EFFECTS OF MOISTURE CONTENT VARIATION ON SOME ENGINEERING PROPERTIES OF ALMOND (Terminalia catappa) SEED

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Abstract
The physical and mechanical properties of Almond seed at different moisture content levels of 6.78%, 12.39%, 17.11% and 21.97% were investigated in this study. The physical and mechanical properties determined using standard procedures were length, width, thickness, arithmetic and geometric diameter, surface area, sphericity, specific gravity, bulk density, angle of repose and coefficient of static friction (on wood, glass and steel surfaces); rupture force, compressive strength and tensile strength were also determined on the seeds. A total of one hundred and twenty seeds were used for the study. This comprises of thirty seeds (randomly taken) per moisture content level. These thirty seeds were then replicated into three groups of ten seeds for the experiment (three groups of ten seeds for each of the moisture content level). The length, width and thickness obtained for the samples of the almond seeds were in the range of 25.42-28.63mm, 23.69-26.63mm, and 7.51-9.18mm respectively. The calculated values of the geometric mean diameter and sphericity ranged from 16.48-19.07mm and 64.66-66.63% respectively. The results of the surface area varied from 853.6-1143.04mm^2. A high variation in the surface area of the seeds was observed with respect to the different moisture content levels. The mechanical properties showed that the fracture force and compressive strength decreased from 2689N to 2499N, 410N/mm^2 to 398 N/mm^2 respectively with an increase in moisture content (6.78%-21.9%). The tensile strength obtained for moisture levels of 6.78%, 12.39%, 16.11% and 21.9% were 3.20Mpa, 3.90Mpa, 4.20Mpa and 4.60Mpa respectively. From the study, it was observed that the physical properties of the seed determined as function of moisture content varied significantly (at $p \leq 0.05$) with increase in moisture content as the average length, width, thickness, surface area of the seed, specific gravity, sphericity and coefficient of static friction (on all three surfaces) increased; while the weight and angle of repose were not affected significantly by the moisture content. However, true and bulk density decreased as moisture content of the seed was increased. The tensile strength of Terminalia catappa increased with increase in moisture content while the fracture force and compressive strength reduced with increase in moisture content. These parameters are important in designing equipments and systems for harvesting, handling, storage and processing operations of the seed.

Keywords: Almond seed, moisture content, physical properties, mechanical properties, bulk density

Introduction
Almond (Terminalia catappa) is a large tropical tree in the family of cambretaceae that grows mainly in the tropical regions of Asia, Africa, and Australia. The tree is known as umbrella tree in Nigeria; it provides shade for relaxation and meeting points in some compounds. The crop is one of the lesser known legumes in the tropics and in Nigeria ecosystem (Mbah et al., 2013). The fruit is called Mkpuru edo in Igbo language. The seed forms an important source of balanced food because it is rich in protein (14.1-24.7%), fat (21.8-23.8%), ash content (3.5-4.1%), fiber (6.4 14.0%), carbohydrate (29.5-39.2%), calcium (20.7-29.8mg/100g), phosphorus (16.0-17.2mg/100g), iron (0.7-1.4mg/100g), zinc (0.8-1.2mg/100g), tannin (0.3-0.4mg/100g), phytate (0.1-0.3mg/100g) (Mbah *et al.*, 2013).

The fruit pulp is fibrous, sweet and edible when ripe which is widely eaten by children as forage snack. The seed has an important place in the human nutrition and it can be used in fresh, dried or processed form (Akpabio, 2012). According to Mbah *et al.*, (2013), the seed is highly cherished by children and is used by many rural dwellers in Southern Nigeria to fortify the local complimentary foods which are low in protein. It also forms part of the local feedstock for tropical aquarium fishes in Nigeria (Agatemor & Ukhun, 2006).

Increase or decrease in the moisture content of almond seed can affects its physical and mechanical properties. The moisture content is the quantity of water present in the seed and it is usually expressed in percentage. Today, much study have been published on the physical and mechanical properties of grains and legumes by other researchers such as Saçılık *et al.* (2003) for hemp seed; Paksoy & Aydın (2004) for squash seed; Yalçın (2006) for cowpea seed; Orhevba *et al.*, (2013) for dika nuts; Kibar *et al.*, (2010) for rice; Gunner *et al.*, (2003) for hazelnut; Altuntaș and Demirtola (2007) for some legumes seeds; Yalçin et al. (2007) for pea seed; Pradhan *et al* (2008) for karanja; Altuntaș and Yildiz (2007) for faba seeds kernel; Amin *et al.*, (2004) for lentil seeds and Çalısir *et al.* (2005) for rape.

The development of adequate harvesting, storage and processing systems and machine are influenced by the physical and mechanical properties of almond seed. Most of these machines and systems used are generally designed without considering some of these engineering properties of almond seed, resulting in inadequate applications, reduction in work efficiency and an increase in production loss. There are few data describing the effect of moisture on some physical and mechanical properties of almond seed. Thus, this project was undertaken to investigate and provide concise information and data on some selected engineering properties of Terminalia catappa. This is to aid the design and development of machines and systems for the harvesting, handling storage and processing of the seed. Thus, the objectives of this study are to determine some selected physical and mechanical properties of almond seed under different moisture contents.

Materials and Methods

The almond fruits samples used for this study were obtained from trees around the Federal University of Technology, Minna, Niger state. The outer flesh of the fruits was manually removed with a knife and were oven dried for six hours to a moisture content of 6.57% to enable easy removal of the seeds from the nuts with least percentage of cracking.

A total of One Hundred and twenty seeds were used for the study. This comprises of thirty seeds (randomly taken) per moisture content level. These thirty seeds were then replicated into three groups of ten Seeds for the experiment (three groups of ten seeds for each of the moisture content level). The samples were numbered to avoid the repeat of measurements with the same seed. All foreign materials such as dust, stones, chaff, immature and broken seeds as well as bad seeds were removed by winnowing and picking. Sample selection was randomized all through the tests.

The initial moisture content of the seed was determined using the method employed by Aviara *et al.*, (2014) in determining the moisture contents of Shea nuts. The samples were transferred to separate polythene bags and reconditioned to moisture content levels of 6.78%, 12.39%, 17.11% and 21.97% W.B. The reconditioning technique to attain the desired moisture content for kernel was reported by Bart-Plange *et al.*, (2012). This process involves the addition of a calculated amount of distilled water added to each sample and the bags were then sealed tightly. The samples were refrigerated at a temperature of 5°C for a week to enable the moisture to be distributed uniformly throughout the sample.

The required quantity of the samples were then taken out of the refrigerator and allowed to warm up to room temperature for about 2 hours. Measurements of length (L), Width (W) and Thickness (T) were done using a vernier caliper with resolution of 0.01mm for each of the moisture content levels. The arithmetic and geometric average diameters of almond seed was calculated according to the method reported by Kiani Deh Kiani et al., (2008).

The weights of the seeds were determined with the use of a digital weighing balance. The sphericity φ (%) was calculated using the relationship reported by Davies (2010). The surface area (S) of the seed was determined using the relationship reported by Arthur (2009). The bulk density of the samples was determined by the method reported by Kibar et al. (2010). The liquid displacement method, as described by Tavakoli et al. (2009), was used to determine the true density of the seed samples.

The static coefficient of friction was determined with respect to three test surfaces namely: plywood galvanized steel sheet and glass; as described by Mingjin et al. (2003). The angle of repose was determined by the geometrical approach described by (Chukwu and Akande, 2007).

The specific gravity was obtained according to the method described by Olaoye (2000), Adejumo (2003). The mechanical properties of the seed which include fracture force, compressive strength and tensile strength were obtained using Testometric Machine (ZDM50-2313/56/18, Germany).

Data analysis

Data obtained were analysed using design expert software; this is with a view to determine the relationship between moisture content and the properties.

Results and Discussion

The results of the study are as presented in Tables 1 to 17.

Table 1: Effect of Moisture Content on some Physical Properties of Terminalia catappa at Different Moisture Content

Parameters	6.78% wb Sample A	12.39% wb Sample B	17.11% wb Sample C	21.97% wb Sample D
Length (mm)	25.42 ± 0.47^a	26.70 ± 0.50^b	27.57 ± 0.25^c	28.63 ± 0.18^d
Width (mm)	23.69 ± 0.68^a	25.13 ± 0.22^b	26.27 ± 0.19^c	26.63 ± 0.23^c
Thickness (mm)	7.51 ± 0.43^a	7.71 ± 0.03^a	8.24 ± 0.03^b	9.18 ± 0.07^c
Geometric mean diameter (mm)	16.48 ± 0.05^a	17.26 ± 0.11^b	18.08 ± 0.02^c	19.07 ± 0.06^d
Arithmetic mean diameter (mm)	18.88 ± 0.24^a	19.84 ± 0.18^b	20.69 ± 0.03^c	21.48 ± 0.10^d
Surface area (mm^2)	853.69 ± 6.57^a	936.38 ± 11.32^b	1027.08 ± 1.97^c	1143.04 ± 6.59^d
Weight of seed (g)	7.06 ± 0.03^a	7.59 ± 0.29^a	7.64 ± 0.13^a	8.82 ± 0.70^b
Sphericity (%)	64.66 ± 0.81^a	64.87 ± 1.44^a	65.41 ± 0.57^a	66.63 ± 0.23^b
Bulk density (g/cm^3)	0.58 ± 0.01^a	0.54 ± 0.01^b	0.50 ± 0.01^c	0.48 ± 0.01^d
True density (g/cm^3)	1.27 ± 0.01^a	1.09 ± 0.01^b	1.04 ± 0.01^c	0.98 ± 0.01^d
Angle of repose (^{0})	38.84 ± 1.64^a	46.74 ± 0.85^b	51.54 ± 1.81^c	52.29 ± 2.0^c
Specific gravity	0.79 ± 0.01^a	0.87 ± 0.01^b	0.91 ± 0.01^c	0.95 ± 0.01^d
Coefficient of friction				
Wood surface	0.52 ± 0.02^a	0.57 ± 0.03^b	0.59 ± 0.05^b	0.67 ± 0.04^b
Glass surface	0.49 ± 0.01^a	0.51 ± 0.02^a	0.54 ± 0.01^b	0.57 ± 0.02^b
Steel surface	0.52 ± 0.02^a	0.54 ± 0.02^{ab}	0.57 ± 0.02^b	0.62 ± 0.03^c

*values followed by same superscript alphabet are not significantly different at (P□0.05) along the rows. Values are Mean ±Standard deviation.

Table 2: ANOVA for Length

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	5.534193569	1	5.534193569	1316.657118	0.0008
A-Moisture content	5.534193569	1	5.534193569	1316.657118	0.0008
Residual	0.008406431	2	0.004203215		
Cor Total	5.5426	3			
Std. Dev.	0.06483221		R-Squared	0.998483305	
Mean	27.08		Adj R-Squared	0.997724958	
C.V. %	0.239409934		Pred R-Squared	0.994690656	
PRESS	0.029427568		Adeq Precision	69.26441392	

Table 3: ANOVA for Width

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	5.023056035	1	5.023056035	41.83370617	0.0231
A-Moisture content	5.023056035	1	5.023056035	41.83370617	0.0231
Residual	0.240143965	2	0.120071982		
Cor Total	5.2632	3			
Std. Dev.	0.346514044		R-Squared	0.954373012	
Mean	25.43		Adj R-Squared	0.931559518	
C.V. %	1.362619126		Pred R-Squared	0.713943304	
PRESS	1.5055736		Adeq Precision	12.34630464	

Table 4: ANOVA for Thickness

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.671669713	2	0.835834857	6415.34116	0.0088
A-Moisture content	1.521435793	1	1.521435793	11677.5815	0.0059
A^2	0.168909888	1	0.168909888	1296.44576	0.0177
Residual	0.000130287	1	0.000130287		
Cor Total	1.6718	3			
Std. Dev.	0.011414328		R-Squared	0.99992207	
Mean	8.16		Adj R-Squared	0.9997662	
C.V. %	0.139881475		Pred R-Squared	0.99601514	
PRESS	0.006661887		Adeq Precision	168.45472	

Table 5: ANOVA for Geometric Mean Diameter

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3.701268775	2	1.850634387	297272.779	0.0013
A-Moisture content	3.683640447	1	3.683640447	591713.868	0.0008
A^2	0.028644206	1	0.028644206	4601.20206	0.0094
Residual	6.22537E-06	1	6.22537E-06		
Cor Total	3.701275	3			
Std. Dev.	0.00249507		R-Squared	0.99999832	
Mean	17.7225		Adj R-Squared	0.99999495	
C.V. %	0.014078544		Pred R-Squared	0.999914	
PRESS	0.000318319		Adeq Precision	1199.11988	

Table 6: ANOVA for Arithmetic Mean Diameter

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	3.747246282	1	3.747246282	6099.4426	0.0002
A-Moisture content	3.747246282	1	3.747246282	6099.4426	0.0002
Residual	0.001228718	2	0.000614359		
Cor Total	3.748475	3			
Std. Dev.	0.024786262		R-Squared	0.99967221	
Mean	20.2225		Adj R-Squared	0.99950831	
C.V. %	0.122567746		Pred R-Squared	0.99869814	
PRESS	0.004880004		Adeq Precision	149.079831	

Table 7: ANOVA for Surface Area

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	46251.36669	2	23125.68334	73934.0953	0.0026
A-Moisture content	45863.23693	1	45863.23693	146627.318	0.0017
A^2	565.0126628	1	565.0126628	1806.37689	0.0150
Residual	0.312787804	1	0.312787804		
Cor Total	46251.67948	3			
Std. Dev.	0.559274355		R-Squared	0.99999324	
Mean	990.0475		Adj R-Squared	0.99997971	
C.V. %	0.056489649		Pred R-Squared	0.9996542	
PRESS	15.99360327		Adeq Precision	596.917314	

Table 8: ANOVA for Weight of Seed

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	1.410039095	1	1.410039095	11.4807247	0.0772
A-Moisture content	1.410039095	1	1.410039095	11.4807247	0.0772
Residual	0.245635905	2	0.122817952		
Cor Total	1.655675	3			
Std. Dev.	0.350453923		R-Squared	0.85164002	
Mean	7.7775		Adj R-Squared	0.77746003	
C.V. %	4.505997087		Pred R-Squared	0.29605863	
PRESS	1.165498123		Adeq Precision	6.4678281	

Table 9: ANOVA for Sphericity

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	2.335789769	2	1.167894885	212.916272	0.0484
A-Moisture content	2.062486587	1	2.062486587	376.00726	0.0328
A^2	0.302500024	1	0.302500024	55.1480944	0.0852
Residual	0.005485231	1	0.005485231		
Cor Total	2.341275	3			
Std. Dev.	0.074062344		R-Squared	0.99765716	
Mean	65.3925		Adj R-Squared	0.99297148	
C.V. %	0.113258162		Pred R-Squared	0.88020492	
PRESS	0.280473226		Adeq Precision	30.227682	

Table 10: ANOVA for Bulk Density

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.005807942	1	0.005807942	126.180171	0.0078
A-Moisture content	0.005807942	1	0.005807942	126.180171	0.0078
Residual	9.20579E-05	2	4.6029E-05		
Cor Total	0.0059	3			
Std. Dev.	0.006784465		R-Squared	0.98439696	
Mean	0.525		Adj R-Squared	0.97659544	
C.V. %	1.292278976		Pred R-Squared	0.92198292	
PRESS	0.000460301		Adeq Precision	21.4422016	

Table 11: ANOVA for True Density

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.043347615	1	0.043347615	24.4047943	0.0386
A-Moisture content	0.043347615	1	0.043347615	24.4047943	0.0386
Residual	0.003552385	2	0.001776193		
Cor Total	0.0469	3			
Std. Dev.	0.0421449		R-Squared	0.92425618	
Mean	1.095		Adj R-Squared	0.88638427	
C.V. %	3.848849312		Pred R-Squared	0.53052189	
PRESS	0.022018523		Adeq Precision	9.4299935	

Table 12: ANOVA for Angle of Repose

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	114.4299374	2	57.21496869	177.720672	0.0530
A-Moisture content	102.8183138	1	102.8183138	319.373412	0.0356
A^2	10.33069248	1	10.33069248	32.0891132	0.1112
Residual	0.321937613	1	0.321937613		
Cor Total	114.751875	3			
Std. Dev.	0.567395464		R-Squared	0.99719449	
Mean	47.3525		Adj R-Squared	0.99158347	
C.V. %	1.198237609		Pred R-Squared	0.8565474	
PRESS	16.46145527		Adeq Precision	27.8583961	

Table 13: ANOVA for Specific Gravity

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.013697446	1	0.013697446	90.5454175	0.0109
A-Moisture content	0.013697446	1	0.013697446	90.5454175	0.0109
Residual	0.000302554	2	0.000151277		
Cor Total	0.014	3			
Std. Dev.	0.012299475		R-Squared	0.97838899	
Mean	0.88		Adj R-Squared	0.96758348	
C.V. %	1.397667563		Pred R-Squared	0.8611967	
PRESS	0.001943246		Adeq Precision	18.1638144	

Table 14: ANOVA for Coefficient of Friction on Wood Surface

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.011009641	1	0.011009641	33.0938547	
A-Moisture content	0.011009641	1	0.011009641	33.0938547	
Residual	0.000665359	2	0.000332679		
Cor Total	0.011675	3			
Std. Dev.	0.018239499		R-Squared	0.94300997	
Mean	0.5875		Adj R-Squared	0.91451495	
C.V. %	3.104595596		Pred R-Squared	0.73568151	
PRESS	0.003085918		Adeq Precision	10.9811417	

Table 15: ANOVA for Coefficient of Friction on Glass Surface

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.003613847	1	0.003613847	118.190847	0.0084
A-Moisture content	0.003613847	1	0.003613847	118.190847	0.0084
Residual	6.11527E-05	2	3.05764E-05		
Cor Total	0.003675	3			
Std. Dev.	0.005529591		R-Squared	0.9833598	
Mean	0.5275		Adj R-Squared	0.9750397	
C.V. %	1.048263612		Pred R-Squared	0.89630287	
PRESS	0.000381087		Adeq Precision	20.7522762	

Table 16: ANOVA for Coefficient of Friction on Steel Surface

Source	Sum of Squares	df	Mean Square	F-value	p-value
Model	0.005672672	2	0.002836336	1218.48957	0.0203
A-Moisture content	0.005416572	1	0.005416572	2326.9587	0.0132
A^2	0.000302753	1	0.000302753	130.062666	0.0557
Residual	2.32775E-06	1	2.32775E-06		
Cor Total	0.005675	3			
Std. Dev.	0.001525696		R-Squared	0.99958982	
Mean	0.5625		Adj R-Squared	0.99876947	
C.V. %	0.271234802		Pred R-Squared	0.97902671	
PRESS	0.000119023		Adeq Precision	75.1970958	

The results showed that the different levels of the moisture content had significant differences ($p<0.05$) on the length, width, thickness, arithmetic and geometric diameter, surface area, sphericity, specific gravity and coefficient of static friction (on wood, glass and steel surfaces) of the seed with the exception of weight and angle of repose; the different levels of moisture content had no significant differences ($p<0.05$) on weight and angle of repose.

From Table 1, physical properties such as length, width, thickness, geometric and arithmetic mean increased with increase in moisture content from 6.78% to 21.79% w.b. The length, width and thickness increased from 25.42 to 28.63mm; 23.69 to 26.63mm and 7.51 to 9.18mm respectively with increase in moisture content; Chukwu and Musiliu (2010) reported the following values for cowpea: Length (9.48 ± 1.46 mm), width (6.75 ± 0.66 mm), thickness (5.35 ± 0.73 mm).

Figures 1 to 13 graphically shows the effect of moisture content on the length, width, thickness, arithmetic and geometric diameter, surface area, sphericity, specific gravity and coefficient of static friction (wood, glass and steel surfaces) of the almond seeds.

There was significant difference in the length (Figure 1) as the moisture content increased from 6.78% to 21.97% ($p>0.05$). Similar results have been reported by Saçılık *et al.* (2003) for hemp seed, Paksoy and Aydın (2004) for squash seed, and Yalçın (2006) for cowpea.

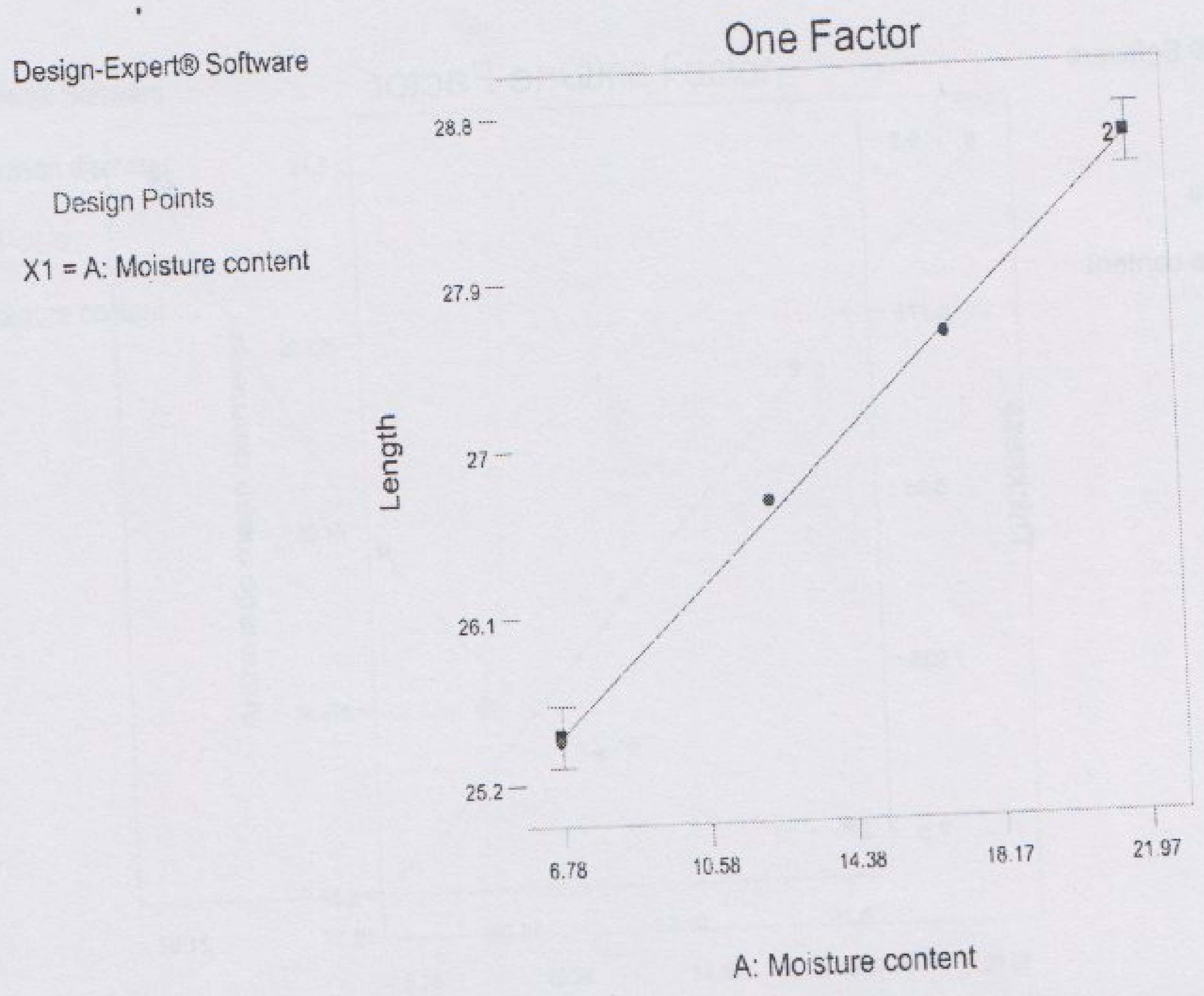

Fig.1: Effect of Moisture content on Length

There was significant difference in the width and thickness (Figures 2 and 3) as the moisture content increased from 6.78% to 21.97% ($p>0.05$). The increase in the values may be attributed to its dependence on the three linear dimensions. Similar results have been reported by Saçılık *et al.* (2003) for hemp seed; Paksoy and Aydın (2004) for squash seed, and Yalçın (2006) for cowpea. Wang *et al.*, (2007) found the thickness of fibered flaxseed to be polynomially related to moisture content, while Isik (2007) found an exponential relationship between the projected area of round red lentil grains and moisture content.

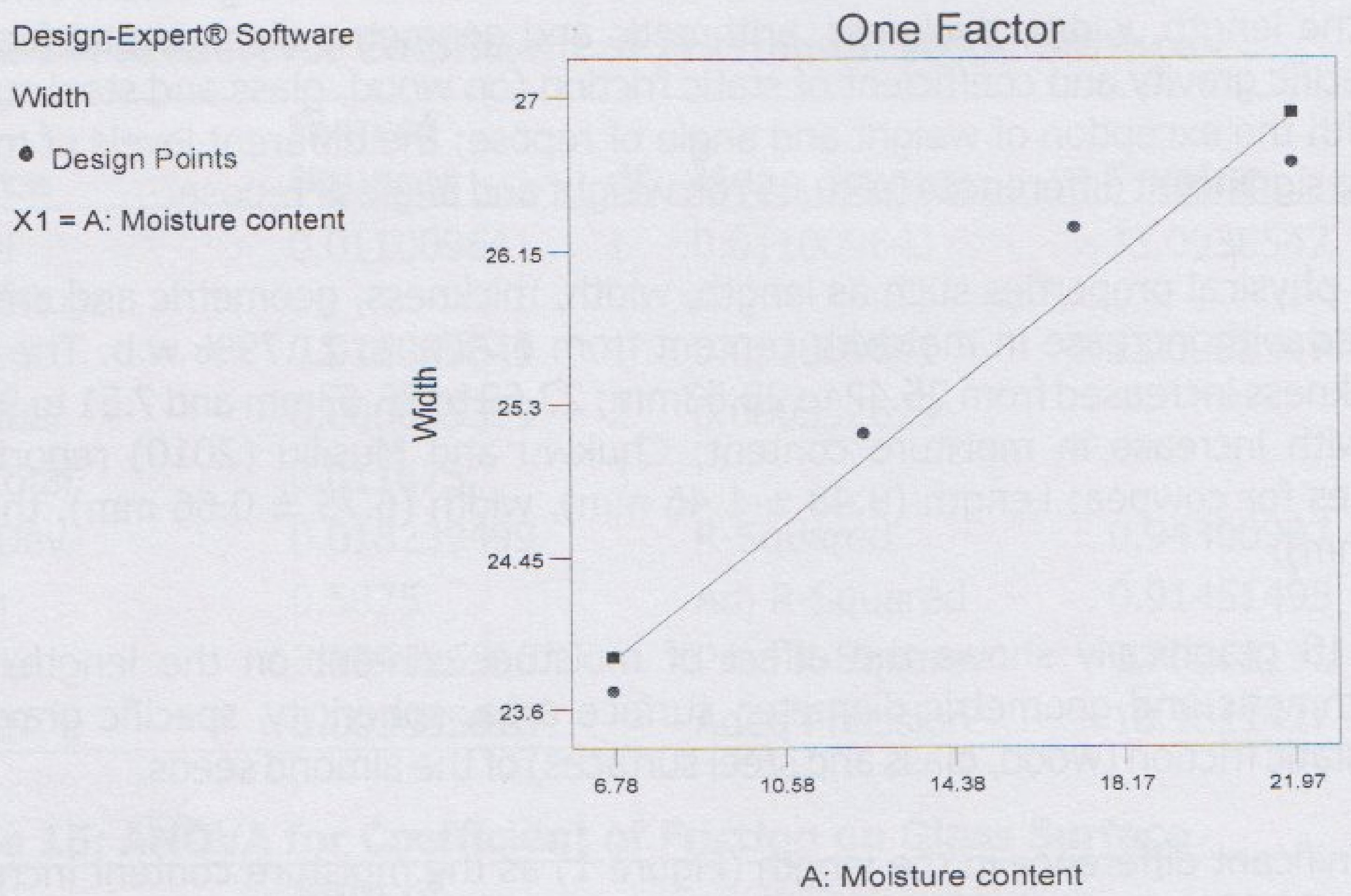

Fig. 2: Effect of Moisture content on Width

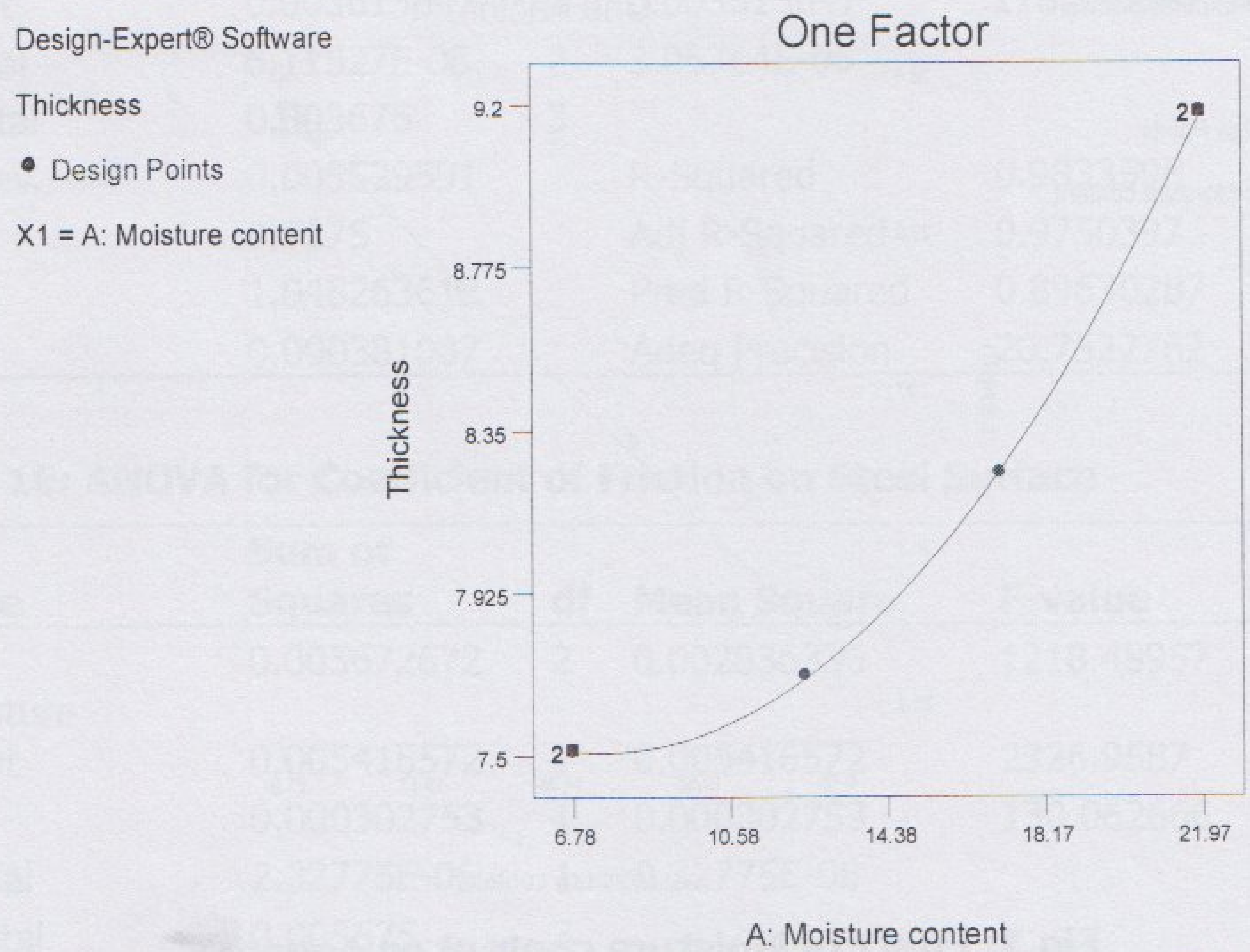

Fig. 3: Effect of Moisture content on Thickness

Figures 4 and 5 shows that the geometric mean diameter and arithmetic mean diameter increased as the moisture content increased, this agrees with the report of Irouwa et al., (2016) for Achi.

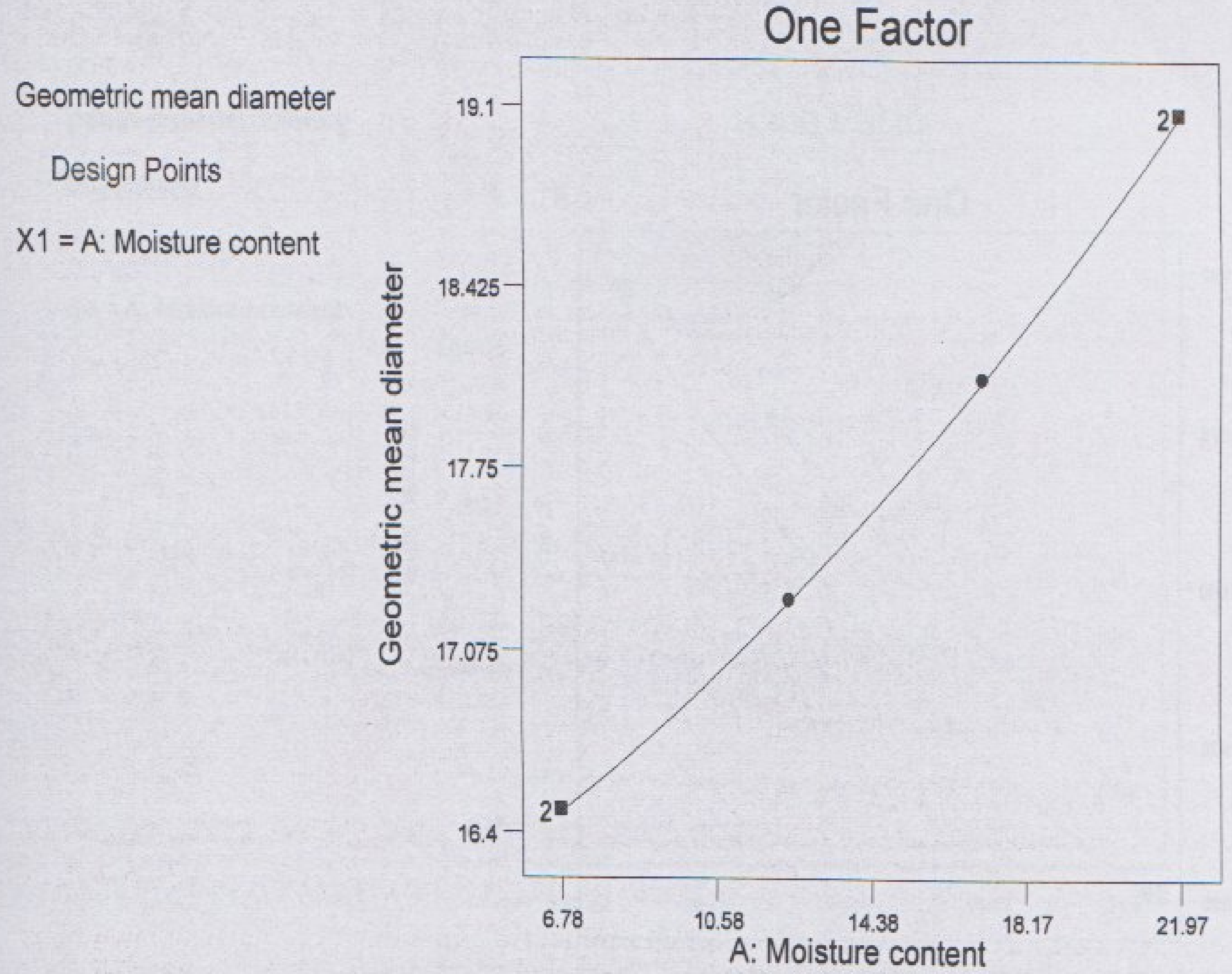

Fig. 4: Effect of Moisture content on Geometric Mean Diameter

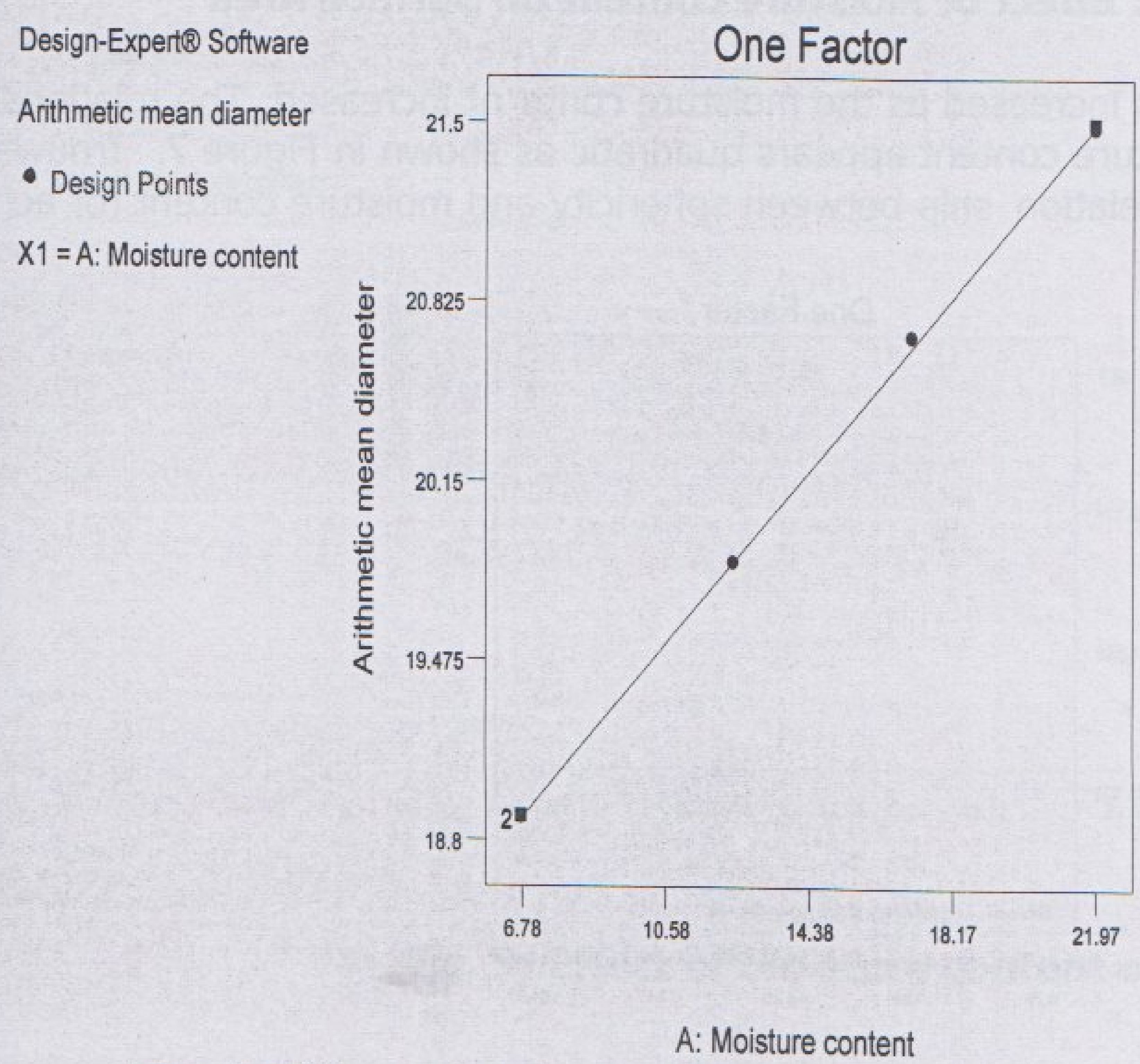

Fig. 5: Effect of Moisture content on Arithmetic Mean Diameter

It can be seen from Figure 6 that the surface area increases with an increase in moisture content. Similar trends have been reported by Irouwa *et al.*, (2016) and Asoegwu *et al.* (2006) for Achi and African oil bean respectively.

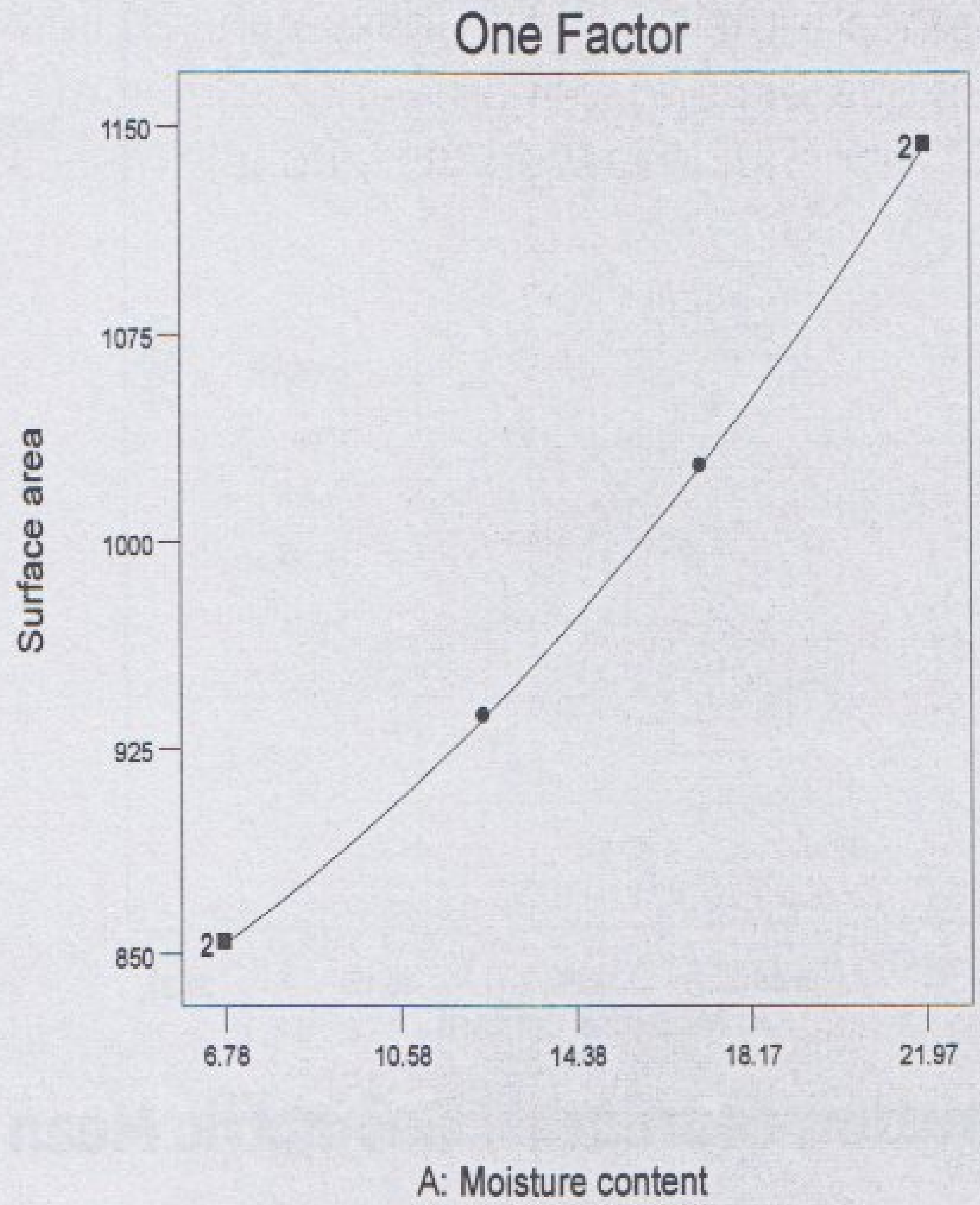

Fig. 6: Effect of Moisture content on Surface Area

The sphericity of the samples increased as the moisture conte nt increased. The relationship between sphericity and moisture content appears quadratic as shown in Figure 7. Irouwa *et al.* (2016) reported a linear relation ship between sphericity and moisture content for achi seeds.

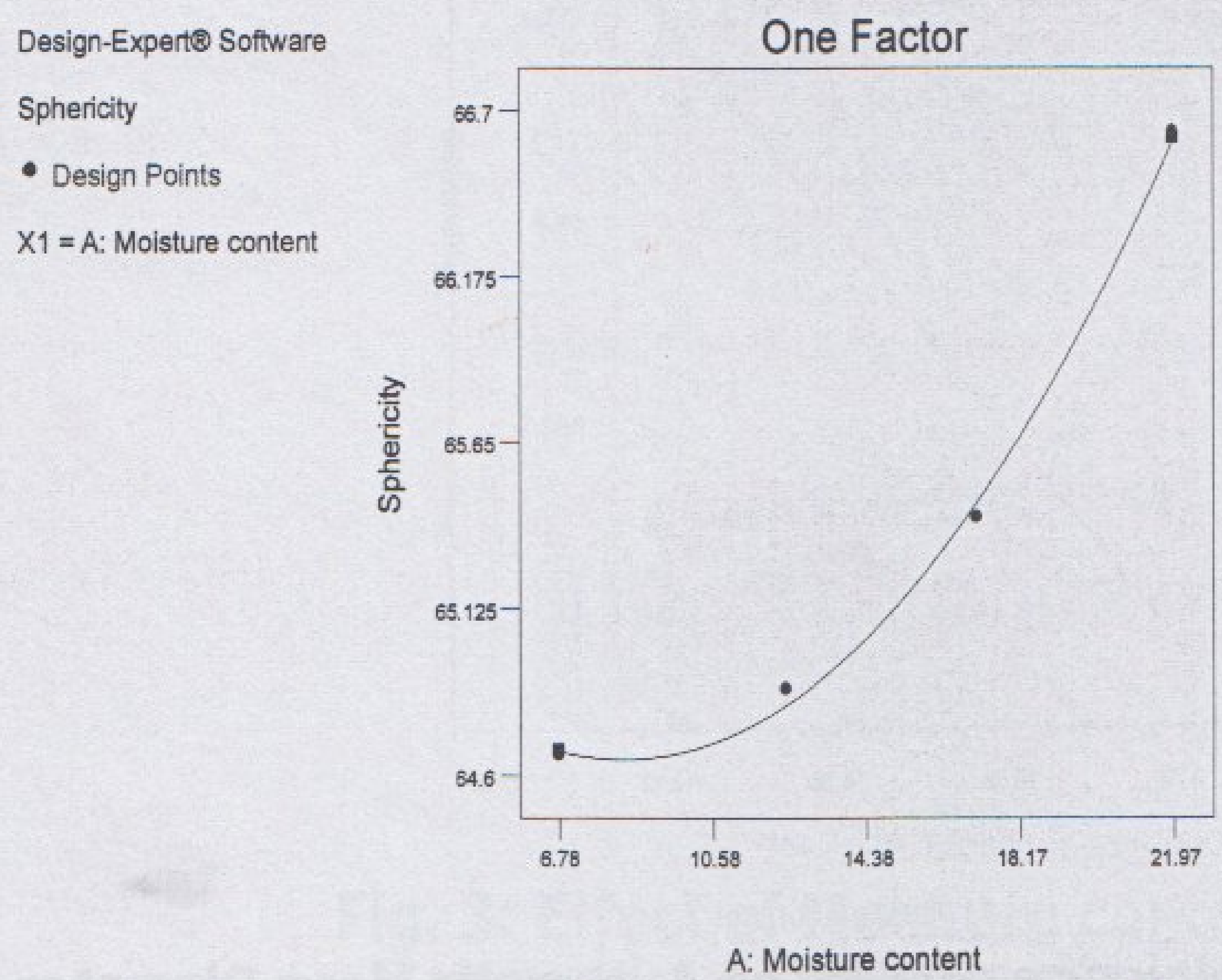

Fig. 7: Effect of Moisture content on Sphericity

The relationship between bulk density and moisture content (Fig. 8); true density and moisture content (Fig. 9) were statistically significant (p□0.05).

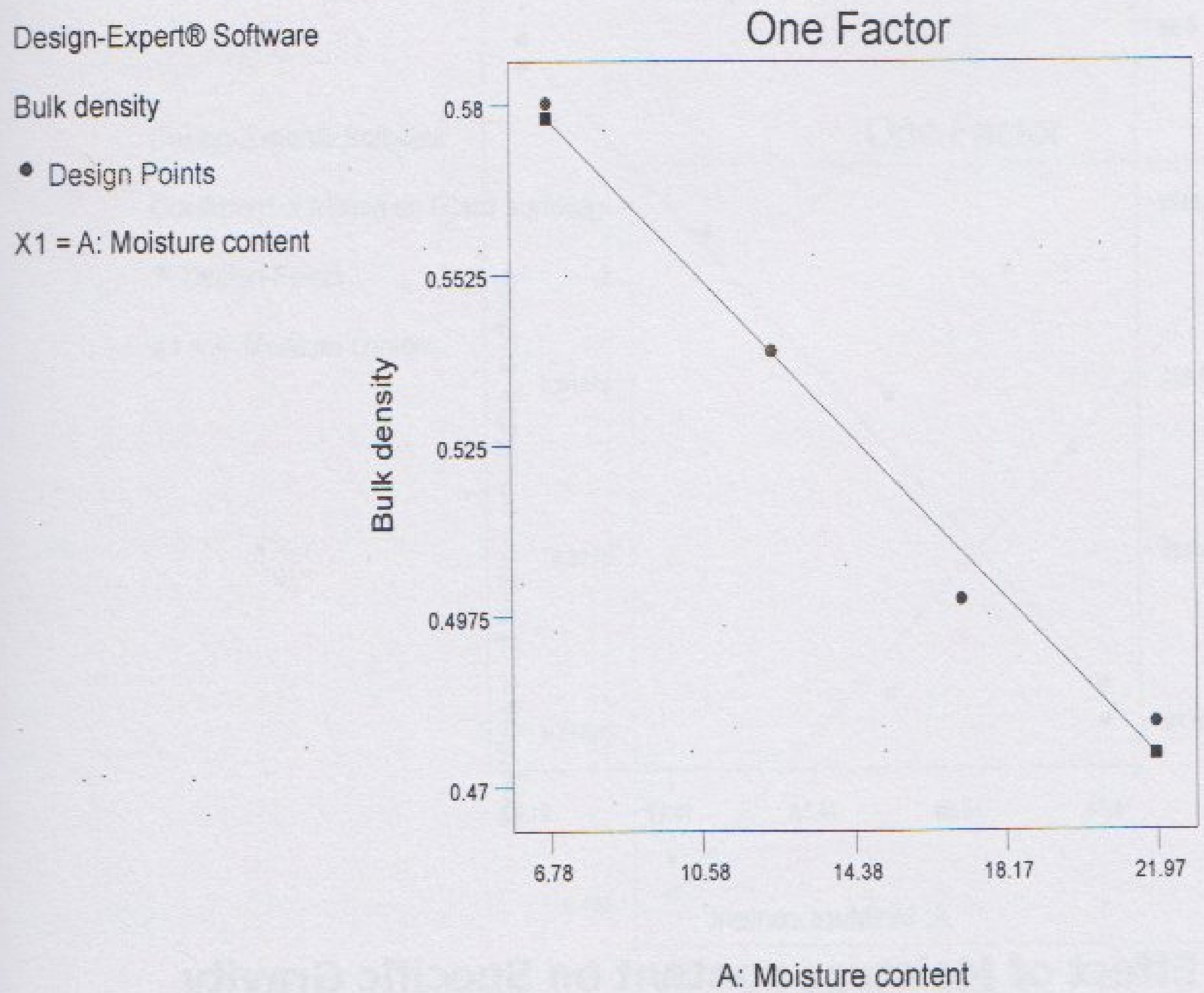

Fig. 8: Effect of Moisture content on Bulk Density

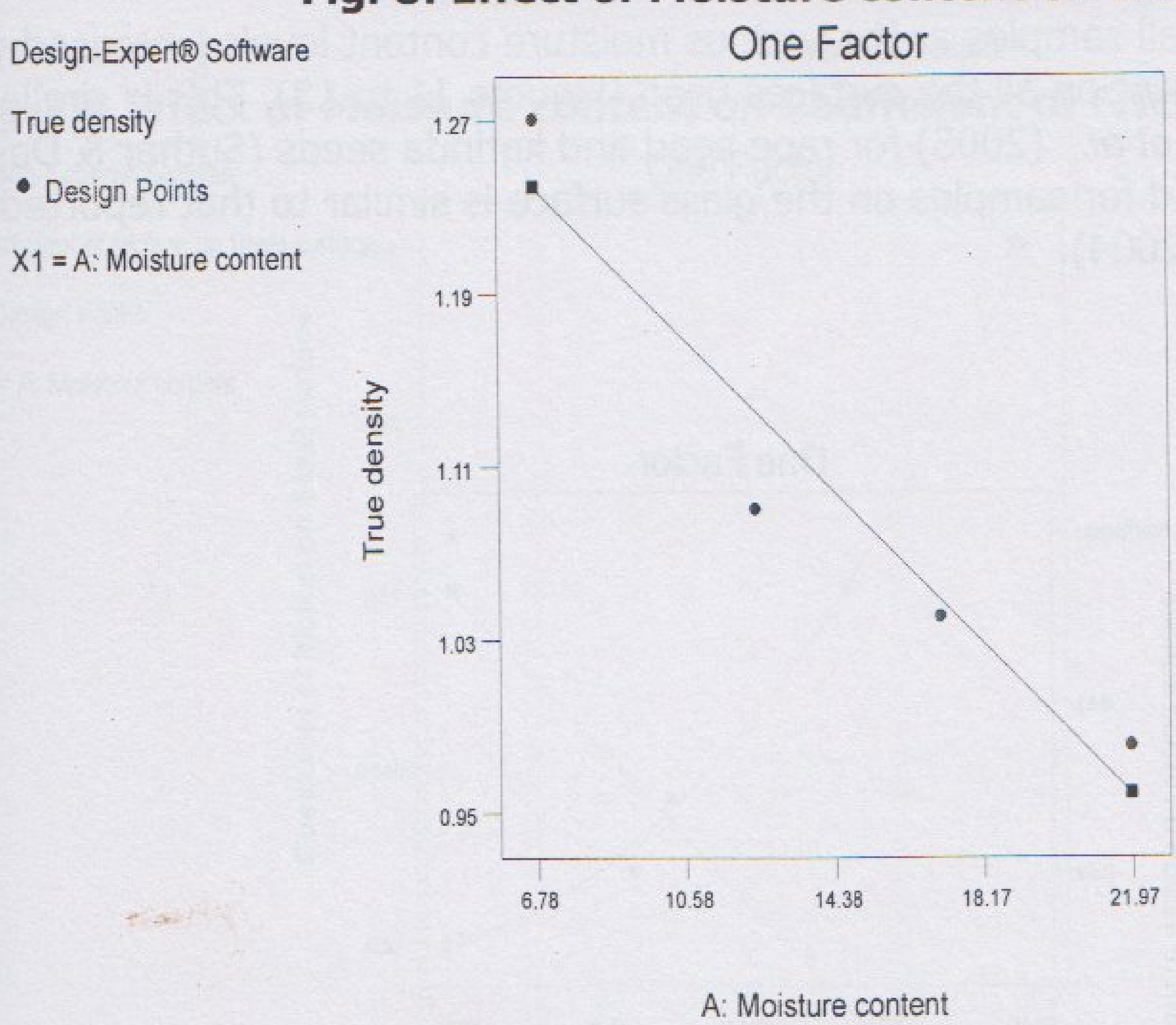

Fig. 9: Effect of Moisture content on True Density

Specific gravity increased with increase in moisture content. Specific gravity is an important quality criterion for processing of biomaterials. It is used as an estimate of solid or dry matter content of biomaterials. The higher the dry matter content, the lower the water content and the higher the specific gravity. The relationship between specific gravity and moisture content was statistically significant ($p>0.05$). Fig. 10 graphically shows the effect of moisture content on specific gravity.

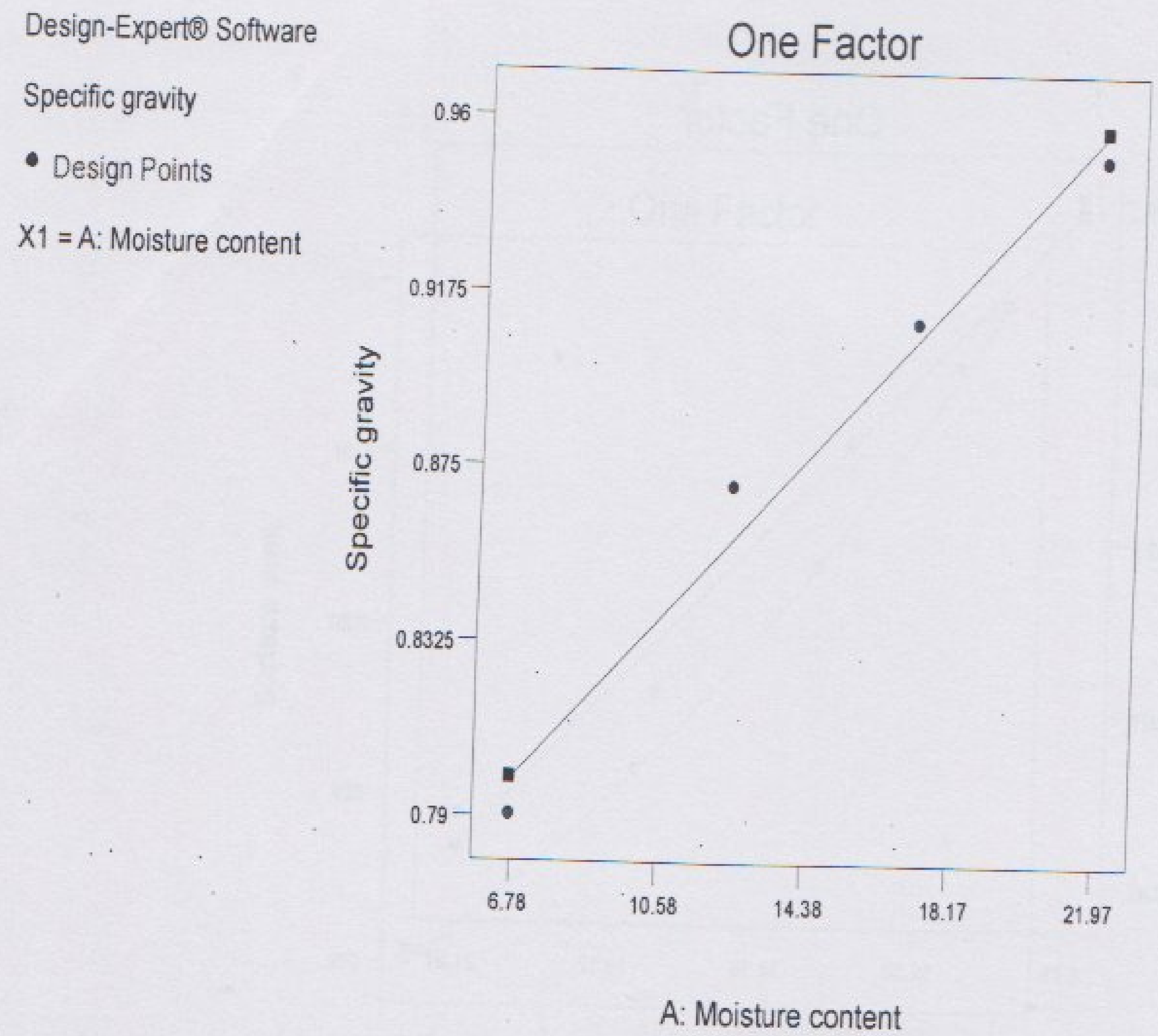

Fig. 10: Effect of Moisture content on Specific Gravity

Coefficient of friction for all samples at the various moisture content levels increased with increase in moisture content on all the surfaces used (Figures 11 to 13). This is similar to that reporte d by Çalısir *et al.* (2005) for rape seed and karinda seeds (Suthar & Das, 1996). The result obtained for samples on the glass surface is similar to that reported for lentil seeds (Amin *et al.*, 2004).

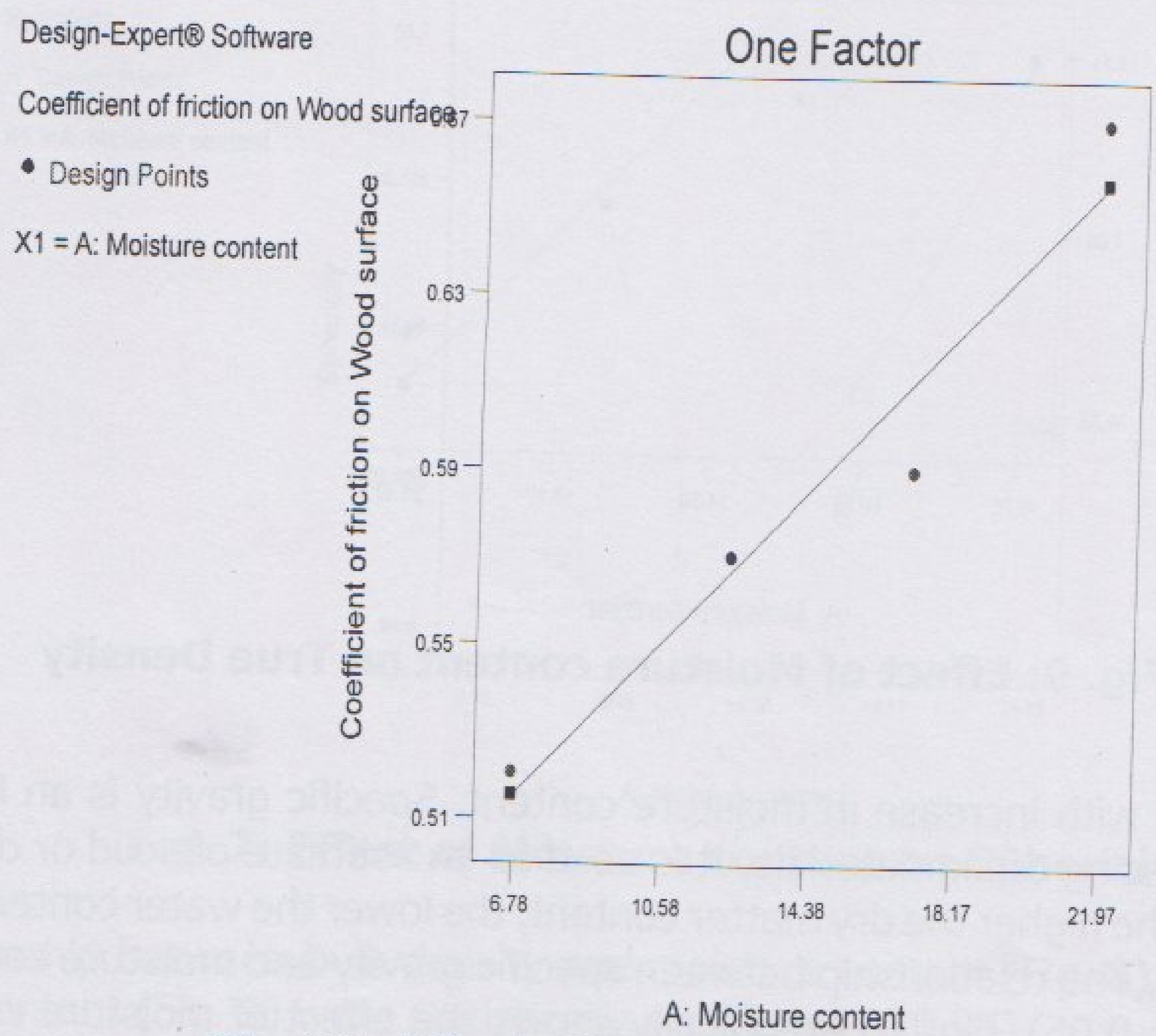

Fig. 11: Effect of Moisture content on Wooden Surface

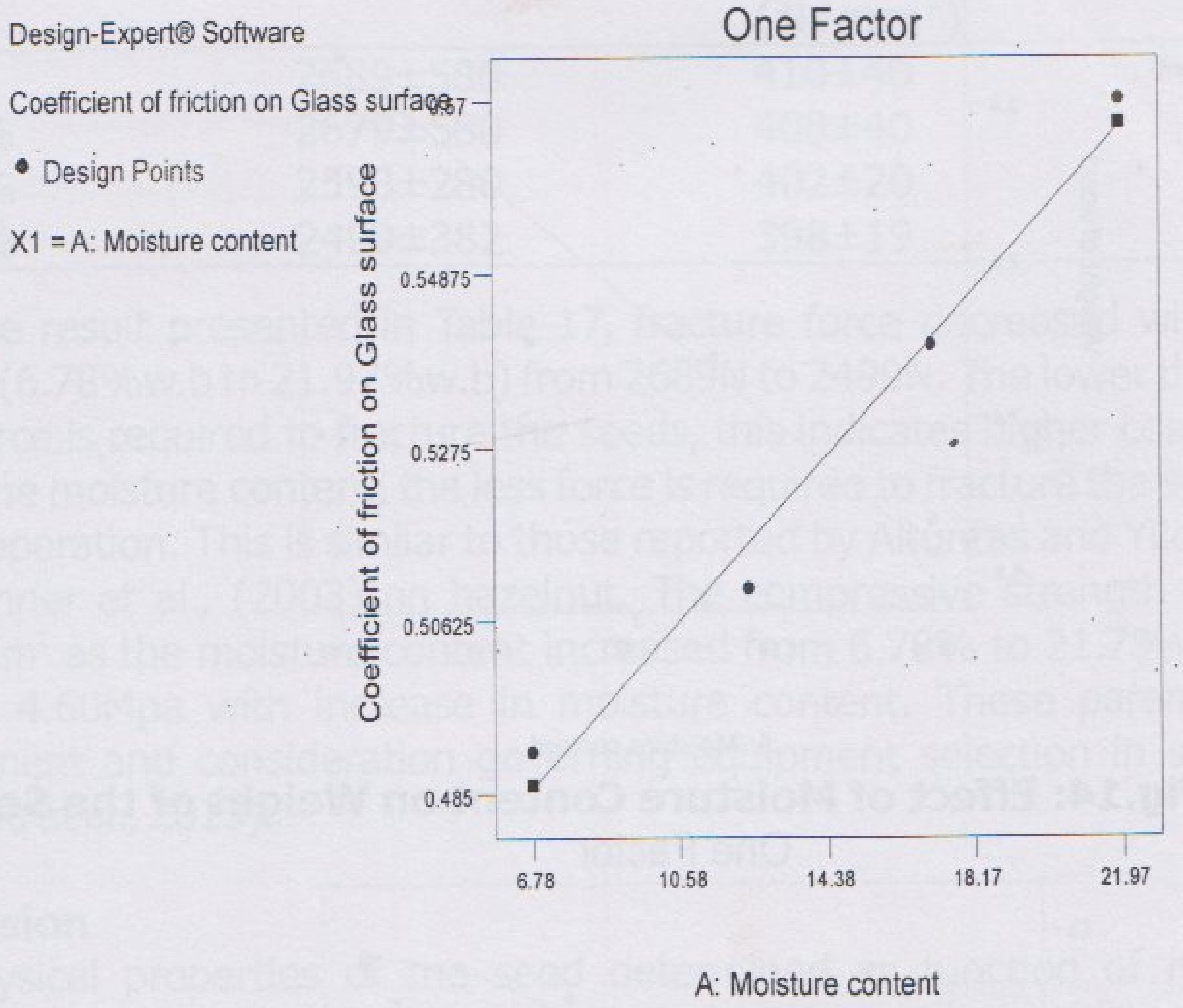

Fig.12: Effect of Moisture content on Coefficient of Friction on Glass Surface

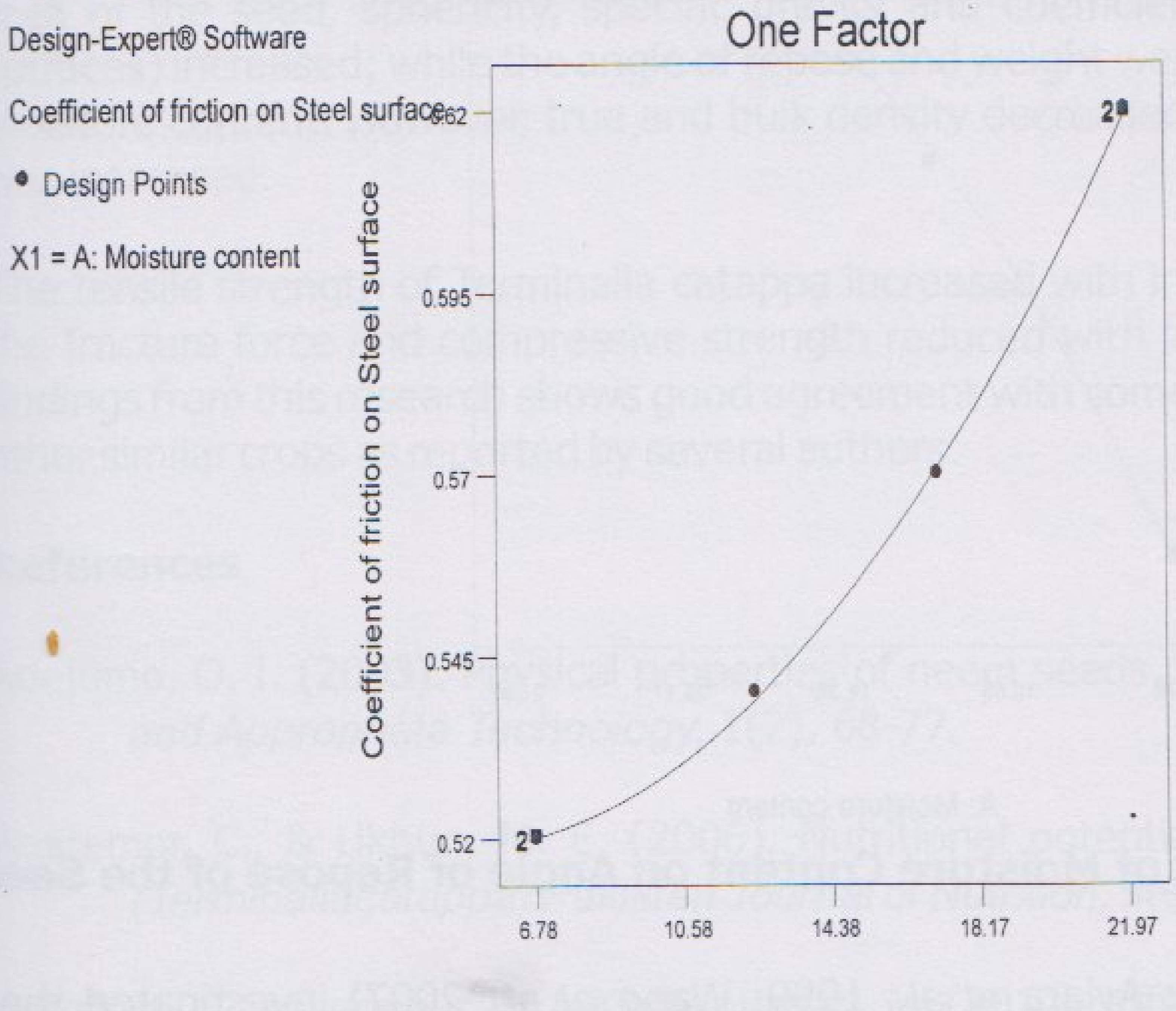

Fig.13: Effect of Moisture content on Coefficient of Friction on Steel Surface

The result also showed that the different levels of the moisture content had no significant differences ($p<0.05$) on the weight and angle of repose of the seed. The effect of moisture content on the weight and angle of repose of the seed is also shown graphically in Figures 14 and 15.

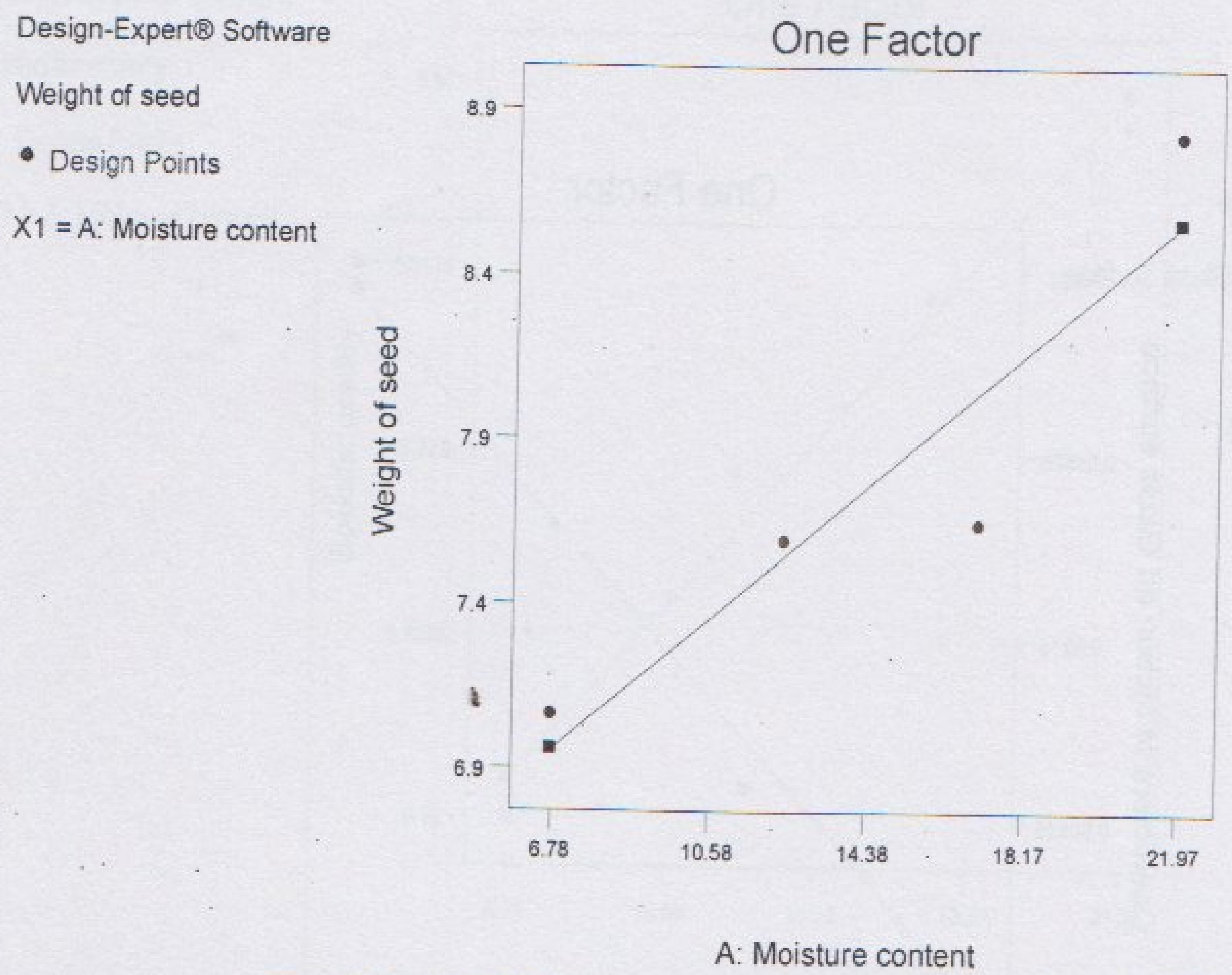

Fig.14: Effect of Moisture Content on Weight of the Seed

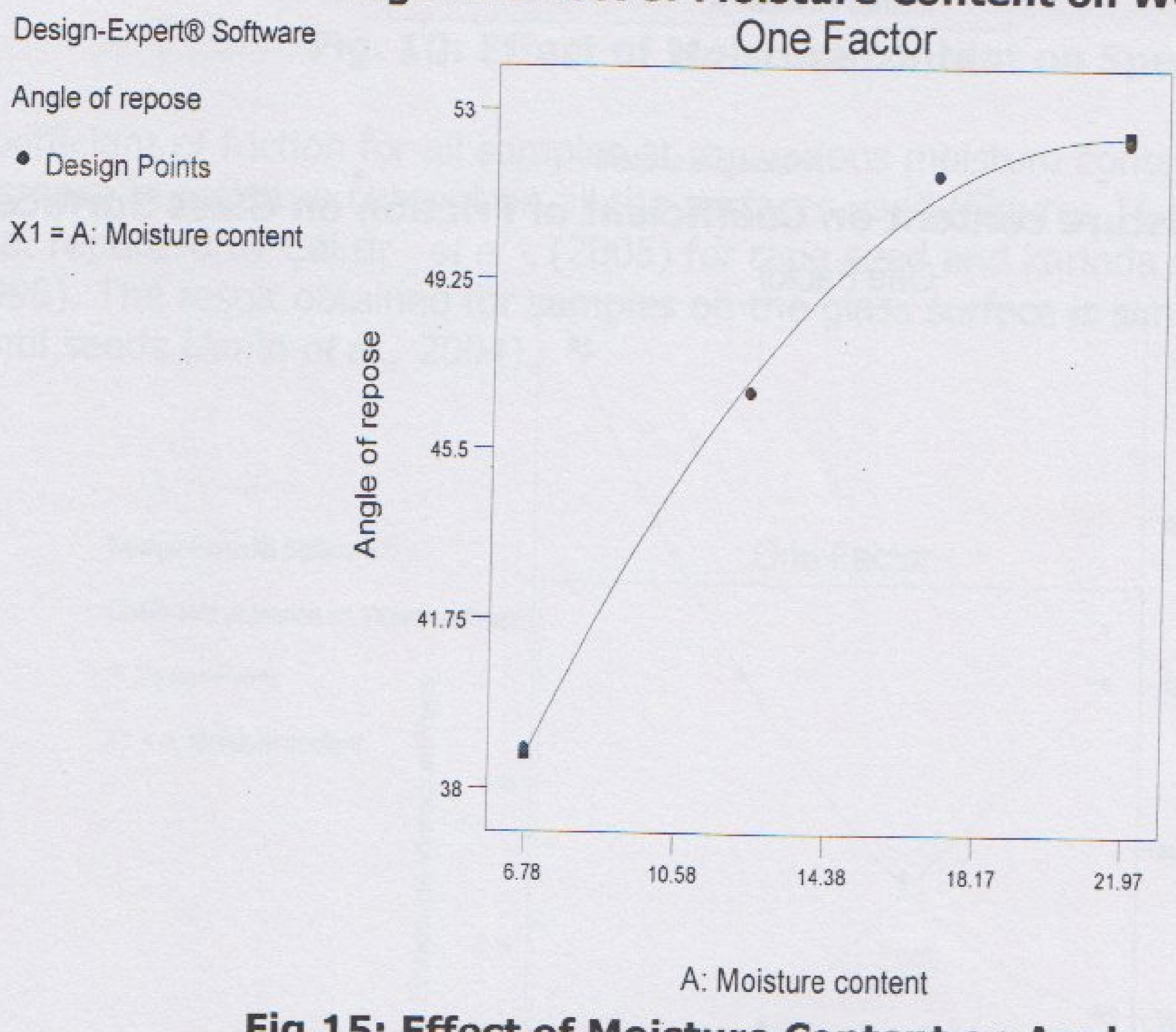

Fig.15: Effect of Moisture Content on Angle of Repose of the Seed

Many researchers (Aydin, 2003; Aviara *et al.*, 1999; Wang *et al.*, 2007) investigated the moisture dependence of physical properties of oil seeds and nuts (almond nut, high oleic sunflower seed and fibered flax seed) and reported increase of these properties with moisture content with the exception of bulk density that decreased with the increase in moisture content; in this study, true and bulk density decreased as moisture content of the seed was increased. According to Irouwa *et al.*, (2016), there is an important and positive relationship between moisture content and axial dimensions of grains and seeds.

Table 17: Effect of Moisture Content on Mechanical Properties of Almond Seed

Moisture Content (%)	Fracture Force (N)	Compressive Strength (N/mm^2)	Tensile Strength (Mpa)
6.78%	2689±580	410±40	3.20±1.10
12.39%	2679±580	408±40	3.90±1.80
16.11%	2598±280	402±20	4.20±1.23
21.97%	2499±382	398±19	4.60±1.11

From the result presented in Table 17, fracture force decreased with increase in moisture content (6.78%w.b to 21.97%w.b) from 2689N to 2499N. The lower the moisture content, the more force is required to fracture the seeds, this indicates higher cost of operation. Also, the higher the moisture content, the less force is required to fracture the seed; this indicates lower cost of operation. This is similar to those reported by Altuntas and Yildiz (2007) on faba seeds and Gunner et al., (2003) on hazelnut. The compressive strength decreased from 410 to 398N/mm^2 as the moisture content increased from 6.78% to 21.7%w.b and tensile strength 3.20 to 4.60Mpa with increase in moisture content. These parameters give the energy requirement and consideration governing equipment selection in size reduction operation (Orhevba et al., 2013).

Conclusion

The physical properties of the seed determined as function of moisture content varied significantly with increase in moisture content as the average length, width, thickness, surface area of the seed, sphericity, specific gravity and coefficient of static friction (on all three surfaces) increased; while the angle of repose and weight were not significantly affected by the moisture content. However, true and bulk density decreased as moisture content of the seed was increased.

The tensile strength of Terminalia catappa increased with increase in moisture content while the fracture force and compressive strength reduced with increase in moisture content. The findings from this research shows good agreement with some of the general trend obtained for other similar crops as reported by several authors.

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