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Kinetics of almond skin separation as a function of blanching time and temperature

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ABSTRACT

This study was undertaken to better characterize the process of almond seed coat (a.k.a. skin) separation via hot water submersion, a process often referred to as 'blanching'. The degree of skin separation on individual almonds was measured after varying treatment times and temperatures, and modeled empirically. At all tested temperatures (100–70 °C), separation progressed along a sigmoidal logistic curve. Applying the concepts of microbial lethality kinetics to seed coat separation, $D_{separation}$ values were 24 s at 90 °C (194 °F), 118 s at 80 °C (176 °F), and 443 s at 70 °C (158 °F). From these, the $z_{separation}$ value between 70 °C and 90 °C was 15.85 °C. The skin separation rate decreased quickly below 90 °C (194 °F). By comparing the rate of seed coat separation, almond varieties, as well as growing, harvesting, and processing conditions could be quantitatively evaluated for their impact on skin separation.

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1. Introduction

California produced nearly 1.7 billion pounds of almonds in 2010, earning nearly $2.7 billion (Almond Board of California, 2011). Many of these were blanched (seed coat removed using hot water) for use whole, and as slices, dices, slivers, and almond flour (Harris et al., 2012). Despite the prevalence of this postharvest treatment, the optimal conditions of the blanching process are poorly characterized. The general protocol for almond blanching includes exposing the almond kernels to 85–100 °C water for 2–5 min, and then peeling off the skins (Almond Board of California, 2009).

Some almond cultivars have been shown to blanch more easily than others (Lampinen et al., 2002). In consulting with growers and processors, some harvest and postharvest processes are suspected of affecting skin adherence and ease of blanching. These include orchard growing temperatures and watering schedules, almond maturity at harvest, drying method, and stockpiling and pasteurization conditions. Despite the industry perception that some or all of these processes affect the ease of blanching, there is no information in the published literature pertaining to tailoring the blanching protocol to compensate for these factors. Over-blanching can lead to deleterious texture, flavor, nutrient, and color changes, while under-blanching fails to remove enough skin, necessitating costly reprocessing.

Understanding the kinetics of how almond skin separates from the kernel during blanch-processing can help optimize the process to save energy and lower production costs. Blanch-processing can also be used as a model system for exploring and quantifying unintentional seed coat separation, which grades as a defect according to USDA standards.

This study examines the effects of water temperature and duration of exposure on almond skin adherence in order to uncover the kinetics of the almond seed coat separation process. Quantification of the skin separation response can also be used as a more precise method of evaluating the effect of various pre-harvest and postharvest treatments on almond skin adherence.

1.1. Seed coat development

As shown in Fig. 1, the seed coat develops from the inner and outer integuments of the ovule (*OI* and *II*, respectively). These are maternal tissues that surround the nucellus and enclosed female gametophyte. An inner cell layer, thought to be endosperm (marked *En*), often adheres to the seed coat. If it is the endosperm, it is a triploid nutrient tissue that resulted from double fertilization; the other fertilization event produced the embryo. In genetic terms, the endosperm is neither maternal nor embryonic (Hawker and Buttrose, 1980). The peeled almond nut is almost entirely embryonic cotyledon tissue (*Co*), with only a small embryonic axis

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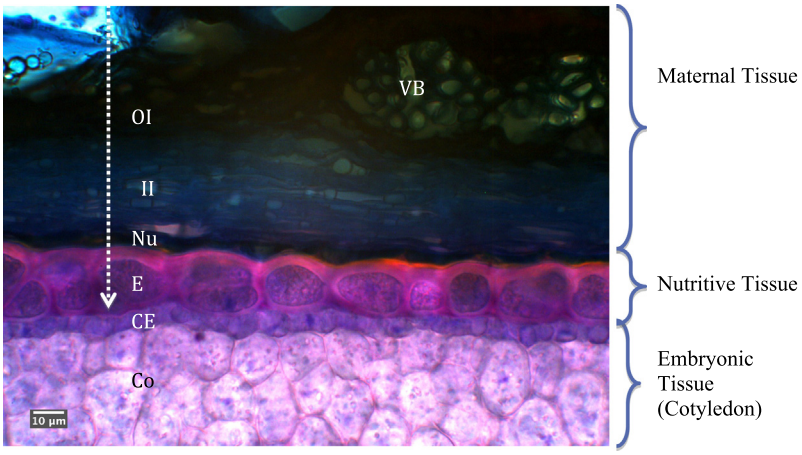

Fig. 1. Micrograph of a Nonpareil almond seed in cross-section, stained with toluidine blue O, showing the layers that originated from maternal tissue (outer integument, *OI*; inner integument, *II*; vascular bundles, *VB*; nucellus, *Nu*); from the triploid nutritive tissue (endosperm, *En*), and from the embryonic tissue (cotyledon epidermis, *CE*; and underlying cotyledon tissue, *Co*). Arrow indicates the seed coat layers that dissociate from the embryo during seed coat separation.

to which the cotyledons are attached; the most superficial cell layer of the peeled almond is the cotyledon *epidermis* (*CE*).

During development, nutrients pass from the maternal tissue to the embryo through vascular bundles (*VB*) within the seed coat (Sarfatti, 1960). There is no direct vascular connection between the embryo and maternally derived tissue such as the seed coat (Pascual-Albero et al., 1998). The seed coat tissue begins to degenerate and its innermost cells collapse around 14–16 weeks after bloom, and it is dried out by 28 weeks (Hawker and Buttrose, 1980). Hull-split generally occurs 30–35 weeks after bloom, depending on the heat exposure experienced by the tree (Hawker and Buttrose, 1980; Kester et al., 1996). In Northern California, bloom usually occurs in mid to late February and hull split occurs between late August and early September.

The mature seed coat is comprised of 14.30% fat, 3.66% soluble sugars, and 10.50% protein, on a dry weight basis. It is high in pectin, while gum and mucilage content is only 0.23% (Saura-Calixto et al., 1983).

At almond maturity, the microscopic residual monolayer of endosperm cells is firmly attached to the nucellar remnant and integuments, together making up the seed coat or "skin" of the almond kernel (Kester et al., 1996; Mandalari et al., 2010). The maternal tissue, triploid nutrient tissue, and embryonic tissues fit tightly together.

1.2. Current understanding of seed coat separation

There is little published information on the mechanism of seed coat separation in almonds. It is known that the cleavage point of tissues during seed coat separation (Fig. 1, arrow) is always located between the cotyledon epidermis and a persistent monolayer of cells that are considered to originate from the endosperm (Mandalari et al., 2010). The maternal tissue and residual nutrient tissues separate from the embryonic tissue. This location of separation is consistently observed, regardless of whether thermal or non-thermal methods (successive liquid nitrogen dips) are used to separate the seed coat, as shown by Mandalari et al. (2010). In other words, the location of seed coat separation is not an artifact of heat exposure.

Beyond the specificity of the tissue cleavage location and its independence from heat, nothing has been published about *why* seed coats separate from the cotyledons at this boundary, the mechanism by which the separation progresses, or how temperature and duration of submersion in hot water affect the rate of seed coat separation. The only clues to these lingering questions are case studies of circumstances where seed coat separation has been observed.

Seed coat separation has been observed in cases of over-drying in batch dryers, especially in almonds close to the heat-source at the bottom of bin-driers (time and temperature conditions unspecified). Brittleness of the seed coat was seen in conjunction with brittleness of the nutmeat itself (Thompson et al., 1996).

Paulsen and Brusewitz (1976) determined that in peanuts, seed coats have a smaller coefficient of thermal expansion than do the skinless peanut kernel, and therefore peanut seed coats separate as peanut kernels expand faster than the seed coats. In contrast, our preliminary experiments on almond seed coat separation using hot water indicate that almond skins expand faster than kernels in this experimental system; however, this was examined more closely as part of the scope of this research.

Seed coat separation was strikingly more prevalent in the 2008 harvest crop, compared to previous years. This trend was reportedly seen across the entire California growing region (personal communication, Almond Board of California), and caused speculation regarding the effect of cultivation and processing variations such as growing temperatures, watering sources and schedules, almond maturity at harvest, and the use of circulating hot air driers on seed coat adhesion.

This project explored the kinetics of almond seed coat separation as a function of hot water treatment duration and temperature. Development of an empirical model of almond skin separation in response to these variables will facilitate optimization of the blanch-processing, allowing for measurement and characterization of the seed coat separation process.

2. Methods and materials

2.1. Raw materials

Almonds used in kinetics modeling experiments were harvested over the 2009–2011 seasons from almond orchards maintained by the UC Davis Department of Plant Sciences. These almonds were harvested at commercial maturity and hulled before storage in plastic bags at room temperature, out of the sunlight, until use.

Almonds used in all experiments were the Nonpareil variety. Individual almonds exhibiting any USDA graded defects were excluded from study.

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