

Feasibility of pupillary light reflex analysis to identify vitamin A deficiency in Japanese black cattle

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Abstract:

To produce beef with a higher marbling standard, Japanese black cattle farmers usually actively attempt to lower the serum vitamin A level in the fattening period to a minimum desired level (about 30 IU/dL). However, early identification of suboptimal vitamin A deficiency in the cattle is important to prevent them from becoming susceptible to contracting serious diseases. In this study, we investigated the feasibility of using Pupillary Light Reflex (PLR) analysis to identify vitamin A deficient cattle during this fattening period. PLRs of 43 cattle were recorded monthly from June 2012 to February 2013 using a 2CCD camera based handheld machine vision system. A new image processing algorithm to segment the pupil from the background was developed. Compared with manually selected results, the root mean square error associated with the constriction amplitude (CA) acquired by the image processing algorithm was only 2.3%, indicating the

effectiveness of this algorithm. No significant differences were found between results of *CA* from fattening cattle in the high (>60 IU/dL) and low (<30 IU/dL) vitamin A period. However, two fattening cattle were identified with severe vitamin A deficiency, because of their weak PLR (*CA*<10%). Initial pupil roundness (*IPR*) results showed cattle in a dark environment possessed less-dilated pupils during the vitamin A deficient period ($p<0.05$). These results highlight the potential, as well as the limitations of this method. Due to the natural variation of PLR in healthy cattle, monthly measurements are not sufficient to make accurate identification. To realize early identification of severe vitamin A deficiency in fattening cattle, a more frequent PLR measurements regime needs to be explored.

Keywords: Machine vision, Image processing, Pupillary light reflex, Vitamin A deficiency, Japanese black cattle, Precision livestock farming

1. Introduction

Marbling -intramuscular fat- is the intermingling or dispersion of fat within the lean muscle tissue of beef cattle. The degree of marbling is the most influential factor in determining beef quality grade in the USA, Japan, and Australia (Strong, 2004), since it is indicative of the expected taste characteristics (tenderness, juiciness and flavor) of the cooked product. In Japan, the Beef Marbling Standard (BMS), established by the Japanese Meat Grading Association, is applied to the grading of beef. Silicon resin models of the BMS are shown in Fig. 1. These are used to standardize the degree of marbling. The No. 12 model indicates the highest marbling standard.

In an attempt to optimize the degree of marbling, Oka (1998) found that maintaining a low serum

vitamin A level in Japanese black cattle during the fattening period, from 15 to 23 months old, could produce beef with significantly higher BMS. Similar experiments conducted by other researchers (Siebert et al., 2006; Gorocica-Buenfil et al., 2007; Kruk et al., 2008) also confirmed this finding. Currently, most Japanese black cattle farmers actively manipulate the vitamin A levels in cattle to ensure beef with a high BMS. An ideal course for serum vitamin A level in cattle during the fattening stage (Hyogo Prefectural Hokubu Agricultural Institute) is shown in Fig. 2. However, maintaining such a low minimum vitamin A level is difficult. Moreover, lowering the vitamin A level too much, below 30 IU/dL, increases the susceptibility of the cattle to diseases, such as night blindness, xerophthalmia, or diarrhea, and even death (Moore, 1941; O'Donoghue, 1955; Millemann et al., 2007; Issi and Gül, 2010). Thus, it is important to monitor changes in vitamin A levels in cattle to assure they remain in a healthy condition during the vitamin A manipulation period. Currently, a blood assay is the conventional way to measure serum vitamin A level during this time. However, it is invasive and stressful to the cattle. Furthermore, this measurement is inconvenient and expensive; many farmers cannot afford it. Thus, an alternative system which can identify cattle with suboptimal vitamin A levels below 30 IU/dL would contribute to a feeding management regime that does not subject the cattle to vitamin A levels below a threshold value.

Early clinical signs of vitamin A deficiency usually include ocular changes, like papilledema, mottling of the tapetum, pallor of the nontapetum, and xerophthalmia (Maggs et al., 2008). Previous studies from our group showed there existed a negative relationship between serum vitamin A level and tapetum reflection (Takahashi et al., 2011), as well as with the red component ratio of cattle pupils (Takao et al., 2011; Han et al., 2013). Pupil color showed the highest

correlation with serum vitamin A level. A serum vitamin A estimation model, with an estimation error of about 10 IU/dL has been developed based on color (Han et al., 2013). To make the identification of vitamin A deficient cattle more reliable, consideration of multiple factors is necessary. In this study, the relation between Pupillary Light Reflex (PLR) and serum vitamin A level was investigated.

O'Donoghue (1955) reported some cattle, which were vitamin A deficient, showed dilated pupils and no response to light. Another report confirmed the loss of PLR in cattle, as seen in clinical signs of vitamin A deficiency (Issi and Gül, 2010). PLR analysis is an indirect measure of neural network function. Some features extracted from PLR, such as initial pupil diameter, constriction latency, constriction amplitude, constriction velocity, and pupil diameter at maximum constriction have been studied in relation to aging (Bitsios et al., 1996; Daluwatte et al., 2012), time-of-day (Yu et al., 2007) and function of melanopsin-containing retinal ganglion cells (Ishikawa et al., 2012) in humans. PLR analysis is a reliable test, and has the potential to be used to assist the diagnosis of eye related diseases.

Speculating that vitamin A deficiency may also affect PLR in cattle, Matsuda et al. (1999) investigated the relation between constriction duration and vitamin A level. Their results showed that cattle with lower vitamin A levels tended to need a longer time to halt constriction. These findings indicate that the potential to use PLR analysis to identify vitamin A deficient cattle. In the experiment Matsuda et al. (1999) conducted, it usually took more than 10 seconds to record the full PLR of cattle. Such a long illumination time could stress the cattle. With considerations for animal welfare and a more rapid identification methodology, a one second PLR was used in this experiment.

In previous work, we reported a new machine vision system based on a 2CCD camera (Han et al., 2011). The handheld machine vision system is capable of capturing images in a full PLR process. Using that machine vision system, we investigated the relation between PLR and serum vitamin A level based on five characteristics: pupil area, normalized pupil area, starting shrinking time, slope of pupil contraction regression line, and the ratio of max length and breadth of pupil before shrinking. No linear correlations between these factors and vitamin A level were, however, found (Han et al., 2011). It must be noted though, in that preliminary experiment, the PLR analysis was not carried out accurately. The pupil area calculation was based on binarization by the hue value, which was calculated from RGB using a HSI color model (Gonzalez and Woods, 2010). The identified pupil area was incorrect when the boundaries of the pupil overlapped with the bright image of the LED ring that was formed by a specular reflection. Such an image of the LED ring is shown in Fig. 4. Especially, after the constriction, the pupil was usually small and frequently overlapped with the image of the LED ring. Therefore, the objective of the present study was to develop a robust image segmentation algorithm to calculate pupil area and to investigate the feasibility of using a one second PLR analysis to identify vitamin A deficient cattle during the vitamin A manipulated fattening stage.

2. Materials and methods

2.1. Cattle

This experiment was conducted from June 2012 to February 2013 at Hyogo Prefectural Hokubu Agricultural Institute, Japan. PLRs of the right eye of 43 Japanese black cattle, including 25 females and 18 males, were recorded once a month. At the beginning of the experiment, the ages

of the cattle ranged from 13 to 16 months and vitamin A levels ranged from 38 to 151 IU/dL (mean $\pm$ SD 76 $\pm$ 18 IU/dL). From April 2012, the cattle were subjected to a low vitamin A diet. The objectives and methods of this study were explained to, and approved by, researchers from Hyogo Prefectural Hokubu Agricultural Institute.

2.2. Device

A 2CCD multi-spectral camera AD-080CL (JAI) installed with a NT63-240 lens (Focus Length 12 mm, F 1.8, EDMUND) was used to acquire both color and Near Infrared (NIR) images. The camera was combined with two ring-shaped LED lights: a MDRL-CW50 (MORITEX) white LED light, and a MDRL-CIR31 (MORITEX) NIR LED light with a central wavelength of 850 nm. A plastic tube was installed in front of the LED lights to block out any ambient light. A sketch of the device is shown in Fig. 3. The captured image is 1024 pixels in width and 768 pixels in height.

2.3. Experimental Procedures

The experiments were usually started at 9:30 in the morning and ended at 4:30 in the afternoon. Firstly, the animal's head was fastened to a fence by ropes. Then, the eyes of the cattle were covered by a ordinary black cloth for about two minutes to allow them to adapt to a dark environment. This black cloth cover was kept on during image recording. Before beginning measurements, the light intensity at the end of the plastic tube was set to 1700 lx and the same lighting condition was kept for all measurements. To maintain a constant pupil position throughout recording, the plastic tube in the front of the machine vision system was kept perpendicular to and in contact with the outer surface of the eyelids. The upper and lower eyelids were held open by

hand to guarantee the visualization of the pupil. The focus of the camera was adjusted to the cattle's eye with the NIR LED lighting. After a focused image of the pupil was obtained on the NIR video monitor, the white LEDs were turned on and eye images were recorded simultaneously at 30 frames per second. Sample images are shown in Fig. 4. A blood sample was taken one to two days before the image acquisition. Serum vitamin A level in the blood was determined using the High-Performance Liquid Chromatography (HPLC) method of Bieri et al. (1979).

2.4. Image Processing

Due to the reflection of the white LED light from the tapetum lucidum of the cattle, a unique blue color can be seen in the pupil area. It is easier to segment the pupil from the background with these color images than it is with the NIR images, as shown in Fig. 4. Color images were processed by a program developed in Matlab 2007 (Mathworks). The procedure for pupil area acquisition is shown in Fig. 5.

The color image was converted from the RGB color space into the HSI color space (Gonzalez and Woods, 2010), which is claimed to be the closest approximation to human interpretation of color. The hue image is shown in Fig. 6 (b). After binarization based on the hue value, as shown in Fig. 6 (c), the boundary of the largest region of interest (ROI) was selected, as shown in Fig. 6 (d). Because the pupil was partially overlapped by the image of the LED ring, it was difficult to select the correct pupil area by thresholding, as shown in Fig. 6 (c). Because the pupil of a cow is oval shaped, an ellipse is good for estimation of pupil area. The boundary of the largest ROI, after removing the overlapping LEDs' reflection, as shown in Fig. 6 (e), was used to conduct ellipse fitting based on a least squares method introduced by Rosin (1993). The fitted result is shown in

Fig. 6 (f). The ellipse shown in Fig. 6 (g) was used to represent the pupil area for subsequent PLR analysis. To evaluate the performance of this image algorithm, the pupils in the images were carefully circled by hand in ImageJ (Abràmoff et al., 2004). The total number of pixels inside the circled area was taken as the gold standard.

2.5. Pupillary Light Reflex Analysis

In order to correct for differences in the pupil area between cattle and measurements, all pupil data were normalized by regarding the resting pupil area, the largest pupil area before turning on the white LED light, as a baseline. Once all normalized pupil areas were calculated from the 30 images taken over the 1 second duration, a pupilogram curve was constructed after smoothing by using a Savitzky–Golay filter (Savitzky and Golay, 1964), as shown in Fig. 7. The following parameters were used for subsequent analysis: Constriction Amplitude over 1 second (*CA*), and Initial Pupil Roundness (*IPR*).

After the onset of white LED light, there is latency time of about 0.3 second, as shown in Fig. 7.

CA over the 1 second was calculated using the following equation (1).

$$CA = \frac{s_0 - s_1}{s_0} \quad (1)$$

Where s_0 is the resting pupil area and s_1 is the pupil area at the end of 1 second constriction.

IPR was used as an indicator of resting pupil shape. The *IPR* was calculated using the following equation (2).

$$IPR = \frac{4\pi S}{P^2} \quad (2)$$

Where S is the area of the pupil and P is the perimeter of the pupil.

2.6. Data Analysis

The image processing results were evaluated by root mean square error (RMSE). To study the effect of vitamin A deficiency on PLR, data were investigated by unpaired *t* tests and paired *t* tests to examine differences between the means of low (< 30 IU/dL) and high (> 60 IU/dL) vitamin A level groups for PLR parameters, *CA* and *IPR*.

3. Results and Discussion

3.1 Evaluation of image processing

Sixty PLR measurements were randomly selected from nine months of experiments conducted between June 2012 to February 2013 on 43 Japanese black cattle. The first and thirtieth images from each measurement were used for comparisons. Pupil area results acquired by image processing were compared with those collected by hand. The correlation coefficient between these methods was 0.99 and 0.95 for pupil area and *CA*, respectively. Root mean square error (RMSE) of pupil area and *CA* was 930 pixels and 2.3%, respectively. As shown in Fig. 8, the results of pupil area and *CA* were normally distributed around the line of equality, which means the results acquired by these two methods were close to each other. Paired *t* tests showed there was no significant difference between the means of these two results ($p>0.05$). This indicates the proposed image processing method is effective at estimating pupil area and *CA*.

3.2 PLR of low and high serum vitamin A group

The serum vitamin A levels in all the cattle gradually declined during the experimental period. Once the vitamin A levels in cattle, as measured by blood assay, were lower than 30 IU/dL, oral

supplementation with vitamin A was conducted. However, the restoration of vitamin A levels usually took weeks. There were many cattle that possessed vitamin A levels lower than 30 IU/dL at the end of the experiment.

3.2.1 CA of low and high vitamin A group

Initial pupil shape will have an effect on the CA, but to avoid a complicated discussion on this effect, only the CA with a *IPR* larger than 0.89, indicating those with a fully dilated resting pupil, were used for subsequent comparisons. Seventy measurements of cattle with vitamin A levels higher than 60 IU/dL were placed in a high vitamin A group. On the other hand, seventy seven measurements of cattle with vitamin A levels under the minimum desired vitamin A level (30 IU/dL) were placed in the low vitamin A group. Their histogram is shown in Fig. 9. Unpaired 2-tailed *t* test showed there was no significant difference between mean CAs of the high (mean $\pm$ SE 28.8 $\pm$ 0.7%) and low (mean $\pm$ SE 28 $\pm$ 0.8%) vitamin A group ($p=0.44$). However, the low group showed a larger deviation, which may be caused by vitamin A deficiency. To exclude the effect of individual differences, a paired *t* test was carried out on 30 cattle, which appeared both in the high and low vitamin A groups. A paired 2-tailed *t* test also showed there was no significant difference between the mean CAs of the high (mean $\pm$ SE 28.3 $\pm$ 1.2%) and low (mean $\pm$ SE 28.8 $\pm$ 1.5%) vitamin A groups ($p=0.78$). During our experiment two cattle showed a loss of PLR or weak PLR, a result similar to that reported by O'Donoghue and Issi and Gul (O'Donoghue, 1955; Issi and Gül, 2010). CAs of these two cattle were less than 10%, as shown in Fig. 9 and Fig. 10. The possible reasons for no significant differences between the mean CA of the high and low vitamin A groups might be attributed to a lack of measurements, individual differences between

cattle in their tolerance to vitamin A deficiency, natural variation of PLR in healthy cattle, and the effect of unavoidable physical stimulation on PLR during recording.

Currently, because of the complicated procedures and cost of blood tests, we could only afford to do a monthly PLR analysis. More frequent measurements are necessary to make a clear judgment on the early detection of vitamin A deficiency. Besides that, the pupils were affected by physical stimulation. In this investigation, patting the back of cattle by hand was regarded as a physical stimulation. Six cattle were selected to record their PLRs while continuously patting their back. The results showed clearly that *CA* becomes smaller, as Fig. 11 shows. This is because the emotional status of the cattle (*e.g.*, fear, anger, or excitement), influences the sympathetic nervous system and causes pupillary dilation (Maggs et al., 2008). Even though we tried to keep the cattle calm during recording, the action of holding the upper and lower eyelids of cattle may have affected the PLR results randomly. In the current experiment, only two cattle were successfully identified as severe vitamin A deficiency by PLR analysis, but even two cattle can still cause a significant economic loss to farmers; and also the changes of PLR are difficult to be noticed by farmers during daily feeding. In the next step, to realize early identification and free cattle from stress, an automatic image capturing system installed at the watering place that does not need to fix the head of the cattle in position needs to be appraised.

3.2.2 *IPR* of low and high vitamin A group

An unpaired 2-tailed *t* test showed that *IPR* of the low (mean $\pm$ SE 0.888 ± 0.002) vitamin A group was significantly smaller than the high (mean $\pm$ SE 0.895 ± 0.001) vitamin A group ($p=0.007$). To

avoid the effect of individual differences, a paired 2-tailed *t* test was carried out between *IPR* of 34 cattle during the high (mean $\pm$ SE 0.898 $\pm$ 0.002) and low (mean $\pm$ SE 0.886 $\pm$ 0.005) vitamin A period. A similar result was obtained ($p=0.013$). Resting pupil size may be related to its' dark adaptation ability. It is possible that when vitamin A deficiency occurred, the dark adaption process become sluggish in cattle, as it does in humans (Kemp et al., 1988). That might explain why there were more less-dilated pupils during the vitamin A deficient stage, as shown in Fig. 12. This result indicates *IPR* may also be used as an indicator of vitamin A deficiency. To our knowledge, this is the first report that vitamin A deficient cattle have smaller resting pupils after a two-minute dark adaption.

4. Conclusions and Future work

An image processing algorithm based on a least squares ellipse fitting was successfully applied to pupil area calculation from images of cattle eyes. The root mean square error of *CA* was only 2.3% compared to the manually selected results, which were taken as the gold standard. A two sample *t*-test and paired *t*-test showed there was no significant difference ($p>0.05$) in *CA* between the low and high vitamin A cattle groups. However, two cattle were identified with weak PLR ($CA<10\%$), a result similar to that reported by O'Donoghue, Issi and Gul (O'Donoghue, 1955; Issi and Gül, 2010). It shows that abnormal PLR, which is caused by severe vitamin A deficiency, can be quantitatively assessed by our method. Because of the natural variability in PLR of healthy cattle and the infrequent measurement regime of cattle in this experiment, most cattle with serum vitamin A levels lower than 30 IU/dL were not correctly identified. A more frequent sampling regime is worth testing to see if the effectiveness of this method can be improved. On the other

hand, compared with cattle during the high vitamin A stage, there were more cattle that had smaller resting pupils ($p < 0.05$) in a dark environment during the vitamin A deficient stage. *IPR* may also be used as an indicator of vitamin A deficiency. To realize more frequent and economical measurements, an automatic image capturing system installed at the watering place is one suggested solution. *CA* and *IPR* can be analyzed each cattle come to drink water. Besides that, water use of individual cattle can also be recorded. As feeding and watering can be closely related (Kashiha et al., 2013), any reduced drinking activity may indicate anorexia, another early clinical sign of vitamin A deficiency (Issi and Gül, 2010).

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Figure captions

Fig. 1. Silicone resin models used for the evaluation of beef marbling developed by the Japanese National Institute of Animal Industry.

Fig. 2. Ideal serum vitamin A levels in cattle during the fattening stage. The red line indicates the minimum desired level (30 IU/dL) of vitamin A in Japanese black cattle. For vitamin A, 1 IU is the biological equivalent of 0.3 µg retinol, or of 0.6 µg beta-carotene. (Provided by Hyogo Prefectural Hokubu Agricultural Institute).

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355 Fig. 3. Sketch of experimental device.

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357 Fig. 4. Color and NIR images of cattle's right eye.

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359 Fig. 5. Pupil area acquisition procedure.

360

361 Fig. 6. (a) Original color image, (b) Hue image, (c) Binarized image by hue value, (d) Color image with boundary
362 of largest region of interest shown in red, (e) Color image with boundary of pupil selected for fitting shown in
363 yellow, (f) Fitted ellipse based on least squares method with its long and short axis shown in red, (g) Fitted ellipse
364 used to represent pupil area.

365

366 Fig. 7. A pupilogram of cattle's right eye in response to white LED light stimulation with light intensity of 1700 lx.

367

368 Fig. 8. Pupil area (a) and CA (b) acquired by manually and image processing.

369

370 Fig. 9. Histogram of CA from high (>60 IU/dL) and low (<30 IU/dL) vitamin A group cattle. Two cattle with CA
371 less than 10% were recognized as loss of PLR and weak PLR, respectively.

372

373 Fig. 10. Examples of Loss of PLR, Weak PLR and Normal PLR.

374

375 Fig. 11. CAs from six cattle's PLRs recorded normally and with intentional physical stimulation.

376

377 Fig. 12. Relationship between *IPRs* and vitamin A levels.

378

Highlights:

- ◆ An image segmentation method to calculate pupil sizes of cattle was developed.
- ◆ Two cattle were identified as severe vitamin A deficiency by our method.
- ◆ Cattle had smaller resting pupil in the dark during vitamin A deficient stage.

Fig. 1

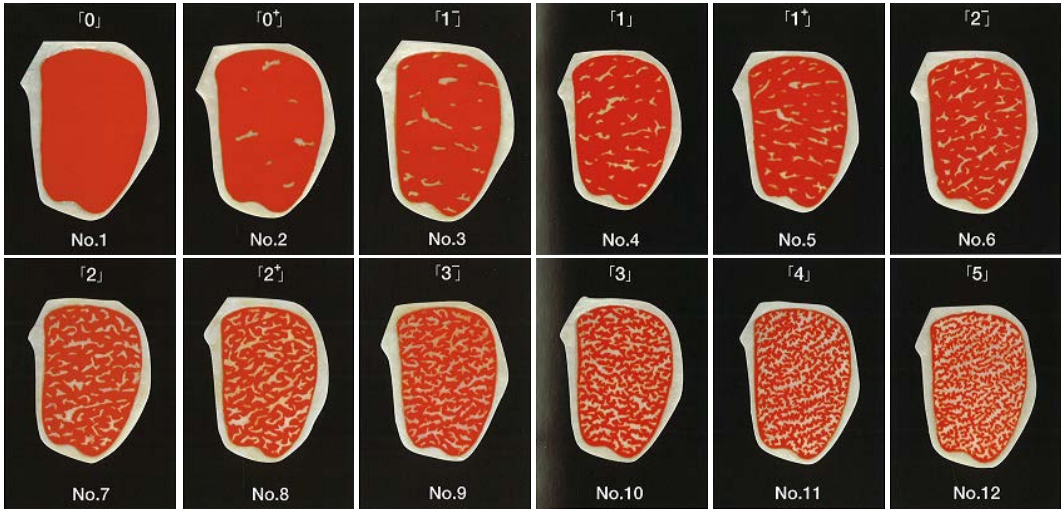


Fig. 2

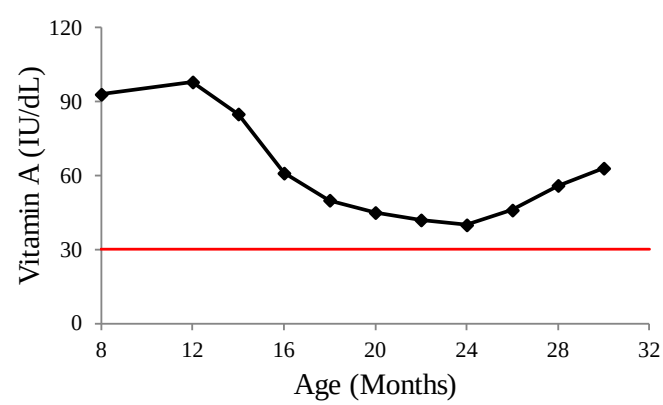


Fig. 3

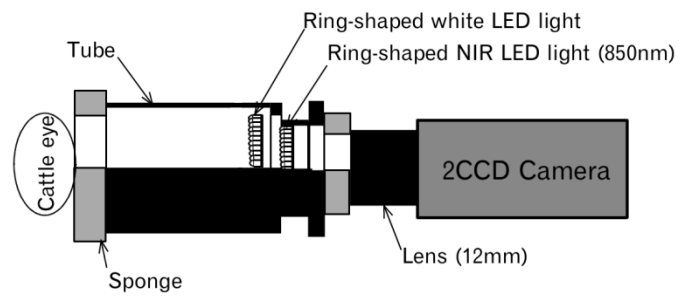


Fig. 4

The image of LED ring.

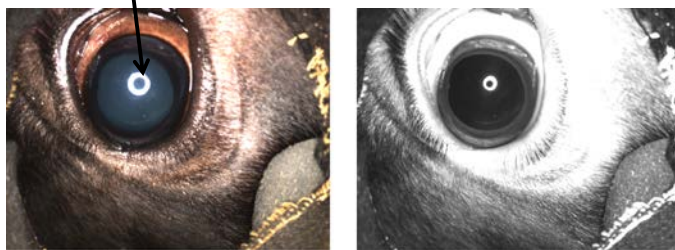


Fig. 5

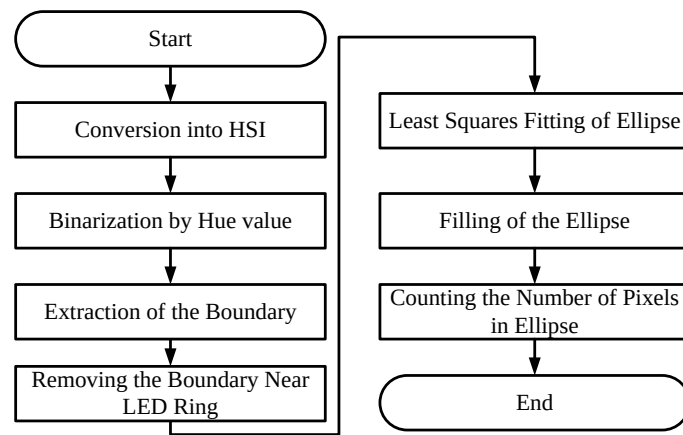


Fig. 6

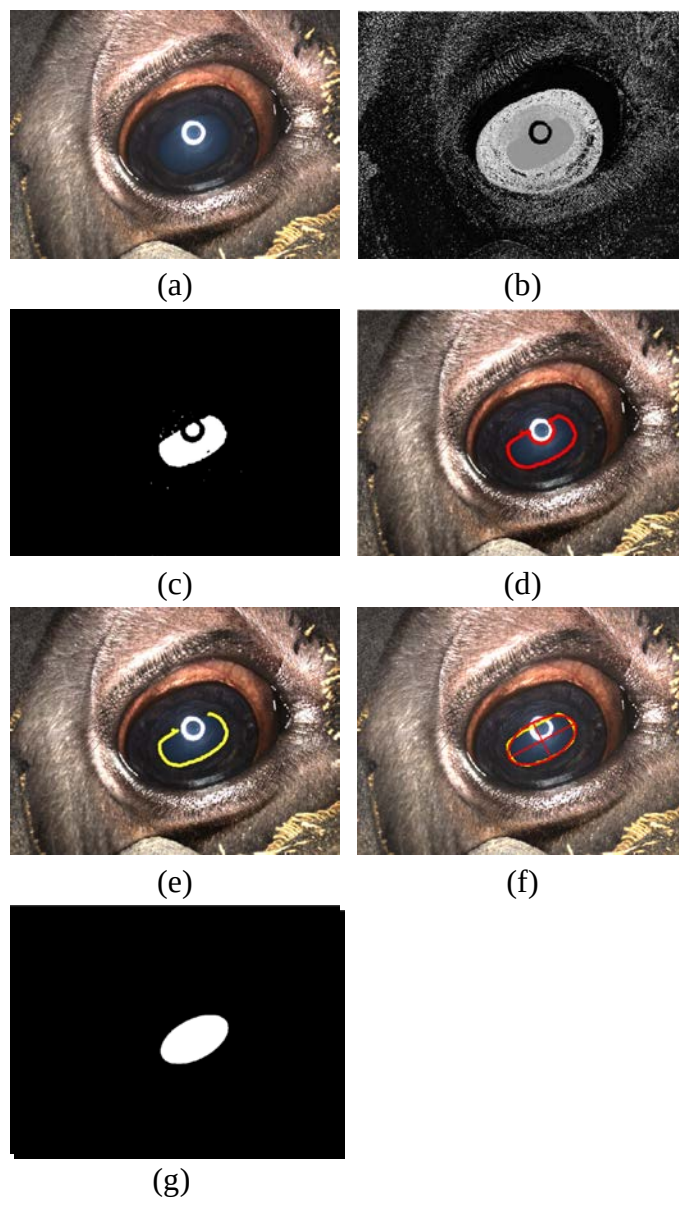


Fig. 7

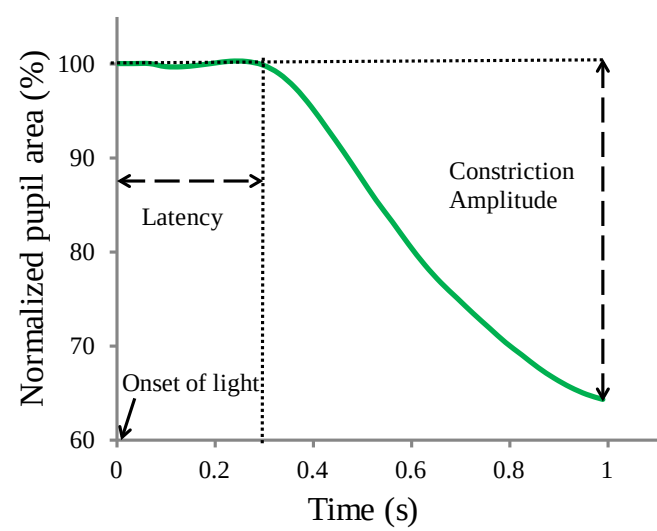


Fig. 8

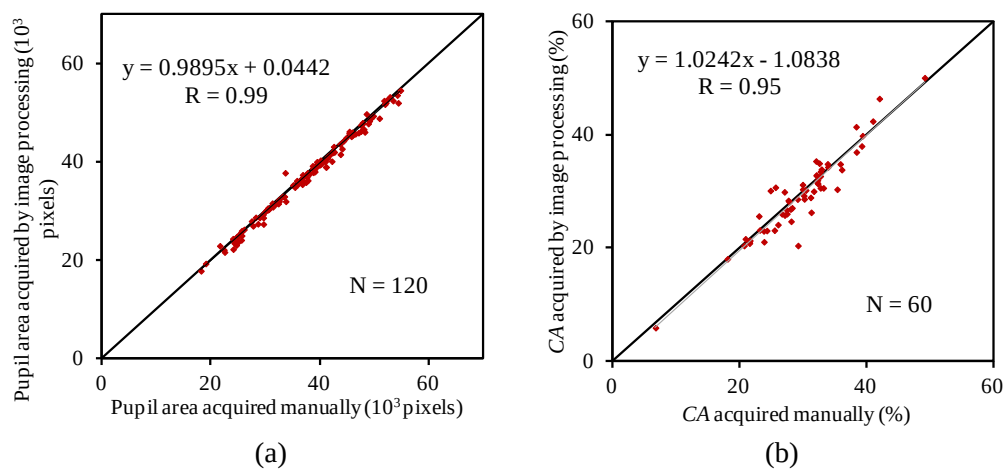


Fig. 9

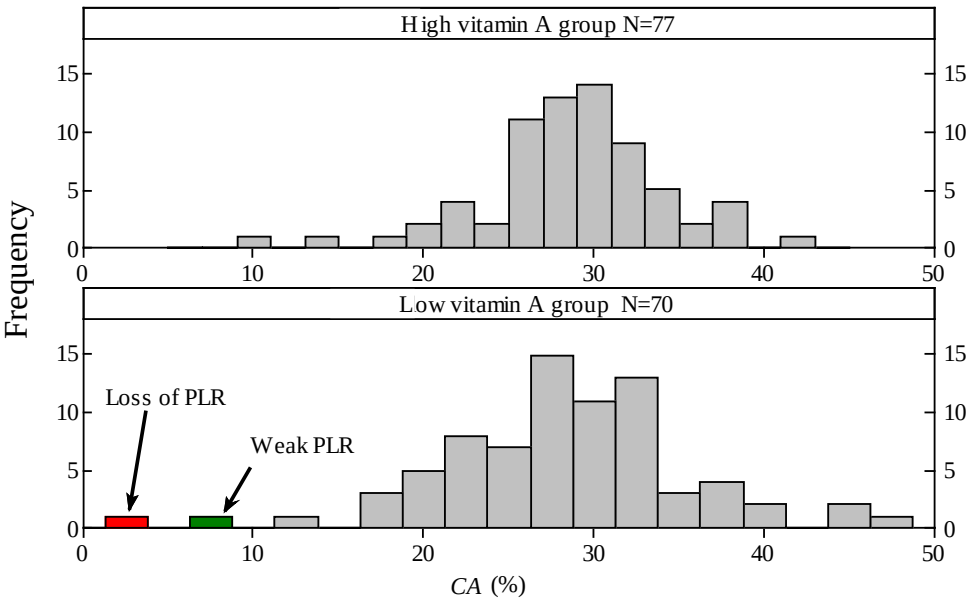


Fig. 10

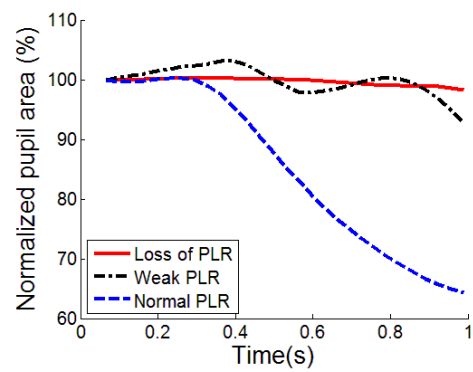


Fig. 11

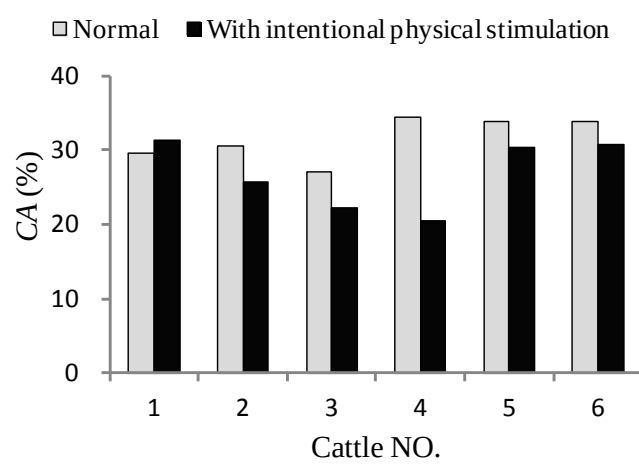


Fig. 12

