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Improved processes for the conversion of mango peel into storable starting material for the recovery of functional co-products

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ABSTRACT

Fresh industrial mango peel waste (MPW_0) has to be processed into a storable commodity to enable its upgrading into dietary fibers or pectin and antioxidants regardless of its seasonal availability. In this feasibility study, 19 prototype processes that involved hot-air drying for stabilizing the juicy MPW_0 of fully ripe fruit were evaluated regarding the efficiency of the drying step, the recyclable mass percentage of MPW_0, and the functional quality of the dried mango peel (DMP). Depending on the process variant, hot-air drying was applied directly or after different types of peel preprocessing in order to assess the efforts needed for mechanical dewatering, the prevention of enzymatic browning by peel blanching, the control of the Maillard reaction by adjusting the drying temperature, and the removal of mesocarp from MPW_0 by blanching or pressing. As shown by principal component analysis, the process variants, which proved to be most efficient regarding drying due to included peel blanching (88 °C, 1 min), pressing (150 bar, 5 min), and cutting, also ensured optimal performance of DMP. At best, the yields and purity of extractable pectins (11.4–13.2 g hg^{-1} with 77–83% of galacturonic acid) as well as the dietary fiber contents, the antioxidant capacity, and the technological functionality were maximal. Especially the slurry viscosity of powdered DMP (15%, w/v; 16–31 Pa s at 2.5 s^{-1}) and the water-holding capacity (6.5–7.1 g g^{-1}) were decisively improved, but at the expense of slurry yellowness and β-carotene contents. Separation of puree (61 g hg^{-1}) from MPW_0 by intensive pressing before peel processing into DMP (8.7 g hg^{-1}) yielded the maximal amount of reusable by-products without affecting DMP functionality.

1. Introduction

Value-adding reduction of the huge waste volumes that arise from industrial mango processing due to high mass portions of peel and seed (Vásquez-Caicedo et al., 2002) has been of interest for a long time (Eipeson and Ramteke, 2003). The peel may be processed into juice, wine, and vinegar (Beerh et al., 1976). Besides kernel fat and antioxidants (Schieber et al., 2001), kernel flour (Arogba, 1999) and antimicrobial agents (Engels et al., 2012) can be recovered from the seeds. In addition to such co-products from the kernels, the production of wine, vinegar, and juice from pulper waste and pectin, cattle feed, and alcohol from the peel was suggested for utilizing the entire range of mango by-products (Anand and Maini, 1997).

More recently, bench scale recovery of co-products from the peel has been evaluated intensely. Mango peel has been deemed

Abbreviations: ABTS, assay with 2,2′-azinobis-(3-ethylbenzothiazoline)-6-sulfonate diammonium salt ($ABTS^{2-}$); AcO-80, extract(ion) with acetone/ultra-pure water (80:20, v/v); AIS, alcohol-insoluble substance; DE, degree of esterification; DMP, dried mango peel; DPPH, assay with 2,2-diphenyl-1-picrylhydrazyl ($DPPH^{\bullet}$); EC, evaporative capacity; FBD, fluidized-bed laboratory dryer; GalUA, galacturonic acid; IDF, insoluble dietary fiber; MC, moisture content; MeOH-75, extract(ion) with methanol/ultra-pure water (75:25, v/v); MPW_0, fresh industrial mango peel waste; OHC, oil-holding capacity; PC(A), principal component (analysis); PP, polypropylene; PPO, polyphenol oxidase; *r*, Pearson correlation coefficient; SBC_{DMP}, sugar-binding capacity of dried mango peel (gelling units); SC, swelling capacity; SDF, soluble dietary fiber; *t*, time; *T*, temperature; TDF, total dietary fiber; TEAC, Trolox-equivalent antioxidant capacity; TSS, total soluble solids; WHC, water-holding capacity; *Y*, yield of dried mango peel; η, viscosity.

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a promising source of dietary fiber (Aziz et al., 2012; García-Magaña et al., 2013; Larrauri et al., 1996), pectin (Koubala et al., 2009; Sirisakulwat et al., 2010), enzymes (Amid et al., 2012a,b), and bioactive compounds, including polyphenols, carotenoids, and anthocyanins (Ajila et al., 2007b; Berardini et al., 2005b). Via their antioxidant activity, flavonol *O*- and xanthone *C*-glycosides (Berardini et al., 2005a; Schieber et al., 2003), gallotannin and benzophenon derivates (Berardini et al., 2004), alk(en)ylresorcinols (Knödler et al., 2008, 2009), β-carotene and xanthophylls, tocopherol, and ascorbic acid (Ajila et al., 2007a, 2010b) add an extra value to dietary fibers, which may be used as ingredients of bakery (Ajila et al., 2008; Vergara-Valencia et al., 2007) and pasta (Ajila et al., 2010a) products. Due to technological and/or bioactive properties, the peel (Iqbal et al., 2009) or co-products thereof (De Souza et al., 2013; Taing et al., 2013) are also of interest for various non-food uses (Endress, 1991; Femenia, 2007; Hotchkiss et al., 2009; Vos et al., 2007).

However, industrial upgrading requires the availability of the peel waste as a storable commodity of constant quality, regardless of seasonal fruit processing. Since the peel waste is perishable owing to its high moisture content, it usually has to be processed into a stable by-product by prompt drying. Thus, its exploitation is profitable, provided that the costs for drying, packaging, shipment, and storage (Cardona et al., 2010; Endress et al., 2006) can be outweighed by the revenues from the recovered co-products. Despite notable incentives for waste minimization (Laufenberg et al., 2003; Waldron, 2007), upgrading has thus become commercial only for the by-products from the key sectors of juice production, such as apple pomace and other traditional sources of hydrocolloids, dietary fibers, and ethanol (Panouillé et al., 2007). One challenge is that physical key features of dietary fibers, such as granularity and capillary properties, require specific processing (Endress and Fischer, 2001; Larrauri, 1999), which includes proper by-product drying (Garau et al., 2007). The recovery of mango pectin has been hindered by repeated noncompliance with the minimum galacturonic acid content of pectins (65%, w/w; JECFA, 2009) plus varying yields and functional quality (Neidhart et al., 2009).

In mango processing plants, facilities for instant residue drying are usually unavailable, in contrast to the production of apple and citrus juices. As required for subsequent upgrading, mango peel drying must be fast and economic, while sensitive high-value compounds, which are prone to browning (Vásquez-Caicedo et al., 2007), oxidation, and isomerization (Pott et al., 2003), ought to be preserved. However, this is complicated by the nature of mango peel waste. Commonly, industrial mango processing involves manual peeling with a knife (Neidhart et al., 2009; Sirisakulwat et al., 2010), because other fruits and vegetables are often processed on these versatile peeling lines as well. For mangoes, juicy strip-shaped residues accrue at the waste outlet. Fresh mango peel thus consists of the firm, relatively impermeable skin (exocarp) with varying portions of soft flesh on its inner surface. In contrast, fresh apple pomace accumulates as pre-dewatered solid waste ready for drying, because the mash, produced by grinding the whole fruit, is pressed for the extraction of the juice (Endress et al., 2006).

Therefore, the present feasibility study dealt with technological options for the conversion of fresh mango peel waste into a storable by-product for potential upgrading through dietary fiber production or the recovery of pectin and antioxidants. For this purpose, different process steps were examined to assess their effects and necessity for stabilization processes that yield optimal functionality of the dried peel with minimal input of resources. These steps included short-term color stabilization by blanching of the peel waste as well as pre-dewatering, cutting, and one- or two-stage hot-air drying. The aim was to identify optimized alternatives to tedious direct peel drying. More complex prototype processes, which differed in the number, order, and parameter settings of individual steps, were therefore evaluated regarding the efficiency of the drying step, the effects on key quality features of the dried peel, and the reusable mass percentage of the waste. On this basis, the attainable functional quality of dried mango peel was to be specified.

2. Material and methods

2.1. Mango fruits and fresh peel waste

Directly after manual knife peeling for the industrial production of frozen food, fresh mango peel waste (MPW_0) was used for experimental by-product stabilization on a pilot plant scale in close vicinity to the residue outlet of the peeling lines in Chiang Mai, Thailand, during the season 2011 (February–June). Preliminary studies of enzyme deactivation by peel blanching involved fully ripe 'Maha Chanok' and 'Nam Dokmai' mango (*Mangifera indica* L.) fruits and MPW_0 batches of the season 2010.

2.2. Testing of process conditions for the hot-water blanching of peel waste

The fruits used for the enzyme deactivation studies were peeled manually to obtain single-cultivar peel batches of 200 g that were instantly blanched in 1.5 L of water (85 °C) for 1 and 5 min, respectively, and rinsed with 250 mL of cold water (4–8 °C). Free water was subsequently removed by centrifugation in a salad spinner. The blanched peel and aliquots of the respective fresh peel batch were shock-frozen in liquid nitrogen, freeze-dried, and stored at −80 °C until shipment on dry ice to Hohenheim University by air freight for the quantitation of the polyphenol oxidase (PPO) activity (cf. Section 2.5.5). For the same purpose, industrial peel waste batches were treated and analyzed by analogy.

The settings, which were finally factored in for the blanching step of various process lines (cf. Section 2.4.1), were deduced from a $4^1 \cdot 6^1$ design for peel blanching at 4 temperature (T) and 6 time (t) levels with indirect testing for PPO deactivation via monitoring of the peel color retention. At each level of T (73, 78, 83, 88 °C), 20 peel strips of a MPW_0 batch ('Nam Dokmai') were blanched for 1, 2, 3, 4, and 5 min, respectively, in 40 L of drinking water (Thai FDA, Thai DLD and WHO quality standards; Cl_2: 0.1–0.5 ppm, hardness < 100) and recooled by immersion in cold drinking water (4–8 °C) for 60 s. After drainage (~3 min) in a shaken plastic sieve, the peel color was rated based on the CIE red (a^*) and lightness (L^*) values directly after blanching (a^*_b, L^*_b) and after 120 min of post-blanching storage at 24 ± 0.8 °C (a^*_{b+2h}, L^*_{b+2h}). Color changes were expressed as $\Delta a^*_{2h} = a^*_{b+2h} - a^*_b$ and $\Delta L^*_{2h} = L^*_{b+2h} - L^*_b$, respectively. Fresh peel strips of the MPW_0 batch used per temperature level served as the control (t = 0 min) and were analogously analyzed both promptly and after 2 h of storage. For the settings that were finally chosen for T and t, the maximal peel/water ratio (12.5 g L^{-1}) that enabled blanching at a constant temperature was identified by treatments of different peel amounts, while monitoring the water temperature with a digital thermometer GTH 175/Pt (Greisinger, Regenstauf, Germany).

2.3. Testing of process conditions for the mechanical dewatering of peel waste by pressing

The conditions that were finally used for mechanical dewatering with the hydraulic rack-and-cloth juice press described in Section 2.4.2 were deduced from a series of trials at different pressure settings. For this purpose, MPW_0 batches of 2500 g were pressed at 10, 25, 50, 100, and 150 bar, respectively, for 300 s, including a pressure build-up time of 90 s. The mass, moisture content, and peel