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# Sex Determination of Silkworm Pupae using VIS-NIR Hyperspectral Imaging Combined with Chemometrics

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Abstract: To explore an accurate and non-destructive method to discriminate the sex of silkworm pupae, the visible and near-infrared (VIS-NIR) hyperspectral imaging (HSI) technique was employed in this paper. First, a total of 520 hyperspectral images of silkworm pupae of four species were captured using a push-broom HSI system in the spectral region of 363nm to 1026nm and then calibrated for reflectance. The mean spectral data were extracted from the region of interest (ROI). Second, five optimal wavelengths (403, 440, 505, 533, 721nm) were selected by successive projection algorithm (SPA). Then gray-level co-occurrence matrix (GLCM) analysis was implemented on the 500nm image. Finally, Support vector machine (SVM) and radial basis function and neutral network (RBF-NN) models were established based on full spectra, textural data, spectral data and fusion data, respectively. The SVM and RBF-NN modles using fusion data reached the most satisfactory performance with a high correct classification rate of 98.75%. Furthermore, the built SVM model based on fusion data could be promoted to identify the sex of another two species of silkworm pupae with accuracy of 97% and 96%, indicating that HSI technology can be served as a new method to differentiate the sex of silkworm pupae.
Keywords: silkworm pupa; sex; identification; hyperspectral imaging; GLCM;

## 1. Introduction

China is one of the biggest silkworm silk producer and exporter countries in the world. The crossbred silkworm pupae, which are bred using different kinds of varieties, can produce higher quality silks. Silkworm breeding is an important section in the silkworm raising process. In breeding season, the sex of silkworm pupae is usually separated by the skillful workers, which is time consuming and acquires large amounts of labors. It may also cause false identification, resulting in female and male silkworm pupae being mixed. Hence, it is important to find an intelligent method to replace the manual work.

In order to automatically identify the sex of silkworm pupae with high accuracy, many researchers have done related studies, which are divided into two categories: non-image processing method and image processing method. In the non-image processing section, Seo et al. [1] analyzed the mass of silkworm pupae to classify the sex of silkworm pupae. However, it offered an unaccepted accuracy of 50%.

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With the development of image processing technology, pattern recognition is widely employed in identifying the sex of silkworm pupae. Pan et al. [2], Liu et al. [3] and Cai et al. [4] respectively adopted near infrared (NIR) spectroscopy, Magnetic Resonance Imaging (MRI) and X-ray imaging technique to determine the sex of silkworm pupae. But the equipment was too expensive. Jordan et al. [5] designed an automatic electronic vision system to discriminate the female and male silkworm pupae. Due to the low accuracy and efficiency, the application of this system was limited. Sumriddetchkajorn et al. [6] utilized a fault-tolerant optical-based system, which integrated the image processing operations including image inversion, blob filtering to identify the sex of silkworm pupae, and the accuracy reached 95%. Kamtongdee et al. [7] constructed the normalization cross-relation (NCC) method to discriminate the sex of silkworm pupae, only with a low accuracy of 88%.

In conclusion, non-image processing method universally has the problems of low accuracy. The image processing method cannot effectively extract the features of tail gonad and the equipment was expensive. Consequently, it is of importance to seek a new, non-destructive and accurate method for identifying the sex of silkworm pupae.

Hyperspectral imaging (HSI) processing technology, which combines the spectroscopy and computer vision techniques simultaneously to acquire the spectral and spatial data [8-9], has attracted many attentions due to its non-contact and reliable properties. The acquired hyperspectral images are saved as a three dimensional raw data form, including the spatial information and spectral information, which can effectively reflect the chemical characteristic of the analyzed sample and their spatial distribution. HSI has been widely applied in classifying and quantifying many agriculture products and fruits, such as lettuce [10], pork [11], apple [12], and so on. However, many of these studies have a common problem that they