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# Applicable Models Based on Equi-Energetic Servings: Part 3 PLSR Based Models Predicting the Insulinemic and Glycemic Response of Common Individual and Mixed Food Products, and the Explanation Why Just Equi-Energetic Servings Can be Modelled: A Meta-Analysis

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## Abstract

**Background:** PLSR based models capable to predict the glycemic response of common, processed food products can only are developed using equi-energetic rather than equi-carbohydrate servings.

**Objective:** To understand based on formal grounds, why model formation is not possible using 50 g carbohydrate servings, but is possible using equi-energetic servings.

**Method:** A theoretical based argumentation was formulated enabling to understand why model formation to predict the glycemic behaviour of common food products is possible using equi-energetic servings and is not possible using equi-carbohydrate servings.

**Results:** To obtain a better insight into the similarity and differences between the GI approach, based on 50 gram carbohydrate servings, and the GlyS approach, based on 1 MJ servings. The similarities and differences between these two approaches were worked out on a formal, theoretical basis. Using this approach, as an example, two different products were mixed in any ratio and the consequences for the glycemic response and glycemic load, either using the Gl or the GlyS approach, were simulated. This approach also shows that for products either just containing sugars, or for meals, the energy based weighted sum of either the individual sugars, or of the individual food products forming a meal, are proper predictors of the GlyS of these products respectively. In addition, the relation between the GlyS and insulinemic score (InsS) is described.

**Conclusions:** The use of the GI concept makes it impossible to accurately predict the consequences of the addition of protein, fat, carbohydrate, or fibre on the glycemic response. This inability is abolished using equi-energetic serving. In this latter case it is possible to develop predictive models based on the macronutrient composition of each individual product for common, processed food products, for products, just containing sugars and for meals.

***Keywords:*** *Predictive models; Equi-energetic servings; Glycemic score/index; Glycemic load; Insulinemic score/index*

**Abbreviations:** GI: Glycemic Index (50g carbohydrate servings); GlyS: Glycemic Score (1 MJ servings); InsS: Insulin Score; GL: Glycemic Load based on GI; GlySL: Glycemic Load based on GlyS; GlyS-equi: GlyS of complex products; PLSR: Partial Least Squares Regression; RMSEC/P: Root Mean Square Error of Calibration/Prediction; TDF: Total Dietary Fibre

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## Introduction

The concept of the addition of a numerical value to a food product to describe its postprandial glycemic behaviour, compared to a reference product [1], the glycemic index (GI), is very valuable. The GI concept is based on the glycemic response of any food product containing 50g carbohydrate (starch plus sugar). This way each product can be categorized [2] ranging from low (GI < 55), medium (55 < GI < 70) to high (GI > 70) GI products. The GI value of a product describes its glycemic behaviour under academic conditions. A more practical approach is the use of the glycemic load (GL) of a product. The GL is calculated as the amount of carbohydrate (g) a given serving of a product contains, times its GI value, and divided by 100. By summing the GL values of all carbohydrate containing products consumed during a meal, or a day, a value is obtained that can be used for epidemiological purposes [3,4].

The major problems encountered using the GI concept are that the addition of either protein or fat to a product decreases the GI value of that product in an unpredictable way [5,6], and that the GI value of a meal, consisting of at least two different products with known GI value cannot accurately been predicted [7,8].

Recently it was shown [9,10] that using equi-energetic servings (1 MJ) it is possible to develop predictive models enabling the prediction of either the perceived satiety of fresh and processed food products or the glycemic response, glycemic score (GlyS), of common, processed food products, using relevant macronutrients as prediction factors. In addition it was shown that, due to the constraint that the amount of energy of a serving is fixed at 1 MJ, an increase in the amount of protein and/or fat, there by consequently decreasing the amount of carbohydrate, leads to a decrease in the glycemic response. This increase in amount of protein and/or fat is inversely related with the decrease in the glycemic response, emphasising the (indirect) contribution of protein and fat to the GlyS value of any food product [10]. Under these conditions the amount of protein and/or fat can never exceed (1000 kJ/ (17 kJ/g) =) 58.8 gram protein, or (1000 kJ/(37 kJ/g) =) 37.0g fat; under GI conditions these amounts of protein or fat can exceed these values. To address to modelling potential of the GlyS approach this was worked out further for products high in sugar and low in starch, for products just containing sugars and, for meals. Based on the results obtained the similarities and differences between the GlyS and GI approach for singular products and for mixtures of two products (meals) has been worked out on formal grounds. Simulations were performed to describe the numerical consequences of the differences in approach, including the glycemic load.

## Material and Methods

### General

The data acquisition of fruit, confectionary and dairy products, the application of the transformation scheme to come from glycemic index (GI), based on 50g carbohydrate servings, to glycemic score (GlyS), based on 1 MJ servings, the PLSR based model formation and the definition of outliers are identical as described previously [10].

### Glycemic sum

For those products that only contain either mono-, and/or disaccharides (fruit, confectionary, dairy products) as carbohydrate fraction, the glycemic response is calculated as the sum of the weighted contribution of the individual mono-, and disaccharides. The maximum total amount of sugar in a product amounts 1 MJ and is equal to (1000 kJ/ (17 kJ/g)) =58.8g. Per individual sugar, "*i*", the glycemic contribution per gram sugar, "*a*", can be calculated, (ai = GlyS$^i$/58.8g). This allows the calculation of the GlyS value of a mixture of sugars within a product, which a total energy content set at 1 MJ, according to:

$$GlyS - equi = \sum_{1}^{i} a_i \bullet W_i \qquad \text{Eqn. 1}$$

where $a_i$ is the value of the glycemic response per gram of sugar "*i*", and $W_i$ is its weight (g) of sugar "*i*". The weight of each sugar reflects its energy content. To distinguish between the GlyS value of a product as calculated from its GI value, the calculated weighted sum (see Equation 1) is named GlyS-equi. Based on literature information [11,12] the following GS values were used for; glucose = 141, fructose = 17, sucrose = 80, lactose = 68 and maltose = 150. After transformation from GI to GlyS, [10] the GlyS values of 1MJ glucose = 176, of fructose = 22, of sucrose = 99, of lactose = 82, and of maltose = 186.

In addition, a linear regression was performed between the percentage energy contained by "protein + fat" and the per product measured GlyS values and the calculated GlyS-equi values [10]. Samples were omitted from this analysis if the energy content of "protein + fat" was smaller than 0.1%. This analysis was only performed for the group of non-diabetic test persons, since for the diabetic group of test persons more than half of the samples contained less than 0.1% "protein + fat", and the remainder of the samples (n = 18) showed an unbalanced distribution.

### Meals

A meal is considered to be an assembled product containing varying amounts of at least two individual food products. From each individual food product contributing to a meal, its GlyS value was estimated using the regression model for non-diabetic test persons of the food group to which the product belongs [10]. Next, the percentage energy contribution of each individual food product to the meal was calculated, multiplied with its estimated GlyS value, summed for all food products constituting the meal and divided by 100%. The outcome of this calculation was used as the estimate for the GlyS value of that meal. The calculation of the GlyS value of a meal is, in fact, identical to the determination of the glycemic sum of products just containing sugars (see Equation 1). Similar to products only containing sugars, the calculated GlyS value of a meal will be indicated by GlyS-equi.

### Insulin Score

The insulin score (InsS), based on 1MJ servings, was derived from the Insulin Index (II), in exactly the same way the GlyS value was obtained for individual products [10]. The values for II and IS of a food product are of the same order of magnitude. Samples were directly excluded from analysis in case the II differed more than a factor 1.8 from the II. These samples were always recognized as outlier [10].

### Simulation

### Description of the samples used to construct a meal

The consequences of mixing two different products in any ratio for the GI, GlyS, GL and GlySL (glycemic load of a serving containing 1 MJ rather than 50g carbohydrate) were simulated. As described above each product obtained by mixing is formally a meal. The first product was white bread with a GI and a GlyS value of 100 [10]. The second product consists of commercially prepared beans [13] to which, in a simulation process, incremental amounts of fat were added. In total 20 new bean products were created. From each new bean product the macronutrient composition was re-determined applying the constraint of a 1 MJ serving. The GlyS value of each new product was estimated using the PLSR model for legumes and non-diabetic test persons [10]. The GI values of this series of bean based products were calculated based on 50g carbohydrate per sample as described previously [10]. The glycemic load, both GL and GlySL, of any constructed meal was calculated as the product of the carbohydrate content (g) of a given sample times its GI, respectively GlyS value and divided by 100 [3,4]. In addition per sample, the GL/MJ was calculated.

### Description of the construction of a meal

For simulation purposes the white bread sample was mixed with one of the twenty bean samples this mixing took place using fifteen different ratios between the amount of white bread and the bean samples, either using the GI values or the GlyS values of the samples, resulting in 300 meals each with its own composition.

## Results and Discussion

### The GlyS value of products high in sugar and low in starch

Previously [10] PLSR models were developing for starch containing products that also contained sugars. For these products the average amount of starch and sugar are 36.1g/MJ and 6.1 g/MJ respectively. For the products analysed here [14-25] these amounts are 8.9 g/MJ and 36.9 g/MJ respectively. The sugar/starch ratio between these two groups differs by a factor of 25. The low starch product group consists of fresh products like banana's and processed products like pudding, ice cream, and also candy-, and sports bars. The results of the model formation are presented in Table 1. In this case, only results for non-diabetic assessors were available. As can been expected sugar is the most relevant regression coefficient. The GlyS value of 1MJ starch in the absence of fibre is estimated to be 94, the estimated change in this value by fibre is -1, 3 GlyS units /gram TDF.

### The GlyS value of products just containing sugar

For products just containing sugar [14,15,17,19-21,24-33] the estimate for the GlyS value of the individual products was per product calculated as the weighted sum of the individual sugars (see Equation 1). This calculated GlyS value was directly related to the determined GlyS value. This analysis was performed separately for diabetic and non-diabetic test persons (see Table 1) since these two groups of test persons showed a different glycemic response ($P < 0.05$) for this group of products. The values of r and RMSEC (Root Mean Square Error of Calibration), the modelling error, for the diabetic and non-diabetic test persons are similar to the values obtained previously for processed food products [10] indicating that the weighted sum of the individual sugars, GlyS-equi, is the most relevant determinant of the GlyS value of non-starch containing products. It is noticeable that in this case TDF does not affect the glycemic response of this product group, this in contrast to all starch containing products [10]. Similar to the previous results [10] the RMSEC value for the diabetic test persons is lower compared with this value for the non-diabetic test persons, though the value of R of the diabetic group is lower than of the non-diabetic group.

| Product Group | Number of samples | Number of outliers | r | $^1$RMSEC | Regression coefficients | | | Estimated GlyS value |
|---|---|---|---|---|---|---|---|---|
| | N | n | | | Sugar (g) | Starch | TDF (g) | Starch;1MJ<br>Sugar=TDF=0 |
| High sugar - low starch products (Non-Diabetic test persons) | 36 | 3 | 0.79 | 12.7 | 1.02 | 0.66 | 0.27 | 94 ± 15 |
| Only sugar containing samples | | | | | GlyS-equi | | | |
| Non-Diabetic test persons | 65 | 1 | 0.89 | 17.6 | 0.87 | | | $^2$NR |
| Diabetic test persons | 39 | 4 | 0.71 | 10.4 | 0.71 | | | NR |
| | | | | | | | | |
| Meals (Non-Diabetic) | 42 | 0 | 0.85 | 11.3 | 0.85 | | | NR |

***Table 1:*** *Results of the PLSR model formation of products high in sugar and low to absent in starch and the numerical values of the regression coefficients of the models able to predict the Glycemic Score of individual food products, and the values of the regression correlation, the RMSEC and the estimate per product group of the Glycemic Score of 1 MJ Starch in the absence of sugar and TDF by either diabetic or non-diabetic test persons.*

*$^1$RMSEC: Root Mean Squares Error of Calibration; $^2$NR: Not relevant*

As shown previously, the higher the energy content of a sample in the form of protein and/or fat, the lower the glycemic response of the sample [10]. The relations observed between the percentage energy contained in the form of "protein + fat" and the measured, the predicted and the normalized weighted sum of the individual sugars, GlyS-equi, are respectively:

%Energy (protein + fat) = -0.0076. (GlyS-measured) + 0.78 (r = 0.83; n=55) (Eqn. 2a)

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%Energy (protein + fat) = 0.0085. (GlyS-predicted) + 0.83 (r = 0.97; n=55) (Eqn. 2b)

%Energy (protein + fat) = -0.0095. (GlyS-equi) + 0.92 (r = 0.97; n=55) (Eqn. 2c)

Obvious is the excellent fit between the percentage energy contained by fat plus protein and both the predicted GlyS values and the calculated GlyS-equi values.

### Meals

For the determination of the GlyS values of meals [34-42], basically the same approach is chosen compared with products just containing sugars. The GlyS value of a meal is calculated as the weighted sum of the individual GlyS values of the food components contributing to the meal. The value of the correlation coefficient between the calculated and measured GlyS values is r = 0.85. The value for the RMSEC = 11.3 and n = 42. These values for r and RMSEC are similar compared with these values obtained for the PLSR models for the five product groups obtained by non-diabetic test persons as described previously [10].

### The insulinemic response of food products

In Table 2 the results of the analyses relating the glycemic with the insulinemic response of food products are presented [14,18,19,21,24,26-28,30-33,36,40-73]. A proper relation is observed between the GlyS and InsS for a large variety of fresh and processed food products with the glycemic response being the only relevant regression factor for the insulinemic response. For none of the analyses discussed below a different behaviour was observed between diabetic and non-diabetic test persons. For this reason these two groups were analysed together. (see Table 2). The values of *r* and RMSEC are similar to the values previously obtained for the processing dependent glycemic response of food groups [10]. When the glycemic response (GI) was compared with the insulinemic response (II) the correlation between GI and II is worse compared to the correlation between GlyS and InsS. However, if both the GI and II responses are expressed per MJ product, the regression result obtained is very similar to the result when comparing the GlyS with the InsS. Comparing the GlyS with the II and the GI/MJ with the InsS, similar results were obtained when the GI was compared with the II. Obviously the use of equi-energetic servings, rather than servings based on 50g carbohydrate, enables a proper relation between the glycemic and insulinemic behaviour of a wide range of fresh and processed food products.

| Analysis | Number of samples | Number of outliers | *r* | [1]RMSEC | Linear regression | |
|---|---|---|---|---|---|---|
| | | | | | slope | intercept |
| GlyS vs. InsS | 339 | 3 | 0.82 | 19.4 | 0.86 | 15.7 |
| GI vs. II | 339 | 0 | 0.60 | 29.1 | [2]NR | NR |
| GI/MJ vs. II/MJ | 339 | 6 | 0.84 | 19.6 | 0.83 | 18.0 |
| GlyS vs. II/MJ | 339 | 0 | 0.59 | 35.4 | NR | NR |
| GI/MJ vs. InsS | 339 | 0 | 0.62 | 27.0 | NR | NR |

***Table 2:*** *Regression analysis of the glycaemic response versus the insulinemic response.*

*[1]RMSEC, Root Mean Squares Error of Calibration; [2]NR, not relevant*

### A theoretical based argumentation concerning the relevance of the use of equi-energetic servings

In Table 3 a systematic overview is given concerning the similarities and differences, by either using the GI approach (Eqn. 3a-3g), or the GlyS approach (Eqn. 4a-4g), with emphasis on the consequences of the simultaneous consumption of two different amounts of two different food products, a meal, and the calculated glycemic responses for the GI and GlyS approaches respectively. For the GI approach two different products "A" (Eqn. 3a) and "B" (Eqn. 3b) are defined characterized by an energy content of "M" and "N" MJ respectively, each containing 50g carbohydrate (starch plus sugars), equivalent to 0.85 MJ, and their corresponding GI values. This approach

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allows the definition of the sum of the amount "Protein + Fat", expressed in MJ. The relevance of the sum of the amount of protein and fat to the glycemic response has been shown previously [10] and above. Eqn. 3c and 3d describe the same situation as above, but than for the amounts "pA" and "qB" respectively, where "p" and "q" each represent an arbitrary numerical value. Eqn. 3e describes the result when Eqn. 3c and 3d are summed, representing any combination of "A" and "B". Eqn. 3f and 3g are basically identical to Eqn. 3e, but describe this last equation normalized to either 1MJ, or 50g carbohydrate respectively. The same approach is followed for the GlyS, with both products "A" and "B" containing 1 MJ. Here it can be seen that for the GlyS "Carb" and "Protein + Fat" (Eqn. 4a, b) are, in contrast to the GI approach (Eqn. 3a, b), inversely related to each other. If Carb = λ, than "Protein + Fat" =1-λ; this inverse relation does not exist in case of the GS approach. In the last column of Eqn. 4a and 4b the relation between the GlyS and GI value of a product is reminded [10]. Comparing Eqn. 1e (GI approach) and 2e (GlyS approach), where pA and qB are summed it can easily be shown that for any combination of p and q a linear relation exists between the values of the GI sum and the corresponding values of the GlyS sum ($R^2 = 1$). Though more difficult to see, this linear relation ($R^2 = 1$) also exists between the GL (Eqn. 5a) and the GlySL (Eqn. 5b). In addition it is rather obvious that for the normalized equations, either normalized to 1 MJ servings, or 50g carbohydrate servings, no linear relation can respectively been observed between Eqn. 3f and Eqn. 4f and between Eqn. 3g and Eqn. 4g, given the difference in their denominators.

### Simulation the GI and GlyS of mixed products

For simulation purposes the information given in Table 4 was used. Samples 1a-1d, 2a-2d and 3a-3d form a representative part of the 20 newly formed bean products. With regard to the estimated GlyS values (samples 2a-2d) it is obvious that the more fat added, the lower the amount of carb, the lower the GlyS value. With regard to the calculated GI values (samples 3a-3d) it can be seen that at a constant carbohydrate content (50g) and an increasing amount of fat, despite the constant amount of carbohydrate, the GI decreases. This observation is similar to observations previously made that addition of fat and/or protein to a sample decreases its GI value [5,6]. This observation can be explained as follows. Addition of protein and/or fat to a 1MJ containing serving enhances the total energy content of that serving. To predict a new GlyS value of this new serving the macronutrient composition has to be recalculated based on 1MJ energy content of the new serving. Anyhow, in this new situation the amount of carbohydrate is decreased and the amount of "protein + fat" is increased resulting in a decrease in the GlyS and the GI value of this new product. This conclusion can also be also be confirmed based on the theoretical grounds given in Table 3

Using the numerical information given in Table 4 to simulate the equations given in Table 3 the following results were obtained. Comparing the simulation results for the non- normalized equations (Eqn. 3e versus Eqn. 4e, Eqn. 5a versus Eqn. 5b), as already discussed above, $R^2 = 1$ for the numerical comparison of the respective simulation results. For the numerical comparison of the normalized equations (Eqn. 3f versus Eqn. 4f, and Eqn. 3g versus Eqn. 4g) the results of can be described by the following equation:

$$GI = \alpha.\exp(\beta.GlyS) \qquad \text{(Eqn. 6)}$$

In all cases it was observed that the more fat the bean samples contained, the smaller the value of α and the larger the value for β. In addition the value of the correlation coefficient between the simulated GI and GS values and their corresponding values predicted by Eqn. 6 was in all cases $R^2 > 0.99$.For the glycemic load the same the simulation results were obtained as described above for the GI versus the GlyS. For the non- normalized equations (Eqn. 5a versus Eqn. 5b) $R^2 = 1$ for the numerical comparison of the respective simulation results. For the numerical comparison of the normalized equations, normalized either per 1 MJ, or 50g carbohydrate, the results can be described by Eqn. 6.

| GI approach; Carb =50 gram (GI white bread =100) | | | | | |
|---|---|---|---|---|---|
| Eqn. | Product (g) | Carb (MJ) | Protein + Fat (MJ) | MJ total | GI |
| 3a | A | 0.85 | M-0.85 | M | GI(A) |
| 3b | B | 0.85 | N-0.85 | N | GI(B) |
| GI approach; mixing A and B | | | | | |
| 3c | pA | 0.85p | p(M-0.85) | pM | p.GI(A) |
| 3d | qB | 0.85q | q(N-0.85) | qN | q.GI(B) |
| 3e | pA + qB | 0.85(p+q) | p(M-0.85)+ q(N-0.85) | pM+qN | p.GI(A) + q.GI(B) |
| 3f | (pA+qB)/(pM+qN) | 0.85(p+q)/ (pM+qN) | ((p(M-0.85)+ q(N-0.85))/ (pM+qN) | 1 | (p.GI(A)+ q.GI(B))/(pM+qN) |
| 3g | (pA+qB)/(p+q) | 0.85 | ((p(M-0.85)+ q(N-0.85))/ (p+q) | (pM+qN)/(p+q) | (p.GI(A)+ q.GI(B))/(p+q) |
| GlyS approach;1MJ energy per product (GlyS white bread =100) | | | | | |
| 4a | A/M | 0.85/M | (M-0.85)/M | 1 | GlyS(A)(=1.05GI(A)/M) |
| 4b | B/N | 0.85/N | (N-0.85)/N | 1 | GlyS(B)(=1.05GI(B)/N) |
| GlyS approach; mixing A and B | | | | | |
| 4c | pA/M | 0.85(p/M) | p(M-0.85)/M | p | p.GlyS(A) |
| 4d | qB/N | 0.85(q/N) | q(N-0.85)/N | q | q.GlyS(B) |
| 4e | (pA/M)+(qB/N) | 0.85(p/M+q/N) | p(M-0.85)/M+q(N-0.85)/N | p +q | pGlyS(A) +qGlyS(B) |
| 4f | ((pA/M)+(qB/N))/ (p+q) | 0.85(p/M+q/N)/ (p+q) | (p(M - 0.85)N+ q(N-0.85)M)/MN.(p+q) | 1 | (pGlyS(A)+q.GlyS(B))/(p+q) |
| 4g | ((pA/M)+(qB/N))/ (0.85(p/M+q/N) | 0.85 | (p(M-0.85)/M) + q(N-0.85)/N))/(p/M+q/N) | (p+q)/(p/M+ q/N) | (pGlyS(A) + (qGlyS(B))/ (p/ M+q/M) |
| Glycemic load (GL) based on GI approach | | | | | |
| 5a | GL=(0.85p2GI(A)+085q2GI(B))/100 | | | | |
| Glycemic Load (GlySL) based on GlyS approach | | | | | |
| 5b | GL=(0.85$p^2$.N.GlyS(A)+085$q^2$.M.GlyS(B)/N)/((M+N).100) | | | | |

***Table 3:*** *Mixing two different amounts of two different products and the consequences for their GI, GlyS GL/GlyS values.*

## Conclusions

In line with the previous results [10] for products containing a high sugar to low starch ratio the same type of model could be developed (see Table 1) compared to products low in sugar and high in starch. For the high sugar low starch products sugar is the most relevant regression factor, rather than starch. For products just containing different types of sugars, the glycemic response equals the weighted sum of the individual sugars (see Equation 1). Since each sugar has the same energy content per gram, in fact, similar to meals, the percentage energy of each sugar is multiplied by its GlyS value and summed for all sugars. This, together with the results obtained for meals, supports the concept that the dimension energy, rather than the dimension weight (50g carbohydrate) is the relevant link to the numerical description of the human satiety [9] and glycemic [10] responses upon food consumption. Each sugar is characterized by its own GI value (see above). It is interesting to note that the average GI value of glucose and fructose equals the GI value of glucose. In other words these data suggest that the simultaneous consumption 25g glucose and 25g fructose results in the same glycemic response after consuming 50g sucrose. Since the GI value of lactose is 68, half the value for glucose, this suggests that the GI value for galactose is virtually zero. Here it has to be realized that the mutual numerical ratios of the GI values of the sugars mentioned here is identical to those of the corresponding GlyS values. For products just containing sugars, it is also observed that the glycemic response significantly differs between diabetic and non-diabetic test persons ($P < 0.05$). In addition, TDF does not affect the glycemic response of this product group, in contrast to the starch containing common, processed food products. For all glycemic response models mentioned here and previously [10], the total number of samples (N) analysed is 745, the correlation (r) between the measured and predicted GlyS values is 0.88, the RMSEC = 8.4 and the number of outliers is 25 (= 3.4%), suggesting the correctness of the approach chosen. Previously [10] it was shown that per product group an inverse relation exists between the GlyS value of products belonging to a product group and the percentage energy contained by protein plus fat in this group. This relation is also observed for the two product groups mentioned in Table 1(data not shown for the "High sugar - low starch products). This relation is also formulated in Table 3 for the GlyS approach (see Eqn. 4a and 4b).

| Sample | GlyS | Carb (g) | Sugar (g) | Starch (g) | TDF (g) | Fat (g) | Protein (g) | Energy (MJ) | [3]GlySL | GlySL/MJ |
|---|---|---|---|---|---|---|---|---|---|---|
| White Bread | 100 | 48.3 | 2.1 | 46.2 | 2.0 | 1.4 | 7.5 | 1 | 48.3 | 48.3 |
| [1]Beans | 57.5 | 41.5 | 15.3 | 26.2 | 20.3 | 1.7 | 13.7 | 1 | 23.9 | 23.9 |
| Addition of incremental amounts of fat | | | | | | | | | | |
| 1a | [2]tbd | 41.5 | 15.3 | 26.2 | 20.3 | 15.0 | 13.7 | 1.49 | tbd | tbd |
| 1b | tbd | 41.5 | 15.3 | 26.2 | 20.3 | 40.0 | 13.7 | 2.42 | tbd | tbd |
| 1c | tbd | 41.5 | 15.3 | 26.2 | 20.3 | 80.0 | 13.7 | 3.90 | tbd | tbd |
| 1d | tbd | 41.5 | 15.3 | 26.2 | 20.3 | 120.0 | 13.7 | 5.38 | tbd | tbd |
| Estimation of the GlyS (1 MJ servings) after fat addition | | | | | | | | | | |
| Sample | GlyS | Carb | Sugar | Starch | TDF | Fat | Protein | Energy | GlySL | GlySL/MJ |
| 2a | 41.2 | 31.7 | 11.7 | 20.0 | 15.5 | 7.6 | 10.5 | 1 | 13.1 | 13.1 |
| 2b | 22.2 | 20.3 | 7.5 | 12.8 | 9.9 | 14.6 | 6.7 | 1 | 4.5 | 4.5 |
| 2c | 8.1 | 11.8 | 4.3 | 7.4 | 5.8 | 19.8 | 3.9 | 1 | 1.0 | 1.0 |
| 2d | 2.3 | 8.3 | 3.0 | 5.2 | 4.1 | 22.0 | 2.7 | 1 | 0.2 | 0.2 |
| Calculation of the GI (50 g carbohydrate) | | | | | | | | | | |
| Sample | GI | Carb | Sugar | Starch | TDF | Fat | Protein | Energy | 4GL | GL/MJ |
| White Bread | 100 | 50 | 2.2 | 47.8 | 2.1 | 2.2 | 8.0 | 1.05 | 50.0 | 47.6 |
| Beans | 66.0 | 50 | 18.4 | 31.6 | 24.5 | 2.0 | 16.5 | 1.20 | 33.0 | 27.4 |
| 3a | 59.5 | 50 | 18.4 | 31.6 | 24.5 | 18.1 | 16.5 | 1.80 | 29.7 | 16.5 |
| 3b | 47.3 | 50 | 18.4 | 31.6 | 24.5 | 48.2 | 16.5 | 2.91 | 23.7 | 8.1 |
| 3c | 27.9 | 50 | 18.4 | 31.6 | 24.5 | 96.4 | 16.5 | 4.70 | 13.9 | 3.0 |
| 3d | 8.5 | 50 | 18.4 | 31.6 | 24.5 | 144.5 | 16.5 | 6.48 | 4.2 | 0.7 |

***Table 4:*** *Estimate of the consequences of the addition of incremental amounts of fat to industrial processed beans for the GlyS, the GlySL/MJ, the GL and the GL/MJ.*

*[1] Beans from ref (13);*

*[2] tbd, to be determined;*

*[3] GlySL, glycemic load using 1 MJ servings, where GlySL = GlyS *Carb (g)/100;*

*[4] GL, glycemic load using 50g carbohydrate serving, where GL = GI *Carb (g)/100).*

***Citation:*** Cees van Dijk. "Applicable Models Based on Equi-Energetic Servings: Part 3 PLSR Based Models Predicting the Insulinemic and Glycemic Response of Common Individual and Mixed Food Products, and the Explanation Why Just Equi-Energetic Servings Can be Modelled: A Meta-Analysis". EC Nutrition 2.5 (2015): 452-464.

The results given in Table 2 show that a proper linear relation is obtained between the glycemic score and the insulinemic score. Here no difference in this relation between glycemic and insulinemic responses was observed between diabetic and non-diabetic test persons. The glycemic and insulinemic responses to glucose are strongly coupled processes. For this reason it can be argued that the difference in the glycemic response observed between diabetic and non-diabetic test persons is reflected in a similar way in the insulinemic response. This would explain the absence in differences in the relation between the glycemic score and the insulinemic score between diabetic and non-diabetic test persons. In addition if both the GI and II values of all individual products are normalized to 1 MJ almost the same linear relation is obtained compared with the relation between GlyS and InsS. Table 3 clearly shows that proper relations between glycemic and insulinemic response only under the condition of equi-energetic servings are obtained.

Relating the results obtained based on the more theoretical considerations (Tables 3, 4), it is shown that a perfect ($R^2 = 1$) relation exists between the GI and GlyS and between the GL and GlySL for single products and mixed products. However, this relation becomes exponential (see Equation 6) in case of normalisation either per 1MJ or 50g product ($R^2 > 0.99$). Furthermore in Table 4 it is demonstrated that increasing the fat content of a product the GI value, based on 50g carbohydrate, as well as the GlyS values decrease. The GlyS approach allows the prediction of samples where either fat or protein is added; this is not possible using the GS approach.

Here, and in the previous study [10] it is clearly shown that for a large range of common fresh and processed food products, exhibiting a wide range in physical/textural properties, starch, sugar and fibre are the only relevant regressions factors explaining the glycemic response of these products. Previously, it is suggested that the product thickness is also a factor contributing to the glycemic product response [73]. Based on the results of this and the previous meta-analyses [10] there is no indication whatsoever supporting this suggestion. Here it is suggested that the observations made concerning the product thickness are rather caused by experimental processing artefacts than the effects of product thickness.

In epidemiological research the GL is used to assess the total glycemic contribution of all carbohydrates consumed [3]. As such this is a valuable approach, but ignores the GL lowering effect of the consumption of additional proteins and fat, e.g. the consumption of fish, meat, butter, gravy etc. during a meal. For example, the GI and GL of a bun of a Big Mac are respectively estimated to be 87 and 43. These estimated values for a Big Mac itself are 46 and 20 respectively, indicating the effect GI and GL lowering effects of meat on these values. In other words the GL is probably overestimated if the consequences of additional fat and/or protein are not taken into account.

### Compilation of the major conclusions

Based on the results of the meta-analyses presented here and previously (9,10) the following conclusions can be made:

1. Given the experimental measuring conditions to determine the postprandial glycemic, insulinemic and satiety responses of food products the dimension energy (J) rather than amount of carbohydrate (g) is the basis enabling to adequately numerically relate these responses to relevant macronutrients.
2. The models developed are only applicable applying the standard measuring conditions, to establish the SatS, GI and/or II of food products.
3. Relevant macronutrients to predict the glycemic response of common fresh and processed food products are starch, sugar and fibre.
4. Fibre affects the glycemic response of starch containing products; it enhances the glycemic response of legumes and decreases the glycemic response of all other food products; the actual mode of action of fibre is not understood.
5. For products just containing sugar the (energy based) weighted sum of the individual sugars, the GlyS-equi, determines the glycemic response; fibre does not affect this response.
6. For meals, similar to products just containing sugars, the energy based weighted sum of the individual products constituting the meal, determines the glycemic response.

7. In all cases the glycemic response of diabetic test persons differs from non-diabetic test persons, resulting in different numerical relations between food relevant macronutrients and their glycemic response. In contrast, the insulinemic response does not differ between non-diabetic and diabetic test persons.
8. Due to the large number of samples analysed, it is possible to define outliers.
9. Given the observed differences in the macronutrient composition of white bread as reference product, together with the change of this composition during storage due to staling, it is suggested to use sucrose (GlyS=99) as reference product rather than white bread.
10. Theoretical considerations (Table 3) and simulation of these considerations (Table 4) concerning the similarity and differences between the GI and GlyS approach lead to the conclusions that:
    A. The type of modelling applied here and else (9,10) is only than possible using equi-energetic (1MJ) servings and not possible using equi-carbohydrate (50g) servings,
    B. The value for the GL in epidemiological studies (3) is probably an overestimation of the real glycemic load since the GI lowering effect due to the consumption of additional protein and fat (meat, fish, eggs, cheese, etc.) is not taken into consideration.

## Bibliography

1. Jenkins DJA., *et al*. “Glycemic index of foods a physiological basis for carbohydrate exchange”. *American Journal of Clinical Nutrition* 34.3 (1981): 362-366.
2. www.gisymbol.com/about/glycemic-index
3. Salmeron J., *et al*. “Dietary fiber, glycemic load, and risk of non-insulin-dependent diabetes mellitus in women”. *JAMA* 277.6 (1997): 472-477.
4. Salmeron J., *et al*. “Dietary fiber, glycemic load, and risk of NIDDM in men”. *Diabetes Care* 20.4 (19970): 545-550.
5. Westphal SA., *et al*. “Metabolic response to glucose ingested with various amounts of protein”. *American Journal of Clinical Nutrition* 52.2 (1990): 267-272.
6. Blythe Owen and Thomas MS Wolever. “Effect of fat on glycaemic response in normal subjects: a dose-response study”. *Nutrition Research* 23.10 (2003): 1341-1347.
7. Flint A., *et al*. “The use of glycaemic index teables to predict glycaemic index of composite breakfast meals”. *British Journal of Nutrition* 91.6 (2004): 979-989.
8. Wolever TMS., *et al*. “Food glycemic index, as given in glycemic index tables, is a significant determinant of glycemic response elicited by composite breakfast meals”. *American Journal of Clinical Nutrition* 83.6 (2006): 1306-1312.
9. Dijk van C. “Applicable models based on equi-energetic servings: Part 1 PLSR based models predicting the perceived satiety of common food products”. *EC Nutrition* 2.5 (2015): 327-436.
10. Dijk van C and Dijk van Gerben H. “Applicable models based on equi-energetic servings; Part 2 PLSR based prediction models of the glycemic response of common, processed food products: a meta-analysis”. *EC Nutrition* 2.5 (2015): 437-450.
11. Lee BM and Wolever TMS. “Effect of glucose sucrose and fructose on plasma glucose and insulin responses in normal humans: comparison with white bread”. *European Journal of Clinical Nutrition* 52.12 (1998): 924-928.
12. Foster-Powell K., *et al*. “International table of glycemic index and glycemic load values”. *American Journal of Clinical Nutrition* 76 (2002): 5-56.
13. Traianedes K and O’Dea K. “Commercial canning increase the digestibility of beans in vitro and postprandial metabolic responses of them *in vivo*”. *American Journal of Clinical Nutrition* 44.3 (1986): 390-397.

14. Otto H and Niklas L. "Différences d' action sur la glycémie d' aliments contenant des hydrates de carbone consequences pour le traitmentdietetique du diabetesucre". *Médicine et Hygiène* 38 (1980): 3424-3429.
15. Jenkins DJA., *et al*. "Glycemic index of foods a physiological basis for carbohydrate exchange". *American Journal of Clinical Nutrition* 34.3 (1981): 362-366.
16. Jenkins DJA., *et al*. "The glycemic index of foods tested in diabetic patients: A new basis for carbohydrate exchange favouring the use of legumes". *Diabetologia* 24.4 (1983): 257-264.
17. Kurup PG and Krishnamurthy S. "Glycemic Index of selected foodstuffs commonly used in South India". *International Journal for Vitamin and Nutrition Research* 62.3 (1992): 266-268.
18. Ercan N., *et al*. "Plasma glucose and insulin responses to bananas of varying ripeness in persons with noninsulin-dependent diabetes mellitus". *Journal of the American College of Nutrition* 12 (1993): 703-709.
19. Brand Miller JC., *et al*. "The glycaemic index of foods containing sugars comparison of foods with naturally occurring versus added sugars". *British Journal of Nutrition* 73.4 (1995): 613-623.
20. Lunetta M., *et al*. "No important differences in glycaemic responses to common fruits in type 2 diabetic patients". *Diabetic Medicine* 12.8 (1995): 674-678.
21. Holt SHA., *et al*. "An insulin index of foods: the insulin demand generated by 1000-kJ portions of common foods". *The American Journal of Clinical Nutrition* 66.5 (1997): 1264-1276.
22. Hertzler S. "Glycemic index of "energy" snack bars in normal volunteers". *Journal of the American Dietetic Association* 100.1 (2000): 97-100.
23. Perry T., *et al*. "Glycaemic index of New Zealand foods". *New Zealand Medical Journal* 113.1108 (2000): 140-142.
24. Brand Miller J., *et al*. "Cocoa powder increases postprandial insulinemia in lean young adults". *Journal of Nutrition* 133.10 (2003): 3149-3152.
25. Brand Miller J., *et al*. "Physiological validation of the concept of glycemic load in lean young adults". *Journal of Nutrition* 133.9 (2003): 2728-2732.
26. Ionescu Tirgoviste A., *et al.* "Blood glucose and plasma insulin responses to various carbohydrates in type 2 (non-insulin dependent) diabetes". *Diabetologia* 24.2 (1983): 80-84.
27. Gannon MC., *et al*. "The serum insulin and plasma glucose responses to milk and fruit products in type 2 (non-insulin-dependent) diabetic patients". *Diabetologia* 29.11 (1986): 784-91.
28. Gregersen S., *et al*. "Glycaemic and insulinaemic responses to orange and apple compared with white bread in non-insulin-dependent diabetic subjects". *European Journal of Clinical Nutrition* 46.4 (1992): 301-303.
29. Wolever., *et al*. "Glycaemic index of fruits and fruit products in patients with diabetes". *International Journal of Food Sciences and Nutrition* 43.4 (1993): 205-2012.
30. Östman EM., *et al*. "Inconsistency between glycemic and insulinemic responses to regular and fermented milk products". *The American Journal of Clinical Nutrition* 74.1 (2001): 96-100.
31. Nilsson M., *et al*. "Glycemia and insulinemia in healthy subjects after lactose-equivalent meals of milk and other food proteins: the role of plasma amino acids and incretins". *The American Journal of Clinical Nutrition* 80.5 (2004): 1246-1253.
32. Acrot J and Brand-Miller JC. "A preliminary assessment of the glycemic index of honey". (2005).
33. Hoyt G., *et al*. "Dissociation of the glycaemic and insulinaemic responses to whole and skimmed milk". *British Journal of Nutrition* 93.2 (2005): 175-177.
34. Jenkins DJA., *et al*. "Glycemic responses to foods: possible differences between insulin-dependent and noninsulin-dependent diabetics". *The American Journal of Clinical Nutrition* 40.5 (1984): 971-998.
35. Wolever TMS., *et al.* "Lactose in the diabetic diet: A comparison with other carbohydrates". *Nutrition Research* 5.12 (1985): 1335-1345.

36. Chew I., *et al*. "Application of glycemic index to mixed meals". *The American Journal of Clinical Nutrition* 47.1 (1988): 53-56.
37. Jenkins DJ., *et al*. "Wholemeal versus wholegrain breads: proportion of whole or cracked grain and the glycaemic response". *British Medical Journal* 297.6654 (1988): 958-960.
38. Mani UV., *et al*. "Glycaemic index of conventional carbohydrate meals". *British Journal of Nutrition* 68.2 (1992): 445-450.
39. Wolever TM., *et al*. "Prediction of the relative blood glucose response of mixed meals using the white bread glycemic index". *Diabetes Care* 8.5 (1995): 418-428.
40. Mehio Z., *et al*. "Glycemic and insulinemic responses of normal subjects to selected meals commonly consumed in the Middle East". *Journal of Nutritional & Environmental Medicine* 7.5 (1997): 275-286.
41. Noriega E., *et al*. "Glycaemic and insulinaemic indices of Mexican foods high in complex carbohydrates". *Diabetes, nutrition & metabolism* 13.1 (2000): 13-19.
42. Wolever TMS., *et al*. "Food glycemic index, as given in glycemic index tables, is a significant determinant of glycemic response elicited by composite breakfast meals". *The American Journal of Clinical Nutrition* 83.6 (2006):1306-1312.
43. Crapo PA., *et al*. "Postprandial hormonal responses to different types of complex carbohydrate in individuals with impaired glucose tolerance". *The American Journal of Clinical Nutrition* 33.8 (1980): 1723-1728.
44. Bornet FR., *et al*. "Insulinemic and glycemic indexes of six starch-rich foods taken alone and in a mixed meal by type 2 diabetics". *The American Journal of Clinical Nutrition* 45.3 (1987): 588-595.
45. d'Emden MC., *et al*. "Postprandial glucose and insulin responses to different types of spaghetti and bread". *Diabetes Research and Clinical Practice* 3.4 (1987): 221-226.
46. Krezowski PA., *et al*. "Insulin and glucose responses to various starh-containing foods in type II diabetic subjects". *Diabetes Care* 10.2 (1987): 205-212.
47. Ross SW., *et al*. "Glycemic index of processed wheat products". *The American Journal of Clinical Nutrition* 46.4 (1987): 631-635.
48. Spiller GA., *et al*. "Effect of protein dose on serum glucose and insulin response to sugars". *The American Journal of Clinical Nutrition* 46.3 (1987): 474-480.
49. Brand J., *et al*. "The glyceaemic and insulin indices of realistic meals and rye bread tested in healthy subjects". *Diabetes, nutrition & metabolism* 3 (1990): 137-142.
50. Granfeldt Y., *et al*. "On the importance of processing conditions product thickness and egg addition for the glycaemic and hormonal responses to pasta, a comparison with bread made from 'pasta ingredients". *European Journal of Clinical Nutrition* 45.10 (1991): 489-499.
51. Granfeldt Y., *et al*. "Determination of glycaemic index; some methodological aspects related to the analysis of carbohydrate load and characteristics of the previous evening meal". *European Journal of Clinical Nutrition* 60.1 (1991): 104-112.
52. Holt S., *et al*. "Relationship of satiety to postprandial glycaemic insulin and cholecystokinin responses". *Appetite* 18.2 (1992): 129-141.
53. Le Floch JP., *et al*. "Influence of non-carbohydrate foods on glucose and insulin responses to carbohydrates of different glycaemic index in type 2 diabetic". *Diabetic Medicine* 9.1 (1992): 44-48.
54. Liljeberg H., *et al*. "Metabolic responses to starch in bread containing intact kernels versus milled flour". *European Journal of Clinical Nutrition* 46.8 (1992): 561-575.
55. Granfeldt Y., *et al*. "Glucose and insulin responses to barley products: influence of food structure and amylose-amylopectin ratio". *American Journal of Clinical Nutrition* 59.5 (1994): 1075-1082.
56. Liljeberg H and Björck I. "Bioavailability of starch in bread products. Postprandial glucose and insulin responses in healthy subjects and *in vitro* resistant starch content". *European Journal of Clinical Nutrition* 48.3 (1994): 151-163.
57. Liljeberg H., *et al*. "Products Based on a high fiber barley genotype, but not on common barley or oats, lower postprandial glucose and insulin responses in healthy humans". *Journal of Nutrition* 126.2 (1996): 458-466.

58. Rasmussen O., *et al*. "Comparison of blood glucose and insulin responses in non-insulin dependent diabetic patients. Studies with spaghetti and potato taken alone and as part of a mixed meal". *European Journal of Clinical Nutrition* 42.11 (1998): 953-961.
59. Leinonen K., *et al*. "Rye bread decreases postprandial insulin response but does not alter glucose response in healthy Finnish subjects". *European Journal of Clinical Nutrition* 53.4 (1999): 262-267.
60. Granfeldt Y., *et al*. "An examination of the possibility of lowering the glycemic index of oat and barley flakes by minimal processing". *Journal of Nutrition* 130.9 (2000): 2207-2214.
61. Liljeberg-Elmståhl H and Björck I. "Milk as supplement to mixed meals may elevate postprandial insulinaemia". *European Journal of Clinical Nutrition* 55.11 (2001): 944-999.
62. Behall KM and Hallfrisch J. "Plasma glucose and insulin reduction after consumption of breads varying in amylose content". *European Journal of Clinical Nutrition* 56.9 (2002): 262-267.
63. Juntunen KS., *et al*. "Postprandial glucose insulin and incretin responses to grain products in healthy subjects". *American Journal of Clinical Nutrition* 75.2 (2002): 254-262.
64. Englyst KN., *et al*. "Glycaemic index of cereal products explained by their content of rapidly and slowly available glucose". *British Journal of Nutrition* 89.3 (2003): 329-339.
65. MacIntosh CG., *et al*. "The degree of fat saturation does not alter glycemic insulinemic or satiety responses to a starchy staple in healthy men". *Journal of Nutrition* 133.8 (2003): 2577-2580.
66. Flint A., *et al*. "The use of glycaemic index tables to predict glycaemic index of composite breakfast meals". *British Journal of Nutrition* 91.6 (2004): 979-989.
67. Parcell AC., *et al*. Glycemic and insulinemic responses to protein supplements". *Journal of the Am Dietetic Association* 104.12 (2004): 1800-1804.
68. Östman EM., *et al*. "Vinegar supplementation lowers glucose and insulin responses and increases satiety after bread meal in healthy subjects". *European Journal of Clinical Nutrition* 59.9 (2005): 983-988.
69. Garsetti M., *et al*. "The Glycemic and insulinemic index of plain sweet biscuits, relationships to in vitro starch digestibility". *Journal of America Collection Nutrition* 24.6 (2005): 441-447.
70. Leeman M., *et al*. "Vinegar dressing and cold storage of potatoes lowers postprandial glycaemic and insulinaemic responses in healthy subjects". *European Journal of Clinical Nutrition* 59.11 (2005): 1266-1271.
71. Jenkins DJA., *et al*. "Almonds decrease postprandial glycemia, insulinemia, and oxidative damage in healthy individuals". *Journal of Nutrition* 136.12 (2006): 2987-2992.
72. Rizkalla SW., *et al*. "Effect of baking process on postprandial metabolic consequences: randomized trials in normal and type 2 diabetic subjects". *European Journal of Clinical Nutrition* 61.12 (2007): 175-183.
73. Granfeldt Y., *et al*. "On the importance of processing conditions, product thickness and egg addition for the glycaemic and hormonal responses to pasta: a comparison with bread made from 'pasta ingredients'". *European Journal of Clinical Nutrition* 45.10 (1991): 489-499.

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