Journal of Food Engineering 216 (2018) 42–51

Contents lists available at ScienceDirect

Journal of Food Engineering

journal homepage: www.elsevier.com/locate/jfoodeng

Kinetics of colour changes in pasteurised strawberry juice during storage

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ARTICLE INFO

Article history:
Received 22 March 2017
Received in revised form
3 July 2017
Accepted 2 August 2017
Available online 4 August 2017

Chemical compounds:
Ascorbic acid (PubChem CID: 54670067)
Cyanidin-3-glucoside (PubChem CID: 92131208)
Dehydroascorbic acid (PubChem CID: 440667)
Pelargonidin-3-glucoside (PubChem CID: 443648)
Pelargonidin-3-malonylglucoside (PubChem CID: 443913)

Keywords:
Color changes
Storage
Accelerated shelf-life testing
Kinetics
Strawberry juice

ABSTRACT

Colour changes during storage are an important quality defect of fruit-based products. Therefore, this work investigated the effect of storage time, storage temperature and oxygen availability (through the type of bottle) on changes in CIEL^*a^*b values, anthocyanin and ascorbic acid content of shelf-stable strawberry juice (produced with a spiral-filter press under vacuum conditions) using kinetic modelling. The colour-related attributes changed significantly during storage at ambient (20 °C) and accelerated temperatures (28–42 °C) in both types of bottles. The change in all attributes was accelerated at higher storage temperatures. A higher oxygen availability resulted in a faster change of all attributes. As oxygen availability was not fully controlling colour changes, they are caused by complex oxidative and non-oxidative reactions. The results of this work demonstrate the applicability of a kinetics-based accelerated shelf-life testing approach to obtain faster insight into colour changes of strawberry juice and to be used for shelf-life investigations.

1. Introduction

Strawberries (*Fragaria x ananassa*) are one of the most popular berry fruits worldwide because of their attractive colour, pleasant flavour and the presence of different bioactive compounds. They can be consumed fresh and are processed into different products such as juices and jams (Cao et al., 2012; Giampieri et al., 2012). One of the main problems of strawberry-based products (e.g. shelf-stable strawberry juice) is that their red colour easily changes upon storage and is replaced by a dull brownish colour (Gössinger et al., 2009). This is the result of the simultaneous degradation of natural red anthocyanin pigments to colourless compounds (Kirca & Cemeroğlu, 2003; Mercadante and Bobbio, 2008) and the formation of brown pigments due to enzymatic and/or non-enzymatic reactions (Bharate and Bharate, 2014; Garzón and Wrolstad, 2002; Gössinger et al., 2009). In shelf-stable pasteurised strawberry juice, browning is primarily related to non-enzymatic reactions because quality-degrading enzymes are inactivated by the applied thermal treatment. Non-enzymatic browning reactions are related to ascorbic acid (AA) degradation, Maillard-associated reactions and acid-catalysed sugar degradation. Intermediates of AA and sugar degradation, such as carbonyl compounds, can polymerise or can react with amino acids and participate in Maillard-associated

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http://dx.doi.org/10.1016/j.jfoodeng.2017.08.002

List of abbreviations

AA	ascorbic acid
ASLT	accelerated shelf-life testing
DHAA	dehydroascorbic acid
DKG	2,3-diketogulonic acid
JCR	90% joint confidence regions
OTR	oxygen transfer rate
PET	polyethylene terephthalate
SSE	error sum of squares

List of symbols

$\alpha_{T,\ T_{ref}}$	acceleration factor at temperature T compared to a reference temperature T_{ref}
a^*	colour index from greenness to redness
b^*	colour index from blueness to yellowness
ΔE^*	total colour difference
E_a	activation energy (kJ/mol)
k_T	apparent reaction rate constant at a temperature T
k_{Tref}	apparent reaction rate constant at a reference temperature T_{ref}
L^*	colour index for degree of lightness
n	order of a reaction
R	universal gas constant (8.314 J/mol K)
$R^2_{adjusted}$	adjusted coefficient of determination
T	storage temperature (°C or K)
t	storage time (weeks)
T_{ref}	reference temperature (20 °C or 293 K)
X	response at time t
X_0	initial response before storage ($t = 0$ weeks)
X_f	plateau response which is stable as a function of time

reactions to form brown-coloured pigments (melanoidins) (Belitz et al., 2009; Bharate and Bharate, 2014; Roig et al., 1999; Yuan and Chen, 1998). In other words, browning in strawberry juice represents a complex case of colour changes due to multiple simultaneous reactions. Furthermore, anthocyanin degradation and non-enzymatic browning reactions are affected by different factors, including pH, the concentration of AA, sugars and amino acids, oxygen availability and processing and storage conditions (Bharate and Bharate, 2014; Castañeda-Ovando et al., 2009; Mercadante and Bobbio, 2008).

Although browning of fruit-based products during storage was already investigated intensively, there is still a limited understanding of this problem (Bharate and Bharate, 2014). Nevertheless, it is important for food industries to prevent colour changes during storage, as consumers associate an unattractive food colour with poor quality. In addition, food colour will determine product acceptability and consumer purchase behaviour and the market value of a discoloured product will be reduced (Garzón and Wrolstad, 2002; Wrolstad et al., 2005).

The shelf-life of shelf-stable fruit-based products, such as strawberry juice, is primarily determined by colour changes during storage (Cao et al., 2012; Gössinger et al., 2009; Wang et al., 2015). Therefore, the main objective of this work was to gain quantitative insight into changes in colour-related attributes such as CIE $L^*a^*b^*$ values, anthocyanin and vitamin C content of shelf-stable strawberry juice during storage. More specifically, the effect of three storage factors, namely storage time, storage temperature and oxygen availability (related to the type of bottle), on changes in selected colour-related attributes was evaluated on a kinetic basis. As an innovative processing strategy, a shelf-stable strawberry juice was produced under low oxygen conditions in a spiral-filter press. By this, the impact of oxidative reactions on the colour during juicing was minimised and colour changes were mainly related to storage. Strawberry juice was stored at ambient (20 °C) and three accelerated temperature conditions (28–42 °C) in two types of PET (polyethylene terephthalate) bottles with a different oxygen transfer rate (OTR). To the best of our knowledge, kinetic parameters, and especially activation energies, describing changes in colour-related attributes of shelf-stable strawberry juice during storage are scarce in literature, thereby showing the need for this comprehensive study. Kinetic data will allow to describe colour changes with mathematical equations, to have a better understanding into the browning problem, to develop a science-based ASLT (accelerated shelf-life testing) approach to evaluate colour changes of strawberry juice and to perform shelf-life predictions.

2. Materials and methods

2.1. Preparation and processing of strawberry juice

One batch (450 kg) of fresh strawberries (*Fragaria x ananassa*, cultivar Elstanta) was supplied by Veiling Hoogstraten CVBA (Hoogstraten, Belgium) and was stored for one day in a cooling room (4 °C) before processing. Fresh strawberries were washed and were shredded in a Multicut system (Bruckner Liquid Food Tech, VaculIQ GmbH & Co. KG, Hamminkeln, Germany). During shredding, nitrogen gas was added to create an inert atmosphere to prevent oxidation. Next, the strawberry mash was processed into strawberry juice under vacuum conditions using a spiral-filter press (VaculIQ 1000-300, VaculIQ GmbH & Co. KG, Hamminkeln, Germany). By this, oxygen catalysed (enzymatic) reactions during juicing were minimised and a high quality juice was obtained (De Paepe et al., 2015). The strawberry juice was collected in a vacuum vessel which was directly connected to the spiral-filter press. Next, this vessel was connected to a UHT pilot plant installation (APV SPP, SPX Corporation, Gatwick, UK) to pasteurise the fresh strawberry juice. During pasteurisation, the juice was preheated to 65 °C, then heated to 95 °C and held at this temperature for 120 s. In the next step, the juice was cooled to 65 °C and subsequently to 9 °C. All heating and cooling steps were performed via an indirect tubular heat exchanger. The selected processing conditions were sufficient to produce a shelf-stable juice (Silva and Gibbs, 2004). The pasteurised juice was then manually filled under aseptic conditions into two types of 500 ml PET bottles, a standard monolayer bottle and a multilayer bottle with an extra oxygen barrier. Screw caps with an aluminium liner were used to close the bottles with induction sealing. The headspace of the multilayer bottles was flushed with nitrogen gas before closing. The OTR at 20 °C for a closed monolayer bottle (i.e. the configuration that was used in the storage experiment) was 0.0437 cm^3/(bottle day). According to the information sheet of the manufacturer, the OTR of a closed multilayer bottle at 20 °C was nine times smaller than the OTR of a closed monolayer bottle. Both types of PET bottles had a maximal diameter of 71 mm and the height until the neck was 177 mm. Bottles and caps were supplied by Resilux NV (Wetteren, Belgium) and were sterilised beforehand by gamma radiation (Synergy Health, Etten-Leur, The Netherlands). All processing steps were performed in the Food Pilot (Melle, Belgium).