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Expansion in chickpea (*Cicer arietinum* L.) seed during soaking and cooking

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A b s t r a c t. The linear and volumetric expansion of chickpea seeds during water absorption at 20, 30, 50, 70, 85 and 100°C was studied. Length, width and thickness of chickpea seeds linearly increased with the increase in moisture content at all temperatures studied, where the greatest increase was found in length. Two different mathematical approaches were used for the determination of the expansion coefficients. The plots of the both linear and volumetric expansion coefficients versus temperature exhibited two linear lines, the first one was through 20, 30 and 50ºC and the second one was trough 70, 85 and 100ºC. The crossing point (58ºC) of these lines was very close to the gelatinisation temperature (60ºC) of chickpea starch.

K e y w o r d s: chickpea, soaking, cooking, swelling, volumetric expansion

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is a nutritious food, contains around 20% proteins and 45% starch (Rachwa-Rosiak *et al.*, 2015). According to the 2012 total production quantities of pulses, chickpea takes the second place after dry beans (FAOSTAT, 2013). Chickpea seeds are processed into a variety of products before consumption. Soaking of dry seeds for around 14-16 h at room temperature followed by cooking in boiling water for 1-2 h is the main process to produce a tender edible product for both domestic use and industrial scale processes. These two processes alter the physical and chemical structure of the seeds and govern the following processes: diffusion of water into the seed, gelatinisation of starch, geometrical and dimensional changes and leaching of soluble solid from seed through the soaking or cooking medium, that are major phenomena taking place in chickpea during soaking and cooking. Swelling, mainly linear and volumetric expansion, of the seed are important parameters for the analysis and design of the process and for designing and constructing the equipment.

Many researchers conducted studies on the geometric changes of agricultural products due to water absorption and/or thermal processing. Hygroscopic linear and volumetric expansions of corn were studied by Muthukumarappan and Gunasekaran (1990) under the humid air conditions of 75, 85 and 95% RH each at 25, 30, 35, and 40°C. These two parameters were found to vary linearly with the moisture content in the range of 13-24%. Hygroscopic expansion of rice was studied at 25, 35, 45, and 55°C by Perez *et al.* (2011). The change in the dimensions of rice was observed by a video microscope. The changes in length and projected area of rice kernel were followed during soaking. Mendes *et al.* (2011) conducted studies on the variation in shape and size of Adzuki bean during soaking at 18, 27, 36, and 45°C. They fitted different mathematical models to the experimental values of volumetric expansion. There are also other studies in the literature reporting on the geometric changes during soaking or cooking of soybean (Singh and Kulshrestha, 1987), lima bean (Aghkhani *et al.*, 2012), lentil (Tang and Sokhansanj, 1993), rice (Yadav and Jindal, 2007), castorbean, mung bean, and cowpea (Leopold, 1983). All the above reviewed previous studies analysed the geometric changes only below or only above the gelatinisation temperature. We could not find a study that covers the analysis of the geometric change of seeds or kernels both below and above the gelatinisation temperature. In addition to that, the main processes taking place during the soaking and cooking of chickpea, such as diffusion of water

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into the seed, gelatinisation properties of chickpea starch, and soluble solid loss, at different temperature of these two basic processes, were already examined in our previous publications (Sayar *et al.,* 2001, 2003, 2011; Turhan *et al.,* 2002). However, no report on the analysis of geometric change of the seeds during soaking and cooking has been reported yet.

Therefore, the main objectives of the present study were to report the changes in dimensions (length, width and thickness) and volume of chickpea seeds during water absorption at temperatures below and above the gelatinisation temperature. It was also intended to process the data by using appropriate mathematical equations for better interpretation of the results.

MATERIALS AND METHODS

Kabuli type chickpea sample (*cv*. Er) was obtained from Field Crops Improvement Centre, Ankara, Turkey. Foreign materials and damaged seeds were removed by hand picking. In order to eliminate the size effect the seeds were sieved and the ones with a diameter between 8 and 9 mm were used in the experiments. Triplicate analysis of protein, ash, lipid and moisture contents were conducted according to AACC Methods 46-08, 08-01, 30-26 and 44-19, respectively (AACC, 2000). Protein, ash and lipid contents of the sample were 18.69, 3.12 and 5.53% (d.b.), respectively. Initial moisture content was 7.72% (w.b.).

The experiments were conducted at 20, 30, 50, 70, 85 and 100°C. The soaking and cooking processes were carried out according to the methods given in our previous publication (Sayar *et al.,* 2003). Briefly, ten chickpea seeds were weighed and placed in a 250 ml capacity beaker containing 150 ml deionised water at the desired temperature. Temperature stability was assured by placing the beakers in a constant temperature water bath, except for the experiments at 100ºC. The experiments at 100ºC were performed according to Sayar *et al.* (2011) in a crude fibre testing equipment recycling the evaporated water back to the beaker (Simsek Laborteknik, Ankara, Turkey). All seeds in a beaker were removed at the end of the predetermined time, superficially dried with a tissue paper, weighed, measured for size and returned to the beaker. The experiments were stopped when the mass increment was equal to or less than 0.001 g (0.02%) g between two consecutive measurements. The experiments were done in triplicate.

The size and volume measurements were performed before and during the soaking and cooking experiments. Length (*l*), width (*w*), and thickness (*t*) of randomly selected 6 seeds from the 10 seeds were measured by using a digital micrometer (Mitutoyo 0.001 mm, Japan). The results were given as the average of the 6 measurements for each dimension.

The volume of the seeds (V) was calculated from the following Eq. (1), assuming that the chickpea seed is a sphere:

$$V = \frac{4}{3}\pi\left(\frac{D_{eq}}{2}\right)^3. \tag{1}$$

where:

$$D_{eq} = \left(l\,w\,t\right)^{1/3}. \tag{2}$$

Sphericity (ϕ) was determined by Eq. (3), according to the method given by Mohsenin (1980):

$$\phi = \frac{\left(l\,w\,t\right)^{1/3}}{l}. \tag{3}$$

The expansion of materials due to water absorption can be characterized by linear and volumetric expansion coefficients. In the current study, two different approaches were used for the determination of the expansion coefficients. The first one, that allows the determination of the volumetric expansion coefficient (λ), is the equation given by Singh and Kulshrestha (1987) as:

$$\left(V - V_0\right) = \lambda\frac{\left(M - M_0\right)}{\rho_w}. \tag{4}$$

where: V is the volume of the seed at time t, V_0 is the initial volume of the seed before water absorption (m^3); M is the weight of the seed at time t, M_0 is the initial weight of the seed (kg); ρ_w is the density of water (kg m^{-3}), and λ is the volumetric expansion coefficient. λ is determined from the slope of the (V-V_0) vs. $\frac{(M - M_0)}{\rho_w}$ graph for each temperature studied.

The second approach for the determination of the expansion coefficient, that uses the analogy of thermal expansion (Charm, 1978), is given below (Eq. (5)). This approach was also used by Tang and Sokhansanj (1993) for the analysis of the volumetric hygroscopic shrinkage of lentil seeds:

$$\beta_v = \frac{1}{V}\left(\frac{\partial V}{\partial X}\right)_T, \tag{5}$$

where: X is the moisture content (% d.b.), and β_v is the volumetric expansion coefficient. Since β_v was assumed to be a constant throughout the water absorption process, Eq. (5) can be integrated as:

$$\beta_v \int_{X_0}^{X} dX = \int_{V_0}^{V} \frac{dV}{V}. \tag{6}$$

By re-arranging Eq. (6) the following equation was obtained:

$$\ln\left(\frac{V}{V_0}\right) = \beta_v\left(X - X_0\right). \tag{7}$$

where: V_0 is the initial volume of the seed before water absorption and X_0 is the initial moisture content of the seed (%, d.b.). Therefore, β_v can be determined from slope of the $\ln\left(\frac{V}{V_0}\right)$ *vs*. graph.

Similar equations were obtained for the determination of the linear expansion coefficients of β_l, β_w, and β_t. (Eq. (8)):

$$\ln\left(\frac{i}{i_0}\right) = \beta_i\left(X - X_0\right), \tag{8}$$

where: $i = l$, w, or t.

The linear expansion coefficient is defined as the increase in the characteristic dimension – length, width or thickness – due to increase in moisture content with respect to the original dimension (Muthukumarappan and Gunasekaran, 1990).

The gelatinisation temperature of chickpea starch was determined using ground chickpea samples, by means of a differential scanning calorimeter (DSC) according to the method given by Sagol *et al.* (2006). Briefly, 3-4 mg of ground chickpea sample was placed in aluminium hermetic DSC pans. Distilled water (sample/water = ¼, w/v) was added to the pan and the pan was hermetically sealed. The pans were kept at 4°C for 24 h and scanned at a heating rate of 5°C/min in a DSC (DSC-6, Perkin Elmer, Waltham, MA) from 20 to 100°C. The onset temperature on the DSC thermogram was taken as the gelatinisation temperature. The experiment was done in triplicate.

All experiments were carried out at least in triplicate, and results were presented as average values ± standard deviation. Statistical evaluations of the data were conducted by using MS-Excel (Microsoft Office 2007, Microsoft Inc., USA).

RESULTS AND DISCUSSION

Length (l), width (w), and thickness (t) of chickpea seed increased linearly with increasing moisture content during water absorption at 20ºC (Fig. 1). The same trend was also obtained at the other temperatures studied. Very high values of the coefficient of determination (R^2 greater than 0.94) were observed between these dimensions and seed moisture content. The linear change in the dimensions of chickpea seed with the entry of water has similar characteristics to the swelling of polymers upon hydration (Lüscher-Mattli and Rüegg, 1982; Leopold, 1983). Linear changes in the dimensions of different legume or cereal samples due to water absorption were also reported in the literature (Aghkhani, *et al.*, 2012; Baryeh, 2002; Leopold, 1983;

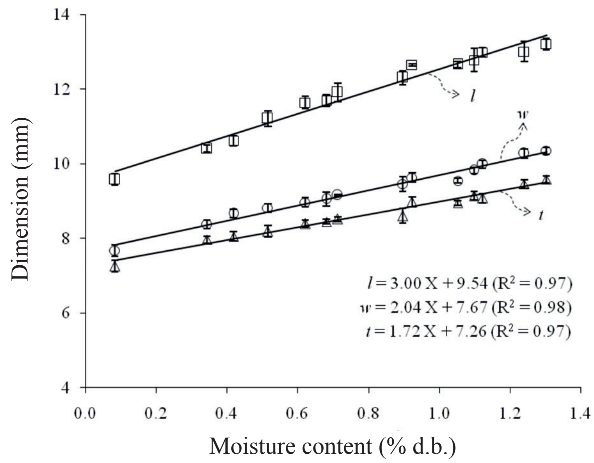

Fig. 1. Changes in the length (l), width (w) and thickness (t) of chickpea seed during water absorption at 20ºC. Vertical bars on each data point indicate standard deviation.

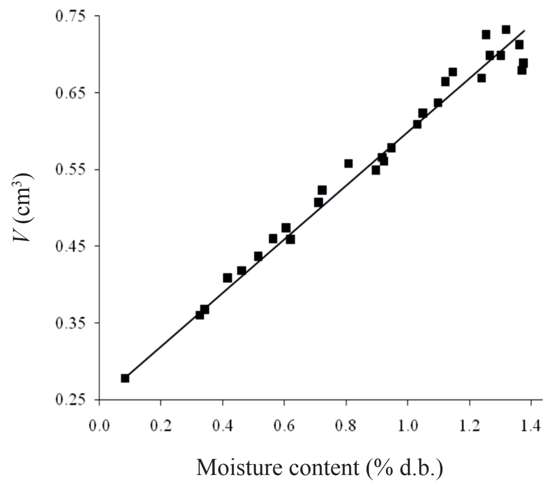

Fig. 2. Changes in the volume of chickpea seed during water absorption at 20ºC.

Mendes *et al*., 2011). The increase in the length of chickpea seed in this study was the highest, followed by those in width and thickness. The highest expansion in length was also found for millet seed during water absorption (Baryeh, 2002). In the case of soybean seed, Deshpande and Ojha (1993) found the expansion to be largest along their thickness in comparison with length and width. The variability in the expansion values of dimensions is attributed to the different cell arrangements along the dimensions of the seeds (Baryeh, 2002).

There was also a linear relationship between the volume of the chickpea seeds and the amount of water absorbed at 20ºC (Fig. 2). This trend was similar at all temperatures studied. The linear increase in seed volume during water absorption has similar characteristics to polymer swelling (Leopold, 1983; Lüscher-Mattli and Rüegg, 1982). It was indicated that the volume increase during water absorption can be explained by the water absorption of proteins and starch (Leopold, 1983; Sefa-Dedeh and Yiadom-Farkye, 1988). Ratkovic and Pissis (1997) determined a linear correlation between the protein content and water absorption capacities of eight different cereals and legumes. Thus, the volume increase during water absorption is more likely to be related to the expansion in protein part of the seeds. Some other studies indicated that the volume increase of cereal grains, accompanying water absorption, might be due to the continuous formation of micro cracks inside the kernels and flow of water into the cracks during the process (Fan *et al.* 1962).

Sphericity values of chickpea seeds were calculated during water absorption at the given temperatures. In the current study, sphericity values were determined between 0.82 and 0.86, which means they were independent of water content and temperature of water. There are contradictory results in the literature regarding the variation of sphericity with moisture content. In a study carried out on chickpea (*cv.* Koçbasi) seed, the sphericity values were also determined to be averagely 0.87 and independent of water content (Konak *et al.*, 2002). Nimkar and Chattopadhyay (2001) reported that the sphericity of green gram decreased from 0.84 to 0.82 by increasing moisture content from 8.4 to 33.4%. The sphericity of soybean seeds was found to decrease from 80.5 to 76.4% with the increase in moisture content from 9.5 to 49.7% (Davies and El-Okene, 2009). The sphericity values obtained in this study were close to 1, which supports the thesis that the chickpea seeds can be assumed as a sphere in Eq. (1).

There are very limited studies in the literature on the mathematical interpretation of the expansion properties of cereal grains or legume seeds. Earlier studies on wheat, corn and sorghum have shown that the increase in grain volume due to water absorption equalled the mass of the water absorbed (Chung *et al*., 1961; Fan *et al*., 1962). Based on the previous findings in the literature, the conservation of the volume of water absorbed was given by the following expression (Singh and Kulshrestha, 1987):

$$\rho_w \Delta V = \Delta M. \tag{9}$$

However, the results obtained by Singh and Kulshrestha (1987) showed that the volume of water absorbed was not always equal to the volume increase in grains and, therefore, they suggested the equation given as the first approach in this study (Eq. (4)). Basically, this equation gives information about the relation between the 'moisture-induced swelling' and the 'volume of water imbibed'. The second approach used in this study has a different mathematical background. It is the analogy of the thermal expansion coefficient. The second approach was also modified for the calculation of the linear expansion coefficients. Consequently, these two

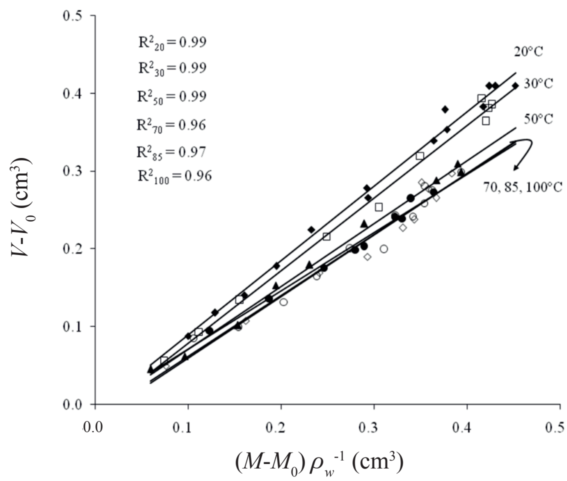

Fig. 3. Relationship between the volume of the water absorbed [$(M\text{-}M_0)\ \rho_w^{-1}$] and the volume increase in grains ($V\text{-}V_0$) during water absorption at different temperatures.

different approaches were used in this study in order to elucidate the swelling properties of chickpea seeds during water absorption at different temperatures.

The volumetric expansion coefficient (λ) was determined from the slope of the ($V\text{-}V_0$) v*s*. $\frac{(M - M_0)}{\rho_w}$ graph (Fig. 3). The volume and moisture content data obtained at different temperatures in this study could be successfully represented in terms of Eq. (4) with coefficients of determination (R^2) of 0.96 or greater (Fig. 3). A linear relationship between the volume of water absorbed and the volume increase in chickpea seed was obtained. Similar results were also obtained during water absorption of wheat, canola, mung bean, castor bean, cowpea, corn, adzuki bean and millet (Baryeh, 2002; Fan *et al.*, 1962; Leopold, 1983; Mendes *et al.,* 2011; Muthukumarappan and Gunasekaran, 1990; Thakor *et al.,* 1995; Sokhansanj and Lang, 1996). The term $\frac{(M - M_0)}{\rho_w}$ in Eq. (4) represents the volume of water absorbed. Thus, if λ is equal to 1, then it means that the volume increase in chickpea seed is equal to the volume of water absorbed. However, all the λ values were determined to be smaller than 1, between 0.731 and 0.946, which indicates that the chickpea seed does not expand as much as the volume of water absorbed. This situation might be expected since some of the water absorbed is just filling the voids in the seed (Turhan and Sağol, 2004) and does not contribute to volume increase.

The variations of λ versus temperature are plotted in Fig. 4. The plot reveals two linear lines, the first one through 20, 30 and 50ºC, and the second one through 70, 85 and 100ºC. It is found that the volumetric expansion due to water absorption is temperature-dependent and decreasing with the temperature increase between 20 and 50ºC.

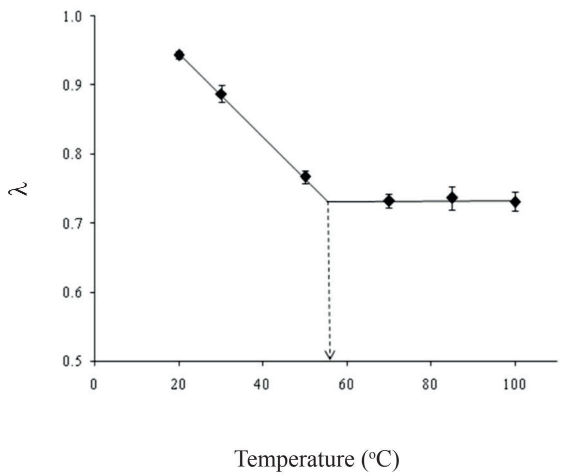

Fig. 4. Effect of temperature on the volumetric expansion coefficient (λ) of chickpea. Vertical bars on each data point indicate standard deviation.

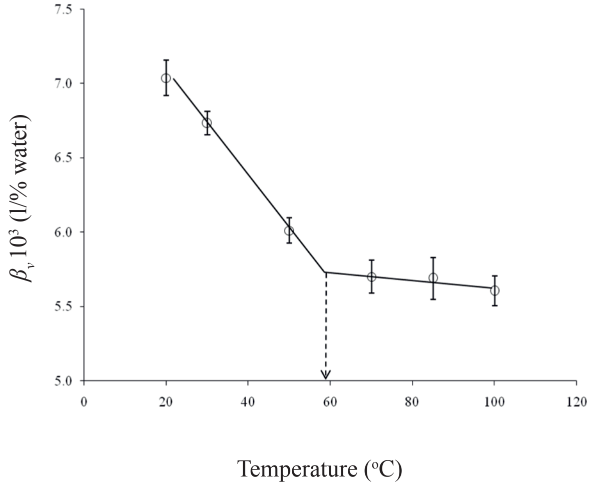

Fig. 5. Effect of temperature on the volumetric expansion coefficient (β_v) of chickpea. Explanations as in Fig. 4.

Then it stays constant between 70 and 100ºC. There are some possible mechanisms that might have an effect on the variation of the volumetric expansion coefficient with temperature. These are mainly physicochemical changes occurring in proteins and/or starch, and the leaching of soluble solids from the seed through soaking or cooking in water. The crossing point of the two linear lines obtained in Fig. 4 was determined to be 58ºC. This temperature is very close to the gelatinisation temperature of chickpea starch which is obtained to be 60ºC by DSC analysis in this study. Therefore, the changes occurring in the physicochemical properties of starch are probably among the effective factors revealing the temperature dependency of λ values. On the other hand, protein denaturation is also expected to start above this temperature (Tiwari and Singh, 2012). Therefore it is very complicated to clarify the mechanism affecting the temperature dependence of the volumetric expansion coefficients. Below the gelatinisation/denaturation temperature the water absorbed into the seed might be interstitial water, penetrating between the macromolecules and letting the volume expand. Another possible reason might be the restricted swelling of proteins as the temperature increases below the denaturation temperature (Zayas, 1997). Above the denaturation/gelatinisation temperature the physical properties of the seed have the same behaviour in terms of the effect of water on expansion. The soluble solid loss is another factor that might have an effect on temperature dependence of λ value. In one of our previous studies (Sayar *et al.*, 2011) it was determined that the amount of solid loss increased as the temperature increased between 20 and 50ºC, and it was constant between 70 and 100ºC. In the current study the amount of solid loss was not taken into account. Therefore, if the amount of solid lost was added to the mass of the seeds for the corresponding data, then the variation of λ values with temperature might have a different behaviour. Thakor *et al.* (1995) determined that the coefficient of expansion for canola seed soaked at 75ºC was lower than at 22 and 50ºC, which was interpreted to be due to the leaching losses.

The expansion of a hygroscopic substance is defined by linear and volumetric expansion coefficients. The volumetric expansion coefficient of substances refers to the changes that occur in the volume during water/moisture absorption. However, the linear expansion coefficient is a value that indicates the change in any major dimension during this process. Using this second approach (Eq. (7)) in the current study the volumetric expansion coefficient (β_v) was determined from the slope of $\ln\left(\frac{V}{V_0}\right)$ vs. (X-X_0) graph. β_v values decreased from 0.0071 to 0.0057 as the water absorption temperature increased from 20 to 100°C. The effect of temperature on β_v is given in Fig. 5. This trend was very similar to the one observed for the effect of temperature on λ in the first approach (Fig. 4). This is an expected result since both the first and the second approaches have a similar mathematical background. Tang and Sokhansanj (1993) determined the average coefficient of volumetric hygroscopic coefficient for whole lentil seeds to be 0.00933 by using the same approach. In their study the effects of drying temperature on the volumetric hygroscopic coefficient were found to be insignificant between 30 and 70 °C.

The effect of temperature on the linear expansion coefficients β_l, β_w, β_t, is given in Fig. 6. The trend was very similar in both Figs 5 and 6, which indicates that the effect of temperature is the same for linear and volumetric expansion coefficients. Two different linear lines on the temperature

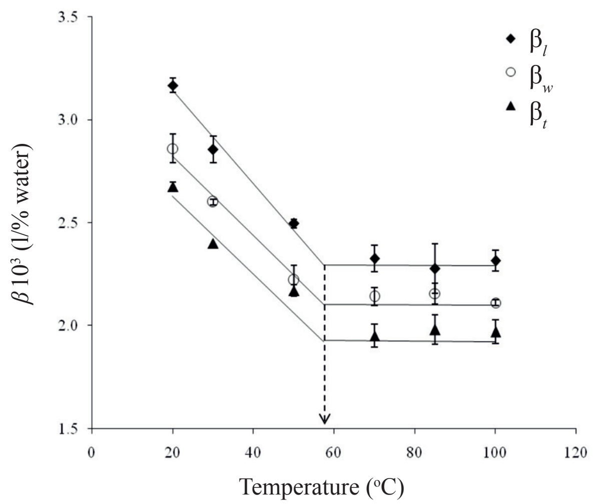

Fig. 6. Effect of temperature on the linear expansion coefficients (β_l, β_w, β_t) of chickpea. Explanations as in Fig. 4.

dependence of linear and volumetric expansion coefficients were also obtained, as in Fig. 4. This change can be explained with the same reasons interpreted above, in the discussion part of the temperature dependence of λ.

CONCLUSIONS

1. The characteristic dimensions of chickpea seed linearly increased with increasing moisture content during water absorption at 20, 30, 50, 70, 85 and 100ºC.

2. The greatest expansion was observed for the length of chickpea seed, followed by those in width and thickness.

3. Two different approaches were used for the determination of the expansion coefficients of chickpea seeds during water absorption at all temperatures studied.

4. All of the linear and volumetric expansion coefficients were linearly decreased between the temperatures of 20 and 50ºC and remained constant between 70 and 100ºC.

5. Starch gelatinisation, protein denaturation and also soluble solid loss during water absorption were interpreted to be the possible reason of the temperature dependence of the expansion coefficients.

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