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Measuring impact elasticity to determine quality in fruit and vegetables

Firmness and elasticity are quality-affecting properties of fruit and vegetables. Quite often the maturation progress of such crops is judged by them. In the processing of fruit and vegetables elasticity values are used to differences in quality. An example is the production of pickled gherkins where quality problems in the form of hollow gherkins often occur. So that faulty gherkins can be sorted-out before processing to slices, a non-destructive testing procedure is necessary. For differentiating between sound and faulty gherkins an elasticity test has been developed in which the vegetables are subject to impact.

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Keywords

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Firmness of flesh has for a long time been used as a criterion for determining maturity of core and stone fruit. With advanced degrees of ripeness the firmness of the flesh decreases. This is a mechanical property which is associated with the „bite feel" of fruit during consumption. Technically, flesh firmness is determined with the aid of a penetrometer which measures the required effort for the penetration of a cylinder rod into the fruit flesh. This method is always associated with the destruction of the fruit and therefore leads to unwelcome losses. For continuous processing controls, non-destructive mechanical testing methods are required. Used increasingly as a suitable principle is the measurement of elastic reaction of the fruit. Although firmness and elasticity modules show similar trends during development of ripeness they are not completely interchangeable with one another.

Determining ripeness through non-destructive elasticity testing

A series of different methods has been developed for the rapid non-destructive quality testing of fruit and vegetables wherein the elasticity parameters are measured under dynamic conditions. For example an impact sensor has been developed for a fruit grading belt with the product lined up one after the other. This lightly taps every fruit during the transport whilst recording the progression of the impact-caused acceleration [1]. There then follows a comparison of the increase in the measured impact progression with the rise in the force-deformation-curve, determined for the same fruit by the classic penetrometer test. The system enables a throughput of six fruits/s. A high correlation between the two parameters was determined in a test with peaches.

For the ripeness grading of apples, nectarines and kiwi fruit, a sensor was fitted to a grading belt. The sensor caused every fruit to vibrate underneath and, with the help of a sensor finger applied to the top, ascertained the acceleration [2]. For evaluation a firmess index was created based on the relationship of the exit signal to the difference between the entry and the exit signal. Testing in a marketing plant returned a grading performance of from 2.5 to 7.5 fruits/s per sorting channel.

Both these testing methods require a relatively high technical input. Compared with this, a simple sensor principle proved suitable for determination of ripeness in melons [3]. Here, the fruit falls from a limited height onto a plate. During the first impact and the two subsequent impacts, the impact force progression is registered. The relationship of the peak force of an impact to the time until the next impact is evaluated. This parameter proved to have a high correlation to the elasticity module. This testing method is, however, only suitable for nearly-round melons which can demonstrate a consistent impact reaction.

Choosing a test method for determining faulty gherkins

With pickled gherkins there is no exterior sign of interior cavities. Where the vegetable is processed into slices, cavities are regarded as a serious quality fault and can lead to substantial economic penalties. In order to limit such losses, gherkins with cavities should be sorted-out before the slicing operation. Appearing to be a promising system for the identification of perfect gherkins and those with cavities after preliminary trials on manually pre-sorted gherkins is the measurement of the elastic behaviour of the vegetables. For this, a principle similar to the above-mentioned simple testing method for melons was applied. But for vegetables with a long shape such as the gherkin the impact reaction could be expected to be irregular in relationship to manner of fall and asymmetry of form. The test method has therefore had to be adapted. It was therefore investigated to what extent a quality evaluation could be carried out based on measurement of force progressions during a single defined impact.

A test stand for laboratory conditions was constructed, consisting of a PC-controlled dropping apparatus (drop height 15 cm), with throw channel and impact plate including piezo-electrical force sensor (*fig. 1*). The PC controlled the action of the throw channel and the recording of the subsequent force measurement data. A special computer

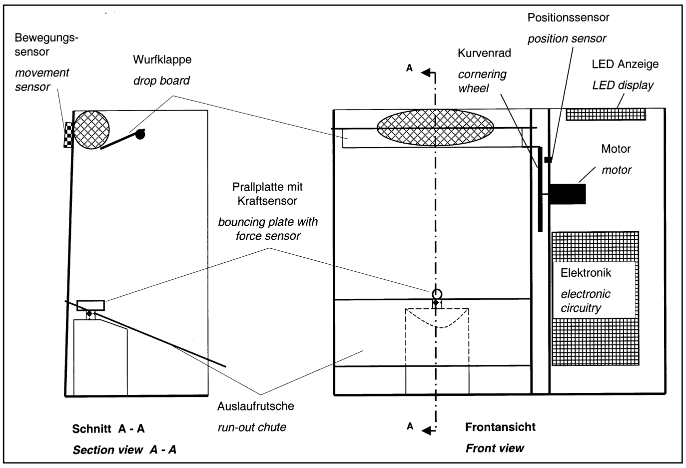

Fig. 1: Scheme of the laboratory test equipment for measuring impact elasticity on gherkins

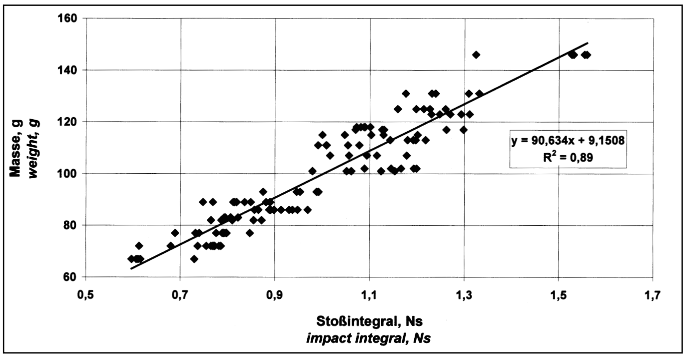

Fig. 2: Relation between integral of impact curve and cucumber weight

program was developed for automatic evaluation of the data and for displaying the differentiating results.

Laboratory proving of the test stand

A preliminary test took place with 24 gherkins, each with five repetitions. The measurement of impact force at contact was made with a data rate of 10000 values/s. The duration of the impact, the peak value of the impact force and the area under the impact force-time-curve (impact integral) were determined from the measurement data as important parameters.

The gherkins were weighted following this process. Interior flesh condition was determined through dissection (13 perfect and 11 hollow gherkins).

The impulse imparted on the impact plate at gherkin contact was taken for evaluation. On the one hand, this was calculated through multiplication of the gherkin weight with its impact velocity. Impact velocity is constant where the fall height is constant, so that the impulse is dependant on the weight alone. Alternatively, the impulse may be determined via the impact integral. The degree of agreement between the two impulse readings calculated in the different ways gives an indication of how exactly quality faults which can be characterised through elasticity can be recognised. The success of an impulse-true impact measurement is therefore of decisive importance for the testing method.

The impulse values for the individual gherkins determined in the preliminary test varied only minimally from one another within the five repetitions. A linear relationship was determined between the impulse values determined by impact measurements and the weight of tested gherkins with an agreement value of $R^2 \approx 89\%$ (*fig. 2*).

Through an ideal impact of the gherkin against a solid body there occurs a direct relationship between the elastic rigidity of the gherkin, its weight, the peak force and the impact velocity. As the velocity is constant, the rigidity k can be calculated from the measured peak force F_{max} and the impact integral $\int F\,dt$

$$k \sim F_{max}^2 / \int F\,dt$$

The trial evaluation according to rigidity did not result in a completely correct quality differentiation. With 100% correct identification of perfect gherkins the identification errors for hollow gherkins amounted to 16%.

In terms of peak force, the increase period and the impact integral an empirical differentiation function was found which led to a 100% correct identification of the interior conditions (*fig. 3*)

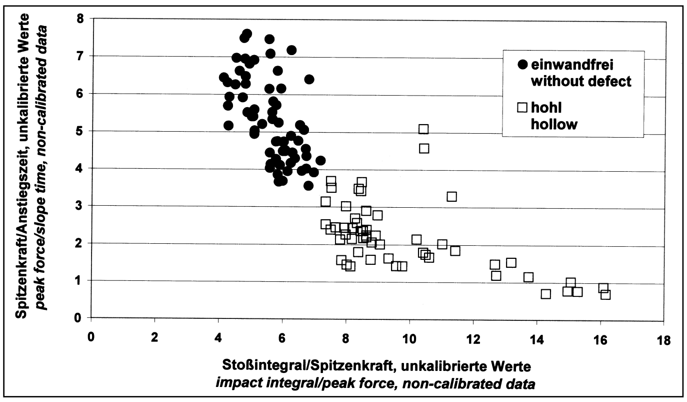

Fig. 3: Discrimination between hollow and non-hollow pickled gherkins by impact test

Results of a practice-near trial series

Statistical evaluations were ascertained through comprehensive sampling in the production. Four basic parameters were applied for the quality evaluation out of the impact progression. Through the subsequently determined interior condition of the gherkin and the parameters determined from the impact measurements, a multiple linear discriminant analysis was carried out.

During the investigation period of several weeks substantial variations in the proportion of cavity gherkins were revealed. Because of this the classification results from the elasticity tests were affected. With regard to the four basic parameters, as well as the five further combined parameters, the discriminant analysis delivered a correct classification of 90.3% of perfect gherkins and 72.7% faulty vegetables over the total sampling period. A calibration program was developed independently from this which enabled the flexible adaptation of the classification according to predetermined grading limitations.

Literature

[1] *Chen, P. and Y. Tjan*: A Real-time Impact Sensing System for On-line Firmness Sensing of Fruits. AgEng., Oslo, 1998, Paper No. 98-F-006

[2] *Peleg, K.*: Development of a Commercial Fruit Firmness Tester. J. Agric. Engng. Res. 72 (1999), no. 3, pp. 231-238

[3] *Ozer, N., B.A. Engel and J.E. Simon*: A multiple impact approach for non-destructive measurement of fruit firmness and maturity. Trans. ASAE, 41 (1998), no. 3, pp. 871-876