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Relationship between pollination and cell wall properties in common fig fruit

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ABSTRACT

Most botanical types in fig *Ficus carica* require pollination to fulfil their development and ensure quality onset of the fruit. Cell wall behaviour and composition was followed in fig fruit in response to pollination during maturity. Figs. when ripe, soften drastically and lose of their firmness and cell wall cohesion. Pollination increased peel thickness, flesh thickness, fresh weight and dry matter content of the fruit. Alcohol insoluble solids (AIS), more concentrated in the flesh tissue, were not influenced by the lack of pollination. Concentrations in uronic acids were higher in the AIS of the peel than that of the flesh and differences were significant between pollinated and non-pollinated fruits. Pectin polymers in figs were high methylated (DM > 50). The methylation degree (DM) increased more with pollination affecting textural properties of the fig receptacle. The major neutral sugars from the AIS were glucose (Glc) from cellulose followed by arabinose (Ara). No significant changes in neutral sugars content could be allocated to pollination. Pollination is essential in fruit enlargement and softening. Minor changes were determined in the cell wall composition of the fruit at maturity. Fertile seeds resulting from pollination may possibly take place in hormonal activity stimulating many related enzymes of the wall matrix depolymerisation in particular polygalacturonase (PG) and pectin methylesterase (PME).

Introduction

The fig *Ficus carica* is an important fruit crop in many parts of the world. It is especially so in countries bordering the Mediterranean sea and is considered among the oldest cultivated plant trees in these areas (Zohary and Hopf, 2000). Fig fruit is well-known for its nutritive value and is consumed fresh or dried worldwide (Solomon et al., 2006). Figs have been used for human consumption for centuries, and recently their nutritive and pharmacological values have been investigated (Lazreg et al., 2011; Trad et al., 2014; Yang et al., 2009).

Botanically, the fig is a syconium, a very remarkable form of fruit. It is a hollow, fleshy receptacle, enclosing a multitude of flowers which never see the light and develop into drupelets within the receptacle after being pollinated. During the last stage of fig development, deep modification processes occur within the fruit as indicated by change of the colour, increase in size and tissue softening (Chessa, 1997). Fig fruit is highly perishable, climacteric and subject to rapid physiological breakdown after harvest. Figs soften drastically when ripe offering to the fruit its fine texture. The softening process is primarily due to a change in cell walls metabolism, resulting in a net decrease in certain structural components (Brummel and Harpster, 2001; Gross and Sams, 1984). As the fruit mature, there is a slight decrease in the polysaccharides and crude fibres (Salunkhe and Desal, 1984). Cell walls of the fruit generally consist of pectin, hemicellulose and cellulose polysaccharide polymers (Owino et al., 2004). Pectin polymers are the most abundant and the most complex class of cell wall macromolecules that are degraded during ripening, undergoing both solubilisation and depolymerisation (Rose and Bennett, 1999).

During ripening, cell wall architecture and the polymers of which it is composed are progressively modified, with the nature or extent of the changes varying between species. The cell wall structure becomes increasingly hydrated as the cohesion of the pectin gel changes, and this is the main factor influencing how easily cells can be split open or separated from one another, which determines fruit texture (Jarvis, 1984). A reduction in cell-to-cell adhesion is caused by a breakdown and dissolution of the pectin-rich middle lamella. It begins early in ripening in a soft fruit such as tomato (Crookes and Grierson, 1983) and late in softening in a crisp fruit such as apple (Ben-Arie et al., 1979).

Particular attention has been paid to cell wall changes during fruit ripening in order to optimise textural attributes and cell wall-dependent quality characteristics (Waldron et al., 2003). The content and structural features of the fruit cell wall polymers vary with species, developmental stage and the tissue type (Brownleader

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et al., 1999). Pollination in figs is essential for the good unfolding of fruit development. Pollinated figs are usually larger, greener than non-pollinated fruits, more prone to splitting and have a darker interior pulp colour (Michailides et al., 2008; Oukabli et al., 2003). Knowledge about the composition of the cell wall material from fig fruit and the possible effect of pollination on cell wall polysaccharides is limited. Cell wall modifications in relation with pollination status of the fig syconium were investigated in the present work. Fig receptacle was subject to cell wall analysis in the two separate tissues (peel and flesh) and changes in structural components were followed at the commercial stage of maturity.

Results and discussion

Pollination effect on physical aspects of figs

Maturity in figs is accompanied by a drastic loss of firmness and pollination contributed to accelerate softening of the fruit. Firmness values fell from 0.43 to 0.36 kg cm^{-2} as the fruit develops following pollination (Table 1). Moreover, the incidence of pollination was clear on peel and flesh thickness. Flesh thickness increased with pollination to reach 20 mm against 14 mm in non-pollinated figs ($p \leqslant 0.01$) and this undoubtedly offers more consistency, taste and flavour to the fruit. Non-pollinated figs showed an important internal cavity, a mark of pedicels development collapse and lack of seeds (Fig. 1.). All these parameters lead to reduced fresh weight. In fact, non-pollinated figs weighed relatively less than pollinated fruits (Table 1). Similar investigations carried out in blueberries showed that differences in final fruit size between pollinated and non-pollinated fruits are due to differences in cell enlargement rather than cell number (Cano-Medrano and Darnell, 1997). Enlargement of plant cells is a complex process in which several aspects of the plant cell wall are of key importance (Cosgrove, 2005). One aspect is the abundance and activity of cell wall-loosening agents. A second aspect is the compositional and structural features of the cell wall itself, allowing it to respond to wall-loosening activity by cell wall extension. These two aspects, in turn, are affected by cell wall pH, synthesis of wall polymers, and their assembly and cross-linking *in muro*. Figs are considered among richest fruit in dry matter, an important criterion when using fig crops for drying (Piga et al., 2003). The lack of pollination reduced dry matter content from 20% to 19% fr. wt with differences being significant ($p \leqslant 0.05$). Ripening in figs is associated with textural changes resulting probably from disassembly of the primary cell wall. The softening of the pericarp and mesocarp tissues is due to the activity of cell-wall degrading enzymes, not starch degradation, as the fruit is known to have little starch content (Bolin and King, 1980).

AIS yield and pollination effect

Table 2 summarises AIS yields of figs in both peel and flesh. For normally developed fruits (pollinated fruits), AIS content varied from 51 to 59 mg g^{-1} fr. wt in the peel and from 110 to 162 mg g^{-1} fr. wt in the flesh. AIS yield could represent a presumption of the dietary fibres content in figs. Dietary fibres are important as nutritive compounds defining quality of foods in general (Vinson, 1999). Among the three cultivars, yellowish 'Thgagli' figs were richer in alcohol insoluble solids (59 and 162 mg g^{-1} fr. wt in peel and flesh respectively). Differences were significant between varieties ($p \leqslant 0.05$) to high significant between fruit tissues ($p \leqslant 0.01$). Figs are considered among richest fruit in dietary fibres with the high concentrations in the fleshy receptacle (AIS concentrations were almost 3-fold higher in the flesh than in the peel). AIS yield of 'Houraishi' figs originated from Japan reached 32 mg g^{-1} fr. wt in the fully ripe receptacle tissue (Owino et al., 2004). AIS levels in plums showed values ranging from 10 to 20 mg g^{-1} fr. wt in the flesh and more than 45 mg g^{-1} fr. wt in the peel (Renard and Ginies, 2009).

AIS yields of non-pollinated fig fruit are summarised in Table 2. Non-pollinated figs showed AIS concentrations ranging from 46 to 52 mg g^{-1} fr. wt in the peel and from 114 to 153 mg g^{-1} fr. wt in the flesh without significant differences compared to the values reported for pollinated fruits. The lack of pollination had no effect on AIS concentrations in both tissues (Table 2). In the peel, AIS concentrations were 55 and 49 mg g^{-1} fr. wt respectively in pollinated and non-pollinated fruit. Concentrations in the flesh were almost the same (131 mg g^{-1} fr. wt). As pollinated fruits were larger than non-pollinated fruits, this indicated higher cell wall biosynthetic activity per fruit in pollinated figs. Total fibres content was demonstrated, in previous work, to diminish with pollination in fig fruit (Mohamed and Mrak, 1942): the discrepancy between whole fruits and tissue is probably linked to the difference in AIS concentrations between peel and flesh and to differences in tissue proportions between pollinated and non pollinated fruits.

Pectin in figs and pollination effect

Pectin content was estimated by the uronic acid concentration as galacturonic acid is the main component of pectins. In pollinated figs, galacturonic acid was more concentrated in the peel ranging from 284 to 339 mg g^{-1} AIS. In the flesh, the highest content was recorded in 'Thgagli' fruits with 257 mg g^{-1} AIS. High concentrations of galacturonic acid in the outer part of the fruit have been reported for many other species (Gross and Sams, 1984). Though AIS concentrations were much higher in the flesh, pectin composing these AIS was rather concentrated in the peel tissue. Pectin polymers are essential in the structural arrangement of the cell wall and become prominent in the AIS of external compartment

Table 1
Physical description of figs in the three selected cultivars. Data are expressed as mean ± s.d. ($N = 3$). BHL: Bouhouli; ZD: Zidi; THG: Thgagli.

		Firmness (kg cm^{-2})	Peel thickness (mm)	Flesh thickness (mm)	Fresh weight (g)	Dry weight (%)
BHL	Pollinated	0.34 ± 0.02	1.5 ± 0.1	19.5 ± 1.5	112.0 ± 4.0	19.7 ± 2.5
	Non-pollinated	0.38 ± 0.02	1.4 ± 0.3	14.0 ± 1.2	65.4 ± 8.9	17.7 ± 0.5
ZD	Pollinated	0.32 ± 0.04	1.7 ± 0.0	23.3 ± 1.3	82.1 ± 11.5	22.7 ± 0.5
	Non-pollinated	0.38 ± 0.04	1.5 ± 0.1	15.0 ± 0.8	48.0 ± 5.0	22.0 ± 3.5
THG	Pollinated	0.45 ± 0.04	1.2 ± 0.1	16.1 ± 1.3	82.9 ± 4.4	19.0 ± 0.0
	Non-pollinated	0.49 ± 0.08	1.1 ± 0.1	13.2 ± 2.0	48.9 ± 5.8	18.7 ± 1.1
Means	Pollinated	0.36 ± 0.04	1.5 ± 0.1	20 ± 1.3	92 ± 6.6	20 ± 1.0
	Non-pollinated	0.43 ± 0.07	1.3 ± 0.1	14 ± 1.3	54 ± 6.5	19 ± 1.7
F-value[a]		6.09*	5.34*	131.20**	206.66**	4.02*

* Significant level ($p \leqslant 0.05$).
** High significant level ($p \leqslant 0.01$).
[a] *F*-Value of the treatment (pollinated and non-pollinated figs).

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