Short Communication

Rapid estimation of the energy content of composite foods: the application of the Calorie Answer™

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The estimation of calories in foods is central in the maintenance of body weight and energy regulation. Conventional laboratory analysis using bomb calorimetry to determine calorie content is expensive and time-consuming. There is a need to explore alternative techniques for calorie estimation that requires less processing and resources. The potential of using near infrared spectroscopy for calorie measurements with Calorie Answer™ was evaluated in this study. The caloric content of 105 different foods was measured, and compared against values reported on nutrition labels. The average percentage relative standard deviation for triplicate measurements was 1.7% for all foods. The percentage difference between stated and measured calories was modest, at 4.0% for all foods. Stated and measured calorie contents were significantly and highly correlated (R^2=0.98, p<0.001). The use of near infrared spectroscopy, using Calorie Answer™, is a rapid, reproducible and cost-effective way of measuring calorie content in a diverse range of foods. Its application in many parts of Asia Pacific and other emerging nations will generate much needed information on the calorie content of complex foods consumed by people living in these regions.

Key Words: calories, food composition, nutrition labels, near infrared spectroscopy, non destructive food analysis

INTRODUCTION

The estimation of calories in foods is central in the maintenance of body weight and energy regulation. There is a paucity of information on the calorie content of composite foods consumed in the Asia-Pacific and other regions in Africa and South America. Indeed, a global challenge is to generate reliable and reproducible information on the calorie content of foods consumed. The current methods for estimating gross energy content of simple and composite food is based on the use of the bomb calorimetry. Bomb calorimetry directly measures the heat of combustion of a food and thus gives a value for gross energy.[1] The gross energy is then corrected for the digestibility of foods (subtracting off calories excreted in urine and stools), yielding the metabolizable energy of foods.

Given how tedious, time consuming and high expenses related to the use of bomb calorimetry are, recent years have witnessed a resurgence of instruments to measure the metabolizable energy of foods. A relatively new technique is the use of near infrared (NIR) spectroscopy. NIR spectroscopy uses the spectral range from 780 to 2500 x 10^{-9}m.[2] The primary constituents in foods consist of C-H, O-H and N-H groups, and these functional groups absorb energy at specific wavelength regions in the NIR spectral range.[3] NIR spectroscopy can thus be used for estimating the protein, fat, carbohydrate and water content of food, which in turn is used to determine the metabolizable energy of the food system. The associated advantages with NIR spectroscopy are that it is a rapid and non-destructive method; there is minimal sample preparation involved and it requires no solvent extraction or reagent preparation.

The Calorie Answer™ was developed by Joy World Pacific Co., Ltd (JWP, Japan) in 2002. This machine utilizes NIR spectroscopy and is calibrated against energy content of foods being derived from standard methods of analysis. The user merely selects the appropriate settings for accurate analysis as each sub-type takes into account the food matrix effect (Supplementary Table 1). The in-built computer software performs calculations to determine the calorie content of the food. Previously reported studies using NIR spectroscopy include measurement of dietary fiber in cereal products and mixed meals,[3-5] prediction of fat and protein content,[6-11] and calorie content measurement in foods.[12-14] The objective of this study was specifically to measure the calorie content of various types of food with NIR spectroscopy using the Calorie Answer™. The potential of using Calorie Answer™ for reliable caloric measurements was evaluated by comparing it with stated values provided on nutrition labels.

MATERIALS AND METHODS
Samples and sample preparation
One hundred and five food products of well-known brands were selected to represent a wide range of foods that are commonly consumed locally in Singapore. These food products were purchased from supermarkets and were categorized as: (1) grains, (2) liquids, (3) prepared foods and (4) snacks and confectionery. All items were purchased between June to September 2014.

Frozen mixed meals were heated according to the instructions available from food packaging. The food samples were homogenized immediately with a kitchen blender (BL 480, Kenwood, United Kingdom) to obtain a smooth and consistent texture. Other types of food were removed from their packaging and homogenized with a grinder (WSG 30, Waring, USA). Liquid samples were well-shaken before analysis. All samples were allowed to equilibrate to room temperature ($20\text{-}25^{o}C$) before NIR analysis.

NIR spectroscopy
Near-infrared spectra of homogenized samples were obtained with Calorie Answer™ (CA-HM, JWP, Japan) over a wavelength range from $(1100\text{–}2200)\times10^{-9}$ m with a resolution of 7.5×10^{-9} m and a data interval of 2.0×10^{-9} m. The main components of the instrument include: a halogen lamp as radiation source; acousto-optic tunable filter (AOTF) as wavelength selector, and light receiving sensors as light detectors. The reflectance mode and transmittance mode were used for solid and liquid samples respectively. Reference reflectance data was obtained with a calcium carbonate filled cell, and reference transmittance data was obtained with air. Triplicates of each sample were scanned in cylindrical sample cells (internal diameter=0.05 m, depth=0.01 m for solid sample holders; internal diameter=0.022 m and depth=0.002 m for liquid sample holders). The relevant setting for analysis was selected for each food product. The inbuilt computer software (CA-HM Measurement Application Software, JWP, Japan) was set so that each triplicate portion was scanned 10 times, which were then averaged to give a mean spectrum for improved accuracy. The data were transformed into log 1/R and calorie content for each sample was then calculated in accordance with regression expressions pre-programmed in the software. The regression expression used depended on the selected setting for analysis. The available settings, as well as the measurement range, are presented in Supplementary Table 1. The analysis time for each measurement (including time for calibration) took about 5 minutes.

Statistical analysis
Mean measured calorie content was calculated as the average of triplicate measurements. Data was represented as mean ± standard deviation (SD). The percentage relative standard deviation (%RSD) of triplicate measurements was determined using the following formula: %RSD=(SD of triplicate measurements) / (mean of triplicate measurements)×100. The percentage difference between stated and measured calorie values was calculated by: (Stated Calorie–Average Measured Calorie) / Stated Calorie×100. Wilcoxon signed rank test and paired sample t-test were conducted to compare measured calorie contents with stated calorie contents for individual categories and for all foods respectively. Pearson's correlation coefficient (r) was used to examine the correlation between stated and measured calorie contents. The Bland-Altman analysis was used to evaluate the validity of comparing measured calorie content with stated calorie content. A range of agreement was defined as mean bias±2×SD. Statistical analyses were performed using SPSS software (version 16.0, USA). A p value of <0.05 was considered to be statistically significant.

RESULTS
One hundred and five foods were purchased in Singapore and analyzed for their calorie contents using the NIR spectroscopy with Calorie Answer™. The %RSD value was used to assess the reproducibility of the technique (Table 1). Calorie Answer™ was found to give reproducible results, with an average %RSD value of 1.7% for triplicate measurements for all foods measured (minimum: 0%, median: 1.1%, maximum: 12.8%). Snacks and confectionery showed the lowest %RSD, followed by grains, liquids and prepared foods.

The percentage difference between stated and measured calorie contents for various categories of food are shown in Figure 1. The average percentage difference between stated and measured calories was used to assess the accuracy of the instrument (Table 1). The measured calorie content was found to be 4.0% deviant from the stated values when all foods were considered. When individual categories of food were looked at, there were no significant differences for grains (p=0.916), snacks and confectionery (p=0.666), and liquids (p=0.071). Prepared food was found to have slightly higher measured calorie contents of 8.05% as compared to stated values from the nutritional labels (p<0.001).

Table 1. Estimation of metabolizable energy of foods by Calorie Answer™

Category	n	Range	Average % difference (Stated-Measured)	%RSD (for triplicate measurements)	p-value	Pearson correlation
Grains	13	107-417	-0.43	1.02	0.916	0.99[**]
Snacks and confectionery	39	198-593	0.07	0.97	0.666	0.97[**]
Liquids	12	22-330	-7.02	1.63	0.071	0.98[**]
Prepared foods	41	88-619	-8.05	2.53	<0.001[*]	0.97[**]
All food	105	22-619	-3.97	1.66	<0.001[*]	0.99[**]

Measured and stated calorie contents were compared using Wilcoxon signed rank test for individual food categories, and paired sample t-test for all foods ([*]p<0.001). All Pearson correlations were found to be significant ([**]p<0.001).
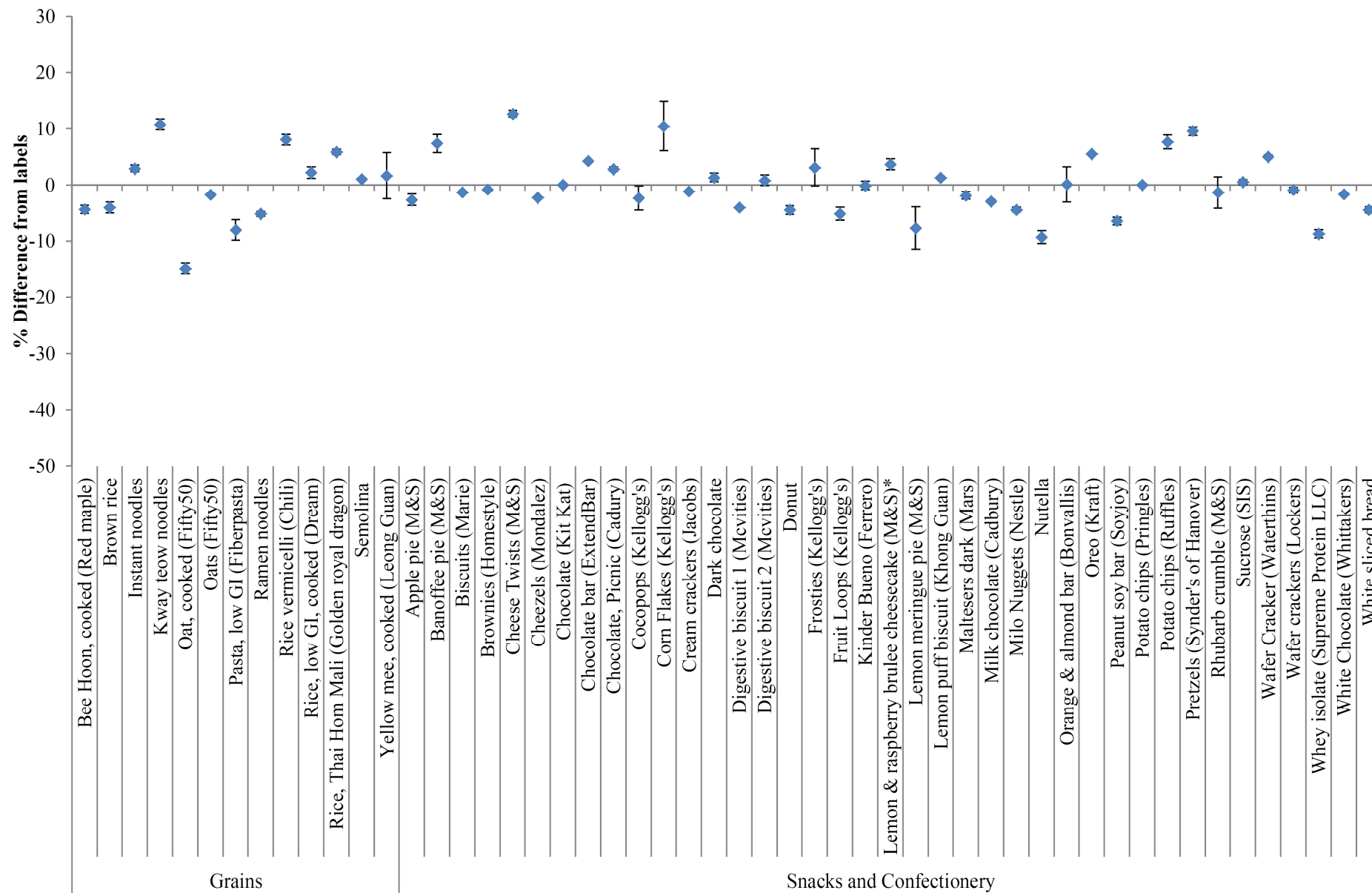
Figure 1. Deviation of measured calories from stated calories (labels). M&S: Marks and Spencer; F&N: Fraser and Neave; GSK: GlaxoSmithKline
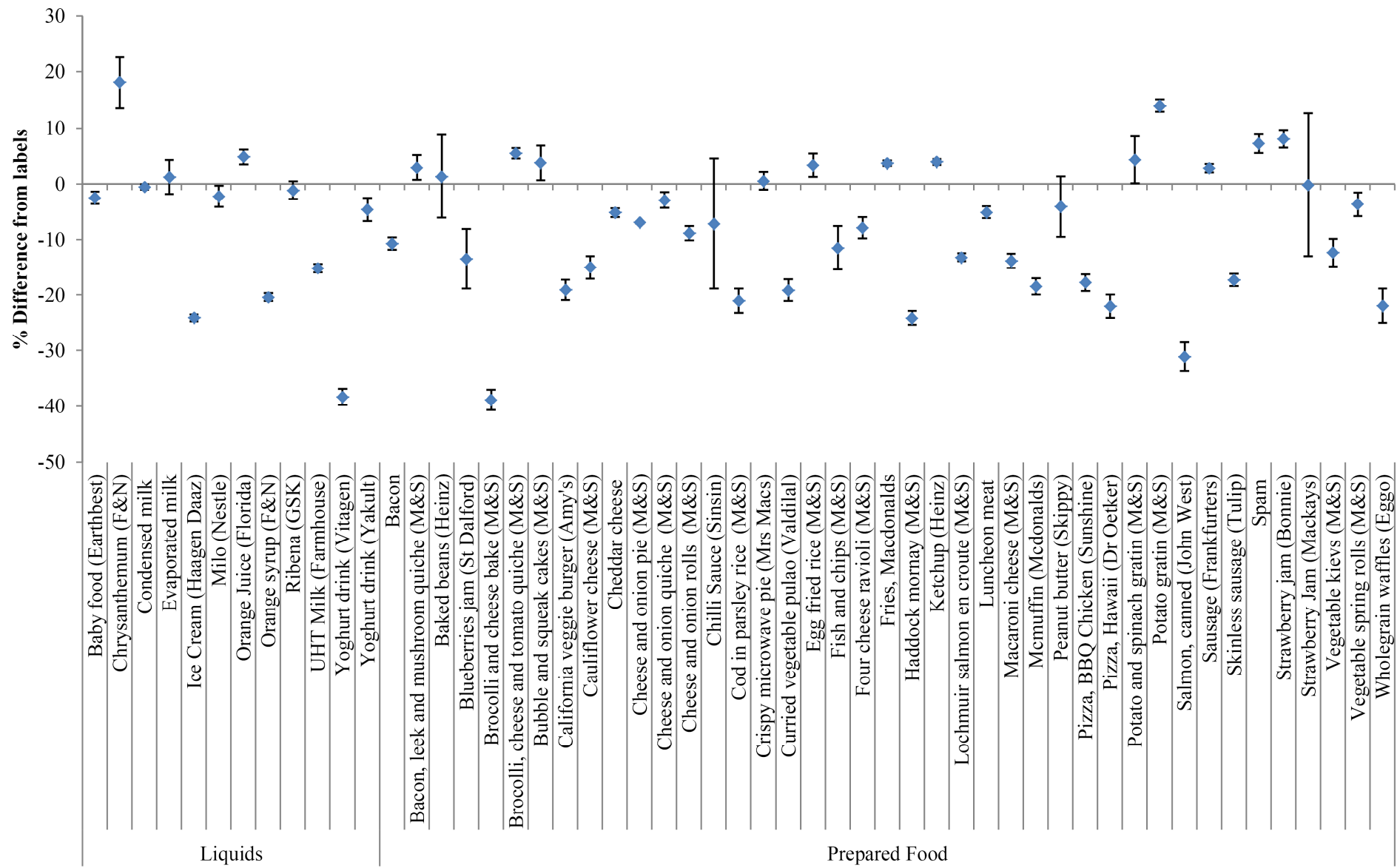
Figure 1. Deviation of measured calories from stated calories (labels). M&S: Marks and Spencer; F&N: Fraser and Neave; GSK: GlaxoSmithKline (cont.)
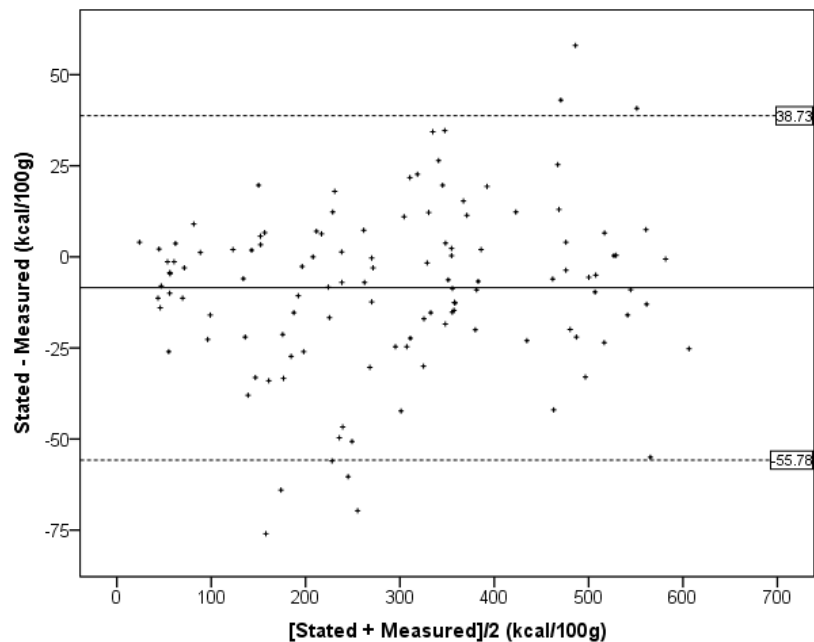
Figure 2. Bland-Altman Plot to assess agreement between estimation of calorie content by standard methods (nutritional labels) and Calorie Answer™

The Pearson correlation coefficient (r) was used to describe the relationship between stated and measured calorie contents (Table 1). Statistically significant strong correlations were found for all categories (p<0.001). The highest correlation was seen for grains (r=0.99), liquids (r=0.98), followed by snacks and confectionery (r=0.97), and prepared foods (r=0.97). On the whole, a statistically significant relationship was observed between stated and measured calorie contents for all foods that were analyzed (R^2=0.98, p< 0.001).

A Bland-Altman analysis was also carried out to evaluate the validity of comparing calorie content results between stated and measured values (Figure 2). It was found that 91.4% of the data was within ±2×SD. of mean difference between stated and measured calorie content, indicating that they were fairly comparable.

DISCUSSION

The main objective of this study was to measure the calorie content of food products using the Calorie Answer™ and to assess the accuracy by comparing the measured values with the stated values on nutrition labels. Food products from renowned multi-national companies were purchased for this study in order to provide a basis for comparison. The stated calorie contents on nutritional labels of these products were taken to be reference values for our comparison. This was in order to validate the reliability of the Calorie Answer™. The precision of Calorie Answer™ was found to be excellent. Only 5 out of the 105 foods analyzed had % relative standard deviation values of more than 5%. These food items were blueberry jam, strawberry jam (Mackays), chili sauce, peanut butter and baked beans. This was largely due to the lack of homogeneity of the mixtures after blending. Snacks and confectionery, as well as grains and liquids, were easily homogenized, and thus had very low %RSD values. The measured calorie contents were marginally higher than

stated values, ranging from 0.07-8.05 % for various categories of food.

The correlation between measured and stated calorie content of all foods measured was found to be in strong agreement, with r=0.99 for all foods. The results from Bland-Altman analysis showed that 91.4% of the data were in agreement within ±2×SD. from mean difference. This study has shown that it is both feasible and acceptable to measure the calorie content of food, with minimal sample preparation steps using the Calorie Answer™. It also showed that the instrument is capable of measuring a diverse range of foods with savings in time and effort, thus making it an attractive alternative to conventional methods of analysis.

Most of the nutritional information for the consumer is currently available in processed and packaged foods. There is a paucity of information on the calorie content from food and beverage purchased from cafes, restaurants and street food vendors. Recently, the U.S. Food and Drug Administration (FDA) had mandated the display of calorie information of foods on menus and menu boards served in chain restaurants (20 outlets or more), similar retail food establishments and vending machines.[15] It is likely that this trend will emerge in Asia and many other countries of the world. In many regions of Asia, Africa and Latin America, where food preparation and dishes are composed of a multitude of food ingredients, it has always been a challenge to estimate the energy content of such foods using the bomb calorimeter. The Calorie Answer™ machine provides rapid, reproducible and cost-effective analysis and appears to be an ideal instrument for generating the energy content of foods from various regions. According to international legislation, the stated energy values on labels must not be more than 20% in excess of the actual food energy.[16,17] This could be achieved by using the Calorie Answer™ as it is a cost-effective and economical way to analyse foods within

acceptable accuracy range, notably for small food businesses.

Conclusion

The calorie content of 105 food items were analyzed using NIR spectroscopy with the Calorie Answer™. Measured values were found to be strongly correlated with stated values on nutrition labels. The Calorie Answer™ required minimal sample preparation, was simple to use and provided rapid analysis on the metabolizable energy content of food. It could potentially be used in place of expensive and time-consuming bomb calorimeter or chemical analysis. Furthermore, its application in many developed and developing countries will generate much needed information on the calorie content of foods from these regions. As information on the calorie content of food is important in treating under-nutrition and over-nutrition, this instrument may become an important tool in providing the calorie content of the composite foods we consume.

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AUTHOR DISCLOSURES

All authors declare no conflict of interest.

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Supplementary Table 1. List of measurement settings for Calorie Answer™

	Calorie range (kcal)
Reflectance mode	
Cereals (under 200 kcal)	35-199
Cereals SCREENING (also powdered rice)	200-580
Cheeses	127-544
Confectioneries, Japanese buns	250-520
Milk powder, grated cheeses	47-544
Powdered cereals, dried noodles	349-434
Prepared foods	120-360
Snacks	370-550
Yogurts	28-74
Transmittance mode	
Coffee drinks	4-95
Condensed milks, ice creams	28-328
Fresh creams	76-435
Lactobacillus drinks	28-192
Milks	37-230
Milks (sweetened)	4-95
Soft drinks	4-60
Yogurt drinks	28-74

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关键词：热量、食物成分、营养标签、近红外光谱、非破坏性食品分析