

Introduction

The objectives of this study were to develop models for estimating fresh weight of Chinese cabbage (*Brassica campestris* ssp. *pekinensis*), with various indices and simple ratio calculated from reflectance bands in remotely sensed canopies by multispectral imaging sensor equipped with fixed-wing unmanned aerial vehicle (UAV) depending on vegetation stages of Chinese cabbage planted on each different dates in growing seasons of 2015 and 2016.

Materials and methods

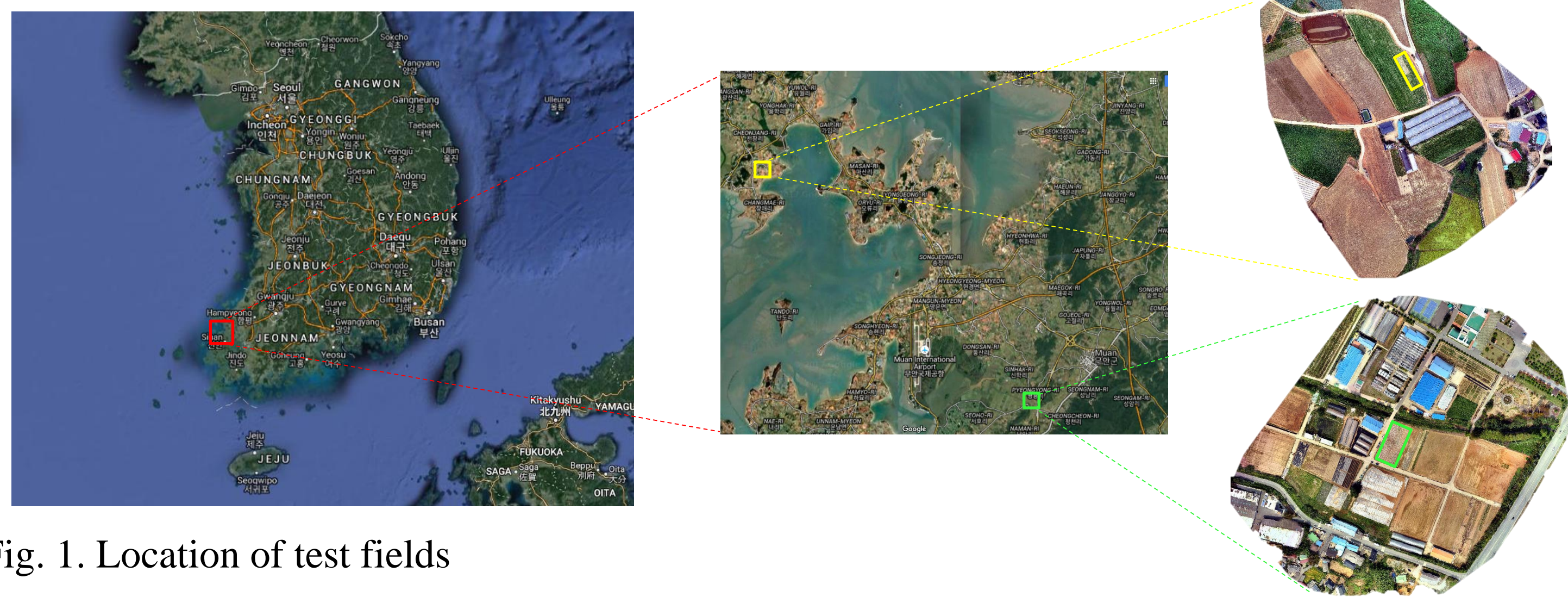


Fig. 1. Location of test fields

Table 1 Variety of test crop

Test crop	Variety
Chinese cabbage	Whistle (Sakatakorea Co., Ltd., Republic of Korea)

Table 2 Test plot information

Year	Planting	Location	Coordinates	Planting Date	Average annual temperature	Average annual rainfall
2015	Normal planting	Republic of Korea	(35°4'11.28" N, 126°18'21.25" E)	7 th September	13.4 °C	948.6 mm
	Delayed planting			19 th , 25 th September		
	Average annual temperature				13.4 °C	948.6 mm
2016	Normal planting	Republic of Korea	(34°58'03.2" N, 126°27'14.6" E)	5 th September	13.6 °C	1272.5 mm
	Delayed planting			13 th , 23 th September		
	Average annual temperature				13.6 °C	1272.5 mm

Table 3 UAV platform, imaging sensor and flight plan

Category	Fixed-wing UAV
Model	eBee
Take-off weight (TOW)	0.69 kg
Wingspan	0.96 m
Duration of flight	Maximum 50 minutes
Flight date	2015 year: 7 th October, 21 th October, 4 th November and 20 th November at midday 2016 year: 29 th September, 6 th October, 14 th October, 20 th October, 27 th October, 4 th November and 11 th November at midday
Category	Multispec-4c imaging sensor
Resolution	1.2-Megapixel
Ground resolution	6 cm/pixel at around 64 m height
Spectral bands	Green, Red, Red edge, NIR

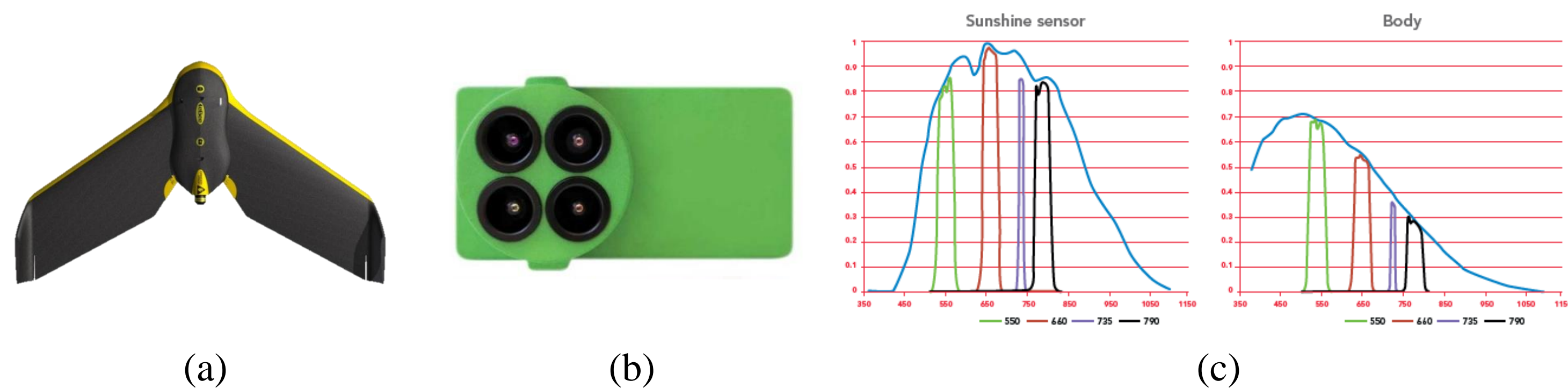


Fig. 2. eBee (a), Multispec-4c imaging sensor (b), Sensitivity of sunshine sensor and body (Camera) for Multispec-4c sensor (c) (Sensefly, Switzerland)

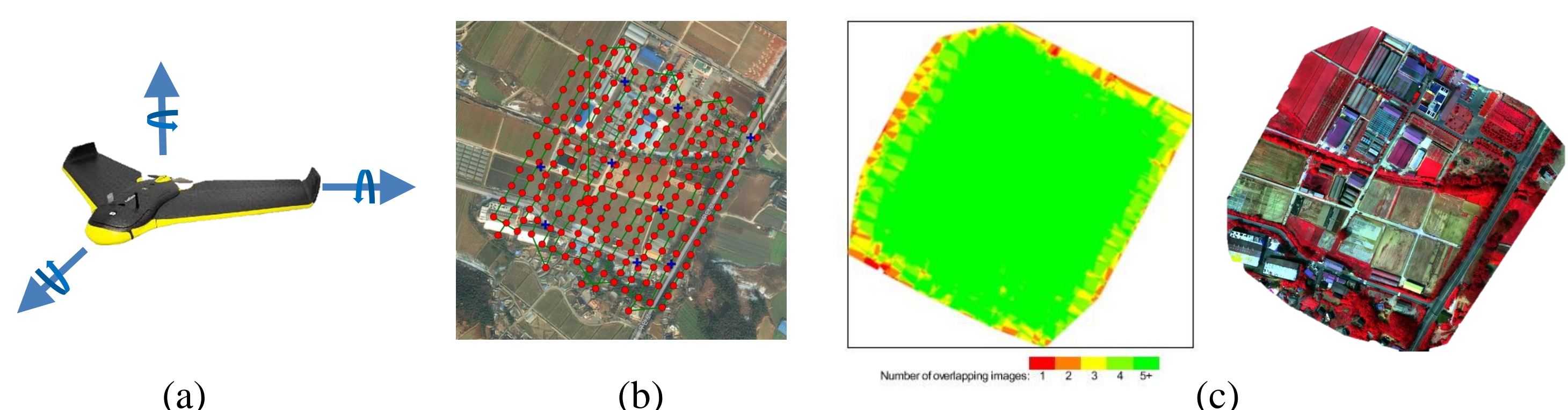
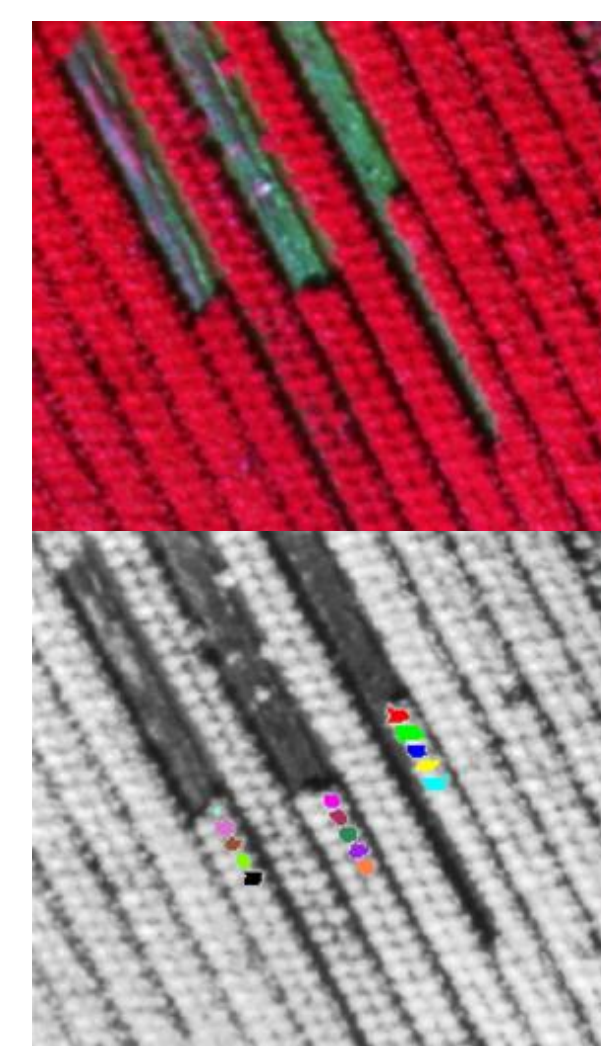


Fig. 3. Gyro information (a), GPS information (b), Mosaic image (c) produced by Pix4d mapper (Pix4d, Switzerland)



Indices	Formulation	Indices	Formulation
Simple ratio	$\frac{\rho_{NIR \text{ or Red edge}}}{\rho_{Green \text{ or Red}}}$	Red edge NDVI	$\frac{\rho_{Red \text{ edge}} - \rho_{Red}}{\rho_{Red \text{ edge}} + \rho_{Red}}$
NDVI	$\frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}}$	Red edge GNDVI	$\frac{\rho_{Red \text{ edge}} - \rho_{Green}}{\rho_{Red \text{ edge}} + \rho_{Green}}$
GNDVI	$\frac{\rho_{NIR} - \rho_{Green}}{\rho_{NIR} + \rho_{Green}}$		

Fig. 4. Separating individual canopies of Chinese cabbage and various indices formulation

Results and discussion

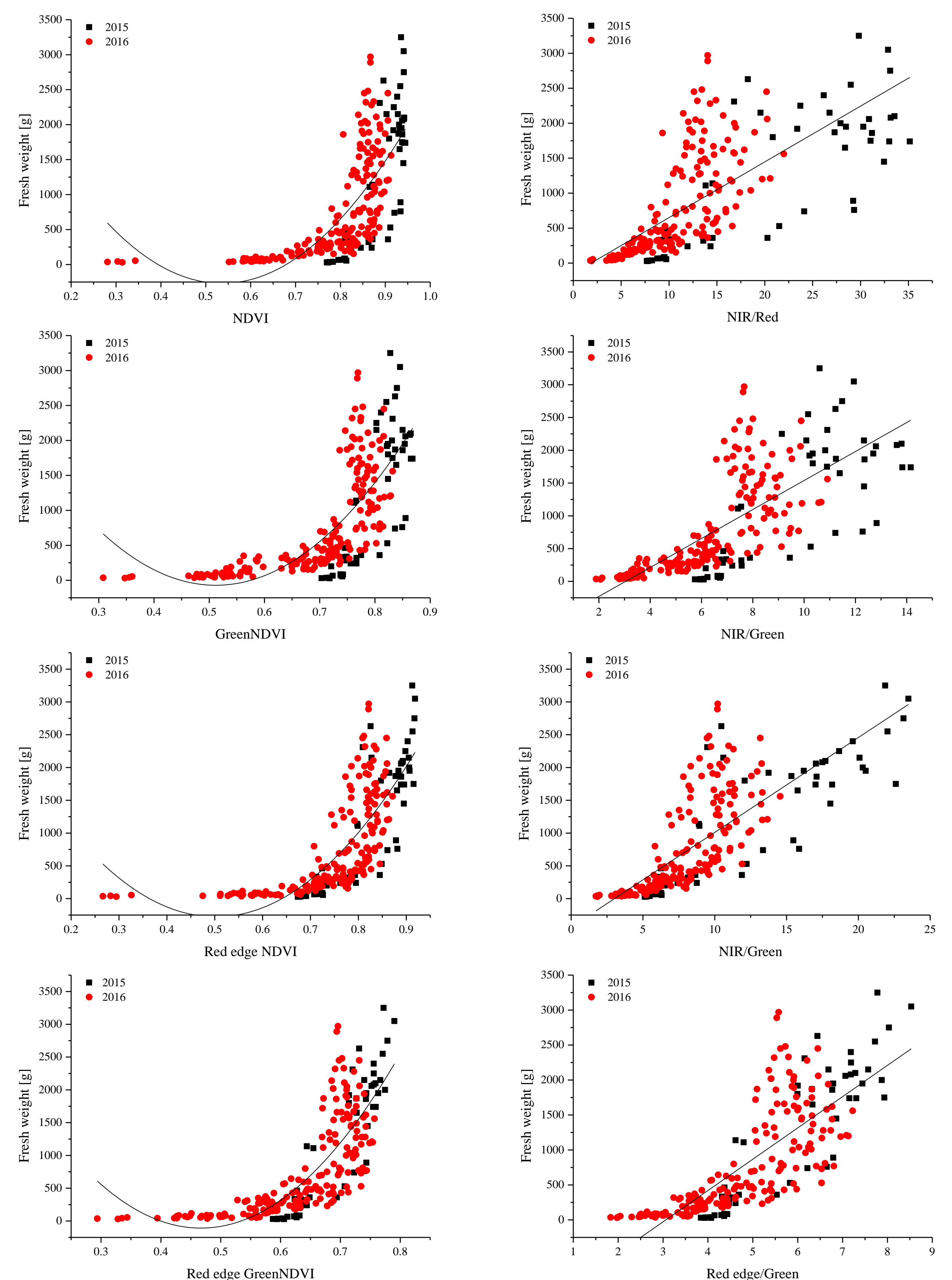


Fig. 5. Relationship between indices vs Fresh weight for Chinese cabbage in growing seasons of 2015 and 2016

Table 4 Linear and polynomial regression models between indices and simple ratio vs Fresh weight for Chinese cabbage in growing seasons of 2015-2016

Indices	n	R ²	RMSE[g]	RE[%]
NDVI	238	0.550	538.1	64
GNDVI		0.565	529.5	63
Red edge NDVI		0.605	504.2	60
Red edge GNDVI		0.648	476.2	56
NIR/Red		0.526	551.3	65
NIR/Green		0.549	537.6	64
Red edge/Red		0.588	513.7	60
Red edge/Green		0.629	487.8	58

- Linear and polynomial estimation models developed by red edge and green bands were better performance in all R² (accuracy) and RMSE (precision) values than other models.
- But, precision of the estimation models was low because it showed low sensitivity at low fresh weight and scattering plot at high fresh weight
- Consistently, it needs to be developed by repetitive experiment and using various bands

Acknowledgement

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