Journal of Food Engineering 164 (2015) 40–54

Contents lists available at ScienceDirect

Journal of Food Engineering

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

Profiling multiple static and transient puff-pastry characteristics with a robust-and-intelligent processor

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ARTICLE INFO

Article history:
Received 28 October 2014
Received in revised form 25 February 2015
Accepted 9 April 2015
Available online 25 April 2015

Keywords:
Puff pastry
Non-linear screening
GRNN
Orthogonal arrays
Stochastic optimization
Intelligent and robust product improvement

ABSTRACT

Enhanced puff-pastry traits are important for competitive product development. We study the concurrent screening and optimization of four puff-pastry product characteristics: (1) an aggregate sensory performance score, (2) the physical height, (3) the pack weight and (4) the moisture content. The choice of the investigated properties is novel because it blends two static (dough) characteristics with two suspected transient (baked dough) responses. Four controlling factors were modulated directly on a modern production line: (1) the water quantity, the margarine temperature, the kneading time, and the lamination folding number. To allow exploring potentially non-linear response tendencies, data has been collected using design of experiments methods. A Taguchi-type orthogonal array ($L_9(3^4)$ OA) was implemented to program the experimental recipes. A new robust and intelligent processor is presented to decipher those effects that synchronously regulate the four selected responses and their respective optimal settings. Smart sampling is used to consolidate various sources of product/process uncertainties by deploying the effect-ranking capabilities of the general-regression neural networks. Nonparametric analysis furnishes the significance of the stochastic hierarchy of the examined effects. This research accentuates the anticipated messiness of the collected datasets and the complexity in handling the multiple types of blended information. The number of laminations is found to be the primary determinant of controlling overall product quality.

1. Introduction

Modern food-processing operations are continuously primed to offer competitive brand-lines by creating and fusing knowledge channeled from three major information streams. When product, process and consumer behaviors are intelligently captured and harmoniously equilibrated, the prospective customer base is bound to be enthralled. State-of-the-art product development requires a strong involvement of data-driven strategies that would permit gaining insight about what it is achievable and how to manufacture it (Singh and Heldman, 2013). Specifically, Taguchi methods have broadened the knowledge discovery tactics in food engineering (Besseris, 2009, 2014b). Taguchi methods originally flourishing in industrial projects for massive operations were geared toward enhancing quality and functionality issues in very diverse end-product lines (Taguchi et al., 2000, 2004). Key goal was to learn about a process and/or a product quickly relying on factual evidence which would guide next the amelioration journey while simultaneously minimizing the costs of the investigation itself. Taguchi methods became particularly popular because cost cutting was insidiously effectuated by conducting product/process screening and parameter optimization in a single step. This strategy also led to reducing enormously the cycle time of experimentation, thus immensely accelerating the decision-making process for product development/improvement. But screening is also an optimization activity since it intends to filter out any weak effects from the initial group of the examined controlling factors (Box et al., 2005). So screening eventually minimizes the original profiling objectives. Nevertheless, it is rare to encounter an acknowledgement in recent literature about the practical value of Taguchi methods in promoting the intermingling of the dual optimization aims through the concurrent exploitation of a single dataset to cope with both purposes (Besseris, 2013a,b). Furthermore, the greatest asset of Taguchi methods stems from the fact that they are directly adaptable to large-scale operations. Consequently, the trial volume needs to be limited and rapidly completed because experimentation detracts the production schedule by wiping out precious machinery availability. To drastically curtail the trial volume, Taguchi methods recommend the implementation of the orthogonal array (OA) designs. The OA-based samplers standardize the structured and cogent organization of experiments by

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http://dx.doi.org/10.1016/j.jfoodeng.2015.04.011
0260-8774/

Nomenclature

DOE	design of experiments
dm_{ij}	absolute difference of m_{ij} from T_{ms} ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)
dw_{ij}	absolute difference of w_{ij} from T_{ws} ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)
GRNN	general regression neural networks
FFD	fractional factorial designs
k	superscript for temporal indexing of responses, $k = 4, 7, 15, 26$ days
m	moisture content (%)
M_i	moisture content vector at the ith replicate ($i = 1, 2, \ldots, r$)
m_{ij}	moisture content vector elements at the ith replicate and jth recipe ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)
MR_j	master response at the jth recipe ($j = 1, 2, \ldots, 9$)
N_f	lamination folding number
NN	neural networks
OA	orthogonal array
PH	physical height (cm)
PH_i^k	PH vector on the kth day and ith replicate ($i = 1, 2, \ldots, r$)
ph_{ij}^k	PH vector elements on the kth day, ith replicate ($i = 1, 2, \ldots, r$) and jth recipe ($j = 1, 2, \ldots, 9$)
PH_{Mj}	median value of ph_{ij}^k across all replicates and time zones at the jth recipe ($j = 1, 2, \ldots, 9$)
PH_{IQRj}	interquartile range value of ph_{ij}^k across all replicates and time zones at the jth recipe ($j = 1, 2, \ldots, 9$)
Q_w	water quantity (l)
r	number of replicates
rdm_{ij}	rank-ordered dm_{ij} ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)
rdw_{ij}	rank-ordered dw_{ij} ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)
rm_j	rank-ordered $srdm_j$ ($j = 1, 2, \ldots, 9$)
rw_j	rank-ordered $srdw_j$ ($j = 1, 2, \ldots, 9$)
rPH_{Mj}	rank-ordered PH_{Mj} ($j = 1, 2, \ldots, 9$)
rPH_{IQRj}	rank-ordered PH_{IQRj} ($j = 1, 2, \ldots, 9$)
rSP_{pj}	rank-ordered SP_{pj} ($j = 1, 2, \ldots, 9$)
rSP_{CIj}	rank-ordered SP_{CIj} ($j = 1, 2, \ldots, 9$)
SP	aggregate sensory score
SP_i^k	SP vector on the kth day and ith replicate ($i = 1, 2, \ldots, r$)
sp_{ij}^k	SP vector elements on the kth day, ith replicate ($i = 1, 2, \ldots, r$) and jth recipe ($j = 1, 2, \ldots, 9$)
SP_{pj}	prediction of the SP vector elements on the 26th day for the jth recipe ($j = 1, 2, \ldots, 9$)
SP_{CIj}	prediction of the 95%-confidence interval SP vector elements on the 26th day for the jth recipe ($j = 1, 2, \ldots, 9$)
$srdm_j$	sum of rdm_{ij} on i ($j = 1, 2, \ldots, 9$)
$srdw_j$	sum of rdw_{ij} on i ($j = 1, 2, \ldots, 9$)
$ssrSP_j$	sum of squared ranks of SP_{pj} and SP_{CIj}
$ssrPH_j$	sum of squared ranks of rPH_{Mj} and rPH_{IQRj}
sSP_j	rank-ordered $ssrSP_j$
sPH_j	rank-ordered $ssrPH_j$
T_k	kneading time (min)
T_m	margarine temperature (°C)
T_{ms}	specification target for the moisture content characteristic (%)
T_{ws}	specification target for the weight characteristic (g)
w	weight response (g)
W_i	weight vector at the ith replicate ($i = 1, 2, \ldots, r$)
w_{ij}	weight vector elements at the ith replicate and jth recipe ($i = 1, 2, \ldots, r$; $j = 1, 2, \ldots, 9$)

exhibiting a high sampling efficiency which is engrained in all fractional factorial designs (FFDs) (Box et al., 2005).

Fractional factorial designs have been fruitful in screening the demanding rice flour extrusion (Guha et al., 2003). Direct applications of the regular Taguchi methodology on food engineering have been published mainly with respect to optimally conditioning various phenomena such as the pumpkin peeling (Emadi et al., 2007, 2008), the citric acid electrodialysis (Nikbakht et al., 2007), the microwave frying of potato slices (Oztop et al., 2007), the fluidized-bed drying of bird's eye chilli (Tasirin et al., 2007), the osmotic dehydration of yam bean (Abud-Archila et al., 2008), the enzymatic acidolysis of sunflower oil (Carrin and Crapiste, 2008), the blending of unifloral honeys (Dimou et al., 2009), and the free bi-axial rotary processing of canned suspensions (Ramaswamy and Dwivedi, 2011). Taguchi-type modulation of culture conditions involve examples from regulating the Monascus spp. culture (Chung et al., 2007), the lactic-acid media (Bhatt and Srivastava, 2008), and the culture preparation for tannase production (Das Mohapatra et al., 2009). The combined influence of mixture and processing variables to a group of rheological and textural characteristics has been investigated in thick syrup (Molina-Rubio et al., 2010). Multiple quality properties of an infant formula have been tested with the Taguchi method to adjust several pneumatic conveying parameters (Hanley et al., 2011). Extraction processes are suitable for optimization as exemplified by the cases of isolating triterpenoid saponins from *Ganoderma atrum* (Chen et al., 2007), the calcium removal in tuning a weak-cation exchange resin (Coca et al., 2010), the microwave extraction of *Chenopodium quinoa* wild (Gianna et al., 2012), the enzyme-assisted maceration of waste carrot-seed oil (Śmigielski et al., 2014) and in supercritical fluid extraction (Sharif et al., 2014).

Baking is a food processing activity that receives unabated attention (Cauvain and Young, 2006; Heenan et al., 2009; Purlis, 2011; Pouliou and Besseris, 2013). Such interest emanates from the multifaceted interplay of polymer-rheological phenomena that govern product properties that shape anything from the product quality status to shelf-life performance (Dobraszczyk and Morgenstern, 2003; Dobraszczyk, 2004; Caballero et al., 2007). The stochastic modeling of baked products is emphatically complex marred by a barrage of uncertainty sources (Rousu et al., 2003; Farid, 2010; Feyissa et al., 2012). In this work, we propose a hybrid intelligent technique to improve puff-pastry sensory performance while attempting a shelf-life requirement extension without relinquishing the target conformance of some key physical characteristics. Puff pastries are baked dough preparations that are enjoyed by many cultures around the world. Puff pastries are distinct for their multiple sandwiching of margarine and dough layers – by the lamination process of folding and rolling out – that makes their resulting flakiness so appealing to consumers. However, work on manipulating simultaneously puff-pastry key controlling parameters such as the kneading time, the lamination level, the added water quantity and the margarine temperature are rather absent in the modern literature (Qia et al., 2008; Wang et al., 2013). The combination of the stated controlling factors while appearing restricting, nevertheless, they implicate the important rheological aspect of the gluten-polymer structure in terminal product transient phenomena (Sliwinskia et al., 2004; Yi and Kerr, 2009).

The unique experimental logistics and the novel multi-response multi-factorial modeling developments of the highlighted puff-pastry case study will be greatly elucidated. A non-linear Taguchi-type OA-sampler programs the data collection for tracking