.(1 - e^{(b).(U-Uo)})$	Corrêa *et al.* (2004)
Corrêa *et al.* (2004)	$V_f = \frac{1}{a + b.e^U}$	Corrêa *et al.* (2004)
Polynomial Quadratic Model	$V_f = a.U + b.U^2 + c$	This paper

Where *a, b*, and *c* are constants, and V_f was substituted by S_f for surface area ratio

3. Results and Discussion

3.1 Kernel Dimension

During the experiments, it was observed that the initial moisture contents of the samples were around 49-64% (d.b.). After the elapsed drying time of about 9 hours, the moisture levels were reduced to about 12-14% (d.b.). It was also found that the moisture contents decreased exponentially across the elapsed drying time.

The kernel orthogonal dimension of NK22 variety was the largest among five varieties observed. As a result, the volume and surface area of this variety were also the largest. The smallest one was indicated by Makmur variety.

The sequence of the kernel volume and surface area magnitudes started from NK22 as the largest, then Bisi-2, DK77, Pioneer, and Makmur as the smallest one, Tables 2 and 3.

Table 2. Average kernel volume across elapsed drying time.

Elapsed Drying Time (hours)	Volume (mm^3)				
	NK 22	DK 77	Pioneer	Makmur	Bisi-2
0	452.193	322.019	284.820	273.434	389.988
1	407.050	294.073	265.690	261.190	359.822
2	385.881	282.808	258.154	251.903	339.479
3	377.715	279.284	253.210	245.934	328.701
4	368.138	276.352	247.830	238.980	320.907
5	362.653	270.947	247.355	238.204	315.412
6	358.019	267.610	246.881	238.882	313.454
7	352.923	264.684	239.892	236.495	308.371
8	350.476	263.896	238.811	236.495	306.649
9	348.657	262.957	238.811	234.301	303.446

Table 3. Average kernel surface area across elapsed drying time.

Elapsed Drying Time (hours)	Surface Area (mm^2)				
	NK 22	DK 77	Pioneer	Makmur	Bisi-2
0	228.150	181.062	162.520	160.328	193.830
1	212.324	169.818	155.989	154.592	182.877
2	206.109	165.748	153.182	151.046	176.224
3	202.592	164.362	151.447	149.166	172.409
4	199.512	163.406	149.562	146.130	170.296
5	197.600	161.625	149.401	145.915	168.464
6	195.540	160.262	149.240	146.148	167.881
7	193.632	159.069	146.341	145.395	165.814
8	192.885	158.606	145.631	145.395	165.350
9	192.070	158.267	145.631	144.668	164.425

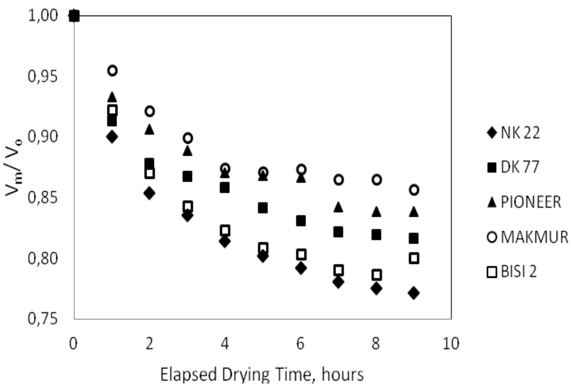

Figure 1. Volume ratio of the corn kernels across drying time

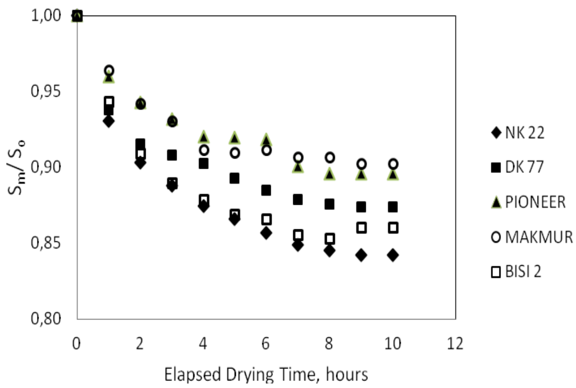

Figure 2. Surface area ratio of the corn kernels across drying time

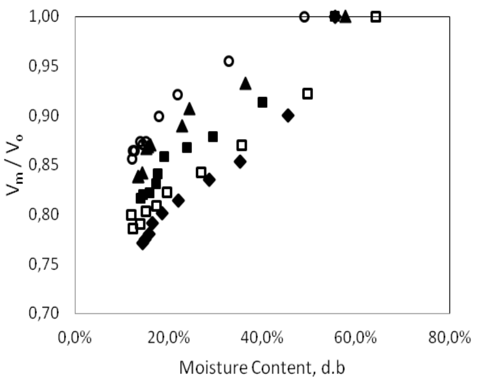

Figure 3. Volume ratio vs. moisture content of corn kernels

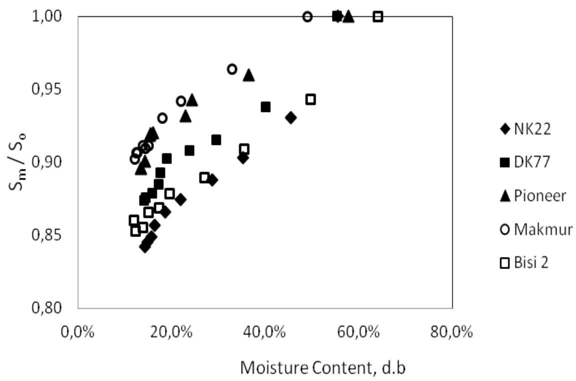

Figure 4. Surface area ratio vs. moisture content of corn kernels

3.2 Kernel Volume and Survace Area Ratios

The volume ratio, V_f, and surface area ratio, S_f, values as shown in Figures 1 and 2 had exactly an opposite order with that of the volume and surface area. This phenomenon strongly indicated that the larger the orthogonal dimension of the kernels, the more susceptible the kernels to shrinkage during the drying process.

Figures 3 and 4 suggested that the trends of the volume and surface area ratios when the moisture content of the kernels decreased during the drying process were close to exponential or polynomial patterns. These patterns were exactly in line with the four models proposed to be evaluated in this study, Table 1.

3.3 Performance Evaluations of the Models

All parameters involved in the models listed in Table 1 and the magnitudes of their R^2, *RMSE* and χ^2 values were then determined. The result summary of the analysis was shown in Tables 4 and 5.

Tables 4 and 5 truly suggested that there was no single model which was consistently more superior than the others across five hybrid corn varieties being studied. This

Table 4. Values of parameters involved in the volume shrinkage models being evaluated along with the values of R^2, χ^2, and *RMSE*

Corn Variety	Model	a	B	c	R^2	χ^2	*RMSE*
NK22	Rahman		-0.5634		0.957491	0.00037311	0.018325
	Adapted Bala & Wood	0.2833	3.552528		0.983961	9.46251E-05	0.008701
	Corrêa *et al.*	1.821415	-0.46455		0.981909	0.000103631	0.009105
	Polynomial Quadratic	0.029378	0.682989	0.762997	0.979911	0.00013142	0.009591
DK77	Rahman		-0.43691		0.973608	6.63494E-05	0.009287
	Adapted Bala & Wood	0.457814	1.177668		0.976041	5.36728E-05	0.008353
	Corrêa *et al.*	1.623461	-0.35838		0.974199	9.27459E-05	0.008614
	Polynomial Quadratic	0.297306	0.173548	0.777607	0.975802	9.9397E-05	0.008341
Pioneer	Rahman		-0.33201		0.952314	0.000127366	0.010707
	Adapted Bala & Wood	2.440445	0.139704		0.95025	0.000150155	0.010960
	Corrêa *et al.*	1.48442	-0.27709		0.919305	0.000231899	0.013621
	Polynomial Quadratic	0.587268	-0.34899	0.775023	0.966709	0.000109241	0.008745
Makmur	Rahman		-0.35953		0.965334	9.13098E-05	0.009065
	Adapted Bala & Wood	2.883822	0.127082		0.963329	0.000108657	0.009323
	Corrêa *et al.*	1.510496	-0.32038		0.930962	0.000172731	0.011755
	Polynomial Quadratic	0.78597	-0.67345	0.775417	0.992178	2.23385E-05	0.003954
Bisi2	Rahman		-0.40862		0.987591	8.42283E-05	0.008707
	Adapted Bala & Wood	0.427596	1.266343		0.993749	3.37607E-05	0.005197
	Corrêa *et al.*	1.634809	-0.33567		0.991783	4.38077E-05	0.005920
	Polynomial Quadratic	0.22748	0.21485	0.76285	0.99345	3.10139E-05	0.005283

Table 5. Values of parameters involved in the surface area shrinkage models being evaluated along with the values of R^2, χ^2 , and *RMSE*

Corn Variety	Model	a	B	c	R^2	χ^2	*RMSE*
NK22	Rahman		-0.38501		0.95915	0.000186027	0.012859
	Adapted Bala & Wood	0.202953	3.238206		0.978728	6.81888E-05	0.007283
	Corrêa *et al.*	1.513841	-0.28941		0.976605	7.23535E-05	0.007502
	Polynomial Quadratic	0.066327	0.400806	0.831768	0.975492	8.84103E-05	0.007677
DK77	Rahman		-0.29975		0.968464	6.16122E-05	0.007400
	Adapted Bala & Wood	0.248726	1.595932		0.973477	5.07603E-05	0.006283
	Corrêa *et al.*	1.399158	-0.22828		0.973799	4.95402E-05	0.006207
	Polynomial Quadratic	0.16889	0.165588	0.852291	0.972804	5.99914E-05	0.006324
Pioneer	Rahman		-0.20751		0.931007	8.5839E-05	0.008735
	Adapted Bala & Wood	-0.04278	-2.6669		0.956364	5.94555E-05	0.006800
	Corrêa *et al.*	1.288979	-0.16599		0.899906	0.000135136	0.010252
	Polynomial Quadratic	0.411692	-0.27853	0.853576	0.953294	7.3543E-05	0.007002
Makmur	Rahman		-0.25092		0.975985	3.06014E-05	0.005215
	Adapted Bala & Wood	36.4315	0.006892		0.975907	3.50946E-05	0.005225
	Corrêa *et al.*	1.338291	-0.2113		0.953857	6.01148E-05	0.006838
	Polynomial Quadratic	0.457478	-0.32800	0.853725	0.98994	1.52831E-05	0.003192
Bisi2	Rahman		-0.28242		0.983754	6.05562E-05	0.007337
	Adapted Bala & Wood	0.255961	1.550879		0.992759	2.09187E-05	0.004034
	Corrêa *et al.*	1.404871	-0.21263		0.992957	1.99694E-05	0.003941
	Polynomial Quadratic	0.133964	0.17532	0.839321	0.992136	2.60129E-05	0.004164

phenomenon was similar to the finding reported by Corrêa *et al*. (2004). Their research also concluded that there was no single model that could fit the volume shrinkage behavior as a function of the moisture content of the three varieties of coffee berry observed.

The research indicated that the Bala and Wood's equation was much better than the other three models when predicting the NK22 (R^2: 0.983961), DK77 (R^2: 0.976041), and Bisi-2 (R^2: 0.992178) volumetric shrinkage behaviors as a function of the moisture contents. On the other hand, the polynomial quadratic model was more suitable for Pioneer (R^2: 0.966709) and Makmur (R^2: 0.992178) behaviors. In term of predicting the surface area shrinkage, the Bala and Wood's equation also performed very well especially for NK22 (R^2: 0.978728) and Pioneer (R^2: 0.956364). However, the polynomial quadratic model had a good agreement on Makmur (R^2: 0.989940) variety. For DK77 and Bisi-2 varieties, the Correa *et al*.'s model was found to be more effective (R^2: 0.973799 and 0.992957, respectively).

The findings also designated that the Rahman's model was the only model that could not show its superiority.

Although none of the models consistently performed better than the others, it was found that the Bala and Wood's equation and polynomial quadratic model demonstrated a relatively consistent high-magnitude of R^2 values compared with the other two models. This phenomenon might suggest that these two models could be applied wisely to predict the volume and surface area shrinkage behaviors of the five hybrid corn varieties observed in this study.

3.4 Goodness of Fit of the Selected Model

To illustrate the goodness of fit of the selected models, a one-to-one relationship between the observed and predicted volume and surface area ratios was plotted in Figures 5 and 6. These two figures indeed strongly indicated that the observed and predicted values had a very good agreement as all observation points fall on the diagonal line of the graph.

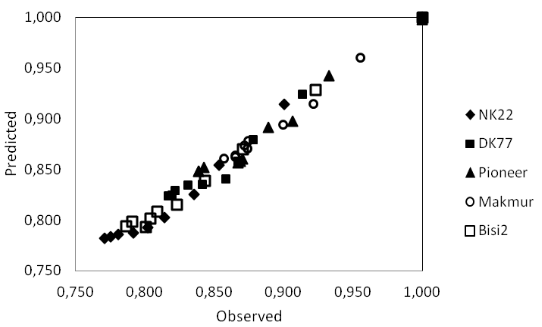

Figure 5. Performances of the selected models when predicting the volume ratio of each corn variety

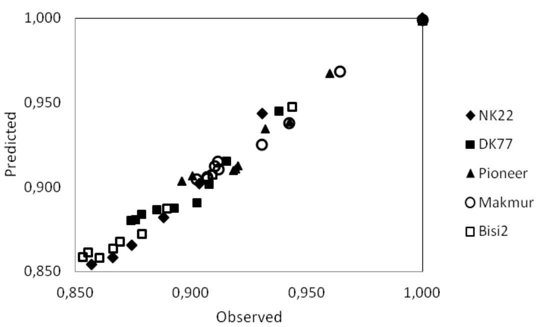

Figure 6. Performances of the selected models when predicting the surface area ratio of each corn variety

4. Conclusion

The corn kernels with larger orthognal dimensions were relatively more susceptible to shrinkages, both volume and surface area, during the drying process. It was also obtained that there was no single model which was consistently more superior to the other models in estimating the volume and surface area shrinkages as a function of the moisture contents of the hybrid corn varieties of NK22, DK77, Pioneer, Makmur, and Bisi-2. Nonetheless, compare with the other two models, the Bala and Wood's equation and the polynomial quadratic model indicated a relatively consistent high-magnitude of R^2 values.

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