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Research paper

Applicability of fruit blanching and intermittent microwave-convective belt drying to industrial peel waste of different mango cultivars for the recovery of functional coproducts

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ABSTRACT

To exploit the full potential of industrial mango peel waste (MPW_0) as a starting material for the recovery of bioactive and functional coproducts despite its seasonality, it must be processed efficiently into a storable dried byproduct of uniform high quality, irrespective of impacts of different cultivars and ripeness. The focus of this feasibility study, performed on the pilot plant scale, was on technological options for three key process stages in the manufacture of dried mango peel (DMP) as a possible bulk commodity: fruit blanching, peel drying, and DMP packaging. Depending on cultivars, hot-water blanching of fruit (65–85 °C) before peeling proved inappropriate for peel color retention, but could even induce enzymatic browning until peel drying, and thus losses of bioactive compounds due to oxidative polymerization and insolubilization. Hence, this process step should be limited to brief washing of the fruit at maximally 65 °C to reduce microbial load. Intermittent microwave-convective drying (IMWC) of MPW_0 in a continuous belt dryer at high peel throughput was feasible at ambient air temperatures. Finalizing initial IMWC of MPW_0 by convective drying (CD, 80 °C) in the falling-rate period avoided local charring. Alternatively, MPW_0 had to be washed before IMWC to remove adherent pulp, but at the expense of soluble solids and β-carotene losses. Unlike the carotenoids, alk(en)ylresorcinols were hardly affected by IMWC. By washing MPW_0, quality defects compared to CD-dried peel in terms of antioxidant capacity, water-holding capacity, and yield and quality of pectin were compensated. Adequate preprocessing plus IMWC was thus deemed to be a promising option, especially for biorefinery concepts including biogas production and congeneration. The minimal moisture barrier properties needed for flexible intermediate bulk containers were estimated from an 11-month shelf-life test of IMWC-dried peel in two climate zones.

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; AR, alk(en)ylresorcinol; a_w, water activity; CD, convective drying; CMWC, continuous microwave-convective drying; DE, degree of esterification; DL, dry lamination; DMP, dried mango peel; DPPH, assay with 2,2-diphenyl-l-picrylhydrazyl (DPPH•); EC, evaporative capacity; FBD, fluidized-bed laboratory dryer; FIBC, flexible intermediate bulk container; GalUA, galacturonic acid; IDF, insoluble dietary fiber; IMWC, intermittent microwave-convective drying; (LLD)PE, (linear low-density) polyethylene; 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; NY, nylon (polyamide); PP, polypropylene; PPO, polyphenol oxidase; PR, pulse ratio; RH, relative humidity; 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; v_{air}, air velocity; WHC, water-holding capacity; Y, yield of dried mango peel

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1. Introduction

Dried mango peel (DMP) has been suggested as a starting material for biorefinery to produce multiple coproducts for food and non-food applications, such as bioactives, antimicrobials, adsorbents, pharmaceutical excipients, enzymes, ethanol, and fuel (Banerjee et al., 2017; Geerkens et al., 2013, 2015a; Nagel et al., 2015, 2017; Nagle et al., 2011; Puligundla et al., 2014). As DMP is only seasonally producible (Okino-Delgado and Fleuri, 2016), its economically viable integration into supply chains as a commodity is crucial. Our previous feasibility study (Nagel et al., 2014), based on small-scale hot-air drying of the perishable industrial peel waste, has turned out the intricacies of processes that yield storable DMP having best possible functional properties for year-round production of dietary fiber, pectins, and antioxidants. Adequate preprocessing of fresh peel proved essential for both DMP quality and time- and energy-efficient drying. Beyond that, various technological issues at all levels from fruit processing to DMP distribution may affect feasibility of DMP production at fruit processing sites.

Early prevention of skin browning during preparation of the fruit for processing may become crucial, since enzyme inactivity restricts oxidative polymerization and insolubilization of bioactive target compounds (Cheynier, 2005). The skin color of the fruit can thus be indicatory for the upgrading of peel waste. Concurrently, an outstanding peel color might generate a unique added value that can qualify derived fiber products for special application fields (Endress and Fischer, 2001; Gondi et al., 2017), compared to peel powders of other sources (Panouillé et al., 2007). All this may suggest initial steaming or hot-water blanching of mango fruit. Commonly, such treatments facilitate peeling (Dube et al., 2004; Vásquez-Caicedo et al., 2007) or improve the quality of fruit products by enzyme inactivation near the fruit surface (Askar and Treptow, 2001) and by reducing the microbial load. Steam blanching of fruit may favor the purity of extractable pectins, but leaching of other target compounds is likely (Geerkens et al., 2015a,b). Knowledge of associated effects on skin color may facilitate process adaptation. Like possible target compounds (Geerkens et al., 2015a,b; Sirisakulwat et al., 2008), ripening-related changes in skin color and polyphenol oxidase activities vary among cultivars (Vásquez-Caicedo et al., 2004).

The resources needed for peel drying are still the major challenge in upgrading mango peel. Based on electrical energy, microwave drying can be an alternative to mere convective drying (CD), since direct energy absorption within the product due to dipole rotation and ionic polarization enables higher process speeds and significant energy savings (Schiffmann, 2006). Electricity generation involving renewable energy sources may contribute to reduce the use of fossil fuel (Orsat et al., 2007). Especially in high-volume applications, potential savings in energy, carbon footprint, and/or space may offset capital costs (Tewari, 2007). At high throughput for later biofuel production, continuous microwave-convective drying (CMWC) of seeds (Fennell et al., 2015) and bagasse biomass (Fennell and Boldor, 2014) on a conveyer belt in a traveling wave applicator proved most efficient at ambient air temperatures. The best microwave power levels for such materials of low and high initial moisture were 600 and 200 W, respectively. The low air temperature was crucial to keep the products < 100 °C (Fennell et al., 2015; Fennell and Boldor, 2014). Changes of dielectric properties during drying due to rising product temperature and declining moisture contents (Calay et al., 1995) and non-uniform distributions of field intensity may require additional control of the product temperature. Depending on uniformity, composition, shape, and size of the products, field-averaging methods may be essential to prevent local scorching and to ensure acceptable product quality. This can be the control of power density by adjusting the microwave energy gradually (Ahrné et al., 2007; Botha et al., 2012) or intermittent microwave-convective drying (IMWC) (Arikan et al., 2012; Esturk et al., 2012; Xu et al., 2012). Alternating power-on and power-off times result in microwave pulses that are interrupted by tempering intervals for temperature equalization (Gunasekaran and Yang, 2007; Kumar et al., 2014a) and the improved transfer of moisture from the center to the surface (Kumar et al., 2014b). IMWC and CD were reported to yield red pepper of comparable sensory quality (Soysal et al., 2009b), but unacceptably high losses of essential oils were found for IMWC-dried oregano (Soysal et al., 2009a). For materials such as osmotically dehydrated pineapple, microwave energy was chiefly useful in the early stages of drying to speed up the process (Botha et al., 2012). In other cases, volume heating may be more beneficial in the falling-rate period, when CD becomes a slow process (Ahrné et al., 2007).

Finally, packaging may be another major issue, since it greatly affects the costs of every logistical activity in DMP distribution and thus the productivity of dried peel and derived coproducts (Twede and Harte, 2011). In storage and distribution of dry, free-flowing feedstuff or industrial intermediate products (e.g., cereal grains, sugar), flexible intermediate bulk containers (FIBC) made of woven polypropylene (PP) fabrics have become common. Great tensile strength and resistance of the latter plus the hydrophobicity and notably low density of PP (900–915 kg m^{-3}; Lee et al., 2008) are the crucial factors (Kirwan et al., 2011). Lamination or coating of the otherwise breathable fabrics may protect the densely packed granules or flakes by additional gas and moisture barriers (Kirwan et al., 2011) and prevent leakage of fine particles, while dustproof inner foil bags are preferred for powders. The key role of packaging is protecting the dry product from moisture. For dried fruits, a maximum water activity (a_w) of 0.6–0.7 at 20 °C has been deemed tolerable (Lee et al., 2008). The moisture content of dried mango slices was shown to be ~17 g hg^{-1} at a_w = 0.6 (Pott et al., 2005). The tolerable maximum gain in moisture during storage of dried foods has been assumed to be ~1% (Lee et al., 2008). The minimal moisture barrier properties for storage and handling under ambient conditions depend on the temperature and humidity fluctuations that have to be expected for different distribution scenarios.

Accordingly, the focus of this feasibility study was on the integration of DMP production into the supply chain. Technological options for the three aforesaid process stages were to be examined on the pilot plant scale in terms of efficiency and the effects on properties that qualify DMP for the production of bioactive peel powders, pectins, and antioxidants. The applicability of (1) fruit blanching in hot water and (2) IMWC of peel in a continuous belt dryer was to be evaluated for different mango cultivars. Finally, storability of resultant DMP in different climate zones was to be assessed by real-time shelf life studies to identify the minimum protection levels that FIBC should ensure under ambient conditions.

2. Material and methods

2.1. Mango fruits and fresh peel waste

Directly after manual knife peeling of fully ripe ‘Nam Dokmai’ (NDM) and ‘Maha Chanok’ (MHC) fruit for industrial processing, fresh mango peel waste (MPW_0) was collected and converted into single-cultivar byproducts on the pilot plant scale (*cf.* Section 2.3) in close vicinity to the residue outlet of the peeling lines in Chiang Mai, Thailand, during seasons 2010 and 2011 (February–June).

Fruits for the use in fruit blanching experiments (*cf.* Section 2.2) were taken directly after postharvest ripening from one of the lots that were used per cultivar for industrial processing in each season.

2.2. Fruit blanching experiments

To evaluate inactivation of polyphenol oxidase (PPO) by blanching the whole fruit before peeling, fully ripe ‘Nam Dokmai’ fruits of season 2010 were blanched at each temperature *T* (70, 75, 80, 85 °C) for 0, 1, and 5 min, respectively, in a water bath WBU45 (Memmert, Schwabach, Germany) (5 fruits in 30 L). At the end of blanching, the