Formulation and development of foods for weight management

Paola Vitaglione
Weight control and energy balance

Energy In

Weight gain

Food intake:
- Carbohydrates
- Lipids
- Proteins
- Alcohol

Weight maintenance

Physical activity (15-30%)
Resting metabolism (60-75%)
Diet-induced thermogenesis (~10%)

Weight loss

Energy Out

Diet - induced thermogenesis (~10%)
To obtain weight loss by diet/food

Decrease calorie intake

- Decrease product energy density and/or portion size
- Increase satiety/satiation

Stimulate energy utilization rather than storage in fat tissue

- Increase resting metabolism (body composition)
- Increase thermogenesis by diet (calorie/fat burning ingredient)
Decreasing calorie intake (energy density of diet)

- Water and fiber provide the lowest energy density ➔ Increase water- and fiber-rich vegetables and fruit!
- Protein and carbohydrates provide less than one-half the energy of fat per gram.
- Fat has a high energy density ➔ Reduce fat intake!
Low-energy-dense diets help people lower their caloric intake while maintaining feelings of satiety and controlling feelings of hunger.

But do reductions in energy density can be successfully employed to manage body weight?

A benefit of this type of eating plan is that it allows people to eat satisfying amounts of food while restricting their energy intake. Furthermore, this type of eating plan uses positive messages (i.e., eat satisfying portions of low-energy-dense foods), which has been shown to result in greater dietary changes than restrictive messages (i.e., eat small portions of all foods)
The problems are:

- How long people respects this regimen?
- How much is the weight reduction?
Increasing satiety/satiation

- **Satiation** The process that leads to the termination of eating, which may be accompanied by a feeling of satisfaction *(intra-meal satiety)*

- **Satiety** The feeling of fullness that persists after eating, potentially suppressing further energy intake until hunger returns *(inter-meal satiety)*
Satiety cascade

Indicates the processes responsible of hunger inhibition.

Foods have a principal role in determining satiety cascade
Satiety cascade (Blundell, 1987)

Believes on food properties and effects

Food smell, taste, temperature, texture

Gastric distension, gastric emptying rate, hormones, stimulation of GI receptors

Direct and indirect action of metabolites on brain exs glucose, AA, ...

Post-absorptive

Post-ingestive

Sensory

Cognitive

Food

Early

Late

Satiety
Physiological mechanisms of satiation

- **Gastric mechanism:** distension (independently of nutrients)
- **Intestinal mechanisms:** Experimental infusions of nutrients directly into the intestine promote satiation

*CCK* rapidly released into the circulation in response to the presence of nutrients in the gut (fats or proteins)

- biomarker of satiation,
- delays gastric emptying
- stimulates pancreatic enzyme secretion and gall bladder contraction (coordinate digestion).
- In the brain, acts as a neurotransmitter involved in reward behaviour, memory and anxiety, as well as satiety.
- Synergism with leptin that signals fat stores
Physiologic mechanisms of satiety

• *‘episodic’ signals* in response to the consumption of food
• *‘tonic’ signals* influenced by the levels of energy stores in the body (leptin and insulin)
• Interactions between the two types
### ‘Episodic’ signals

<table>
<thead>
<tr>
<th>Name</th>
<th>Site of production</th>
<th>Effect on appetite</th>
<th>Mechanism</th>
<th>Additional effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ghrelin</td>
<td>Stomach</td>
<td>↑ hunger</td>
<td>• Ghrelin R (brain)</td>
<td>Long term effect on energy balance (inversely correlated with body fat)</td>
</tr>
<tr>
<td>CCK</td>
<td>Duodenum, Jejunum</td>
<td>↑ satiation</td>
<td>• Vagus nerve</td>
<td>• Delays gastric emptying&lt;br&gt;• Stimulates pancreatic enzyme secretion&lt;br&gt;• Stimulates gallbladder contraction&lt;br&gt;• Neurotransmitters</td>
</tr>
<tr>
<td>GLP-1</td>
<td>Intestine, Brain</td>
<td>↑ satiety</td>
<td>• GLP-1R (brain)</td>
<td>• Incretin (insulin production)&lt;br&gt;• Slows gastric emptying and modulates gastric acid secretion (ileal brake)</td>
</tr>
<tr>
<td>Oxyntomodulin (OXM)</td>
<td>Intestine, Brain</td>
<td>↑ satiety</td>
<td>• GLP-1R (brain)&lt;br&gt;• ↓ ghrelin</td>
<td>• Slows gastric emptying&lt;br&gt;↑ weight loss&lt;br&gt;↑ energy expenditure</td>
</tr>
<tr>
<td>PYY</td>
<td>Ileum, Colon, Rectum</td>
<td>↑ satiety</td>
<td>• Y2 R (brain)</td>
<td>• Slows gastric emptying&lt;br&gt;Slows intestinal transport&lt;br&gt;Reduces gastric secretions</td>
</tr>
<tr>
<td>PP</td>
<td>Pancreas</td>
<td>↑ satiety</td>
<td>• Y2 R (brain)&lt;br&gt;Vagus nerve</td>
<td>---</td>
</tr>
<tr>
<td>Hormone</td>
<td>Predominant site of secretion</td>
<td>Impact on energy intake</td>
<td>Influence of dietary macronutrient composition</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------</td>
<td>-------------------------</td>
<td>-----------------------------------------------</td>
<td></td>
</tr>
<tr>
<td>Leptin</td>
<td>Adipocytes</td>
<td>↓</td>
<td>↑ with high-carbohydrate low-fat meals relative to high-fat low-carbohydrate meals (references 26,27,29)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>No apparent effect of dietary protein or fiber (references 38-40)</td>
<td></td>
</tr>
<tr>
<td>Ghrelin</td>
<td>Stomach</td>
<td>↑</td>
<td>↓ with dietary carbohydrate ingestion (references 33,47,62,63)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Conflicting evidence about the effect of dietary protein (references 38,39,62,63)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>↓ with psyllium fiber supplement (reference 54)</td>
<td></td>
</tr>
<tr>
<td>(\text{PYY}_{3-36}^a)</td>
<td>Distal Gl(^b) tract</td>
<td>↓</td>
<td>Conflicting evidence on the effect of macronutrients; both ↑ with dietary fat and ↑ with dietary protein relative to other macronutrients have been reported (references 72,77)</td>
<td></td>
</tr>
<tr>
<td>CCK(^c)</td>
<td>Upper Gl tract</td>
<td>↓</td>
<td>↑ with dietary fat and protein more than carbohydrates (reference 79)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Habitual high-fat low-carbohydrate diet consumption may reduce CCK-induced satiety (references 87,88,91)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>↑ with dietary fiber consumption (references 40,92-94)</td>
<td></td>
</tr>
</tbody>
</table>
Anorexygenic hormones

[+] Ghrelin

[+] Leptin

[+] PYY

[+] CCK

Decrease Food Intake

Orexigenic hormones

[+] Ghrelin

[+] Leptin

[+] CCK

[+] PYY

Increase Food Intake

Orexigenic hormones

[+] = Concentration Increase

[+] = Concentration Decrease

Orr et al., JADA 2005
Foods and satiety

- Energy value
- Palatability
- Macronutrient composition
- Volume
- Form
- Dietary fibre content
Satiety and energy value

↑ energy density (kcal/g)

↓ satiety

It can be related to the low volume of high energy dense foods compared to the low energy dense

Milk-based preloads differing in volume but having the same energy content and macronutrient composition or palatability → different energy density!

Intake at lunch 30 min later was < 18% after the high volume, low energy density drink than after the low volume, high energy density drink (Rolls et al. 1998).
Satiety and palatability

• Energy dense foods are palatable but not satiating and vice versa
• Palatability directly correlates with hunger and with satiation but not with satiety

**Palatability** is the hedonic reward provided by foods or fluids that are agreeable to the "palate"

*De Graaf et al., Physiol Behav 1999*
Satiety and macronutrients

• Proteins correlates better than the other macronutrients with the sensations of fullness and satiety after a meal

  Proteins > Carbohydrates > Fats

• The relative satiety power of carbohydrates and fats in the different studies vary if macronutrients are studied alone or inside the foods.

• The macronutrient composition did not influence satiety when the energy density was held constant

• When a portion of a diet was manipulated, **energy density**, but not the fat content, affected energy intake
Satiety and food form

Solids > Liquids

There is an effect of mastication that promotes satiety and reduces food intake
(Sakata and Yoshimatsu, 1996; Fujise et al., 1998)

The consumption of the whole fruits and vegetables instead of juice or homogenated increases satiety (dietary fiber effect)
(Haber et al., 1977; Bolton et al., 1981; Moorhead et al., 2006)

Soup case: satiety effect > than beverages due to a cognitv effect (es. Apple juice served as beverage or as soup)
(Mattes et al., 2005)
Satiety and food volume

↑ Volume → ↑ Satiety

Big volumes compared to little volume:

- **Direct effect:** at intestinal level > contact of foods with the receptors along the GI tract
- **Indirect effect:** potential, at cognitive level (association volume-calorie) \( (Rolls \ et \ al., \ 1998) \)

Varying the volume of preload women who ingested a soup (285 g) a big preload, reduced the following meal; the men did not! \( (Kissilef \ et \ al., \ 1984) \)
Satiety and dietary fiber

↑ Dietary fiber  →  ↑ Satiety

• Low glicemic index and reduction of ghrelin concentration (↓ hunger ↑ satiety)
• Differences depending on the type of dietary fibre (soluble-insoluble), on the type of foods tested (solid-beverage) and duration of the study
To maximize the response of anorexogenic hormones (PYY, CCK, leptin) and minimizing the concentrations of orexigenic hormone (ghrelin)

Low energy dense food and palatable.

Macronutrient composition?
Beverage or solid food?
Snack o meal?
Proteins, fibers and calcium

Functional foods for weight management

Fabuless

Pinnothin
Measuring satiation of a food

Method 1): consumption of a fixed amount of food (preload) and a meal-test following

Method 2): ad libitum consumption of food (satiation) and subsequent meal (satiety)
Evaluation of satiety effect of a food

Ad libitum or fixed amount (preload)

...after 15 min – 4 h

Hunger and satiety ratings on visual analogue scale

Evaluation of energy intake

Test meal
What is your desire to eat?

How full do you feel?

What is your satiety?

VAS (Visual Analogue Scale)

Porrini et al., 1995
Very important

• Where? **At familiar atmosphere!**
• Must subjects be informed...
  of the study aim? **No!**
  of the composition of foods tested?
    It depends... No if we don’t want that psychological factors may influence satiety!
• Which is the right control food?
  The same food lacking only of the ingredient / characteristic of the experimental food
Satiating efficiency of a food

2 Preloads (low and high energy value) → Energy intake at meal test

Pendency is the satiating efficiency

It is an index of the capacity of a food to reduce the energy intakes

Kissilef, 1984
Our experience on satiety effect of $\beta$-glucans
Dietary fibre-rich foods using barley flour and thus rich in β-glucans (soluble fibre), for their potential hypolipidemic properties have been developed, produced and tested in clinical trials.
A biscuit containing 13% total dietary fibre (5% β-glucans) has been tested for their satiating efficiency in healthy subjects.
About the biscuits...

Dietary fibre-rich biscuits
Barley Flour:Wheat Flour
70:30 wt:wt

Control biscuits
Wheat flour
100%
## Chemical composition (g/100g)

<table>
<thead>
<tr>
<th></th>
<th>Dietary fibre-rich biscuits</th>
<th>Control biscuits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proteins</strong></td>
<td>6.1</td>
<td>8.6</td>
</tr>
<tr>
<td><strong>Fats</strong></td>
<td>13.9</td>
<td>13.6</td>
</tr>
<tr>
<td><strong>Carbohydrates</strong></td>
<td>61.4</td>
<td>63.2</td>
</tr>
<tr>
<td><strong>Total dietary fibre</strong></td>
<td>12.6</td>
<td>7.2</td>
</tr>
<tr>
<td><strong>soluble</strong></td>
<td>8.3</td>
<td>3.2</td>
</tr>
<tr>
<td><strong>β-glucans</strong></td>
<td>5.2</td>
<td></td>
</tr>
<tr>
<td><strong>insoluble</strong></td>
<td>4.3</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Energy density (kcal)</strong></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>395</td>
<td>410</td>
</tr>
</tbody>
</table>
Snack acceptance

Dietary fibre-rich biscuits
Control biscuits

Outward appearance
Taste
Colour
Consistency
Total acceptance
Energy intake perception
Fat content perception

Total acceptance
Evaluating the “satiating efficiency”

Subjects

20 subjects (10M & 10F)

Age (years): 19-20
BMI (kg/m²): 21-24
How many and which kind of tests?

**Ad libitum with DFB**
- Midmorning snack
- Low EI preload (P1) DFB and CB
- High EI preload (P2) DFB and CB
- Test meal control (lunch without snack)

**Total = 6 tests**

CB = Control biscuits
DFB = Dietary fibre-rich biscuits

Evaluation of hunger and satiety by VAS
Evaluation of energy intake

Test meal (lunch time)
What is your desire to eat?

How full do you feel?

What is your satiety?

VAS (Visual Analogue Scale)

Porrini et al., 1995
VAS...when?

1. At baseline (tb)
2. Immediately after the preload (t0)
3. 15 min later (t15)
4. 30 min later (t30)
5. 60 min later (t60)
6. 120 min later (t120)
Where?

A familiar atmosphere!
Meal test

Bread
Ham
Mozzarella cheese
Provolone cheese
Tuna
Salad
Fruit salad
Yogurt
Water
Test *ad libitum* with DFB

Specific satiety

The subjects consumed the new dietary fibre-rich biscuits till they fell extremely full

\[
69-110 \text{ g} = \sim 8-12 \text{ biscuits (mean=10)}
\]

\[
272-434 \text{ kcal (mean=353 kcal)}
\]
Defining the preloads

Small preload
(Normal consumption)

150 kcal

Large preload
(Over consumption)

450 kcal

Dietary fibre intake

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>DFB</td>
<td>5 g</td>
<td>15 g</td>
</tr>
<tr>
<td>CB</td>
<td>3 g</td>
<td>9 g</td>
</tr>
</tbody>
</table>
For small preload

Control biscuits
Dietary fibre-rich biscuits
Desire to eat

Satiety

Fullness

Hunger

For large preload

Control biscuits
Dietary fibre-rich biscuits
Control meal 800 kcal

Energy intake (kcal)

- P1: Dietary Fibre-rich Biscuits
- P2: Control Biscuits
**Energy intakes**

![Energy intakes diagram](chart.png)

- **P1**: Dietary Fibre-rich Biscuits
- **P2**: Control Biscuits

**Energy intake (kcal)**

- **Preload**
- **Meal test**
Satiating efficiency index (Kissileff)

SEI<1  →  low satiating power
SEI=1  →  compensation
SEI>1  →  high satiating power

Control Biscuits  0.90
Dietary fibre-rich biscuits  0.81
The reasons of contradictions:

- Different sources and amount of beta-glucans
- Different controls
- Evaluation of satiety effect was not the primary objective of the studies
- Different types of subjects
- Different experimental procedures i.e. evaluation of appetite ratings and/or energy intake at subsequent meal *ad libitum* or by food diaries and/or blood analyses)
β-Glucan-enriched bread reduces energy intake and modifies plasma ghrelin and peptide YY concentrations in the short term

Paola Vitaglione*, Roberta Barone Lumaga, Antonio Stanzione, Luca Scalfi, Vincenzo Fogliano

Department of Food Science, University of Naples, via Università 100, 80055 Portici (NA), Italy
Development of foods

Enrichment of bread was obtained using Glucagel™ (> 75% β-glucans)
Subjects

• 14 healthy volunteers (7M/7F)

• mean age 23.9±3 y

• BMI 22.9±2.8 kg/m²

• Each subject participated to 4 tests

To evaluate the physiological response to β-glucans

No influence of some kind of pathology
Two protocols

After a randomized isocaloric breakfast including βGB or CB breakfast...

**Protocol 1**

- From 0900 to 1200:
  Subjects filled out some questionnaires (VAS for appetite ratings)

- At 12.00:
  Subjects were invited to have a lunch *ad libitum*

**Protocol 2**

- From 0900 to 1200:
  Subjects were submitted to blood drawings to determine glucose and satiety-related hormone concentrations (ghrelin, PYY and insulin)
RESULTS
Subjective appetite ratings (VAS)

FULLNESS
+ 25%

HUNGER
- 49%

SATIETY
+ 55%
Energy intake at lunch

- 19%
Blood analyses

Plasma ghrelin concentration vs baseline

---

Time (min) 0 30 60 90 120 150 180

---

Plasma ghrelin concentration vs baseline

---

Blood analyses
ghrelin
Blood analyses

Plasma PYY concentration vs baseline

CB vs βGB

Plasma PYY concentration vs baseline

Time (min)
Biochemical analyses
Glycaemia

Glycaemia relative to baseline

Time (min)
Conclusions

In this study it has been demonstrated for the first time:

- the ability of barley β-glucans to modulate appetite sensations and to reduce energy intake;
- the potential role exerted by ghrelin and PYY in determining a short term satiety effect by β-glucans independent from insulin.
Sugar and dietary fibre composition influence, by different hormonal response, the satiating capacity of a fruit-based and a β-glucan-enriched beverage

Roberta Barone Lumaga, Danilo Azzali, Vincenzo Fogliano, Luca Scalfi and Paola Vitaglione

Food Funct., 2012, 3, 67
<table>
<thead>
<tr>
<th></th>
<th>BGBE</th>
<th>CBE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portion volume (mL)</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>Proteins (g)</td>
<td>0.2</td>
<td>---</td>
</tr>
<tr>
<td>Fats (g)</td>
<td>0.3</td>
<td>---</td>
</tr>
<tr>
<td>Carbohydrates (g)</td>
<td>34.5</td>
<td>37.3</td>
</tr>
<tr>
<td>Total dietary fibre (g)</td>
<td>3.00</td>
<td>---</td>
</tr>
<tr>
<td>β-glucans (g)</td>
<td>3.00</td>
<td>---</td>
</tr>
<tr>
<td>Energy density (kcal)</td>
<td>147.5</td>
<td>149.2</td>
</tr>
</tbody>
</table>

(Barone Lumaga et al., *Food & Function*, 2011)
Subjects:
14 healthy volunteers (8M/6F)
mean age 27.8 ± 4.9;
BMI 20.2–24.6 kg m⁻²
Breakfast (~536 kcal): 1 beverage portion (CBE or BGBE) + 4 slices od toasted bread
BGBE vs CBE
Increased fullness and satiety

Pancreatic polypeptide (PP) response was significantly higher after BGE than CBE, independently from insulin response.

*: p < 0.05 vs baseline value;
#: p < 0.05 vs CBE

BGBE= β-glucan beverage
CBE= control beverage

(Barone Lumaga et al., Food & Function, 2011)
β-glucans enriched beverage - Results

Glucose variation from baseline (mg/dL)

BGBE = β-glucan beverage
CBE = control beverage

*: p<0.05 vs baseline
#: p<0.05 vs CBE
Fig. 2  Energy intakes (kcal) measured at *ad libitum* lunch, post-lunch and over the all experiment day upon consumption of each beverage. *: $p < 0.05$ vs. meal 1.
Role of β-glucans in appetite control - Conclusion

A 3 g dose of barley β-glucans, known for its hypolipidemic effect, included in novel food formulations...
✓ Is able to modulate appetite and energy intake in healthy subjects
✓ This effect is demonstrated after ingestion of both in solid and liquid foods
✓ Different hormonal responses are involved in this modulating capability
✓ Long term studies and in overweight subjects should be runned, to evaluate their efficacy for weight management.
SCIENTIFIC OPINION

Scientific Opinion on the substantiation of health claims related to meal replacements for weight control (as defined in Directive 96/8/EC on energy restricted diets for weight loss) and reduction in body weight (ID 1417), and maintenance of body weight after weight loss (ID 1418) pursuant to Article 13(1) of Regulation (EC) No 1924/2006

The food that is the subject of the health claims is “meal replacement for weight control”, which is defined in Directive 96/8/EC on foods intended for use in energy-restricted diets for weight reduction. Briefly, the energy provided by a meal replacement shall not be less than 840 kJ (200 kcal) and shall not exceed 1 680 kJ (400 kcal) per meal. Meal replacements for weight loss shall provide not less than 25 % and not more than 50 % of the total energy of the product as protein, not more than 30 % of the total available energy as fat, not less than 1 g of linoleic acid (in the form of glycerides), at least 30 % of the dietary reference values for adults of vitamins and minerals, and at least 500 mg of potassium per meal.
<table>
<thead>
<tr>
<th>ID</th>
<th>Food or Food constituent</th>
<th>Health Relationship</th>
<th>Proposed wording</th>
</tr>
</thead>
<tbody>
<tr>
<td>1417</td>
<td>Meal replacement for weight control (as defined in Directive 96/8/EC energy restricted diets for weight reduction)</td>
<td>Safe, effective &amp; healthy weight loss. Greater weight loss than with conventional calorie counting</td>
<td>Scientifically/clinically proven as a safe and effective weight loss programme. A healthy way to lose weight and keep it off. Losing weight with meal replacement plans can maintain healthy lipid profile/blood glucose and insulin/blood pressure. Reaching and maintaining a healthy weight is important in helping healthy lipid profile/blood glucose and insulin levels/blood pressure. People losing weight with meal replacements have shown healthier biomarkers than people dieting on a conventional calorie controlled diet. Removes the need for calorie counting at mealtimes. – Substituting one or two daily meals or snacks with meal replacements is a successful weight loss and weight maintenance strategy.</td>
</tr>
</tbody>
</table>

**Conditions of use**

- For weight loss - Use to replace one or more meals of the daily diet
- Mahlzeitenersatz (gemäß Definition in Richtl. 96/8/EG)
- Replace two meals a day
- Replace two meals a day as part of a weight loss programme
<table>
<thead>
<tr>
<th>Food or Food constituent</th>
<th>Health Relationship</th>
<th>Proposed wording</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meal replacement for weight control (as defined in Directive 96/8/EC energy restricted diets for weight reduction)</td>
<td>Maintenance of weight loss</td>
<td>Safe and effective for long term use for weight maintenance Meal replacements have been shown to be more successful in helping people maintain weight loss than conventional calorie controlled diets Using meal replacements for weight loss and weight maintenance</td>
</tr>
</tbody>
</table>

**Conditions of use**

- Replace one meal a day as a weight maintenance strategy/to keep the weight off