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Development and comparison of quantitative methods to evaluate the curd solidity of cauliflower

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ABSTRACT

Effective determination of curd solidity is a critical component of the evaluation of cauliflower quality. In the current study, a rough solidity index (RSI), the curd voidage (CV), and two instrumental indexes based on the utilization of a texture analyzer, including 'deformation distance of 30 kg force' (DD) and 'gradient from 1 kg force to first peak' (GR), were developed to enable the quantification of the curd solidity of 20 cauliflower cultivars with different curd types. Significant linear correlations were observed between each two of CV, DD, and GR ($0.8989 \leqslant R^2 \leqslant 0.9450$), while RSI was poorly related to them ($0.4716 \leqslant R^2 \leqslant 0.6034$). Similarly, the results of hierarchical cluster analysis (HCA) also showed that RSI produced more distinctive clustering pattern from the others. Our work demonstrated that CV, DD, and GR were useful indexes to evaluate the curd solidity. Meanwhile, their advantages, disadvantages and utilizable perspective were also discussed. These indexes could be very useful to enrich the evaluation system of cauliflower quality, and provide more objective and accurate data for cauliflower breeding and research.

1. Introduction

Curd solidity is one of the factors determining the quality of cauliflower (*Brassica oleracea* L. var. *botrytis L.*) (Gray and Crisp, 1977; Smith and King, 2000; Sharma et al., 2005). Although it is widely believed that the curd solidity is influenced by the time of harvesting, a phenomenon deserves special attention is that individuals of same cultivar always show uniform solidity while different cultivars display distinguishable polymorphisms (Fig. 1) even at the moment the plants are coming into curd, indicating that curd solidity is governed by a number of polygenic factors (Nieuwhof and Garretsen, 1961). Most consumers all over the world prefer cultivars with solid curds, but more and more citizens in China are realizing the distinctive taste and high level of nutritive value (e.g., chlorophyll, carotenoid, vitamin C, and soluble sugar) of loose-curd cauliflower (Zhao et al., 2012; Gu et al., 2012). At present, the sale price of a loose curd in China is much higher than that of a compact curd. Accordingly, it is meaningful to develop quantitative methods to classify the curd solidity level of cauliflower commodities and cultivars. Moreover, quantitative assessments of curd solidity are necessary for cauliflower researchers to perform breeding programs and further curd studies.

Curd solidity could be defined as the sense of a force necessary to attain a given deformation. It seems very difficult to quantify. For a long time, cauliflower researchers have paid close attention to this complex trait and tried to analyze the solidity concept into a number of distinctly measurable factors, such as the diameter of curd, the number of ramifications of the flower stalks, their length and thickness and the angle they make with the main axis (Nieuwhof and Garretsen, 1961), to carry out quantitative assessments. However, these indexes were not competent to comprehensively represent the curd solidity. In order to obtain accurate data for cauliflower research, our lab attempted to use the curd voidage (CV), which was surveyed via respectively measuring the volume of a curd wrapped by plastic film and not wrapped (see Section 2), to represent the curd solidity. Unfortunately, it is too time and labor consuming to measure large quantities of samples by using such method. Thus far, no convenient, accurate and recognized method has been developed and the subjective sensory evaluation is still the routine approach for curd solidity assessment.

Advancements in the science of texture analysis have promoted the development of precise and highly accurate instruments that have revolutionized texture assessment, not only in food industry but across a wide range of other fields. Up to now, many studies demonstrate satisfactory relationships between sensory texture attributes such as firmness and crispness, and instrumental texture measurements including TPA, shear, compression, vibration and tension instruments (Harker et al., 1997). For example, several experiments have been carried out in compression mode by a texture analyzer to assess firmness or hardness of such as apple, bread, mango, almonds, strawberry and grape (Abbott, 1994; Kadan et al., 2001; Al-Haq and Sugiyama, 2004; Varela et al.,

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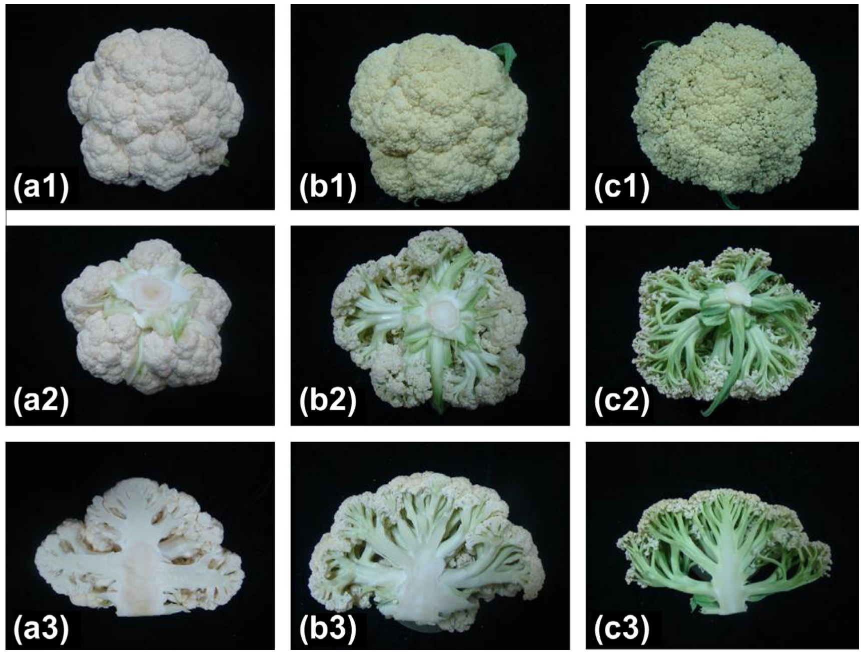

Fig. 1. The polymorphisms in curd solidity of different cauliflower cultivars (a1–a3: C10235; b1–b3: 3203-6; c1–c3: ZHE017).

2006; Curic et al., 2008; Gunness et al., 2009; Iwatani et al., 2011). The sample was deformed by the pressure from a disk and the force response would be shown on digital display. Similarly, this mode is able to simulate the process that a cauliflower curd is pressed by human, hence providing an idea for precise determination of curd solidity.

Based on this concept, the current study explores the possibilities of quantitative methods, especially the using of a texture analyzer, to evaluate the curd solidity. Four solidity indexes were developed and used to discriminate the differences among 20 cauliflower cultivars. Through the comparison of these different solidity indexes, a promising quantitative method to evaluate the curd solidity was developed, providing the first such analysis for cauliflower.

2. Materials and methods

2.1. Plant materials

Twenty cauliflower cultivars, representing a wide range of variation in curd solidity, were selected and subject to the curd solidity evaluation. All the entries were seeded in growing matrix for plug seedling in greenhouse on July 20th, 2011. One month later, the seedlings were field transplanted at the Zhejiang Academy of Agricultural Science experimental station (Hangzhou, China). The plants were cultivated with the same agronomical practices (e.g., cultivation, fertilization, and irrigation). For each cultivar, 12 representative curd samples were harvested for testing on one date during their respective commercial mature periods. The curd solidity of each cultivar was expressed by the mean value of solidity indexes of corresponding 12 samples.

The weight and diameter of each sample were measured soon after harvest, and all the other measurements were finished on each harvest day. Considering loose curd has relatively long flower stalks compared to its weight, a rough solidity index (RSI), which was calculated by RSI = weight/[$\pi \times$ (diameter/2)^2], was used to evaluated the solidity preliminarily (Table 1).

2.2. Determination of CV

The volume of fresh harvested curd wrapped by plastic film (v_1) and not wrapped (v_2) was respectively measured using water displacement (WD) method as described by Jarimopas (2005). The defining equations were CV = $(v_1 - v_2)/v_1 \times 100\%$. This procedure was repeated three times for each sample to determine the mean value. The high CV value represents a loose curd, and the low represents a solid curd.

2.3. Compression test

After the CV determination, each curd sample was symmetrically halved following its central axis. The solidity of each half curd was measured using a texture analyzer TA. TX Plus (Stable Micro-systems, England) equipped with a 30 kg load cell and a 100 mm

Table 1
RSI, CV, DD, and GR of 20 cauliflower cultivars (means ± SD, n = 12).

Cultivar	RSI (g/cm^2)	CV (%)	DD (mm)	GR (kg/s)
C10191	9.22 ± 0.87	15.93 ± 1.63	9.77 ± 1.06	6.55 ± 0.70
CG100	10.86 ± 0.63	17.67 ± 0.92	7.81 ± 0.67	7.16 ± 0.39
C10235	5.79 ± 0.53	21.63 ± 2.63	10.21 ± 0.47	5.66 ± 0.53
C10238	7.01 ± 0.32	22.84 ± 1.16	14.12 ± 0.86	5.51 ± 0.62
LM70	7.23 ± 0.52	25.38 ± 0.49	14.08 ± 1.13	5.50 ± 0.41
C10177	6.22 ± 0.48	28.29 ± 1.90	16.57 ± 1.31	5.14 ± 0.35
C10179	7.16 ± 0.76	31.93 ± 2.45	12.05 ± 1.86	6.10 ± 0.79
C10276	7.65 ± 0.61	33.15 ± 2.37	10.88 ± 1.18	6.22 ± 0.25
C10230	6.26 ± 0.42	36.59 ± 4.48	22.06 ± 0.75	5.21 ± 0.62
C10164	3.31 ± 0.27	39.33 ± 1.04	28.04 ± 1.98	4.19 ± 0.27
Xueli	6.70 ± 0.49	43.26 ± 4.08	46.93 ± 6.61	3.08 ± 0.16
C10245	7.75 ± 0.66	45.55 ± 3.40	53.75 ± 4.29	3.55 ± 0.44
C10212	5.87 ± 0.32	47.92 ± 6.17	35.69 ± 1.29	3.99 ± 0.67
QN65	2.21 ± 0.25	55.41 ± 7.84	67.59 ± 16.59	2.23 ± 0.17
3203-6	3.47 ± 0.12	60.34 ± 6.92	47.77 ± 7.51	2.40 ± 0.05
TS80	7.45 ± 0.56	64.05 ± 4.69	69.82 ± 8.99	1.46 ± 0.06
3202-7	3.00 ± 0.08	64.63 ± 4.93	63.90 ± 3.63	1.31 ± 0.08
3202-5	3.11 ± 0.27	67.05 ± 9.08	80.55 ± 10.87	1.02 ± 0.07
ZHE017	2.68 ± 0.11	69.15 ± 8.27	66.43 ± 6.43	0.85 ± 0.07
3202-4	2.37 ± 0.18	71.04 ± 5.23	78.71 ± 13.05	0.41 ± 0.03