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Mechanical investigation to assess the peel contribution in apple fruit

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ABSTRACT

Fleshy fruits are generally stored before consumption, especially apple, during which several diseases and disorders can occur. Mechanical handling and transportation may cause general wounding, leading to dramatic quality decay and fruit loss, thus to a negative economic impact. Although the majority of the research addressing fruit quality has mainly focused on the flesh, the multi-layered peel tissue complex represents the first natural barrier of a fruit. In this study, a texture analyzer was employed to investigate the peel contribution on the general fruit firmness of apple, assessing a germplasm collection composed by 65 accessions after two months of cold storage. This device generated a mechanical force–displacement profile from which a set of analytical parameters was derived. A comparative analysis between intact and peeled portions performed on each single fruit, enabled the characterization of the contribution of the peel on fruit firmness. By analysing the phenotypic variance of these analytical parameters within the apple collection by a multivariate statistical approach, two clusters were identified, amongst which a specific set of apple cultivars was distinguished by a superior peel contribution. The parameters here isolated and employed are finally proposed as novel traits with a potential impact for breeding, and suitable for the characterization and selection of novel accessions with an enhanced postharvest potential due to an improved mechanical performance of the peel.

1. Introduction

Fruit quality is represented by a set of features considered as driving forces in the evaluation of new accessions, mainly because of their impact on the consumer's appreciation (Harker et al., 2003; Costa et al., 2011). While this concept is comprehensively accepted for all fruit species, in apple also the postharvest fruit quality is important as much as the one acquired at harvest. To guarantee the availability of fruit over a year-round period, apples are in fact normally stored for several months before consumption. For the horticultural management and the general maintenance of fruit quality, the physiological and physical modifications occurring in the fruit during storage play a fundamental role. The relevance of the postharvest practices is also supported by the finding that about 30% of the entire production of fleshy fruit is lost during storage (FAO, 2011). Despite the general thought that fruit quality basically relay on the fruit mesocarp properties, it is also worth noting the important role exerted by the peel, in particular during the postharvest storage (Grotte et al., 2001; Edelmann et al., 2005; Matas et al., 2005; Saladié et al., 2007), as confirmed by the growing number of scientific reports recently published about the structural properties and metabolic processes ongoing during the formation and regulation of the different epidermal tissues (Hen-Avivi et al., 2014).

Anatomically, the peel represents the outer surface of a fruit (Lara et al., 2014), and it consists of cuticle as well as epidermal, subepidermal and a multi-layered hypodermis (Homutová and Blažek, 2006; Konarska, 2012). The cuticle internally adheres to the polysaccharides of the epidermal cell walls, while externally it presents a series of lipids (Konarska, 2012). The cuticular layer is in fact composed by a hydrophobic structure mainly constituted by cutin, covalently linked to scaffold of long-chain fatty acid, and wax, formed by a very-long-chain fatty acid and their derivate, such as alcohols, aldehydes and alkenes (López-Casado et al., 2007; Pollard et al., 2008; Samuels et al., 2008; Hen-Avivi et al., 2014). The cutin matrix embedded with intracuticular waxes and covered with epicuticular waxes are produced and secreted by the epidermal cells (Kunst and Samuels, 2003; Bargel et al., 2006; Yeats and Rose, 2013).

Originally the cuticle had a very important evolutionary role allowing plants to colonize the terrestrial environment (McCourt et al., 2004; Bargel et al., 2006), since it is the primary barrier of aerial organs. Beside this, several other important roles have been afterwards assigned to the fruit peel including protection against abiotic and biotic stresses (Grotte et al., 2001; Domínguez et al., 2011a,b), which can strongly affect the postharvest performance of fruits. The cuticle structural complex prevents, in fact, damage

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from dehydration, pathogen attack and handling, finally extending the fruit shelf-life and quality during storage and transportation (Crisosto et al., 1993; Homutová and Blažek, 2006; Konarska, 2012). It has been reported also for other fleshy fruit species, such as tomato, that defects in the fruit peel have severe repercussion on the general shelf-life. The protection from excessive water loss, mechanical wounding or pathogen attack ensure, in fact, successful fruit marketability and a favorable consumer's appreciation, since the fruit would maintain a high general fruit quality appearance (Domínguez et al., 2011a). On this species, it has also proposed a positive contribute of the fruit cuticle on the fruit firmness properties, suggesting a direct role of the fruit peel on the postharvest performance (Saladié et al., 2007). In the end, it is also worth to mention the impact of the peel during fruit processing. The type of skin thickness might differentiate, for instance, fruit for fresh consumption from those more suitable for canning or industrial processing (Hetzroni et al., 2011).

Over the fruit ontogenic cycle, the metabolism of cuticle initiate already in the early phase of fruit development, to progressively decrease toward the ripening stage (Comménil et al., 1997; Belding et al., 1998; Rosenquist and Morrison, 1988; Dong et al., 2012; Liu et al., 2012; Lara et al., 2014). In apple fruit, the impact of cuticle is magnified by the fact that postharvest is nowadays a routine practice in modern horticultural management. Moreover, the peel thickness resulted to vary considerably among different cultivars (Konarska, 2012), suggesting potential room for genetic improvement. Taking this last concept into consideration, the investigation of the peel mechanical properties in apple would provide important information useful for the postharvest management. Novel parameters related to this feature could be employed, for instance, as novel target traits for breeding programs, oriented to the development of new accession characterized by an improved fruit quality and postharvest performance. Fruit cuticle, in fact, provides a fundamental structural external support to fruit that lacks of hard internal tissues (Lara et al., 2014), helping, as consequence, the fruit tissue integrity.

Despite its important role, very little is known about the effect of peel among the different varieties included in the apple panorama. To date, a number of works have been published about the apple fruit peel structure assessed by histological and different electron microscope approaches, investigating the peel thickness in a specific set of apple cultivars (Homutová and Blažek, 2006; Konarska, 2012, 2013). However these techniques provide a reliable and sophisticated indications about the peel structural properties, they are usually laborious and time consuming, thus not suitable for large-scale screening. In addition, other types of approaches have been also recently proposed, investigating the contribution of the apple peel by force–displacement puncture test (Grotte et al., 2001; Shafiee et al., 2008; Rao and Brown, 2011). However, despite the fact that these studies presented a more fast and easy to use strategies, they were performed on a very limited number of apple varieties, therefore not sufficient for an exhaustive and comprehensive characterization of the peel strength in apple.

The aim of this work was the investigation and characterization of the peel contribution in apple fruit with the use of a novel texture analyzer. This instrument was employed to assess the peel mechanical performance within an apple collection composed by 65 apple varieties. The new set of parameters here defined resulted to be a reliable and efficient screening tool for large sample set, fundamental for breeding purpose and large characterization of fruit features in apple.

2. Material and methods

2.1. Plant materials

To investigate the peel effect and mechanical performance, 65 apple varieties (Table 1), planted and grown in the same plot at the Experimental Station of the Fondazione Edmund Mach-FEM (Trento, northern Italy), were employed. Each individual variety is planted as triplets, and all the accessions were in adult and full fruit bearing stage at the time of the analysis. Plant management activities were performed following standard horticultural practice for pruning, thinning and pest–disease control. Fruit were collected at commercial harvest stage, according to the harvest date established by the FEM Extension Service on the base of common fruit ripening parameters (such as skin color, seed color, starch degradation, sugar and acid content and fruit flesh firmness). In this work, the fruit firmness was measured with the same texture analyzer used to perform the peel investigation, taking into consideration the maximum force (as described in Costa et al., 2011, 2012). Fruit firmness was assessed twice, at the

Table 1
List of the 65 apple accessions employed in the investigation. For each variety the reference number (as reported in the PCA plot illustrated in Fig. 3a) and the name are indicated. Cultivars are listed in alphabetic order.

No.	Cultivar	22	Fiamma	44	Red Chief Camspur
1	Ambrosia	23	Fuji Kiku 8	45	Red Elstar
2	Ananas Renette	24	Galmac	46	Red Field
3	Ariane	25	Gelber Edelapfel	47	Red Idared
4	Ariwa	26	Gold Chief	48	Renetta Canada
5	8S6923 (Aurora Golden Gala™)	27	Gold Rush	49	Renetta Champagne
6	Baumanns Renette	28	Golden Orange	50	Rosmarine rossa
7	Bellida	29	Granny Smith	51	Rubinola
8	Bernen Rosen	30	Gravensteiner	52	Golden Delicious (cl. Rugiada)
9	Boujade	31	Hapke Delicious	53	San Lugano
10	Braeburn standart	32	Kronprinz Rudolph	54	Santana
11	Brixner Platting	33	La Flamboyante (Mairac®)	55	Saturn
12	Calamari	34	Ligol	56	Scarlet Spur
13	Calvilla Bianca	35	Limoncini	57	Scifrech (Jazz)
14	Cameo	36	Magrè	58	Scilate (Envy)
15	Coop 39 (Crimson Crisp®)	37	Milwa	59	Spitzlederer
16	Croncels	38	Napoleone	60	Stayman
17	Dalinette (Choupette®)	39	Nicogreen	61	Summerfree
18	Delblush (Tentation)	40	Nicoter (Kanzi)	62	Tiroler Spitzlederer
19	Delcoros	41	Cripps Pink (Pink Lady®)	63	Topaz
20	Delorina	42	Pinova	64	Weisser Rosmarine
21	Discovery	43	Rafzubin	65	Weisser Wintertaffet