Journal of
Texture Studies

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Journal:	*Journal of Texture Studies*
Manuscript ID	JTS-2362.R1
Manuscript Type:	Research Article
Date Submitted by the Author:	n/a
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Keywords:	fruit texture, firmness, failure, rupture stress, haptics, somasthesis, psychorheology, Poisson's ratio, breaking force

Contribution of Skin and Stone to Texture Measurements of Spherical Model Fruits

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Abstract

Fruits are composite materials often surrounded by a skin and sometimes containing rigid stones (pits). To understand the contribution of skin and stone to the overall texture of the fruit, model fruits were constructed from moulded gelatin spheres, with rigid inclusions and a skin layer.

Cross polarised light revealed the stress distribution during puncture testing and the mechanical measures of firmness, Poisson's ratio and breaking force were determined.

Skin significantly raised the breaking force. Spherical stones raised the firmness – effectively reducing the deformable material in the sphere, resulting in inflated strains. Disc shaped stones compared with spherical ones, with the narrow edge normal to the force acted like an internal blade and significantly lowered the breaking force. Neither skin nor stone had any significant impact on Poisson's ratio.

Three examples of real fruit (raspberries, grapes and cherries) were tested to contextualize the findings.

Practical applications

Consumers gently squeeze fruit to gauge ripeness. Unwittingly, what we perceive while squeezing fruit is not wholly dependent on the texture of the internal flesh.

In this work we have attempted to model how the firmness and breaking force are influenced by the presence of a skin and stones of various size and shape. This has implications in both sensory and instrumental fruit testing.

Introduction

Consumers selecting fruit commonly squeeze the produce gently to sense firmness, elasticity and relaxation. Intuitively and through experience quality and ripeness are gauged. This behaviour is not exclusive to humans, chimpanzees also press a digit into figs to gauge their ripeness (Dominy et al., 2016). However, what might be unique to humans is the creation of instruments to quantify the textural and quality attributes of the fruit. Fresh horticultural produce are often tested prior to harvest in the field with a hand held puncture testers, the fruit are cradled in one hand and a spring mounted probe pressed into the surface until it penetrates the fruit by a fixed distance. Less mobile, but possibly more accurate are the laboratory texture analysers and universal testing machines (Rosenthal, 2015). When laboratory texture tests of fruit are undertaken, the fruit are invariably placed on a plane surface and pressed with a flat plunger. The resisting stress/strain at failure are often taken as a guide to the overall quality of the item or batch.

Harker, Redgwell, Hallett, Murray and Carter (1997) undertook a comprehensive review of the extensive literature dedicated to the texture of fruit. These authors identified a number of contributory factors thought to be responsible for the texture of fruits and their changes during ripening, for example turgor pressure, secondary thickened cell walls, cell shape, skin, seeds, vasculature, etc. The presence of skin is widely known to influence results of texture tests, so much so that the procedure for hand held puncture testers often require the removal of the skin to focus on the underlying tissues (Bourne, 1980).

Accepting the diversity of fruit structure, this study examines the relative contributions of skin and stones to the resisting forces measured during puncture testing of relatively soft fruit. Not only is the presence or absence of stones considered, but also their size, shape and orientation within model fruits.

Rosenthal (2016) used photoelasticity to examine the stress distribution on model fruit gelatin spheres during compression with a flat ended plunger. Gelatin spheres, being cast, allow inclusions of solid objects and subsequent stress analysis is possible during compression. Furthermore, just as leather is derived from collagen through the tanning process, it is also possible to add a tanned layer to the outer surface of these gelatin spheres. Pankhurst (1959) described various tanning reagents to potentially tan gelatin, and the melting temperature of the resultant material. While both formaldehyde and vegetable tannins would achieve a tanned skin, that skin could not be separated from the gelatin sphere by melting. In contrast chrome tanned gelatin melts above 77^{0}C allowing the gelatin core to be selectively melted at lower temperatures, moreover, chrome tanned gelatin takes on a dark blue hue enabling some visualization of the skin.

Methods

Preparation of the gels

A six percent solution of 240 Bloom Pig Skin gelatin (MM Ingredients, Wimborne, UK) was prepared by heating a suspension on a magnetic stirrer until fully dissolved. A 50 mm internal diameter, two part silicone rubber ice cube mould (Dunelm Mill, Leicester, UK) was wiped with a paper towel which had been dipped in a light mineral oil (WD40, San Diego, USA) to act as a mould release agent. The dissolved gelatin solution was then poured into the rubber mould. The solution was degassed by applying 400 mBar vacuum to the mould for one minute – the mould was then refilled and subjected to 100 mBar vacuum for 20 seconds. Finally, the mould was topped up with further gelatin solution. Moulds were placed in a cold room at 4 °C overnight. To remove the gelatin sphere, the mould was immersed in iced water and the edge of the mould top was gently separated from its base. While keeping immersed in ice water the two halves of the mould were opened to release the gelatin sphere. The mould filling hole left an irregularity on the surface of the sphere, though care was taken during subsequent testing to avoid contact between this irregularity and the contact surfaces. Once removed from their mould, gelatin spheres were retained in ice water until ready for use.

Inclusion of stones (pits)

The gelatin and mould were prepared as above, but when pouring the gelatin a two-step filling was undertaken. Initially the lower half of the mould was partially filled, degassed (as above) and the gelatin allowed to set. The inclusion was then placed centrally on the set gelatin and further molten gelatin poured in. Again, the molten gelatin was degassed and the entire mould allowed to set at 4^0C overnight.

Several types of inclusions (spheres and discs) were added:

- 16 and 24 mm diameter spherical glass marbles (van Goch glass, House of Marbles, Torquay, UK)
- 42.7 mm diameter golf ball (Titleist, St Ives, UK)
- 5 pence coins (UK currency), 18 mm diameter and 1.7 mm thick (Royal mint, UK)

For clarity we use the shorthand +st and –st elsewhere in this paper for the presence or absence of 16 mm spherical stones.

Creation of Skins

Skins were prepared by soaking the gelatin sphere in 5% potassium chromic sulphate dodecahydrate – chrome alum (BDH, Poole, UK) for one hour. The sphere was then removed from the tanning solution, washed with water and left soaking in ice cold water until tested.

For clarity we use the shorthand +sk and –sk elsewhere in this paper for the presence or absence of skin.

Compression testing

A rectangular glass tank containing iced water was used to hold the spheres. In addition to temperature control, the tank prevented refraction of light passing through the sphere. Furthermore immersion in water provided buoyancy which supported the sphere from gravitational distortion, moreover it prevented the gelatin from drying out (Rosenthal, 2016). A 1mm thick walled aluminum ring with an external diameter of 28 mm and a height of 2.6 mm was positioned below the spheres to prevent them from rolling around in the tank.

A TA.HD texture analyzer (Stable Microsystems, Godalming, UK) with a ½ inch (12.7 mm) diameter cylindrical probe was used. The entire apparatus was covered with a photographic blackout curtain and the tank was illuminated with polarized light from a sodium lamp. Stress lines were photographed using a Canon 600D (on a tripod) and fitted with a 50 mm, f1.8 standard lens with a polarizing filter. The camera was set to a manual focus mode, aperture priority. The film speed was ISO 1600 and the aperture set to f22. Before the sphere was placed in the tank, the polarizing filters were aligned to create cross polarized illumination.

Stepwise compression, at 1 mm s^{-1} was carried out. Each compression increased the force by 0.5 N after which there was a 30 second wait while a cross polarized image of the sphere was photographed. Then the next stress step was undertaken until the sphere failed.

Firmness (modulus) was calculated by converting the texture analyser output to stress and strain, and then measuring the gradient of the line between 30% and 70% of the maximum stress. Thus we avoided initial contact issues and the point of rupture at the top end of the curve. Calculations of modulus were undertaken with the Stable Microsystems' high stress modulus macro. Calculations were undertaken on spheres being strained to around 30%.

ImageJ 1.50i (National Institute of Health, USA) was used to measure gel dimensions from photoelasticity images and deformation during compression. Photographs of the 50 mm unstressed spheres were used to calibrate the software. The width of the sphere at its equator and the height from the base of the plunger to the base plate were measured during compression, enabling the calculation of Poisson’s ratio.

Real fruit testing

By way of application we have also tested a variety of real fruits: Cherries, Grapes, and Raspberries. As photoelasticity was not an option, we did not use the ice water bath. Unlike the 50 mm diameter gelatin sphere, the diameter of these fruit are substantially smaller, moreover in some cases they are not spherical. Thus tests on these fruit were placed on a plane surface and the firmness and breaking force recorded while puncturing with a 2 mm diameter, flat ended probe at 20^0C. No attempt to measure Poisson’s ratio was undertaken.

Data analysis

Data was manipulated and handled with Microsoft Excel. ANOVA and Tukey tests were undertaken with SPSS.

Results

Figure 1 shows the various gelatin spheres illuminated with monochromatic, cross polarised light, while under compression at 4 N (31,572 Pa with the 12.7 mm diameter probe). The compressing plunger is visible at the top of each sphere as is the narrow ring at the base – intended to stop the spheres from rolling. Close inspection at the base of the spheres does show some slight stress irregularities due to contact of the ring with the spheres, however at 4N force, the sphere deforms to touch the ring and its influence does not penetrate deeply into the gelatin.

{figure 1 around here}

The isoclines are effectively contours of constant stress. Fringe values are specific to the material being tested, but as all of these spheres come from the same batch of 6% gelatin and it is assumed that the value is identical for all the spheres photographed and the larger the number of isoclines across each sphere depicts a greater stress gradient across the same distance. Predictably the stresses concentrate directly below the plunger and then dissipate radially to the base and sides of the gelatin spheres.

Some of the spheres have marks – slight indented lines where the pouring hole or the two halves of the mould contacted during forming. We avoided contact of these locations during tests.

Figure 2 shows the stress distribution of differently sized spherical stones as well as disc-stones examined in three different orientations. In all cases the gelatin sphere was under compression at 4 N force.

{figure 2 around here}

Table 1 shows the average Poisson’s ratios, firmness and breaking force for each of the sphere type. On occasions the plunger did not contact the sphere centrally, causing it to become skewed and distorted – in such cases, measurements of Poisson’s ratio were not included in the data, though we still included the breaking force values. The Tukey post-hoc test was carried out after ANOVA and the superscript letters show similarity ($p>0.05$), thus spheres that do not share a superscript are significantly different.

{Table 1 around here}

Not included in table 1 due to lack of replication are the spheres containing 24 and a 42.7 mm spherical stones. These were sole determination for which the firmness was 215 and 476 kPa (respectively) while the breaking force was 47 kPa for both spheres.

Table 2 shows average firmness and breaking forces of real fruit, purchased in local shops and of a quality and texture deemed suitable for eating. While the model gelatin spheres of any particular type are fairly consistent one to the next, the real fruit shows considerable variation within the sample and consequently larger numbers of each were measured – the number of each being displayed. It should be noted that the firmer nature of the fruit required a smaller probe to be used to contact the fruit, compared to the gelatin spheres.

{Table 2 around here}

Discussion

Gelatin has been used extensively for photoelastic stress analysis, it is easily moulded and its optical sensitivity is greater than that of most other photoelastic materials (Kuske and Robertson, 1974). However, its low modulus can cause it to sag and exhibit stresses under its own weight and it can dry out. By immersing the gelatin spheres in an ice bath, we were able to support the spheres by hydrostatic pressure (preventing sagging), keep the surface wet (preventing drying out) and allows the light passing through the sphere not to be diffracted as it passed through the curved surface.

The photoelastic images of the spheres (Figure 1) show differences in the number and pattern of the isoclines in each sphere. As mentioned earlier, the images were at 4 N applied stress because we had comparable images for even the weakest spheres. Furthermore, it caused relatively little deformation of the sphere against the anti-roll ring.

The Poisson's ratio data (Table 1) was generally measured at 5 N, except for the disc-stones spheres which failed at those stresses and for which Poisson's ratio was determined at 4 N. One way (single factor) analysis of variance shows no significant difference ($p>0.05$) between the Poisson ratio of any of the gelatin spheres regardless of their construction.

Firmness is a measure of deformations to a given force. In physics this is referred to as a modulus and we have used the slope of the force:deformation curve from the texture analyser to quantify it. However moduli normally relate to homogeneous and isotropic materials whereas most of our model fruit (and real fruit) contain skin and/or stones. Moreover if we go to the market and gently squeeze an avocado to gauge its ripeness, we are squeezing the whole item and not just the flesh. Consequently, and so as not to offend purists, we refer to this property as firmness elsewhere in this paper.

Skin (+sk-st) ***vs*** **unmodified sphere** (-sk-st)

The unmodified sphere has more isoclines then the sphere with a skin – suggesting that the stress gradient is greater – presumably the skin is holding the samples back and preventing energy dissipation. Despite this, there is no significant difference between the Poisson's ratios, suggesting that during compression barrelling is of a similar magnitude regardless of skin.

While the presence of a skin does increase the firmness of the gelatin spheres by 20 kPa, this is not statistically significant and from an instrumental testing point of view, there is no difference between the firmness of the fruit with and without skin. Of course, we have no data from this study as to whether this would likely be perceived by human subjects, however Rohm and Raaber (1992) found Weber’s ratio (the just noticeable difference as a proportion of the original stimulus) for firmness of margarine to be 0.196 which is slightly greater than 20 ÷ 118, and in the absence of other data on Weber’s ratio for firmness, we might conclude that it is below the just noticeable difference of these model fruit, with and without a skin. Furthermore, working with gelatin, Munoz, Pangborn and Noble (1986) found a good correlation between puncture tests and sensory perception, however the sensory acuity became less sensitive as the modulus was reduced, this reinforces our speculation that such instrumental differences are unlikely to be perceptible. Essentially, the material making up the bulk of the spheres is identical in both cases and behaves in the same way regardless of any skin. The skin does however increase the force required to rupture the sphere. The increase from 50 to 67 kPa is highly significant). As one may expect a skin which is firmer than the containing material is likely to require a greater force to penetrate/break it, than when absent.

16 mm spherical stones (-sk+st)

Compared to the unmodified sphere (-sk-st), the presence of a stone (-sk+st) does not increase any surface resistance. Consequently the force to rupture the sphere with a stone is identical to that without.

In this study we assume that the firmness of the gelatin (and by analogy that of the flesh of a fruit) is substantially less than that of the stone, and any applied stress results in deformation of the gelatin while no appreciable deformation of the stone occurs. The presence of the stone acts as an undeformable object, a barrier to the transmission of stress and the isoclines skirt round the stone. The inert, rigid stone is displaced and transfers the stress to the gel below, resulting isocline rings below the stone – as though the stone were an independent plunger. Of course, because energy from the texture analyser is partially dissipated before reaching the stone, the isoclines below the stone are less developed then those above.

The firmness of the gelatin sphere with a 16 mm spherical stone is significantly higher than the unmodified sphere (178 to 118 kPa), but the explanation is perhaps an oversight in the calculation of strain. The gelatin spheres are all moulded to 50 mm diameter, yet the inclusion of a 16 mm diameter stone reduces the deformable material proportionally. Perhaps we should revise the initial diameter of the sphere when calculating the strain, to compensate for the presence of the stone. Yet, while with these gel spheres we know the dimensions, in the case of real stone containing fruit, those dimensions are unknown, and no compensation could be made. Thus, the presence of stones in soft fruit will inevitably raise the firmness of each individual item and to an extent proportional to the size of the stone. Consequently, unknowing shoppers perceive firmer fruit when larger stones are present.

Skin & 16 mm spherical stone (+sk+st)

The photo elastic images of the sphere with both skin and stone take on the characteristics of both the sphere with a skin and the sphere with a stone. The presence of the restraining skin reduces the number of isoclines suggesting a lower stress gradient than in either gelatin sphere without a skin. As with the skinless sphere containing a stone (-sk+st), the isoclines form rings of constant stress above and below the stone as energy is transferred through the rigid stone.

The same deduction as for the skinless gels containing a stone can be reached, that the presence of the stone reduces flesh in a sphere’s deformable width compared to their stoneless counterparts. Thus strains which are calculated on the sphere diameter are smaller than those which would be based on the deformable material alone. Predictably there is no statistical difference between the firmness of stone containing spheres with or without skins.

In terms of breaking force, there is no difference between the sphere with skin and stone (+sk+st) and the sphere with a skin alone (+sk-st). However, while table 1 shows no difference in breaking force between the spread of the data of the spheres with skin and stone (+sk+st) and the unmodified sphere (-sk-st), a t-test reveals that the means are different ($p<0.05$, t-test) as is the mean of the skinless sphere containing a stone (-sk+st) ($p<0.05$, t-test). This implies that it is the presence of a skin that raise the breaking force.

Stone size, geometry and orientation

The stress distribution in gelatin spheres in figure 2 reveals differences between spheres containing stones of different shape and size. In real fruit, stones sometimes approach spherical (e.g. cherry), but also exist with sharp points and edges (e.g. peach or apricot). In an attempt to model varieties of stone we have included spherical and disc shaped stones, it is worth noting that none of the gelatin spheres discussed in this section had any skin.

We did run into difficulties in positioning the stones centrally within the gelatin sphere and the photoelastic images of the vertical disc-stones (“end on” and “face on”) as well as the golf ball stone, do show the inclusion to be off centre. However, the influence of these stones were consistent for each situation.

The most obvious differences come in the breaking force. The vertical disc-stones failed at significantly lower stresses ($p<0.001$) than any of the other sphere constructions – including the horizontal disc-stone. The photoelastic images show isoclines packing densely just above the vertical disc-stones (figure 2 d and e), suggesting high stresses in the gel between the plunger and the top of the stone. Having a narrow edge over which stress might concentrate is like having a blade inside the sphere, and perhaps the failure of fruit containing sharp edged stones is caused by the stone cutting the fruit from the inside. Interestingly the amount of stress being conveyed through the vertical disc-stone toward the lower layers of the gelatin is relatively small.

In comparison with the spherical-stone gelatin spheres, the vertical disc-stones have the majority of the isoclines at the top of the disc. If we examine the gels from the widest part of the sphere, the vertical disc-stones have only about four isoclines visible whereas the spherical stone have more.

While the ANOVA and Tukey show no difference between the spread of the breaking force data between the horizontal disc stone and the sphere with a skin and a 16 mm spherical stone (+sk+st), the t-tests does separate their means ($p<0.05$, t-test).

In terms of firmness, the 16 mm spherical stones reduces the deformable gel within the gelatin sphere, yet the smaller volume of the disc-stone is not enough to limit the strain and no significant difference exists for the firmness of the disc-stones and any of the other sphere constructions.

Initially we set out to examine skins and stones with shape effects. The inclusion of the large marble and golf were in many ways an afterthought and only one measurement of each was undertaken. In both cases the breaking forces were unchanged from the small marble spheres, but the firmness increased to 215 and 476 kPa for the large marble and the golf ball respectively. Presumably this is due to the deformable gelatin being progressively limited as the stone enlarges relative to the gel. It is not difficult to recalculate the firmness based on the gelatin mould and stone sizes, but these do not exactly provide identical values to the unmodified sphere and perhaps other factors such as the dimpled surface of the golf ball contribute to the firmness of the sphere.

Clearly there is a stone size effect on firmness of fruit, but that effect seems to be related to stone volume as neither of the disc-stone orientations seem to change the firmness compared to the unmodified sphere (-sk-st). In-line with the argument made of reduced strain achieved by 16 mm spherical stones, the horizontal disc-stone only contributes a negligible height (1.7 mm, 3.4% of the sphere thickness). In contrast, the height of the vertical disc-stone is 18 mm, yet the projected area aligned with the stress is low. Perhaps there is a minimum volume before appreciable changes to the firmness can be detected and while 16 mm spherical stones do affect the firmness, we postulate that small spherical pips will not – though this would need to be tested.

Implications to real fruit

Our choices of real fruit were intended to illustrate the situations mimicked in the model gelatin spheres, that is: virtually skinless (raspberries), fruits with skins but no appreciable stone (grapes) and fruit with skin and stone (cherries).

The raspberries have relatively little skin and no appreciable stones. As with unmodified spheres, the firmness and breaking force are both low relative to the other fruits tested. Coincidentally, the absolute values are actually similar to the unmodified gelatin spheres.

The grapes, as with the model gelatin spheres with skins but no stones had relatively high breaking forces which must dominate the fruit texture. The firmness while much higher than any of the gelatin spheres is relatively low compared to the cherries whose stone limits the deformable flesh during compression as occurs with the stone and skin model spheres.

Conclusions

In conclusion, the presence of stones increase the firmness progressively as the proportion of the stone to flesh within the fruit increases. However, skins in our model fruit do not influence the firmness. Breaking force is more complicated and depends on both the presence of skins which raise the breaking force of both real and model fruits. However, the shape of stones is also influential: such that spherical stones have no effect but disk stones (i.e. stones with sharp edges) when orientated with the narrow edge normal to a force, significantly reduce the breaking force.

Ethical statement

This study does not involve any human or animal testing. The authors declare that they do not have any conflict of interest.

References

BOURNE, M. C. 1980. Texture evaluation of horticultural crops. *HortScience,* 15**,** 51-57.

DOMINY, N. J., YEAKEL, J. D., BHAT, U., RAMSDEN, L., WRANGHAM, R. W. & LUCAS, P. W. 2016. How chimpanzees integrate sensory information to select figs. *Interface Focus*. 20160001

HARKER, F. R., REDGWELL, R. J., HALLETT, I. C., MURRAY, S. H. & CARTER, G. 1997. Texture of fresh fruit. *Horticultural Reviews,* 20**,** 121-224.

KUSKE, A. & ROBERTSON, G. 1974. *Photoelastic stress analysis,* Chichester, Wiley Interscience.

MUNOZ, A.M., PANGORN, R.M. & NOBLE, A.C. 1986. Sensory and Mechanical Attribbutes of Gel Texture. I. Effect of Gelatin Concentration. *Journal of Texture Studies* 17 (1): 1-16

PANKHURST, K. G. A. 1959. Monolayer Studies of Tanning reactions. *In:* DANIELLI, J. F., PANKHURST, K. G. A. & RIDDIFORD, A. C. (eds.) *Surface Phenomena in Chemistry and Biology.* London: Pergamon Press.

ROHM, H. & RAABER, S. 1992. Difference thresholds in texture evaluation of edible fats: firmness and spreadability. *Journal of Food Science,* 57**,** 647-650.

ROSENTHAL, A. J. 2015. Instrumental characterisation of solid and semisolid foods. *In:* CHEN, J. & ROSENTHAL, A. (eds.) *Modifying Food Texture: Sensory Analysis, Consumer Requirements and Preferences.* Cambridge, UK: Woodhead Publishing.

ROSENTHAL, A. J. 2016. Contact Stresses in Gelatin Spheres Under Compressive Die Loading. *Journal of Texture Studies,* 47**,** 457-460.

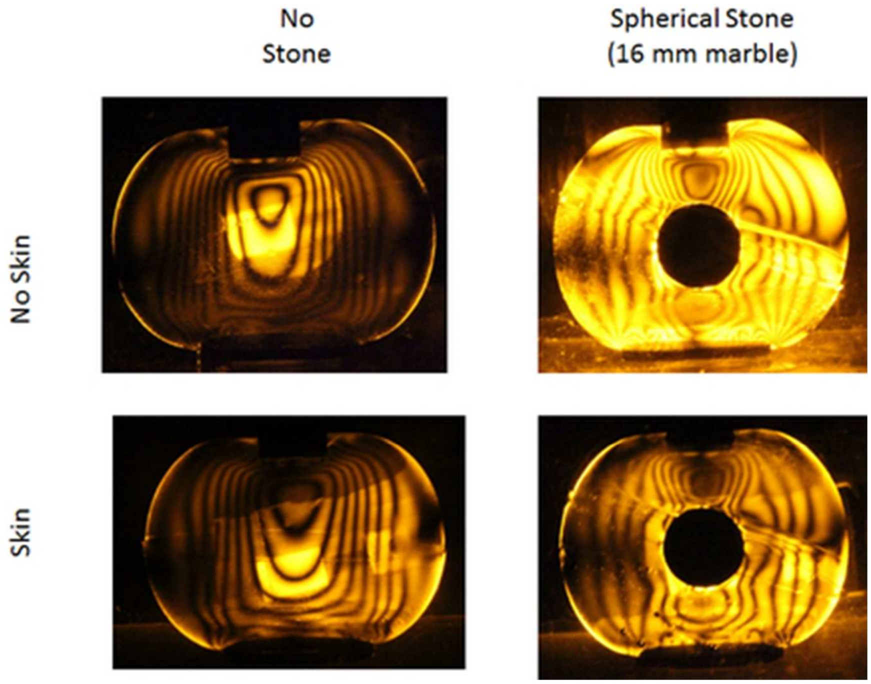

Figure 1: Photoelastic images of the various spheres under 4N compressive loads

37x29mm (300 x 300 DPI)

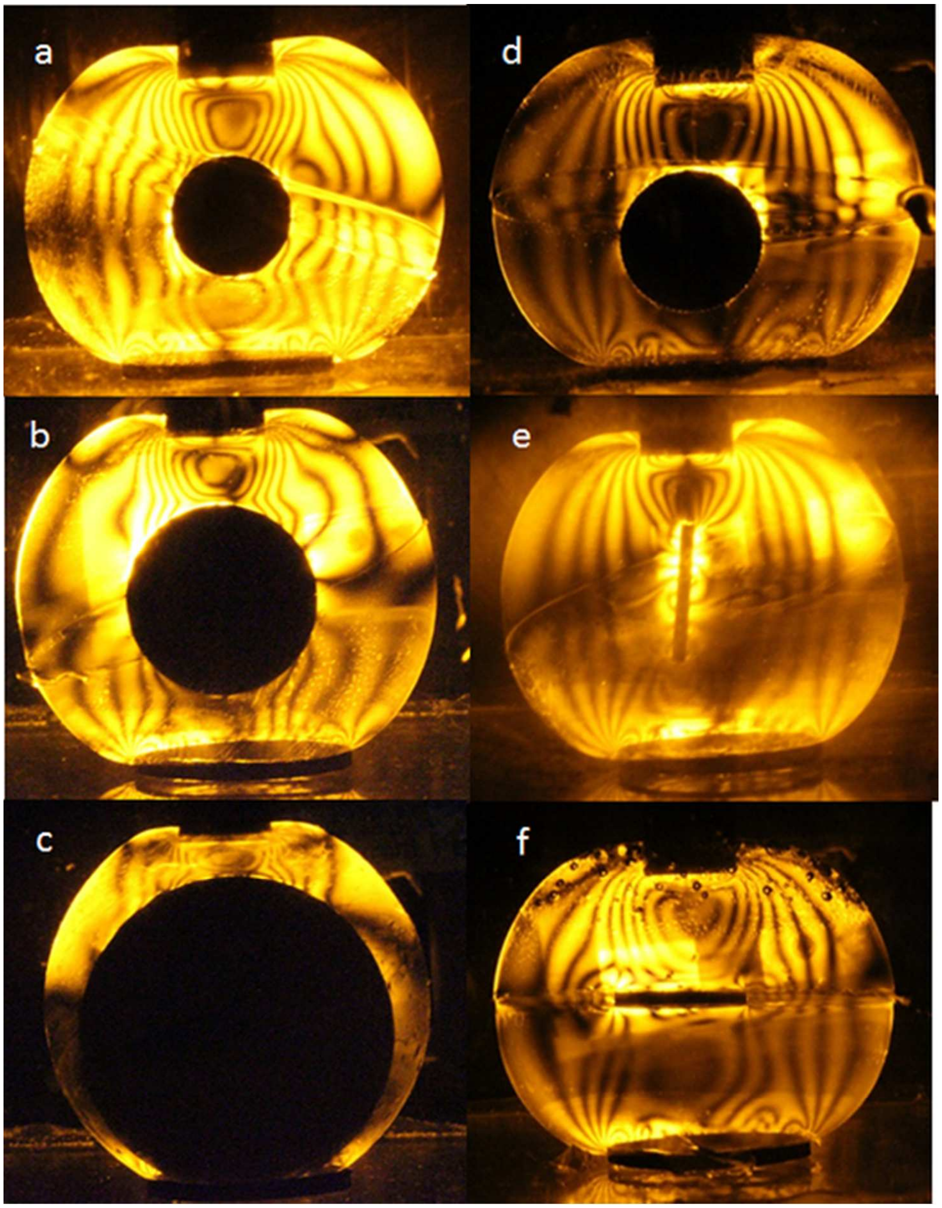

Figure 2: Stone variants at 4N compression. (a) 16 mm spherical stone (as in Figure 1), (b) 24 mm spherical stone, (c) 42 mm spherical stone, (d) 18 mm vertical disc-stone (face view), (e) 18 mm vertical disc-stone (side view), (f) 18 mm horizontal disc-stone

44x56mm (300 x 300 DPI)

Table 1 Average Poisson's ratio, firmness and breaking force for spheres of different construction (curved brackets are one standard deviation, square brackets are the number of samples in the statistical analysis). Sphere construction with the same superscript are statistically similar ($p>0.05$) according to the Tukey test.

	Poisson's ratio	Firmness (kPa)	Breaking force (kPa)
No skin - no stone (-sk-st)	^{a}0.221 (±0.089) [11]	^{c}118 (±24) [6]	^{d}50 (±6) [19]
Skin - no stone (+sk-st)	^{a}0.229 (±0.062) [5]	^{bc}138 (±17) [10]	^{e}67 (±18) [19]
Spherical stone (16mm) - no skin (-sk+st)	^{a}0.179 (±0.069) [8]	^{b}178 (±30) [6]	^{d}50 (±8) [16]
Spherical stone (16mm) & skin (+sk+st)	^{a}0.204 (±0.026) [8]	^{b}172 (±33) [8]	^{de}57 (±10) [11]
Vertical disc-stone – no skin	^{a}0.195 (±0.036) [4]	^{bc}136 (±29) [4]	^{f}38 (±5) [12]
Horizontal disc-stone – no skin	^{a}0.204 (±0.049) [4]	^{bc}143 (±16) [3]	^{df}48 (±4) [12]

Table 2: Number of samples tested, average firmness and breaking force of selected fruits (values in brackets are one standard deviation).

	n	Firmness (kPa)	Breaking force (kPa)
Cherries	40	1,380 (±306)	694 (±101)
Grapes	40	873 (±166)	1,246 (±222)
Raspberries	20	139 (±82)	94 (±28)