Aquacultural Engineering 54 (2013) 64–71

Contents lists available at SciVerse ScienceDirect

Aquacultural Engineering

journal homepage: www.elsevier.com/locate/aqua-online

Digital image analysis as a tool to quantify gaping and morphology in smoked salmon slices

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ARTICLE INFO

Article history:
Received 23 January 2012
Accepted 15 November 2012

Keywords:
Image analysis
Image segmentation
Smoked salmon
Gaping
Slice quality
Slice shape

ABSTRACT

Gaping in salmon fillets refers to the appearance of slits in the muscle. This is unsightly and leads to downgrading and hence economical loss, particularly for salmon smoke houses. Present day manual and semi automatic methods for quantifying gaping are labour intensive and subjective. This study presents an automated and objective image analysis method for quantifying gaping in smoked salmon slices. The slices are first photographed in a photobox and then analysed by the fully automated image analysis method. The method has four main steps: (1) pre-processing, (2) segmentation of slices from the background, (3) labelling of each slice, (4) identification of gaps within the slices (holes), (5) identification of gaps on the perifery (notches) and (6) quantification of gaps and notches. The results obtained by the automatic image analysis are visually convincing and there is a strong correlation with manual quantification of gaps ($r = 0.83$, p-value < 0.05). The automatic image analysis method can easily be extended to also include morphological parameters as shape, red and white muscle area, myocommata and myotome area. Interestingly, the automatic image analysis demonstrated that gaps are strongly associated with white, and not red, muscle tissue.

1. Introduction

Intrinsic characteristics such as colour, texture (the physical feel of the substance), gaping (appearance of slits in the axial muscle) and chemical composition are important for salmon fillet quality (Rasmussen, 2001). During processing the evaluation of salmon fillet quality is performed on the level of raw fillets (Andersen et al., 1994; Ashton et al., 2010; Roth et al., 2009), smoked fillets (Birkeland et al., 2004) and smoked fillet slices (Bernardi et al., 2009; Espe et al., 2004a).

In whole salmon fillets gaping appears as slits, whereas in smoked salmon slices gaping appears as holes in the slices (gaps) and notches into the slice borders. The estimation of gaping is typically done by visually grading fillets or fillet slices, either by counting gaps according to the "Andersen scale" (Andersen et al., 1994) or by evaluating the area covered by gaps (Kiessling et al., 2004). These methods rely on manual assessment by trained evaluators using standardised methodology. Consequently, the significant disadvantages of available approaches for gaping evaluation is that they are both labour demanding and subjective (Lavety et al., 1988; Robb, 2001). There is therefore a need for automated and objective methods for assessing gaping in salmon flesh.

Automated image analysis is a modern and efficient approach for monitoring quality traits in salmonids such as colour (Misimi et al., 2007; Quevedo et al., 2010; Stien et al., 2006), fat content (Stien et al., 2007), amount of red and white muscle (Stien et al., 2006), myocommata and myotome positions (Stien et al., 2006, 2007) and shape (Stien et al., 2006). The evaluation of gaping by using digital photography and computer image analysis can provide accurate and re-analysable data (Ashton et al., 2010). Recently Balaban et al. (2011) developed a semi-automatic method for analysing gaping in salmon fillets using a manually set threshold (Gonzalez and Woods, 2008) for each individual fillet image, where pixels on the fillet surface darker than the selected threshold are classified as gaping. As recognised by the authors, the recently proposed method for gaping evaluation will inherently lead to a certain bias in the threshold determination (threshold to produce two levels (binary) images from grayscale images (Glasbey and Horgan, 1995), as well as error when other dark parts on the fillet surface, such as melanin spots and bruises are mistakenly classified as gaping (Balaban et al., 2011).

Gaping is often concealed in salmon fillets and difficult to spot without handling the fillet (Michie, 2001) or disposing fillets skin-down over a surface with convex curvature (Ashton et al., 2010). Meanwhile, these hidden gaps are clearly revealed as gaps and

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http://dx.doi.org/10.1016/j.aquaeng.2012.11.003

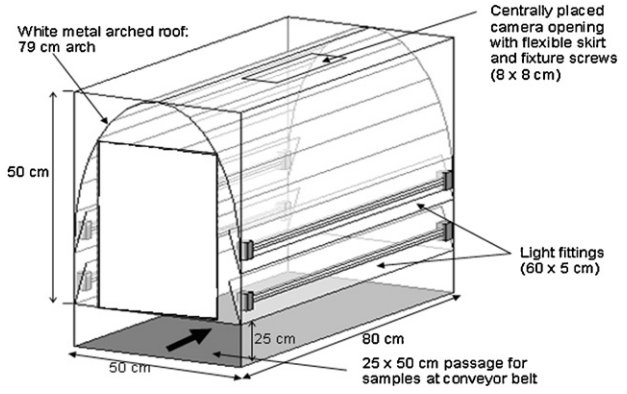

Fig. 1. Photobox (SeaSide AS).

notches once the fillet is sliced. The gaps penetrate the slices exposing the background under the respective slice (Fig. 2). The main aim of this article is to present a fully automatic image analysis method for quantifying gaping in smoked salmon slices. The results from applying this method on a set of slices are compared with results from manual segmentation using the mouse. In addition to investigating gaping in relation to slice morphology, we further developed the image analysis to also include other important quality characteristics as shape, amount of red and white muscle, white stripe (myocommata) and myotome area.

2. Materials and methods

2.1. Sample selection

Market size Atlantic salmon (*Salmo salar* L.) ($n = 135$) were sampled in September 2010 from Nofima Marine research station at Averøy on the West coast of Norway and transported on ice for one week, before machine filleting at Marine Harvest Kritsen fish processing factory (Marine Harvest®, France). After filleting and trimming the right fillet from each fish was weighted. The fillets had a mean (SD) weight of 1.3 (0.2) kg. The remaining left fillets were smoked overnight, machine sliced and packed with 4 slices in each package. A total of 77 packages were then randomly selected and opened.

2.2. Image aquisition

Fillet slices from every package were carefully placed on a horizontal white styrofoam base in a photobox (Fig. 1, SeaSide AS) and photographed directly from above with a digital camera (Basler A102fc®) using the following selected parameters (Exposure time (raw) 1000, red balance ratio 131, black level 0, gain 192, diaphragm 11). The photobox provided uniform and diffuse lighting on the scene in order to avoid reflexes (white areas which effectively remove information from that part of the scene) on the moist and shiny salmon slices and to avoid shadows inside the holes and notches obscuring the white background. The photobox also ensured that the lighting was identical from image to image ($T = 6500$ K, Ra ≥ 90). The output from the camera was RGB colour images (Glasbey and Horgan, 1995; Gonzalez and Woods, 2008). Each pixel (x, y) in an RGB colour image is a triplet corresponding to the intensity of the primary colours (R)ed, (G)reen, and (B)lue at that point (Glasbey and Horgan, 1995; Gonzalez and Woods, 2008). All captured RGB images were stored as files in bit map format (bmp) with a resolution of 1388×1038 pixels (Fig. 2). An object of known size demonstrated that an image area of 28×28 pixels corresponded to 1 cm^2.

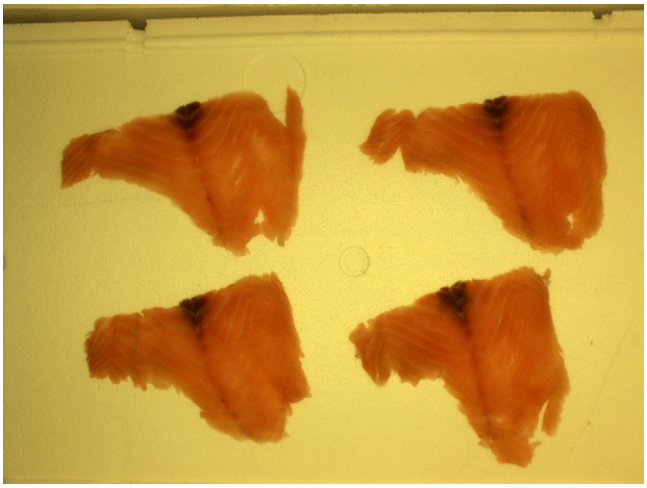

Fig. 2. Example of one of the original RGB images of smoked salmon slices.

2.3. Automatic image analysis method for gaping evaluation

The image analysis method was developed in Matlab (Version 7.10.0499 (R2010a), 32-bit (win 32), The Math-Works Inc., MA, USA) using the MATLAB® Image Processing Toolbox. The methodology is however standard and can be implemented in the many advanced image analysis software or programming languages. The method has six main steps (Fig. 3): (1) pre-processing (Fig. 4), (2) segmentation of slices from the background (Fig. 5) (3) Labelling of each slice, (4) identification and quantification of gaps (holes) inside the given slice region (Fig. 6) and (5) identification of gaps in the border of the slices (notches) (Fig. 7) and (6) quantification of gaps and notches. The operations were performed in the G-colour layer (Green from RGB) since the red tissue slices were clearly darker than the white background in this layer.

(1) *Pre-processing*: An artefact from the imaging procedure was that the images were slightly darker towards the edges than in the centre. To adjust for this, a shading correction (Gonzalez and Woods, 2008) was used (1) for all pixels (x, y), where f_1 is the corrected image, f_0 is the original G-layer image and f_{blank} is the G-layer from an image without salmon slices, i.e. a blank sheet:

$$f_1(x, y) = f_0(x, y)/f_{\text{blank}}(x, y) \quad (1)$$

for all pixels (x, y) in f_0 and f_{blank}. The image f_1 was then median filtered by a 3×3-mask (T) to remove any minor noise (Gonzalez and Woods, 2008) (Fig. 4):

$$f_2 = T(f_1) = \text{medfilt2}(f1, [3\,3]), \quad (2)$$

where 'medfilt2' is a function in the MATLAB Image Processing Toolbox.

(2) *Segmentation from background*: The Otsu thresholding method (Chi et al., 1996; Otsu, 1979) was then used on the median filtered image f_2 to find the threshold (T) between the light pixels of the background and the dark pixels of the slices (Fig. 4) to create a black and white (binary) image $\alpha(x, y)$ (Fig. 5):

$$\alpha(x, y) = \begin{cases} 1 \text{ if } f_2(x, y) < T = \text{graythresh}(f_2) \\ 0 \text{ otherwise} \end{cases}, \quad (3)$$

for all pixels (x, y) in f_2, and where 'graythresh' is a function in the MATLAB Image Processing Toolbox. The 'graythresh' function automatically finds the global image threshold using Otsu's method.

(3) *Labelling of each slice*: Each slice (four slices in each image) was then assigned a unique label in accordance to the location in the image (function bwlabel, Matlab). The output of this operation is an array of the same size as an input array, containing labels for