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Integrated agronomical and technological approach for the quality maintenance of ready-to-fry potato sticks during refrigerated storage

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ABSTRACT

The paper addresses the effect of nitrogen fertilization rate, storage time, packaging film and locust bean gum (LBG)-based edible coating on the quality maintenance of fresh-cut ready-to-fry potato sticks. Quality change was assessed monitoring color and firmness, microbiological parameters and content of bioactive components. Results demonstrate that the highest (280 kg ha^{-1}) nitrogen fertilization rate determines rapid color changes, lower firmness and faster microbial (total mesophilic bacteria and yeasts and molds) growth. Similarly, excess in nitrogen fertilization rate determines lower ascorbic acid levels and a faster loss of nutritional value during storage, while the LBG coating was effective at reducing color changes and microbial growth. Results highlight the need for accurate management of nitrogen fertilization in order to obtain high quality fresh-cut potato sticks, and point out that excess nitrogen fertilization levels enhance the proneness to physical, microbial and nutritional changes.

1. Introduction

In areas characterized by mild winters, such as southern Italy, potatoes are largely grown in a winter–spring cycle (planting from November to January and harvesting from March to early June) for early production. The positive health-promoting effects of potatoes have recently been addressed (Akyol et al., 2016). This positive role relies on many natural antioxidants such as polyphenols, carotenoids, tocopherols, ascorbic acid and selenium (Hamouz et al., 2007).

The total content of phenolic compounds could be a cultivar characteristic (Méndez et al., 2004), but it can be greatly modified by harvesting, post-harvest, and technological processes (Akyol et al., 2016). The early potato crop needs adequate levels of N for a fast plant growth (Ierna et al., 2011). Consequently, the management of N fertilization is crucial for improving crop productivity, earliness and tuber quality. However, excess N supply can carry environmental problems such as groundwater nitrate contamination, release of greenhouse gases and eutrophication of aquatic ecosystems, and may cause plant diseases and an increased amount of nitrates in the tubers.

The application of minimal processing increases perishability due to increased metabolic activities and decompartmentalization of enzymes and substrates. This may cause browning, softening and off-flavor development (Cabezas-Serrano et al., 2009; Gunes and Lee, 1997). Bacteria and fungi generally contaminate the peel of potatoes due to their close proximity with soil and their metabolic activity could limit the potato shelf life, also at refrigerated temperatures. Although during processing a washing step with chlorinated water is generally adopted to reduce microbial contamination, the sanitizing efficacy will depend on the microbial load of raw material, but also on the sensitivity of the microorganism and the accessibility of the agent or of the treatment to the microbiological populations; all these factors strongly affect the microbiological quality of fresh-cut potatoes.

To improve quality of fresh-cut products, surface treatments involving dipping into aqueous solutions containing antimicrobial agents, antioxidants, calcium salts or functional ingredients are widely practiced (Lombardo et al., 2017; Muratore et al., 2015; Oms-Oliu et al., 2010). Other than extending the shelf life of minimally processed potatoes, dipping into coating solutions has been evaluated for decreasing fat absorption and moisture loss during frying (Kilincceker and Hepsag, 2012). Locust bean gum (LBG) is characterized by high thickening and film-forming ability, its rheological properties being influenced by the galactose distribution in the mannose linear chain and xylose content (Rizzo et al., 2004). LBG has been effectively used as edible coating to maintain quality of fruit, serving as carrier of biocontrol agents (Aloui et al., 2015; Parafati et al., 2016), and/or antimicrobial natural compounds (Aloui et al., 2014).

As it has been demonstrated for other crops (Lombardo et al., 2017), different nitrogen fertilization levels might influence the suitability of

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potatoes to minimal processing; moreover, a suitable combination of pre-harvest and minimal processing factors is crucial for the quality maintenance of a fresh-cut product. Considering the lack of specific literature on minimally-processed potatoes, the aim of this study was to evaluate the effects of nitrogen fertilization rate, packaging film and coating on the quality maintenance of fresh-cut ready-to-fry potato sticks.

2. Materials and methods

2.1. Field experimental design, plant material and management practices

The experimental field trial was conducted at a commercial farm located on the coastal plain of Siracusa (37° 01′ N, 15° 12′ E, 30 m above sea level), an area typical for 'early' crop potato cultivation in southern Italy. The soil type is a calcixerollic xerochrepts (USDA, 1975), with pH 7.7 and a soil composition of 48% sand (2–0.02 mm), 18% silt (0.02–0.002 mm), 34% clay (< 0.002 mm), 6% limestone, 1.8% organic matter, 0.2% total nitrogen, 0.0028% available P_2O_5 and 0.018% exchangeable K_2O.

Disease-free, non-pre-sprouted "seed" tubers of cv. Bellini, from a single seed lot, were manually planted adopting a planting density of 4.5 plant m^{-2}. This cultivar was recently used for conventional production of "early" potato in the Mediterranean Basin, where it showed a good adaptation to its pedoclimatic conditions. It has yellow skin and pulp, and is a B cooking type (i.e. multi-purpose cooking) according to the E.A.P.R. (European Association for Potato Research) cooking type scale.

The experiment employed three nitrogen fertilization rates: 0 (as a control), 140 and 280 kg N ha^{-1}, hereafter referred to as N_0, N_{140} and N_{280}, respectively. The highest fertilizer rate (N_{280}) reflected common commercial usage among Sicilian producers. Each plot consisted of 40 plants. A randomized complete-block design with four replicates was adopted. N was soil-applied incorporated by mineral source (ammonium nitrate, at 26% of N) and the total amount was split in 2 applications (10 and 40 d after transplant). Besides the different nitrogen fertilization rates, prior to planting, all plots received the same base fertilization consisting of 80 kg P_2O_5 ha^{-1} and 140 kg K_2O ha^{-1} as mineral phosphate (19% of P_2O_5) and potassium sulphate (50% of K_2O), respectively. Drip irrigation was started once the accumulated daily evaporation rate had reached about 30 mm and the total water supplied was 135 mm. Weed and pest control followed standard commercial practice.

Tubers were harvested manually at the end of the cycle (about 120 d after planting), when about 70% of haulms were fully desiccated.

2.2. Postharvest treatments

A representative sample [each made of at least 120 marketable tubers (35–70 mm), of uniform size and disease-free] for each N fertilizer rate was transported to the Di3A laboratories and processed within 24 h. Tubers were washed with tap water, peeled and cut in sticks (45 × 10 × 10 mm) using a manual cutting machine; finally, they were washed for 5 min with a sanitizing sodium hypochlorite solution (active chlorine 0.23 g L^{-1}). After removing the excess water by manual centrifugation, stick potatoes were dipped into 1% w/v calcium citrate solution (Sigma-Aldrich, Milan, Italy) for 10 min.

2.3. Coating formulation, samples preparation and packaging

The coating was prepared dissolving 10 g Locust Bean Gum (LBG) in 100 mL water at 70 °C for 30 min with constant stirring, until all particles were thoroughly dispersed. Glycerol 1% was added as plasticizer to the LBG solution, then the mixture was placed in ice bath to lower the temperature before use. LBG and glycerol were provided by Sigma-Aldrich (Milan, Italy)

Potato sticks belonging to each nitrogen fertilization rate (N_0, N_{140} and N_{280}) were divided into 4 homogeneous lots and treated as follows:

1 Uncoated, packaged in film A: coextruded polypropylene, thickness: 19 μm; oxygen transmission rate: 1.91×10^{-6} mol m^{-2} s^{-1}; (SP/BY – System Packaging s.r.l., Siracusa, Italy).
2 Uncoated, packaged in film B: cast polypropylene, thickness: 30 μm; OTR: 1.55×10^{-6} mol m^{-2} s^{-1} (Coralife SW AF N – Corapack s.r.l., Como, Italy).
3 Coated with LBG film forming solution, packaged in film A
4 Coated with the LBG film forming solution, packaged in film B

For the last two lots, potato sticks were dipped in the coating solution for 5 min, drained and dried at room temperature for 2 min before packaging. For all lots, about 15 potato sticks (160 ± 6 g) were placed on polypropylene trays (190 × 137 × 38 mm) and sealed in ordinary atmosphere into bags previously prepared with the above-mentioned films.

All samples were stored under refrigerated conditions at 4 ± 1 °C and 90–95% RH until analyses. The determination of quality parameters was performed on 3 replicate bags for each batch after 0 (production day), 4 and 8 d of storage.

2.4. Headspace gas composition analysis

The headspace oxygen and carbon dioxide partial pressures were monitored during the shelf life by a Dansensor Checkpoint portable gas analyzer (Dansensor, Ringsted, Denmark) on three replicates, analyzing 10 mL of the package headspace. An estimation of the respiration rate after 4 days of refrigerated storage was made using the permeable method, considering an average product weight of 160 g, an average headspace volume of 1000 mL, and the permeability values reported in Section 2.3.

2.5. Color determinations

Surface color was measured according to CIE L*, a*, b* scale using a portable chromameter (NR-3000, Nippon Denshoku Ind. Co., Ltd., Japan). The instrument was previously calibrated with a standard white tile (UE certificated) with the following parameters: X = 83.47, Y = 84.43, Z = 95.16 with illuminant C/2° (lightsource used for the daylight). Data, for each treatment, are the mean values of 12 measurements (2 measurements × 6 potato sticks, randomly chosen from 3 bags).

In order to better assess the overall color changes during storage, the total color difference ΔE* was calculated as follows (Licciardello and Muratore, 2011):

$$\Delta E^* = (\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})^{1/2}$$

2.6. Texture profile analysis

The texture properties were evaluated measuring the maximum shear force using a ZwickRoell z 0.5 Texture Analyzer (Zwick GmbH & Co., Ulm, Germany) provided with a 500 N nominal force load cell and a stainless steel probe (length 5 mm). Cutting tests were carried out at the following conditions: preload 0.2 N, test speed 20 mm min^{-1}. Firmness was expressed as the maximum force (Fmax, N): data were determined on three sticks for each of the three replicate samples and were stored and elaborated by the Testxpert II v. 2.2 software (Zwick GmbH & Co., Ulm, Germany).

2.7. Microbiological analyses

Ten grams of potato sticks were removed from each package in