Influence of Inherent Moisture Content on the Deformation Properties of Coconut Tissues During Mechanical Oil Expression

***J. J. Mpagalile[1] and B. Clarke[2]**

[1]Department of Food Science and Technology
Sokoine University of Agriculture, P. O. Box 3006 Morogoro, Tanzania

[2] Millfields Cottage, Mill Lane, Thurston, Bury St Edmunds, IP31 3QB, UK
(Formerly, Senior Lecturer of Agro Process Engineering, Silsoe College, Cranfield University, UK).

Abstract

The effect of moisture content on the deformation properties of coconut (Cocos nucifera) endosperm under mechanical uni-axial compression during a simulated oil expression situation was investigated. Fresh coconut samples at 45% moisture content (wet basis) and prepared samples at 3%, 7%, 11% and 15% wet basis moisture content were used. Results showed that tissues at higher moisture content (11 and 15%) had lower compressive strength hence lower forces at bio-yield point than drier samples and they also experienced higher deformation at bio-yield point. Low moisture samples (3% and 7%) required more force to reach their bio-yield points at 17.7 N and 15.3 N respectively as compared to specimens with moisture content of 11% and 15% which reached bio yield points at 11.4 N and 11.5 N respectively . Results showed that for samples at 3% and 7% wet basis moisture content the difference between bio-yield and oil-points was not significant (P>0.05) but there was a significant difference (P<0.05) for samples kept at 11% and 15% moisture contents. The study confirmed that moisture content has an important role in the deformation of coconut specimen. The compressive force required to deform the cellular structure decreased with the increase in moisture content with 11% moisture content (wet basis) providing the optimum condition. Results from this study has revealed that higher force would be required to express oil from drier oilseeds whereas relatively low forces are adequate to express oil from oil seeds kept at around 11% moisture content. This has high implication on the amount of energy required for oil expression and it is being recommended that further studies be carried out on the influence of moisture content in oil expression.

Key words: Coconut, deformation, compression, bio-yield point, oil-point, moisture content

Introduction

Application of the theories of elasticity and visco-elasticity to the rheology properties of agricultural produces has been studied widely. These theories have been useful in the analysis of the response of the applied loads and deflections during handling and processing (Zoerb, 1967, Paulsen, 1978; Pitt 1982; Pitt and Davis, 1984; Mohsenin, 1986; Hiller *et al.,* 1996). As a result of these studies a number of models have been developed to describe different loading scenarios (Akinoso *et al.,* 2006, Mrema and McNulty, 1984). However, rheological studies on agricultural produces such as coconuts still remains important as their nature is remarkably different from that of other common engineering materials such as metals and synthetics (Mohsenin, 1986). This calls for more investigation in this area so as to add some more understanding in addition to some of the related work that has been carried out on some of the plant materials. For example, although some work has been reported on the rheological properties of coconut milk (Vitali *et al.,* 1986 and Siamung *et al.,* 2004) and other common crops such as apples (McLaughlin, 1987), literature on deformation properties of coconut tissues and its relation to oil expression is generally missing.

**Corresponding author: jjmpagalile@yahoo.com*

Similarly, different theories have been developed which shows the diversity of the behaviour of oilseed matrix during oil expression (Mwithiga, 2007; Akinoso *et al.,* 2006 and Bargale *et al.,* 2000). According to Ward (1976), oil expression involves mechanical rupturing and damaging of the cell walls, which leads to oil being released. On the contrary, Mrema and McNulty (1984) described oil expression as a process involving passage of oil through porous cell wall without necessarily rupturing the cell walls. It is obvious therefore that investigation of the deformation and failure of cell structure during oil expression would lead to a better understanding of the coconut oil expression and the associated oil release mechanisms. In particular, the study of the failure behaviour in relation to the oil-point for the coconut will be very useful. Oil point is defined as a stage at which compression of the bed has sufficiently squeezed the individual seeds for oil to be forced from the interior to their surfaces (Faborode and Favier, 1996; Sukumaran and Singh, 1989, Ajibola *et al.,* 2002). This phenomenon is related to the process of progressive deformation of the seed matrix under application of external pressure and is therefore linked to the physical properties of biological materials. Furthermore, deformation properties as can be used to study and understand the effect of various process parameters. Paulsen (1978) observed that the compressive forces required to cause soybean seed coat rupture depended on the loading position and the moisture content levels. In addition, according to Vincent (1990) moisture content is influential during loading where moisture migration within the specimen is likely to occur.

The purpose of this study was to provide an additional insight into the mechanisms involved in the release of oil from coconut specimens as they are subjected to quasi – static mechanical loading. An attempt was made to relate the deformation behaviour of coconut specimens to their moisture content. The main objective was to determine the effect of moisture content on the force versus deformation characteristics of coconut flesh under compressive forces.

Materials and methods

Materials

The specimens used in this study were made from tufted Sri Lankan tall coconuts. Tufts were removed from the coconuts before they were split into two halves. Coconut is an oil crop belonging to the family palmae and geniuos cocos. The common specie grown in many parts of the world is Cocos nucifera (Woodroof, 1979 and de Tafin, 1998).

Drying

The moisture content of coconut flesh was established using an oven method prior to drying. A representative sample of fresh coconuts was finely ground using a Braun domestic grinder for moisture determination. Three samples of 5 grams each were oven dried for 3 hours using an automatic Gallenkamp forced convection oven (BS Model OV-160; Manchester, UK) at 103oC±2 and their moisture content was calculated according to BS 4289 - Part 3 (1978) standard. The ground samples were dried for three hours at 103oC using a forced convection oven. Similarly, drying was used to reduce the moisture content of samples to 15%, 11%, 7% and 3% (wet basis) for the dried specimens. Wet kernel blocks (10 mm x10 mm) of known moisture content were dried using a preheated oven at 60±1oC. The block's moisture content was determined by monitoring the weight loss and calculating moisture content as drying progressed. Drying was stopped after the intended moisture content was reached. Samples were then placed in airtight polythene bags and sealed to avoid any further moisture loss or absorption. This was followed by moisture equilibration for 24 hours at room temperature of 23oC. The final moisture content of the samples was rechecked prior to testing using an oven method.

Cutting of specimens

The final working specimens were cut from an intermediate area of the coconut kernel blocks as suggested by Darleen *et al.,* (1990) and Vaughan (1970). The outer region, next to the testa, was cut at about 2 mm from the testa surface and the inner region next to the cavity was cut at about 6 mm from surface. This minimized the effect of the zone properties within the kernel. The size of the specimens was accurately measured using a Mitutoyo electronic vernier caliper (Mitutoyo, IP67, Range 0-150 mm, Resolution 0.01 mm). Cylindrical specimens of diameter 4 mm and height 3 mm were cut from the mid-part of the kernel blocks using a 4 mm core borer. The two ends of the specimens were trimmed off using a double bladed razor knife. Three specimens were prepared for each moisture content level and four replicates were used for each combination of moisture content and loading category.

Loading

A universal testing machine (Instron Model 1122, 5KN maximum load) was used to provide the required compression load under quasi-static condition. The measurement of compressive force was carried out automatically using a force data logger (Mecmesin Limited, West Sussex, UK). The data logger was fixed to the Instron machine using a specially designed jig then connected to a computer for monitoring of forces and data processing. The data logger was capable of measuring forces in the range 0 - 500N with a precision 0.1N. Axial loading in compression at a constant deformation rate of 20mm/min was used. To obtain the bio-yield points, samples were compressed to a deformation of 2mm in a vertical position with reference to cavity - testa direction. The oil-point was determined by compressing the coconut samples to their first oil droplet (oil-point). All experiments were conducted at room temperature of 25^{o}C where coconut oil existed in a liquid form.

Factorial experiment using a Completely Randomized Design (CRD) with four replications was used to study the effect of moisture content on deformation properties. Analysis of variance and was carried out to determine the significant differences among the measurements.

Results and discussion

Analysis of coconut samples showed that the average moisture content of the fresh coconuts was 45.08 % (wet basis). The moisture contents of the dried specimens used in this study are shown in Table 1. Results showed that the final moisture contents of the specimens were very close to the targeted values.

Effect of moisture content on compression strength

This study revealed that the deformation behaviour of the coconut samples is highly affected by the level

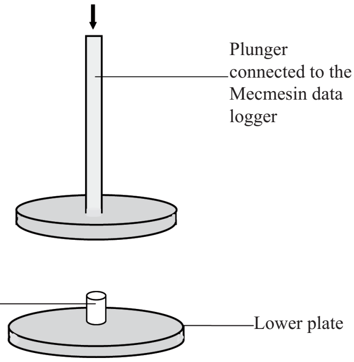


Figure 1: An experimental set up showing the sample and plates used in compression tests.

of moisture content of the samples. The relationship between yield point and moisture content of coconut tissues under compression is depicted in Fig 2. The results showed that tissues with higher moisture content had lower compressive strength at bio-yield point than that of the drier samples. For example, samples at 3% and 7% moisture contents led to high yield points of 17.7 N and 15.3 N respectively compared to 11.4 N at 11% moisture content and 11.5 N at 15% moisture content. Figure 2 show that the yield point at 11% moisture content was not significantly different ($p<0.05$) from that at 15%

Table 1: Average moisture content of the coconut specimens used in the deformation study

Sample number	Target moisture content (%)	Moisture content by weight loss (%)	Moisture content by oven method(%)	Deviation from target value (%)
1	3	03.0008	3.1128	+0.1128
2	7	07.0003	6.9856	-0.0144
3	11	11.0004	11.0234	+0.0234
4	15	15.0002	15.1230	+0.1230

moisture content specimens with both reaching relatively low forces at yield point. However, although specimens at 45 % moisture content failed with the lowest yield point of 8.6 N, they resulted into the expression of a white emulsion of oil - in – water instead of oil. It is clear from these results that tissues with higher moisture content had lower compressive strengths and higher deformation at yield point than for the drier samples. This difference is mainly due to the high turgor pressure experienced in higher moisture specimens as explained by Pitt (1982).

Effect of moisture content on the bio-yield point and oil-points of coconut samples

Fig. 3 shows the force-deformation curves where the effect of moisture content on the oil-point was investigated. The results indicated that specimens at the lower moisture contents of 3% and 7% reached the oil point after exceeding their bio-yield point as indicated in Fig. 3a and Fig. 3b. This suggested that cellular structure of dry specimens failed before oil could be released. Further analysis of the results showed that specimens with 3% moisture content reached their bio-yield points and exhibited further deformation before reaching their oil point unlike the 7% moisture content specimens where the oil-point was observed to occur just after the bio-yield point was reached. The difference was mainly due to the stiffness of the specimens at 3% moisture content were highly dehydrated and therefore experienced higher levels of stiffness. However, it was interesting to note that for the drier samples of 3% and 7% moisture content, there was no significant difference (p>0.05) between the bio-yield and oil point force as shown in Table 2.

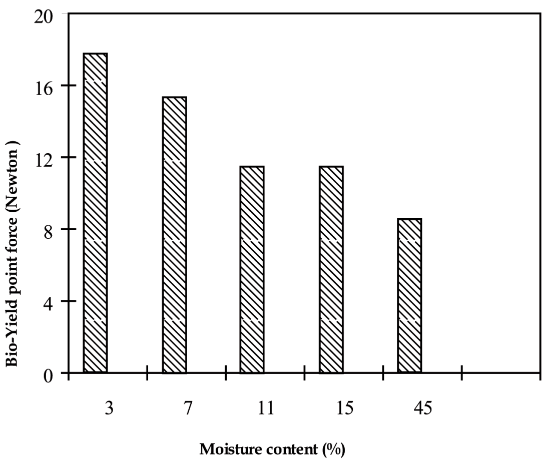
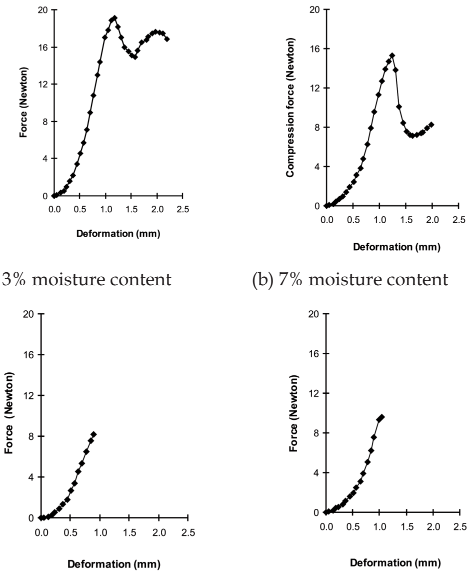


Figure 2: The influence of moisture content of the specimen (diameter 4mm and height 3mm) on the force required to reach the bio-yield point of the materials. ($Lsd_{p=0.05}$)

On the other hand, the specimens kept at 11 % and 15% moisture content released oil well before the bio-yield point was reached as shown in Fig. 3c and 3d. The results shows that oil started to come out of the specimens at 11% moisture content as the load reached 8.6 N that was well before the bio oil yield point of 11.4 N shown in Fig 2 . Also, Figure 3 (c) shows that the force at yield point for materials at 11% was significantly lower than that at all other levels of moisture content. This confirms earlier suggestions (Hammonds *et al.,* 1991 and Etherington *et al.,* 1998) that at the optimum moisture content of about 9-14% oil is released at a relatively low pressure and it also supports a model developed by Mrema and McNulty (1985) which explained that it is possible to carry out oil expression without necessarily rupturing the cells. Under this study, as the specimens were compressed, they changed in shape becoming thinner in the direction of the applied load. It is likely that further compression forced the oil out of the cells through the openings in the plasmalema referred to as 'plasmodesmata' as explained by Mrema and McNulty (1984).

Furthermore, results (Figure 3d) showed that specimens at 15% moisture content showed similar trends to those exhibited by samples at 11% moisture content. However, it was observed that at 15% moisture content (wet basis) both oil and water droplets were being expressed from the samples forming oil in water emulsion which is not desirable in oil expression.

As indicated in Table 2, results of the paired t-test to determine the significance of the difference in force at bio-yield point and oil point for different moisture content level is shown. The result shows that the bio-yield point and oil points were not significantly different at 3 % and 7% moisture content. However they were significant different at 11 and 15%. Table 2 shows that samples with 11% and 15% moisture content had a significant difference (P<0.05) in the forces at yield and oil-points. This phenomenon explains the fact that oil from low moisture content samples is only successfully expressed when using high-pressure expellers, which are capable of collapsing the oilseed's cellular structure. On the contrary, for samples at 3 and 7% moisture content there was no significant difference (P>0.05) between the forces at yield and oil-points. Such is the trend in



(a) 3% moisture content (b) 7% moisture content

(c) 11% moisture content (d) 15% moisture content

Figure 3: Force versus deformation curves showing deformation and force required to reach the oil-point for coconut kernel specimens (diameter 4 mm and height 3 mm) when compressed at 3%, 7%, 11% and 15% moisture content (wet basis)

the design and operation of expellers intended for the drier oilseeds as explained by Uziak *et al.* (2002) whereas low-pressure expellers can be used successfully to extract oil from oilseeds if moisture content is in the range 9 -13% (Hammonds *et al.,* 1991 and Etherington *et al.*, 1998).

Conclusion and recommendation

The influence of moisture content on the forces required for the coconut tissues to reach bio-yield and oil points has been investigated. The study has shown that the mode of deformation and hence oil release during compression is associated with the moisture content of the specimens being compressed. The compressive force required to initiate tissue failure and consequently release the entrapped oil tends to decrease with an increase in the moisture content. Dried samples at lower moisture content of 3% and 7% tend to require more force to reach their bio-yield point which is followed by an oil-point whereas specimens with moisture content of 11 and 15% had their oil-points reached well before reaching bio-yield points. Furthermore, the difference between bio-yield and oil-points for samples at lower moisture content of 3% and 7% was not significant whereas it was significant for samples at higher moisture content of 11% and 15 % with oil-point being significantly lower than bio-yield point. This implies that it is possible to express oil at lower pressure at 11% moisture content which has a huge implication on the energy expenditure during oil expression. It is therefore being recommended that more studies on deformation of coconut tissues be undertaken in the future work to understand better the influence of moisture content on deformation and oil release.

Table 2: Paired t - test to determine the significance of the difference in force at yield point and the oil point.

Moisture content (%)	X (N)	t- value	Degrees of freedom	Standard deviation
3	0.875	2.161	3	0.405
7	0.250	-0.435	3	0.575
11	3.255	5.433*	3	0.594
15	1.875	6.228**	3	0.301

X is the force required to reach the bio yield point minus that required to reach the oil point.
* Significant difference at 95% level, ** significant difference at 99% level.

Acknowledgement

The authors wish to thank the German Academic Exchange Services (DAAD) for the support and generous financial assistance that led to a completion of this study.

References

Ajibola, O. O., Okunade, D.A., and Owolarafe, O.K., (2002). Oil point pressure of soybean. Journal of Food Process Engineering, 25, 407 - 416.

Akinoso, R.; Igbeka, J. C.; Olayanju, T.M.A., and Bankole, L.K., (2006). Modeling of oil expression from palm kernel (Elais Guineensis Jacq.) Agricultural Engineering International: The CIGR EJournal Vol. VIII.

Bargale, P.C.; Wulfsohn, D.; Irudayaraj, J.; Ford, R.J. and Sosulski, F. W., (2000). Prediction of oil expression by uniaxial compression using some varying oilseeds properties. Journal of Agricultural Engineering Research 77(2): 171 – 181.

Bargale, P.C., (1997). Mechanical Oil Expression from Selected Oilseeds Under Uniaxial Compression, Ph.D. Dissertation, University of Saskatchewan, Saskatoon, Canada, 1997, 310 pp.

Darleen, A. Demason and Sekhar, C. N., (1990). Electrophoretic characterization and immunological localization of coconut (cocos nucifera L.) endosperm storage protein. Botanical gazette, 151, (3), 302 - 313.

de Taffin, G. (1998). Coconut. The tropical agriculturalist. Macmillan Books.

Diekert, J. W. and Diekert, M. C., (1976). The chemistry and cell biology of the vascuolar protein of seeds. Journal of Food Science, 41, 475-482.

Etherington, D. M., Zegelin, S. J. and White, I., (1998). Oil extraction from grated coconut: Moisture measurement and oil production efficiency. Tropical Science, 38, 10 – 19.

Faborode, M.O. and Favier, J.F., (1996). Identification and significance of the oil point. Journal of Agricultural Engineering Research, 45, 335 – 345.

Hammonds T.W., Harris R.V. and Head S.W. (1991): The influence of moisture content on the extraction of oil from fresh, grated coconuts. Tropical Science Journal. 31, 73 – 81.

Hiller, S., Bruce, D. M., and Jeominidis, G., (1996). A micro penetration technique for mechanical testing of plant cell walls. Journal of Texture Studies, 27, 559 - 587.

McLaughlin, N. B., (1987). Statistical models for failure of apple tissue under constant-strain-rate loading. Journal of Texture Studies 18, 173 - 186.

Mohsenin, N. N. (1986). Physical Properties of Plant and Animal Materials: Structure, Physical Characteristics, and Mechanical Properties. 2nd Edition.

Mrema G. C. and McNulty, P. B. (1985). Mathematical model of mechanical oil expression. Journal of Agricultural Engineering Research, 31, 361 - 370.

Mrema, G. C. and McNulty, P. B. (1984). Microstructure of rapeseed and cashew as related to mechanical oil expression. Irish Journal of Food Science Technology, 8, 59 - 66.

Mwithiga, G. and Moriasi, L., (2007). A study of yield characteristics during mechanical oil extraction of preheated and ground soybeans. Journal of Applied Science Research 3(10): 1146 -1151.

Paulsen, M. R., (1978). Fracture resistance of soybean to compressive loading. Transaction of American Society of Agricultural Engineering, 21, 1210 - 1216.

Pitt, R. E., (1982). Models for the rheology and statistical strength of uniformly stressed vegetable tissues. Transaction of American Society of Agricultural Engineering, 25, 1776- 1784

Pitt, R. E. and Davis, D. C., (1984). Finite element analysis of fluid filled cell response to external loading. Transaction of American Society of Agricultural Engineering, 27, 976 - 1983.

Siamung, J.; Chiewchan, N. and Tansakul, A. (2004). Effect of fat content and temperature on the apparent viscosity of coconut milk. Journal of Food Engineering, 64, 193-197.

Sukumaran, C. R. and Singh, B.P.N. (1989). Compression of bed rapeseed: Oil point. Journal of Agricultural Engineering Research 42: 77 – 84.

Uziak, J.; Loukanov, I. A. and Foster, J. D. G., (2002). A simplified model of an offset ram press for sunflower oil extraction. African Journal of Science and Technology (AJST). Vol 3, No 1, pp 61 – 68.

Vaughan, J. G., (1970). The structure and utilization of oilseeds. Richard Clay (The Chanier press).

Vitali, A.A.; Soler, M.P. and Rao, M.P., (1986). Rheological behaviour of coconut milk. In Food Engineering and Process Applications, Vol I, Transport Phenomena (Edited by M.Le Maguer and P. Jelen). Pp 33-38. London: Elsevier Applied Science.

Vincent, J. V. F. (1990). Fracture properties of plants. Advances in Botanical Research, 17, 235 - 287.

Ward J.A. (1976): Processing high oil content seeds in continuous screw presses. Journal of American Oil Chemists Society. 53 (6), 261 – 264.

Woodroof, J. G., (1979). Coconuts: Production, processing and products. AVI publishing company, Inc. Westport, Connecticut.

Zoerb, G. C., (1967). Instrumentation and measurement of techniques for detecting physical properties of farm products. Transaction of American Society of Agricultural Engineers, 10 (1): 100 – 109.