Effects of heating temperature and time on some mechanical properties of *Balanites Aegyptiaca* nut

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Abstract: *Balanites aegyptiaca* nuts were pretreated by heating at different temperatures in the range of 30 – 90°C for time durations in the range of 30 – 120 min. Moisture content of the nuts prior to pretreatment was 4.7 % (d.b.). Some strength properties of the pretreated nuts, namely, bioyield, yield and rupture points; bioyield, compressive and rupture strengths; and moduli of elasticity, resilience, stiffness and toughness were determined at lateral and longitudinal axial loading, using a Universal Testing Machine (UTM). Results showed that all the strength properties of the nut decreased with the increase in temperature and varied significantly with heating time at different loading orientations. Temperature and heating time range existed within which the nuts exhibited the typical behavior of biomaterials when they were heated and subjected to compression. After these ranges were exceeded, the nuts' behavior deviated. The study suggested that in addition to conditioning *balanites aegyptiaca* nuts to a moisture level at which they could easily be cracked, further treatment by exposure to heat at a level and for a duration that would not compromise product quality, could be used to enhance energy efficiency. Loading along the longitudinal axis should be applied if the cracking of nut is to be carried out using uniaxial compression.

Keywords: Mechanical properties, *balanites aegyptiaca* , temperature, uniaxial compression, oil seed

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1 Introduction

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Balanites aegyptiaca is one of the important oilseed crops in Northeastern Nigeria (Mamman, Umar and Aviara, 2005). Two accessions of the tree with fruit, nut and kernel shapes that corroborate the findings of Launert (1963) are common in the region; however, the most predominant accession has been the one-end tapered oblong nut cultivar. The nut is obtained after the removal of the flesh and pulp from the fruit. It contains a kernel with oil and protein contents ranging from 20%–60% and 20%–37% respectively (Mamman, Umar and Aviara, 2005; Elfeel, 2010).

The *balanites* seed oil is good for cooking as it has an acceptable scent and taste (Hall and Walker, 1991), and does not smoke excessively when heated (Shanks and Shanks, 1991). The present procedure followed in processing *balanites aegyptiaca* fruit to obtain its seed oil involves soaking it in cold water for three days or hot water for a day and washing off the pulp to obtain the nut. The nut is sun-dried for two days if cold water was used and for eight hours if hot water was used. The kernel is obtained from the nut by cracking with stone on top of another stone or metal. Oil is extracted from the kernel by heating its meal in a pan over an open fire or boiling it in a pot containing water.

The most difficult and risky operation in *balanites* seed oil processing is the cracking of the nut to release the kernel. The nut of the one-end tapered oblong cultivar in particular, has proved to be the most difficult to crack. In an attempt to develop appropriate technology equipment for cracking the *balanites* nuts, Mamman, Umar and Aviara (2005) determined some mechanical properties of the nut relevant in bulk handling and processing at different moisture contents and loading orientations. Nut moisture content and loading orientation were found to have significant effects on the strength properties. Similar findings were reported on cumin seed (Singh and Goswami, 1998), sheanut (Olaniyan and Oje, 2002), walnut cultivars (Altuntas and Ozkan, 2008; Aviara and Ajikashile, 2011), barley grains (Tavakoli et al., 2009), jatropha seeds and kernels (Karaj and Muller, 2010), shea kernel (Manuwa and Muhammad, 2011) and mucuna flagellipes nut (Aviara, Onuh and Ehiabhi, 2012). Preliminary investigations leading to this present study showed that there would be a need to further subject the nuts of *balanites aegyptiaca* to some pretreatments at a given moisture level in order to understand the mode and mechanism that affect the cracking process and enhance the effectiveness of any mechanical cracking device developed to handle the nuts. Khazaei and Mann (2004a, b) noted that the rupture force and modulus of elasticity of sea buckthorn berries respectively decreased with the increase in temperature. Burubai, et al. (2007a, b) reported that the compressive force needed to initiate seed coat rupture of African nutmeg decreased with an increase in both pre-heating temperature and moisture content and noted that the energy demanding and time consuming unit operation of cracking the nut to extract the kernel can be positively manipulated by varying the loading rate and pre-heating time used to condition the nut for mechanical cracking. Dobrzanski and Szot (1997) earlier investigated the resistance of pea seed coat to tension when the seed was dried at different temperatures. Gates and Talja (2004) studied the effects of temperature and moisture content on the mechanical properties of oat and observed that the stiffness of the seed decreased with the increase in temperature and increased with the increase in moisture content.

Davis, Burubai and Eribo (2009) noted that the compressive force, strain energy and elastic modulus of different groundnut varieties decreased as the blanching time increased, while deformation increased linearly with the increase in blanching time.

There appears to be no reported information on the response of the mechanical properties of *balanites aegyptiaca* nuts to such pretreatment as heating over time duration. The objective of this study was therefore to investigate the effect of heating temperature and time on some mechanical properties of *balanites aegyptiaca* nuts that are relevant to the design of the nut cracking and separating equipment, and determine their variation with loading orientation. The mechanical properties include bioyield point, yield point, rupture point, bioyield strength, rupture strength, compressive strength, modulus of elasticity, modulus of stiffness, modulus of resilience and modulus of toughness.

2 Materials and methods

2.1 Sample procurement and preparation

A bulk quantity of fresh *balanites aegyptiaca* fruits was purchased at the market in Maiduguri, Borno State, Nigeria. The fruits were soaked in cold water for three days and washed several times to obtain clean nuts. The nuts were sorted out for those that had oblong shape with one end pointed and these were sundried for two days to reduce the moisture content to a level at which they could be easily cracked manually to obtain the kernels. The moisture content at which the nuts could be easily cracked was determined using the method employed by Oje (1993) and Aviara, Mamman and Umar (2005) in obtaining the moisture content of *thevetia* nut and *balanites aegyptiaca* nuts respectively. The nuts were then sampled for experiments using a multislot riffle box divider. The uniformly sized sample obtained was divided into lots and subjected to the pretreatment of heating in thermostatically controlled Gallenkamp ovens at 30, 60 and 90^{o}C for durations of 30, 60, 90 and 120 min respectively. The pretreated samples were cooled, then sealed in marked polyethylene bags and stored in that condition for a further 24 h period which enabled them to attain a stable and uniform moisture content. The polyethylene bags were transferred into a refrigerator at a temperature in the range of 0-4°C and when needed for experiments, the nuts were allowed to equilibrate in the ambient condition for 6 h.

2.2 Experimental procedure

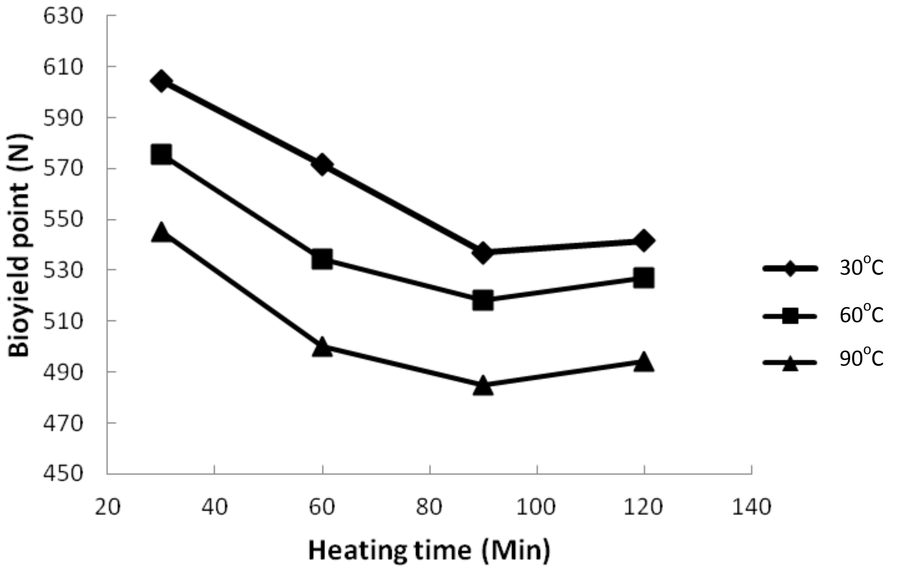
Compression tests were conducted at the axial and longitudinal loading orientation on *balanites aegyptiaca* nuts preheated at different temperatures for different time durations, using a Testometric Universal Testing Machine (UTM) controlled by a micro-computer. Nut compression was carried out at cross head speed of 25mm/min (Mamman, Umar and Aviara, 2005). As compression began and progressed, a force-deformation curve was plotted automatically by the machine in relation to the response of the nut. The results, statistical data and force-deformation curves obtained at each loading orientation were analyzed for bioyield, yield and rupture points; bioyield, compressive and rupture strengths; modulus of elasticity, modulus of resilience, modulus of stiffness and modulus of toughness. The bioyield point was taken as the point on the force-deformation curve at which the compressed nut shell weakened and failed internally without cracking outwardly. At this point, an increase in deformation resulted from either a decrease or no change in force (Mohsenin, 1986), and the nut could be said to have failed in its internal cellular structure (Anazodo, 1982). The yield point was the point on the force-deformation curve at which the visible failure of nut shell became initiated and the shell just began to tear (Aviara, Shittu and Haque, 2007). Rupture point was the point on the force deformation curve at which the nut shell completely became broken and torn with the kernel exposed (Mohsenin, 1986; Anazodo, 1982). The bioyield strength was taken as the stress at which the nut shell failed in its internal cellular structure. The compressive strength was the stress at which the visible failure of the nut shell was initiated so that it began to tear. The rupture strength was taken as the stress at which the nut shell got completely broken. Modulus of elasticity was taken as the ratio of the stress to the strain up to bioyield. Modulus of resilience was taken as area under the force-deformation curve up to bioyield (Aviara, Shittu and Haque, 2007) and was determined from the force-deformation curve of the nut using the method that was followed by Haque et al. (2001). Modulus of stiffness was the ratio of the average maximum force to the average maximum deformation of the nut at failure (Dinrifo and Faborode, 1993; Aviara and Ajikashile, 2011). It was calculated from the force-deformation data of the nut following the method employed by Mamman, Umar and Aviara (2005) and Aviara, Shittu and Haque (2007). Modulus of toughness was taken as area under the force-deformation curve up to failure (Aviara, Onuh and Ehiabhi, 2012) and was determined from the force-deformation curve using the method that was followed by Haque et al. (2001). The test was replicated ten times at each pretreatment and the mean of each property under lateral and longitudinal loading orientations was obtained. The variations of the properties with heating time at different heating temperatures were plotted.

3 Results and discussion

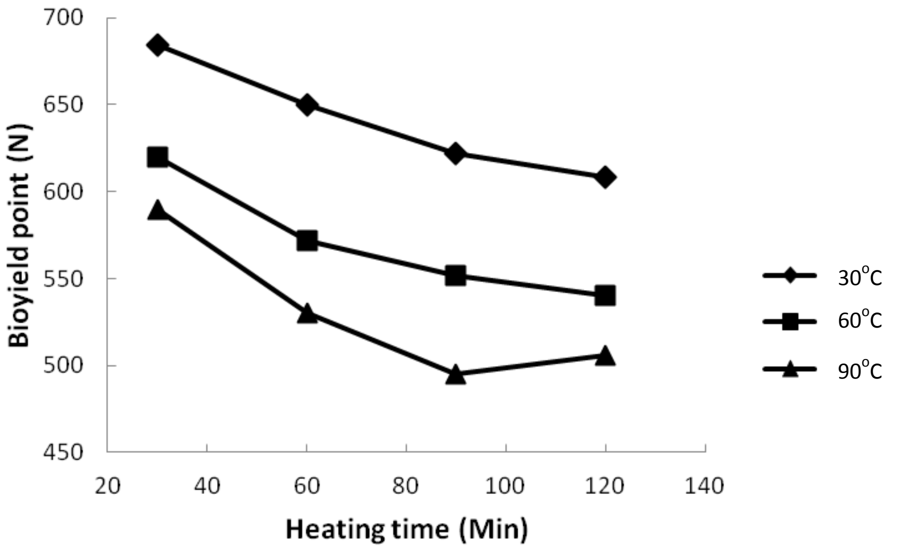
The moisture content range within which the nut could be easily cracked was found to be 4.7%±0.58% (d.b.).

3.1 Bioyield, yield and rupture points

The variations of the bioyield, yield and rupture points of *balanites aegyptiaca* nut with heating time at different temperatures were presented for lateral and longitudinal loading, in Figure 1, 2 and 3, respectively. These Figures showed that under both lateral and longitudinal loading, the bioyield, yield and rupture points of the nut decreased with the increase in temperature with the values on the longitudinal axis being higher. This could be attributable to loss of turgor pressure and chemical changes in the cell wall (Van Buren, 1979), cell separation (Shomer, 1995), rupture (Reeve, 1977; Ramana, Taylor and Wolf, 1992) and loss of firmness (Bourne, 1982) that have been reported to generally accompany the heating of biomaterials. Similar findings were made by Khazaei and Mann (2004a) and Burubai et al. (2007a) on the rupture and compressive forces respectively of buckthorn berries and African nutmeg. In the range of 30 - 90°C under lateral loading, the bioyield point of *balanites aegyptiaca* nut decreased with the increase in heating time to a minimum at 90 min and thereafter, increased with further increase in heating time. The yield point increased with the increase in heating time to a maximum at 90 min and thereafter, decreased with further increase in heating time, while the rupture point decreased continually with the increase in heating time except for heating at the temperature of 90°C where it increased with heating time until 90 min was attained and it decreased with further increase in heating time. On longitudinal loading, the bioyield and yield points decreased with increasing heating time, while rupture point increased with heating time till 60 min after which it decreased with further increase in heating time. The response of these properties to heating time could be attributable not only to loss of firmness but also to the possible denaturation of the nut constituents with prolonged heating. It was observed that heating at 90°C for an extended period of time caused the browning of the nut which could undermine the quality of the end product, therefore, heating of the nut at a temperature that does not exceed 60°C for a duration of no more than 90 min prior to cracking is recommended. A trend similar to that of the yield point with heating time was observed by Burubai et al. (2007b) on the compressive force of African nutmeg.

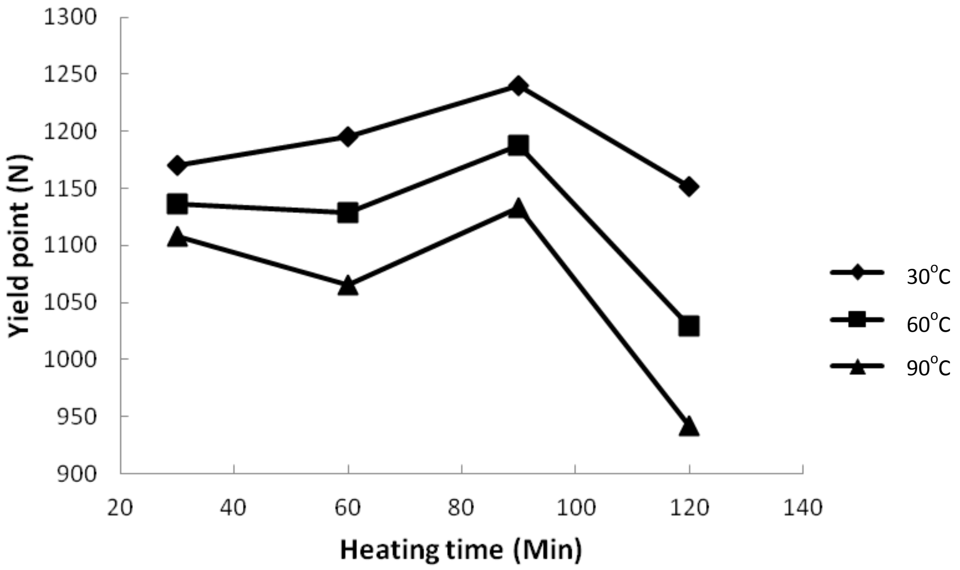


(a) Lateral loading

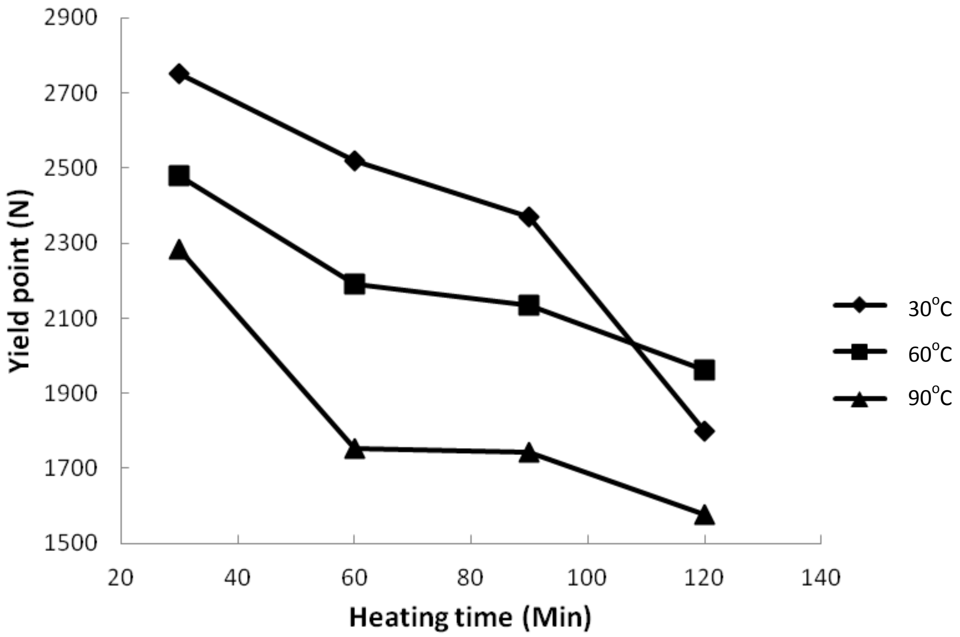


(b) Longitudinal loading

Figure 1 Variation of bioyield point of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations

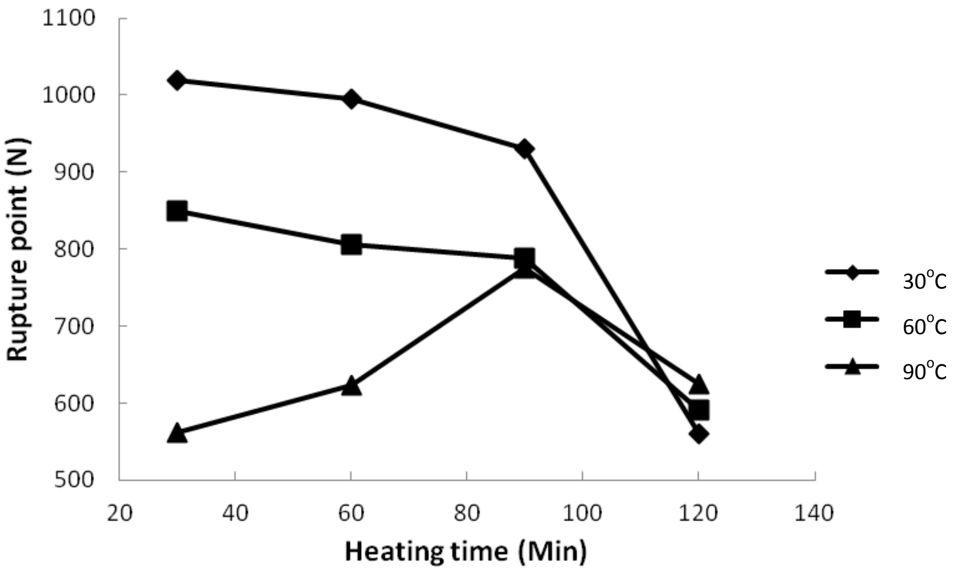


(a) Lateral loading

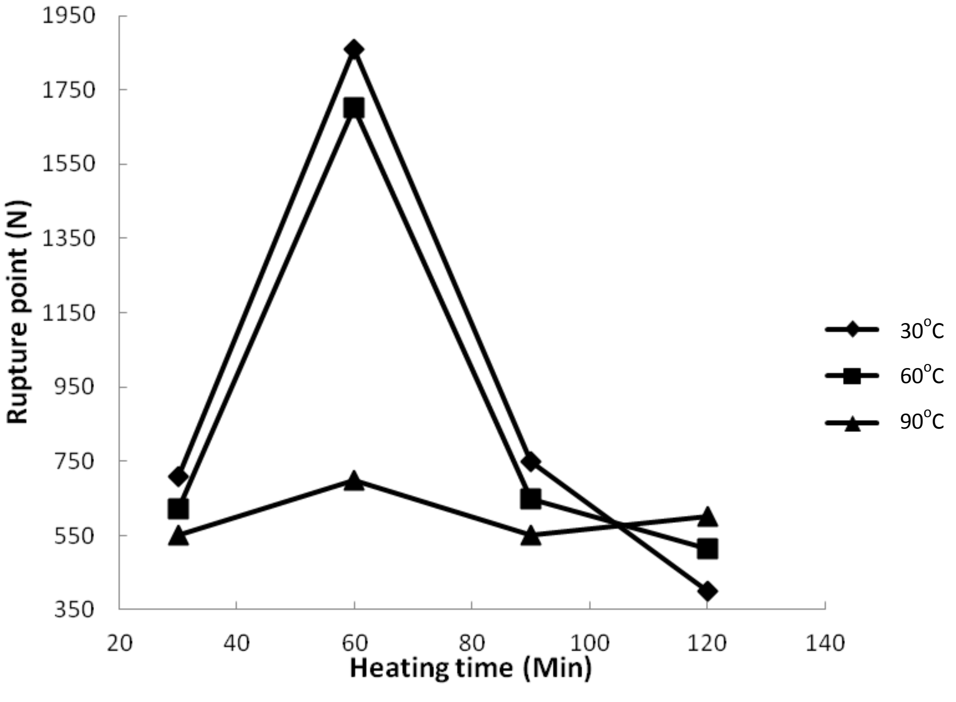


(b) Longitudinal loading

Figure 2 Variation of yield point of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations



(a) Lateral loading

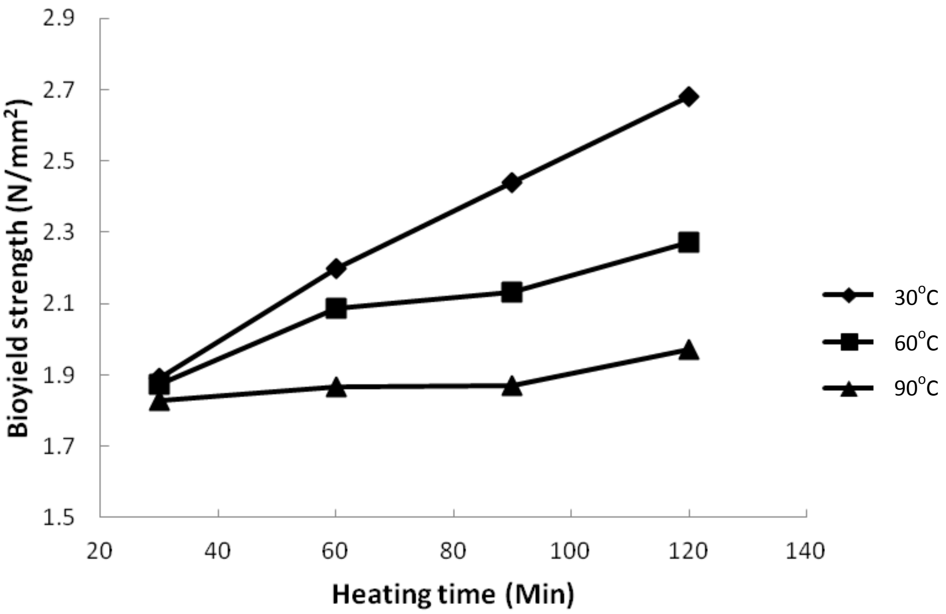


(b) Longitudinal loading

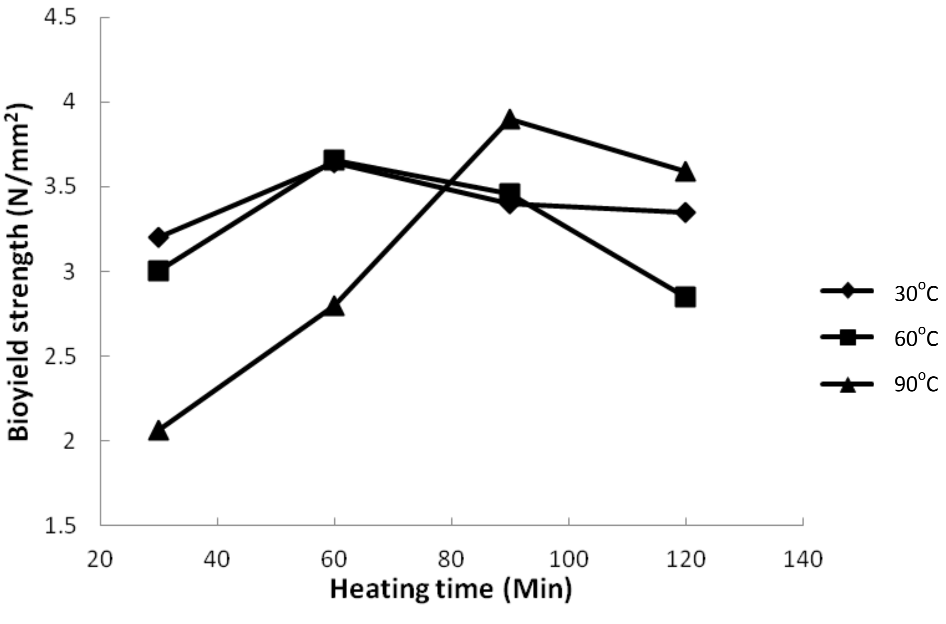
Figure 3 Variation of rupture point of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations

3.2 Bioyield, compressive and rupture strengths

The effects of temperature and heating time on the bioyield, compressive and rupture strengths of *balanites aegyptiaca* nut at the moisture content of 4.7% (d.b.) under different loading orientations are presented in Figure 4, 5 and 6 respectively. From these figures, it can be seen that the bioyield, compressive and rupture strengths of the nut decreased with the increase in temperature under both lateral and longitudinal loading. This is in conformity with the fact that the increase in temperature reduces the cellular integrity of biomaterials (Ramana, Taylor and Wolf, 1992) due to enhanced depolymerization of the nut shell as temperature increased. At a given temperature and lateral loading orientation, the bioyield strength of the nut increased with the increase in heating time, while the compressive strength decreased continually with the increase in heating time at 30^{o}C but decreased to a minimum at 60 min and thereafter, increased with further increase in heating time when the temperature was increased to 60 and 90^{o}C. Rupture strength of the nut decreased to minimum values at 60 min and thereafter, increased with further increase in heating time. On longitudinal loading, the bioyield strength increased with increase in heating time to a point and decreased with further increase in heating time. Compressive strength decreased to a minimum at 60 min and increased with further increase in heating time, while the rupture strength decreased continually with heating time except at the temperature of 90^{o}C in which it increased with the increase in heating time after 90 min was exceeded. The increase of bioyield strength with heating time was unexpected and might not have been unconnected with resistance to deformation that must have built up prior to the disruption of the cellular structure or chemical changes that occurred in the shell fiber of the nut as the heating time increased. The strength of *balanites aegyptiaca* nut was higher on longitudinal loading than at lateral loading. This may be due to smaller contact areas that occurred during loading on the longitudinal axis. Similar findings were reported by Aviara and Ajikashile (2011) and Aviara, Onuh and Ehiabhi (2012) on *conophor* and *mucuna flagellipes* nuts respectively.

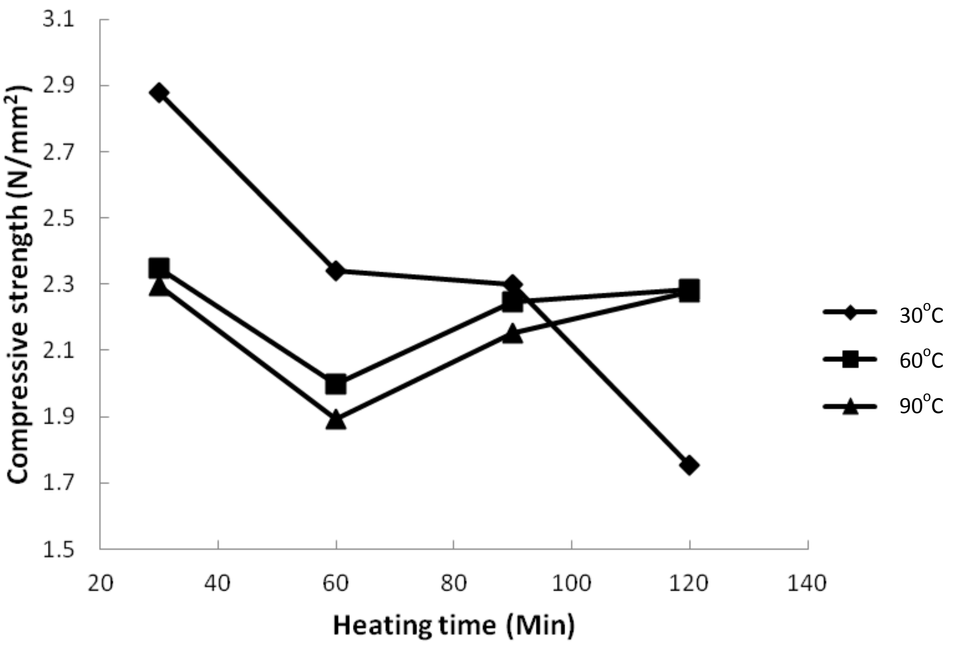


(a) Lateral loading

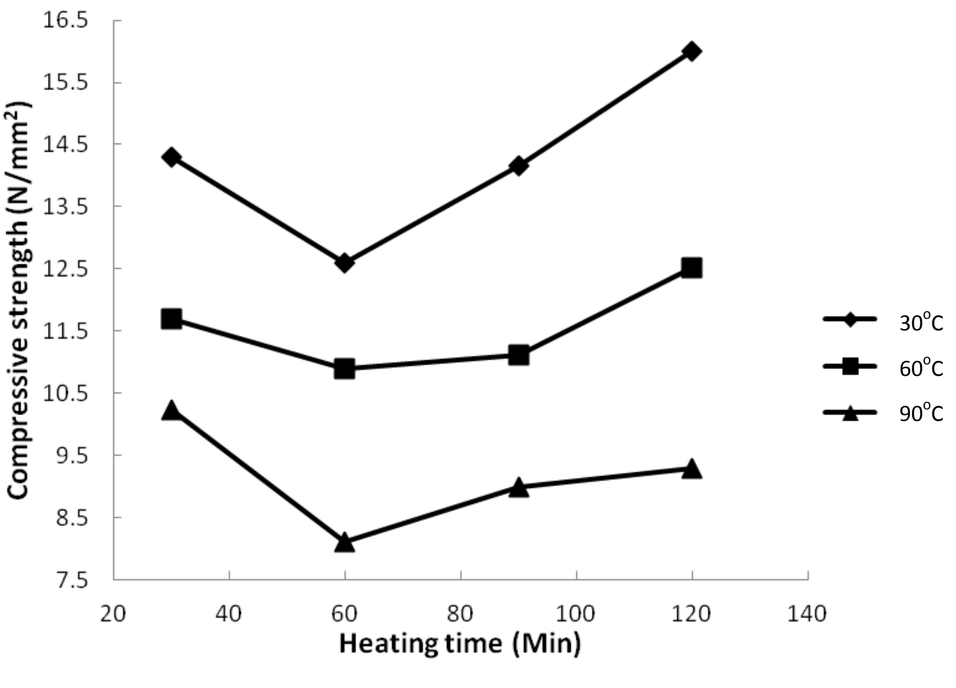


(b) Longitudinal loading

Figure 4 Effect of temperature and heating time on the bioyield strength of *balanites aegyptiaca* nut at different loading orientations

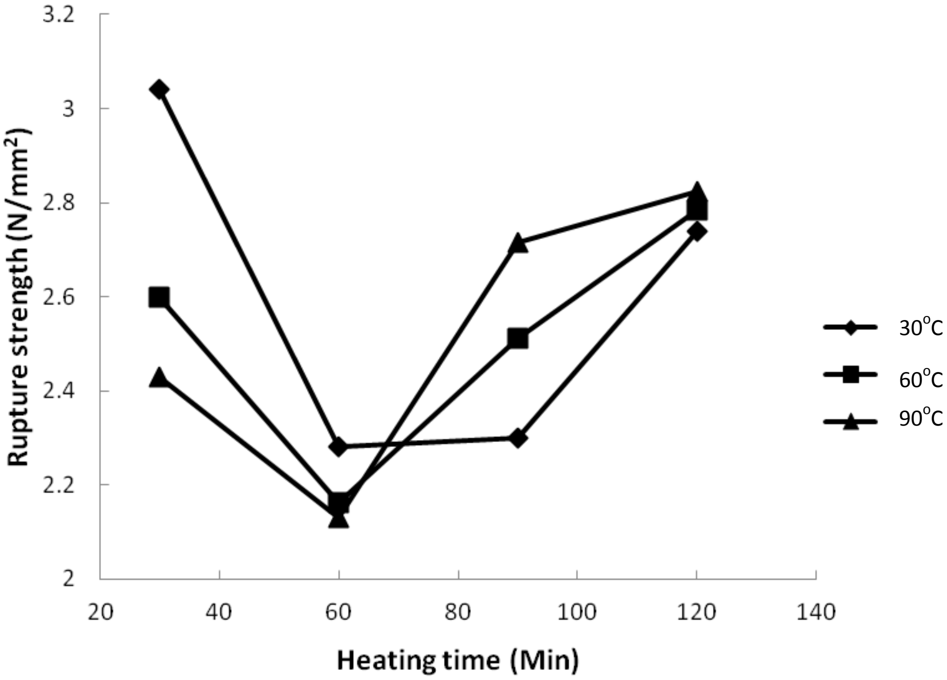


(a) Lateral loading

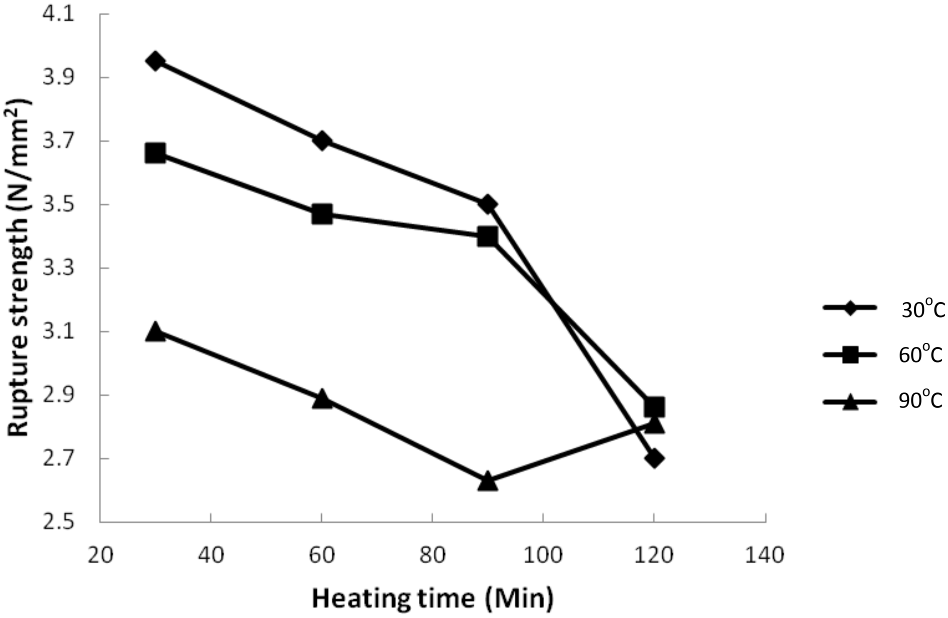


(b) Longitudinal loading

Figure 5 Effect of temperature and heating time on the compressive strength of *balanites aegyptiaca* nut at different loading orientations



(a) Lateral loading

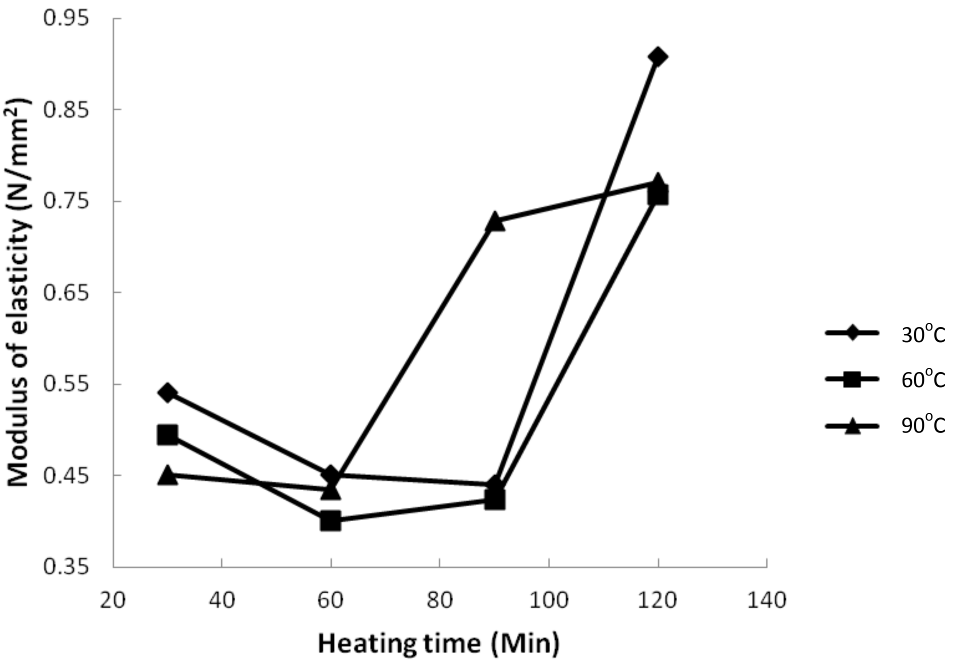


(b) Longitudinal loading

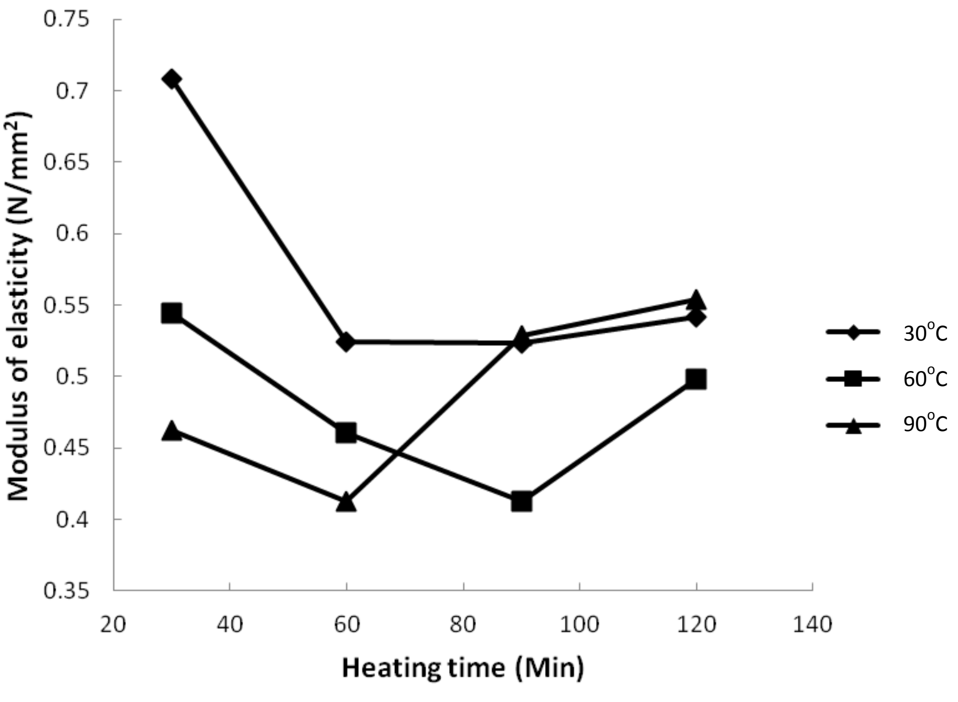
Figure 6 Effect of temperature and heating time on the rupture strength of *balanites aegyptiaca* nut at different loading orientations

3.3 Moduli of elasticity, resilience, stiffness and toughness

The variations of the moduli of elasticity, toughness, stiffness and toughness of *balanites aegyptiaca* nut with temperature and heating time at different loading orientation are presented in Figures 7, 8, 9 and 10 respectively. The modulus of elasticity – in agreement with the findings of Khazaei and Mann (2004b) – decreased with increase in temperature, under lateral loading. However, when the heating time of 60 min was exceeded, its trend with temperature changed. It decreased with increase in heating time until 60 min was attained, then it increased with further increase in heating time with values for the nut heated at 30^{o}C rising remarkably after 90 min of heating. On longitudinal loading, the modulus of elasticity decreased with the increase in temperature and heating time until 60 min of heating, after which its value for the nut heated at 90^{o}C rose remarkably and became higher than the values for nuts heated at 30^{o}C and 60^{o}C respectively. Under both loading orientations, the modulus of resilience decreased with the increase in both temperature and heating time until 60 min was exceeded, then it increased with the increase in only the heating time. The modulus of stiffness of the nut decreased with the increase in temperature and heating time, under lateral loading, until 90 min was exceeded and it increased with further increase in the heating time only. On longitudinal loading, it decreased with the increase in both temperature and heating time, but after 90 min of heating, it increased with both temperature and time. Modulus of toughness on the lateral loading orientation decreased with the increase in temperature and increased with the increase in heating time. After 60 min, it increased with both temperature and time till 90 min and decreased with further increase in heating time. Under longitudinal loading, the modulus of toughness decreased with the increase in temperature and heating time till the 90 min duration after which the values for nuts heated at 30^{o}C continued to decrease, while that of nuts heated at 60^{o}C and 90^{o}C increased with further increase in heating time. The response of the strength properties confirms the fact that loss of cellular integrity (Ramana, Taylor and Wolf, 1992) is not only a function of the exposure of a biomaterial to heat but also that of the duration of the exposure.



(a) Lateral loading



(b) Longitudinal loading

Figure 7 Variation of modulus of elasticity of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations

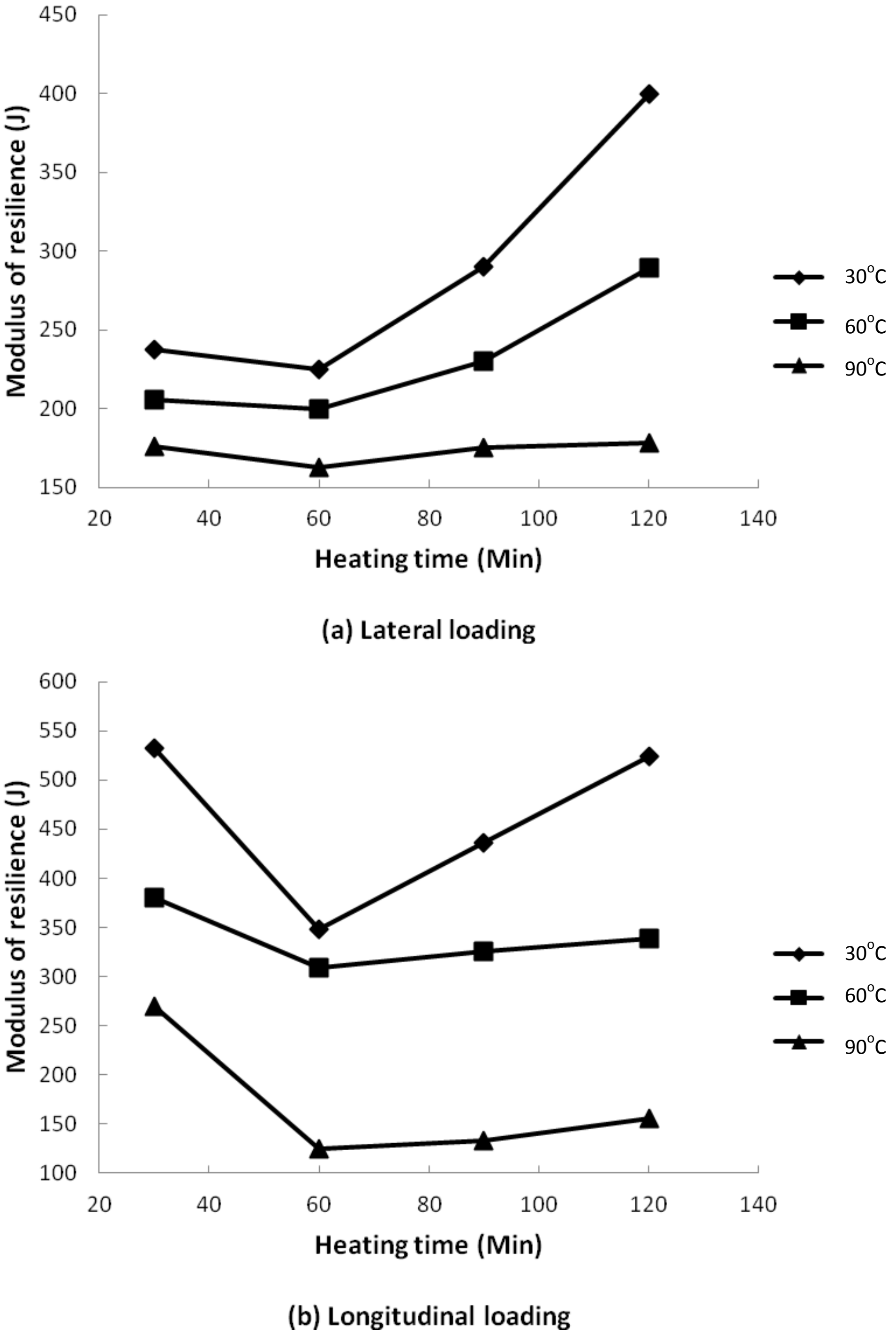
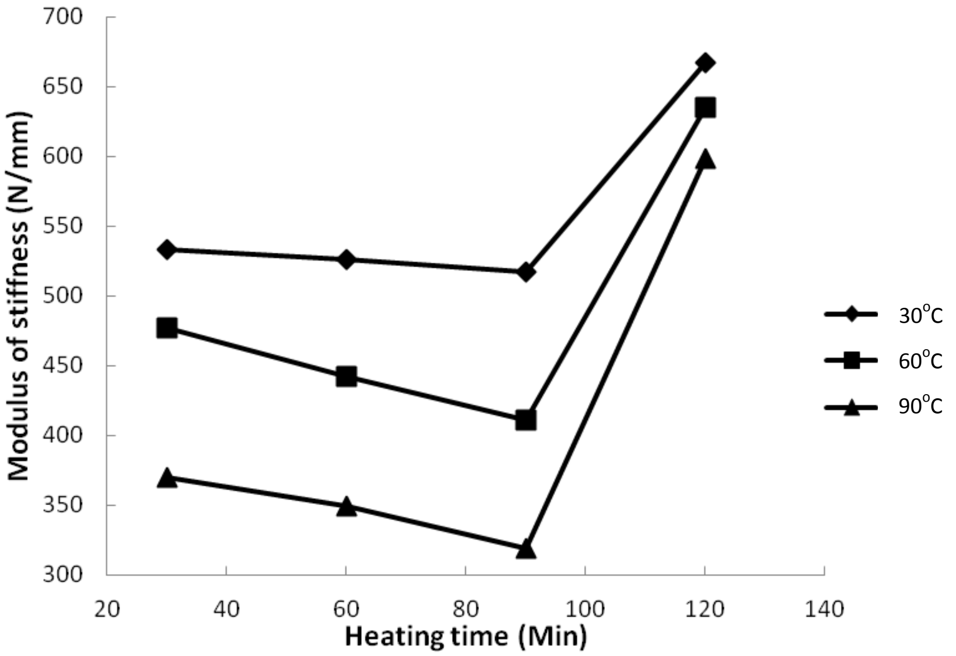
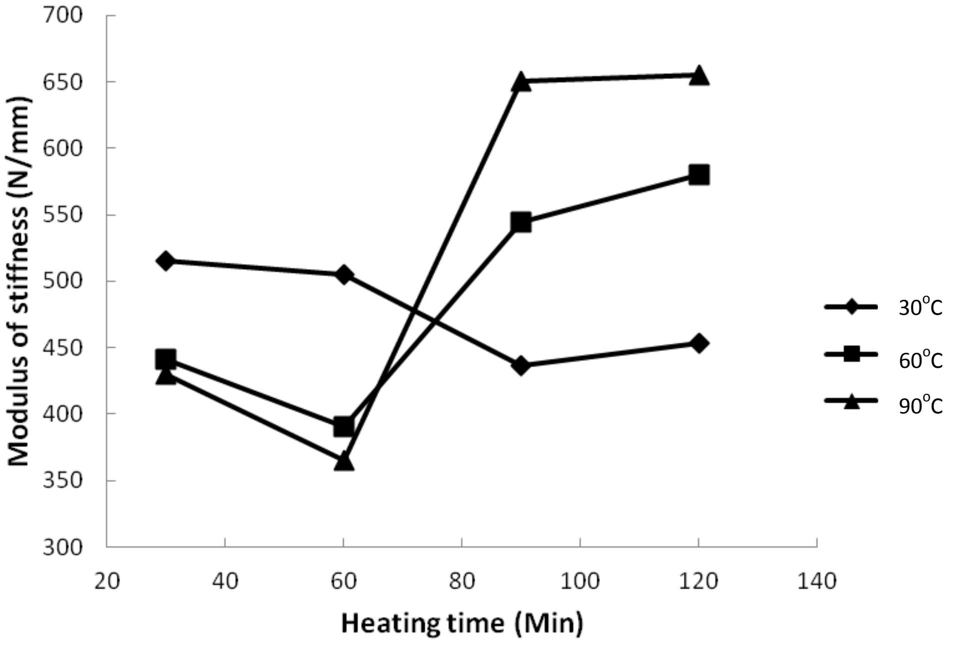


Figure 8 Variation of modulus of resilience of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations

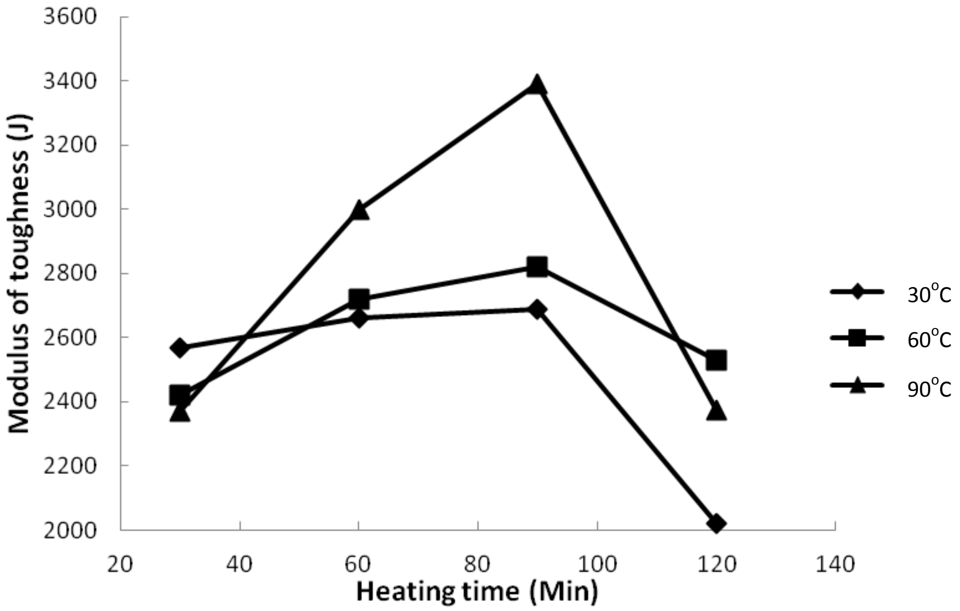


(a) Lateral loading

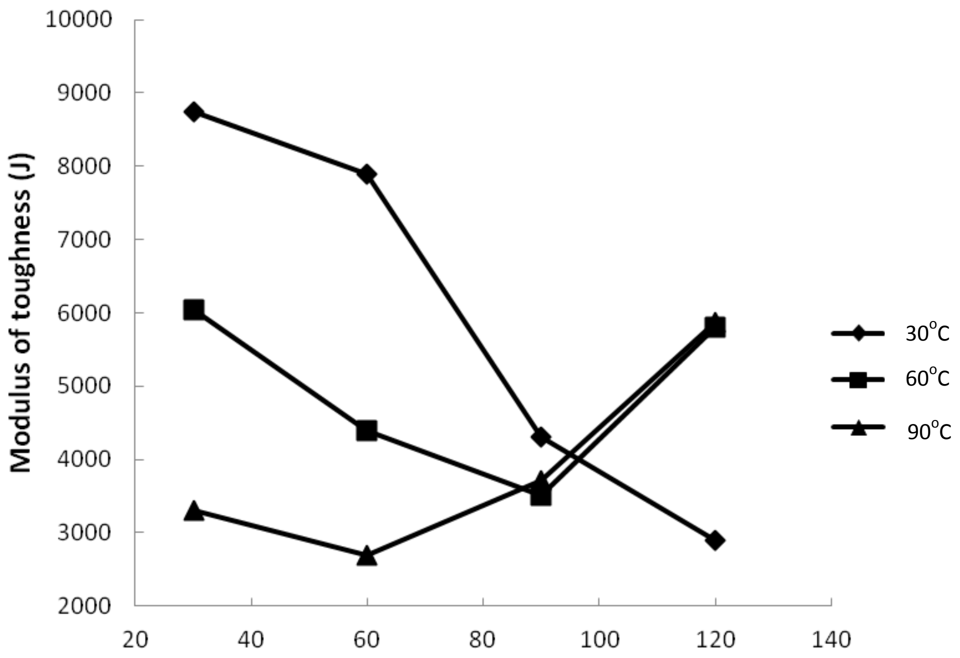


(b) Longitudinal loading

Figure 9 Variation of modulus of stiffness of *balanites aegyptiaca* nut with temperature and heating time at different loading orientations



(a) Lateral loading



(b) Longitudinal loading

Figure 10 Variation of modulus of toughness *balanites aegyptiaca* nut with temperature and heating time at different loading orientations

4 Engineering applications

The implications of the results obtained in this study on the design and development of a mechanical device for cracking *balanites aegyptiaca* nut are as follows:

(1) Apart from conditioning the nut to a moisture level at which it could easily be cracked, further treatment by exposure to heat at a level and for a duration that would not compromise product quality, could enhance energy efficiency.

(2) Loading along the longitudinal axis could be the preferred orientation for cracking the nut if the equipment operates on the basis of compression, as it would likely make the separation of kernel from shell easier. However, a mechanism that could be used to position the nut in such an orientation would be needed.

(3) An investigation of the variation of these strength properties with the moisture content, loading orientation, loading rate, temperature and heating time of *balanites aegyptiaca* nut kernel would be necessary to determine the effect of mechanical cracking on kernel quality attributes.

5 Conclusions

The investigation of effects of temperature and heating time on strength properties of *balanites aegyptiaca* nut revealed the following conclusions:

(1) Bioyield, failure (yield) and rupture forces decreased with the increase in temperature to which the nut was heated prior to loading. Bioyield decreased with the increase in heating time to a minimum on lateral and continuously within the temperature range of 30–60^{o}C on longitudinal loading. Failure and rupture forces increased with heating time to a maximum on lateral loading and decreased with the increase in heating time on longitudinal loading.

(2) Bioyield, yield and rupture strength, moduli of elasticity, toughness, stiffness and toughness of the nut all decreased with the increase in heating temperature. The properties exhibited varied response to heating time at different loading orientations.

(3) The strength properties of the nut at a given temperature and heating time were higher on longitudinal loading than lateral loading except the modulus of stiffness.

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