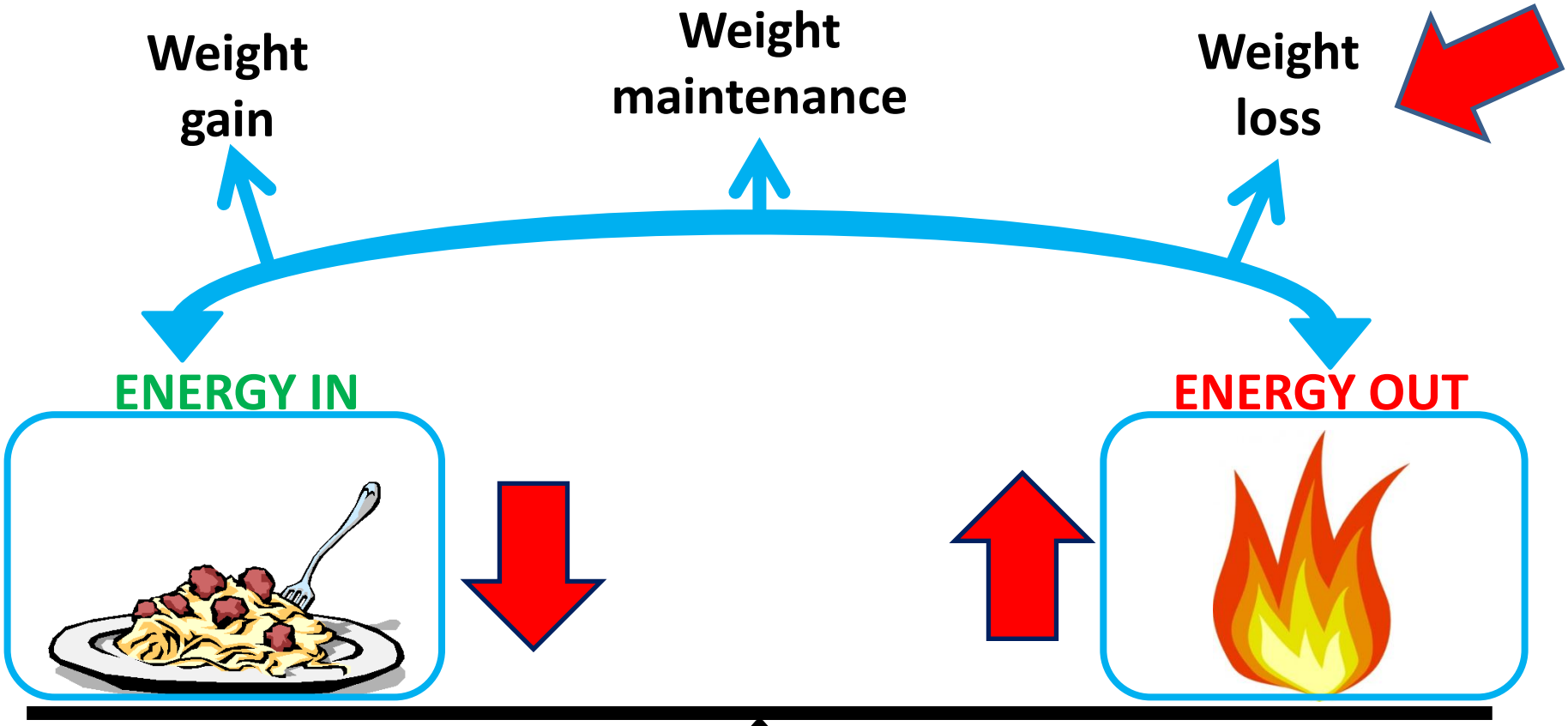
Formulation and development of foods for weight management

Paola Vitaglione

Weight control and energy balance



Food intake:

- ***Carbohydrates***
- ***Lipids***
- ***Proteins***
- ***Alcohol***

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

To obtain weight loss by diet/food

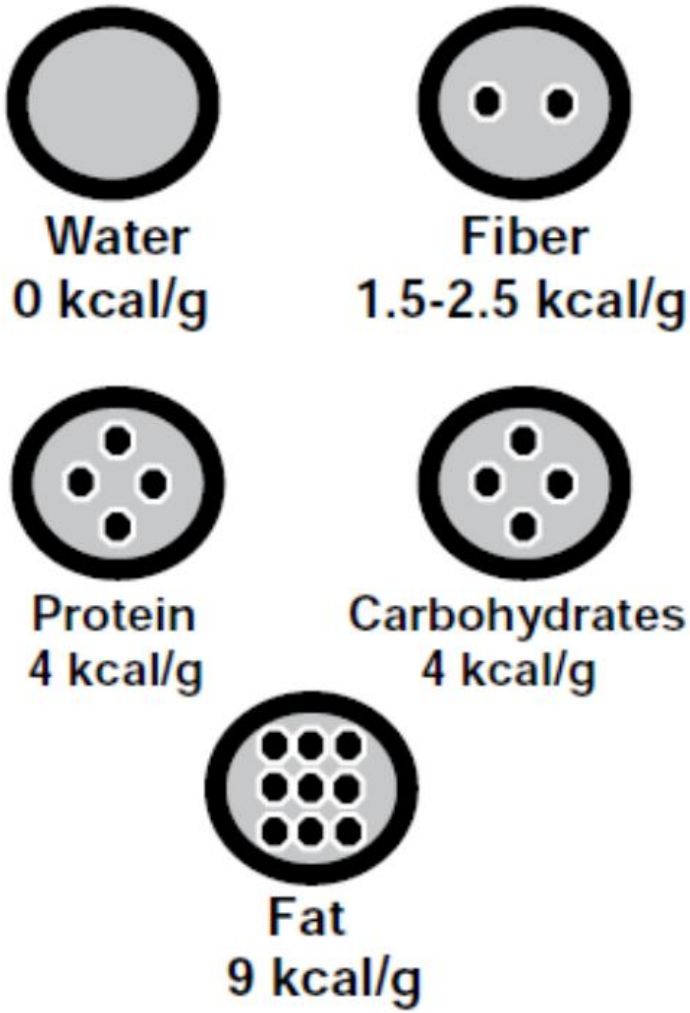
Decrease calorie intake

- **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)



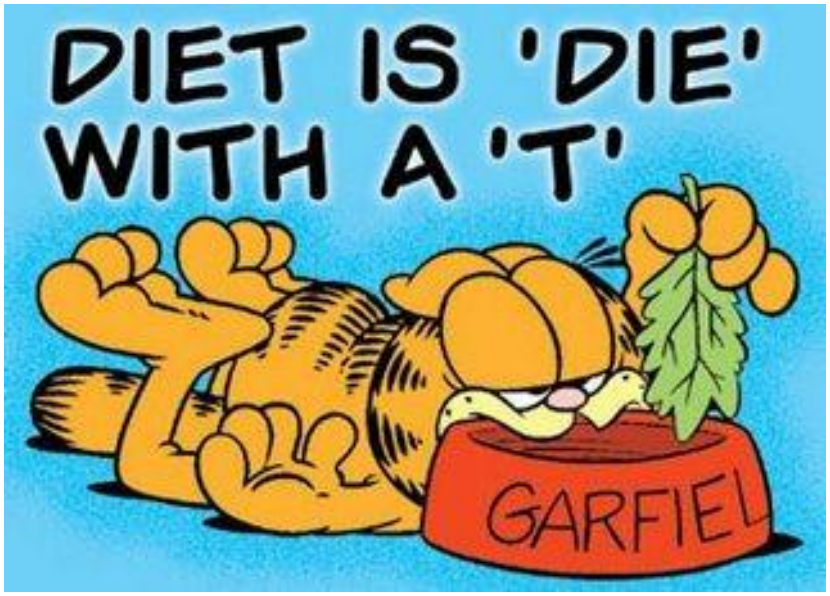
- Water and fiber provide the lowest energy density ➔ *Increase water- and fiber-rich vegetables and fruit!*
- Protein and carbohydrates provide less than one-half the energy of fat per gram.
- Fat has a high energy density ➔ *Reduce fat intake!*

Low-Energy-Dense Foods and Weight Management: Cutting Calories While Controlling Hunger

- *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

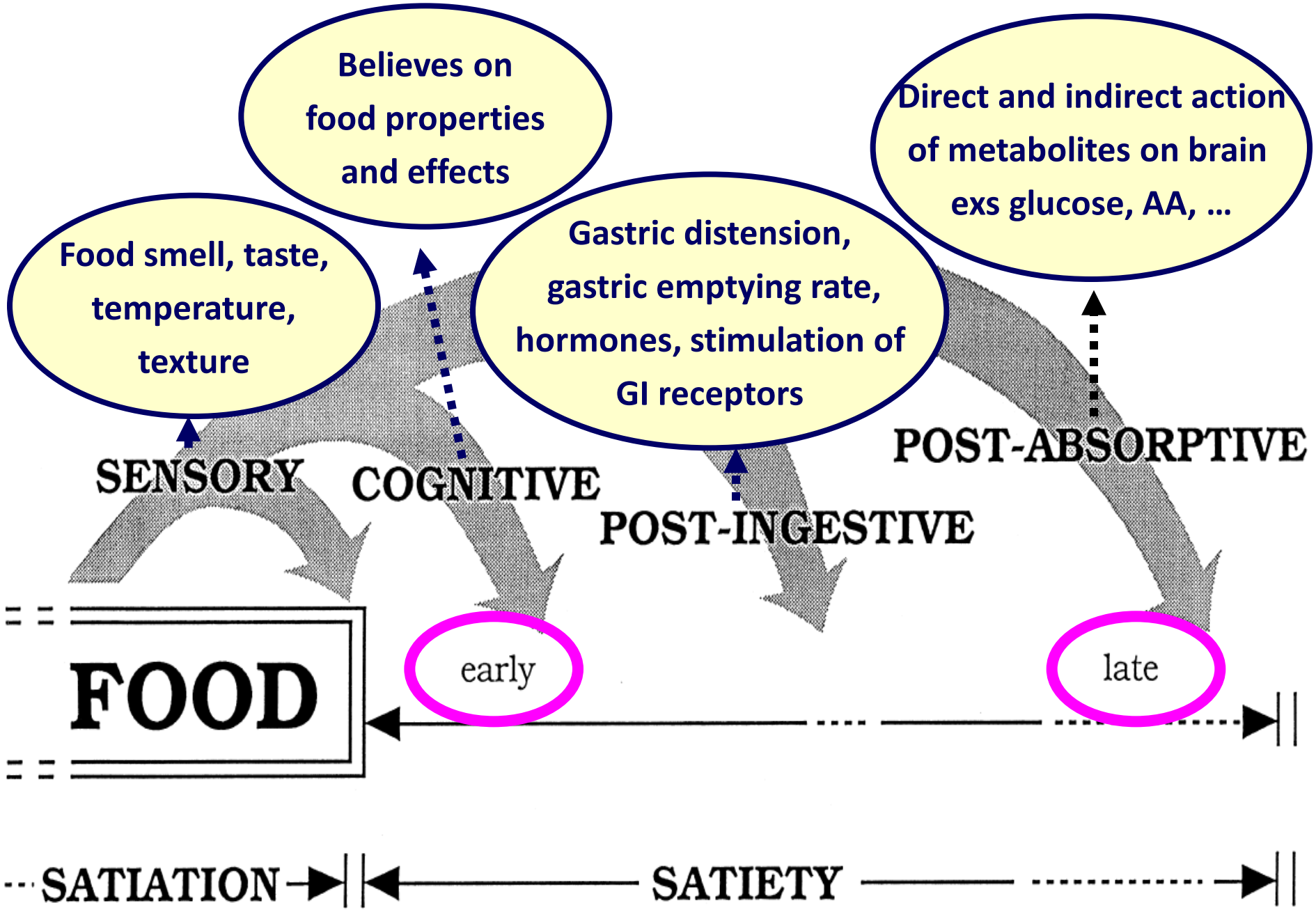
- **Satiation** The process that leads to the termination of eating, which may be accompanied by a feeling of satisfaction **(intra-meal satiety)**
- **Satiety** The feeling of fullness that persists after eating, potentially suppressing further energy intake until hunger returns **(inter-meal satiety)**

Satiety cascade

Indicates the processes responsible of hunger inhibition.

Foods have a principal role in determining satiety cascade

Satiety cascade (Blundell, 1987)



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

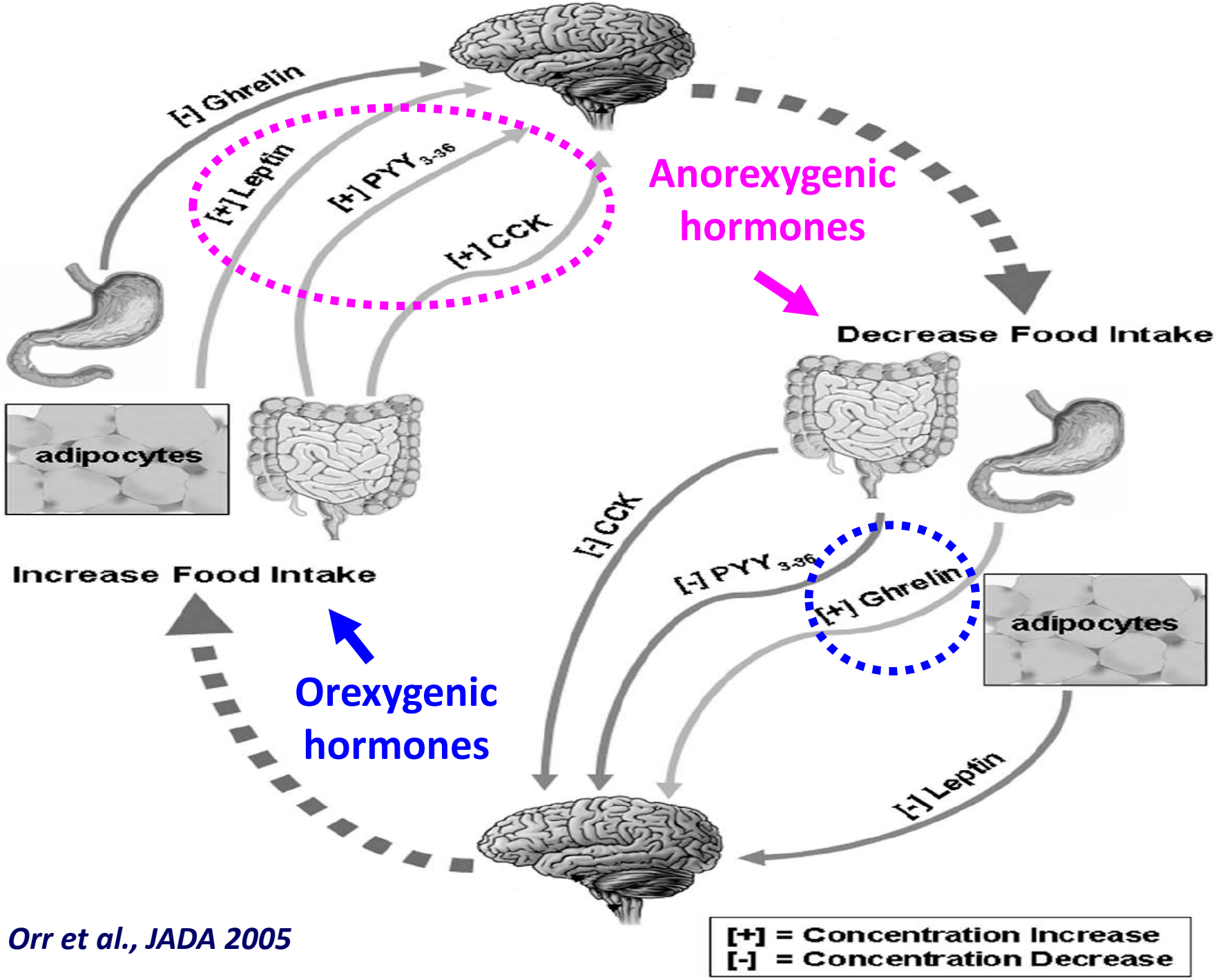
- ‘**episodic’ signals** in response to the consumption of food
- ‘**tonic’ signals** influenced by the levels of energy stores in the body (leptin and insulin)
- Interactions between the two types

‘Episodic’ signals

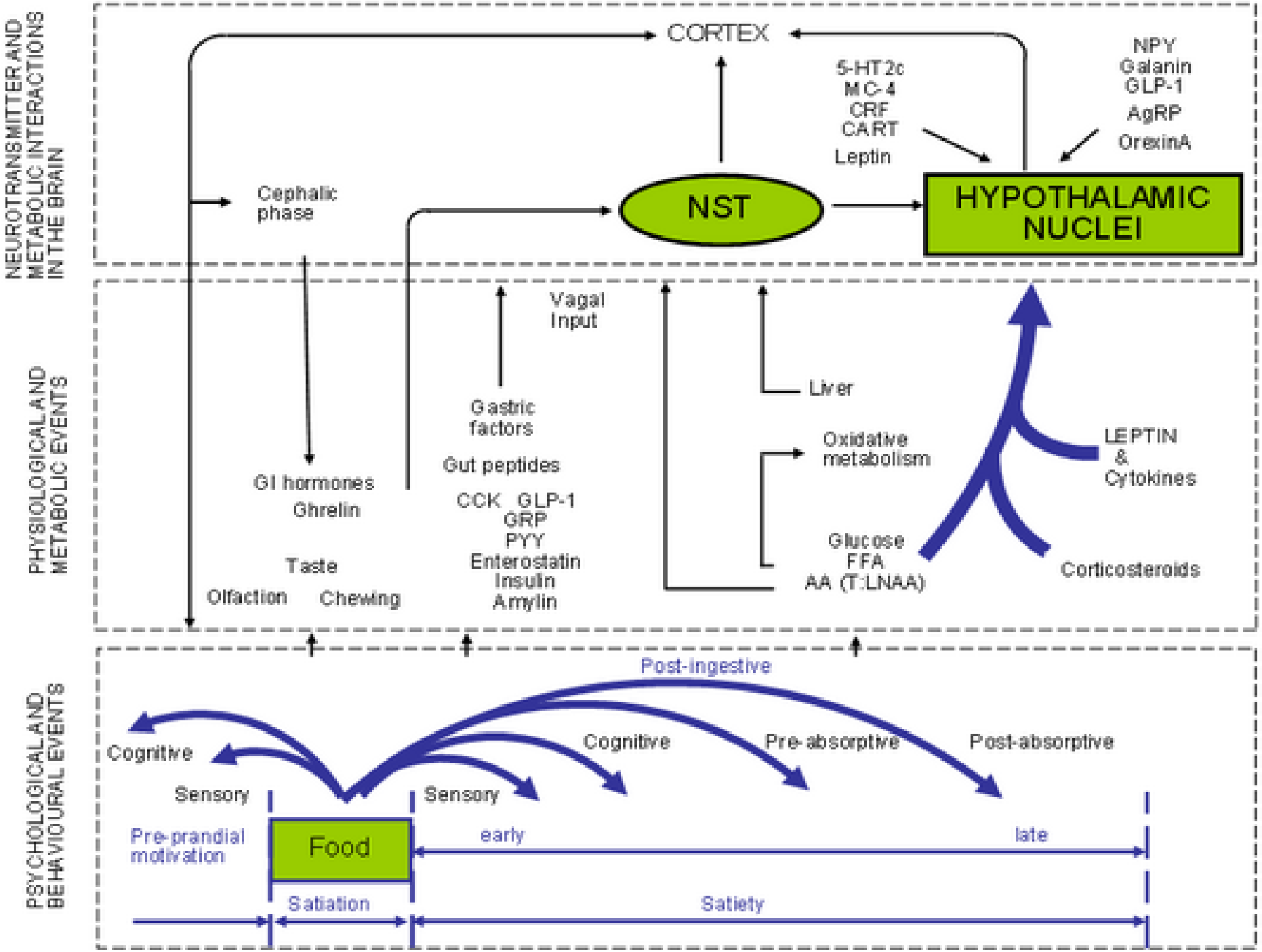
Name	Site of production	Effect on appetite	Mechanism	Additional effects
Ghrelin	Stomach	↑ hunger	• Ghrelin R (brain)	Long term effect on energy balance (inversely correlated with body fat)
CCK	Duodenum Jejunum	↑ satiation	• Vagus nerve	• Delays gastric emptying • Stimulates pancreatic enzyme secretion • Stimulates gallbladder contraction • Neurotransmitters
GLP-1	Intestine Brain	↑ satiety	• GLP-1R (brain)	• Incretin (insulin production) • Slows gastric emptying and modulates gastric acid secretion (ileal brake)
Oxynto modulin (OXM)	Intestine Brain	↑ satiety	• GLP-1R (brain) • ↓ ghrelin	• Slows gastric emptying • ↑ *weight loss* • ↑ *energy expenditure*
PYY	Ileum Colon Rectum	↑ satiety	• Y2 R (brain)	• Slows gastric emptying • Slows itestinal transport • Reduces gastric secretions
PP	Pancreas	↑ satiety	• Y2 R (brain) • Vagus nerve	----

Hormone	Predominant site of secretion	Impact on energy intake	Influence of dietary macronutrient composition
Leptin	Adipocytes	↓	↑ with high-carbohydrate low-fat meals relative to high-fat low-carbohydrate meals (references 26,27,29) No apparent effect of dietary protein or fiber (references 38-40)
Ghrelin	Stomach	↑	↓ with dietary carbohydrate ingestion (references 33,47,62,63) Conflicting evidence about the effect of dietary protein (references 38,39,62,63) ↓ with psyllium fiber supplement (reference 54)
PYY_{3-36}[a]	Distal GI[b] tract	↓	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)
CCK[c]	Upper GI tract	↓	↑ with dietary fat and protein more than carbohydrates (reference 79) Habitual high-fat low-carbohydrate diet consumption may reduce CCK-induced satiety (references 87,88,91) ↑ with dietary fiber consumption (references 40,92-94)

Orr et al., JADA 2005



Orr et al., JADA 2005


NEUROTRANSMITTER AND METABOLIC INTERACTIONS IN THE BRAIN
CORTEX
5-HT2c
MC-4
CRF
CART
Leptin
NPY
Galanin
GLP-1
AgRP
OrexinA
Cephalic phase
NST
HYPOTHALAMIC NUCLEI
PHYSIOLOGICAL AND METABOLIC EVENTS
Vagal Input
Liver
Gastric factors
Oxidative metabolism
LEPTIN & Cytokines
GI hormones
Ghrelin
Gut peptides
CCK GLP-1
GRP
PYY
Enterostatin
Insulin
Amylin
Glucose
FFA
AA (T:LNAA)
Corticosteroids
Taste
Olfaction
Chewing
PSYCHOLOGICAL AND BEHAVIOURAL EVENTS
Post-ingestive
Cognitive
Cognitive
Pre-absorptive
Post-absorptive
Sensory
Sensory
Pre-prandial motivation
Food
early
late
Satiation
Satiety

Foods and satiety

- Energy value
- Palatability
- Macronutrient composition
- Volume
- Form
- Dietary fibre content

Satiety and energy value

↑ energy density (kcal/g)

↓ satiety

It's a matter of food volume /portion!

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 viceversa
- 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, reducd 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

Functional Food and satiety

To maximize the response of anorexygenic hormones (PYY, CCK, leptin) and minimizing the concentrations of orexygenic hormone (ghrelin)

Low energy dense food and palatable.

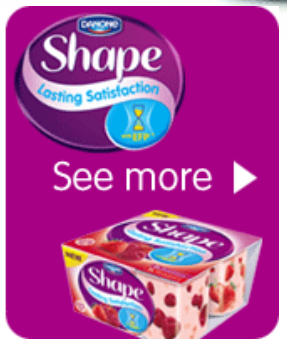
Macronutrient composition ?

Beverage or solid food ?

Snack o meal?

Functional foods for weight management

Proteins, fibers and calcium



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

VAS (Visual Analogue Scale)

What is your desire to eat?

How full do you fell?

What is your satiety?

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?**

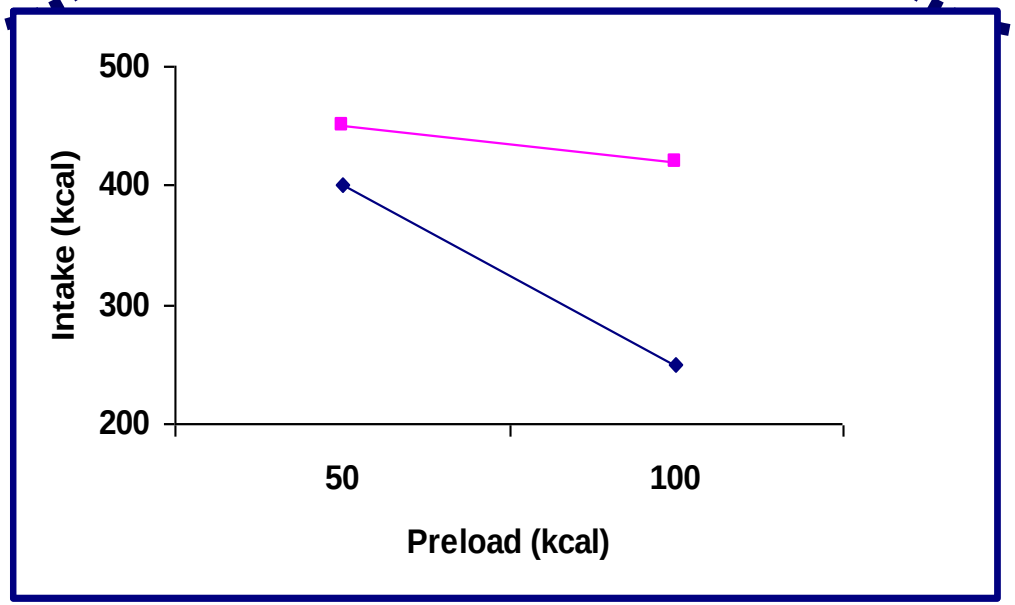
  The same food lacking only of the ingredient / characteristic of the experimental food

Satiating efficiency of a food

2 Preloads (low and high energy value)

Energy intake at meal test

Pendency is the satiating efficency



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

Kissilef, 1984

Our experience on satiety effect of β-glucans

In this framework…

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.

Original Research

Satiating Effect of a Barley Beta-Glucan–Enriched Snack

Paola Vitaglione, PhD, Roberta Barone Lumaga, MSc, Concetta Montagnese, MSc, Maria Cristina Messia, MSc, Emanuele Marconi, MSc, Luca Scalfi, MD

Journal of the American College of Nutrition, Vol. 29, No. 2, 113–121 (2010)

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)

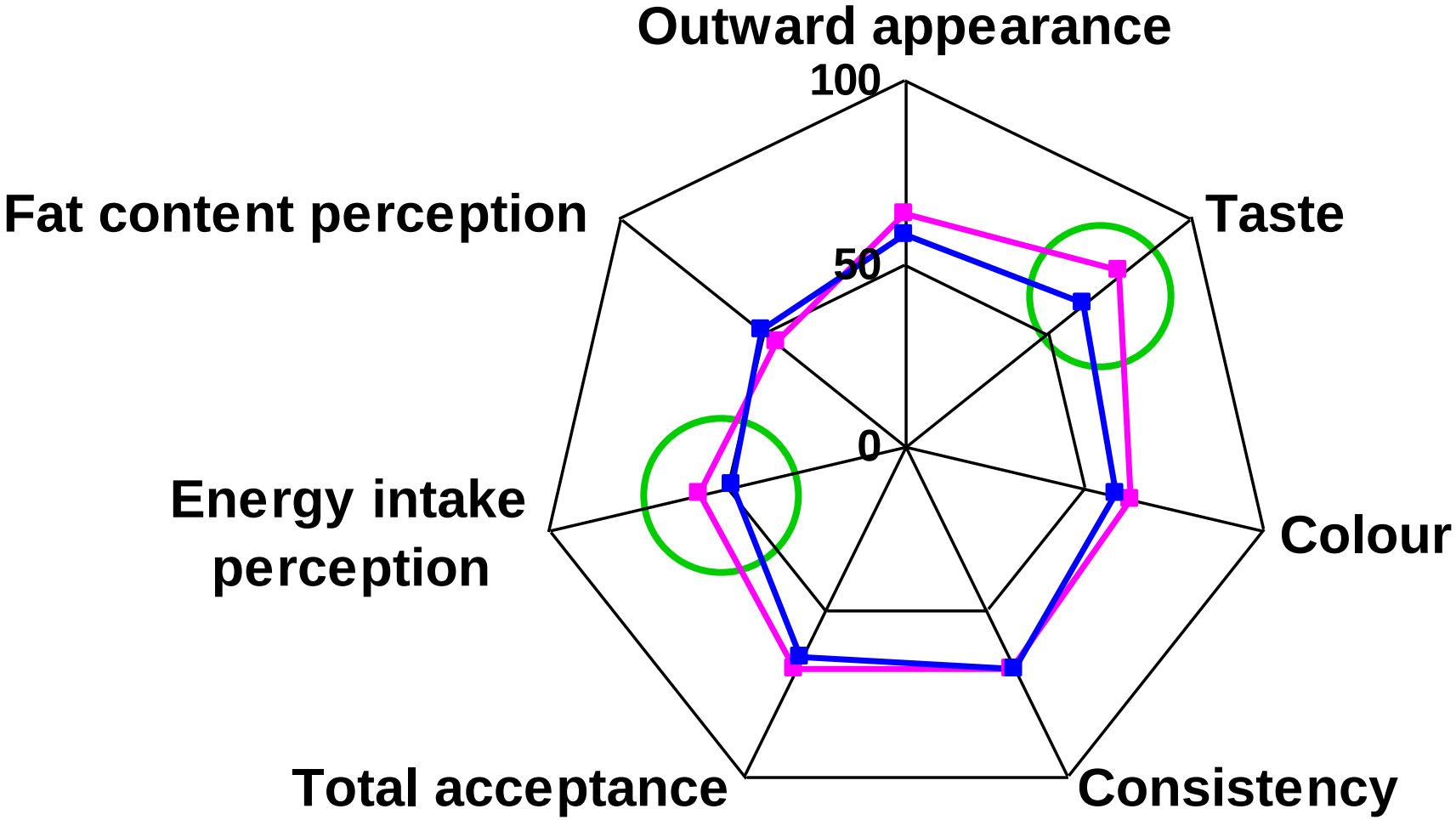
	Dietary fibre-rich biscuits	*Control biscuits*
Proteins	6.1	8.6
Fats	13.9	13.6
Carbohydrates	61.4	63.2
Total dietary fibre	12.6	7.2
soluble	8.3	3.2
β-glucans	5.2	
insoluble	4.3	4.0

Energy density (kcal)	*395*	*410*

Snack acceptance

Dietary fibre-rich biscuits

Control biscuits



Evaluating the “satiating efficiency”

Subjects

20 subjects
(10M & 10F)

Age (years): 19-20
BMI (kg/m^2): 21-24

How many and which kind of tests?

Ad libitum with DFB

Midmorning snack

Low EI preload (P1) DFB and CB

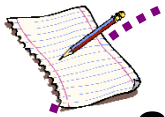
High EI preload (P2) DFB and CB

Test meal control (lunch without snack)

2 h later

Test meal (lunch time)

Total = 6 tests



Evaluation of hunger and satiety by VAS

Evaluation of energy intake

CB = Control biscuits

DFB = Dietary fibre-rich biscuits

VAS (Visual Analogue Scale)

What is your desire to eat?

How full do you fell?

What is your satiety?

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?

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 g = ~8-12 biscuits (mean=10)

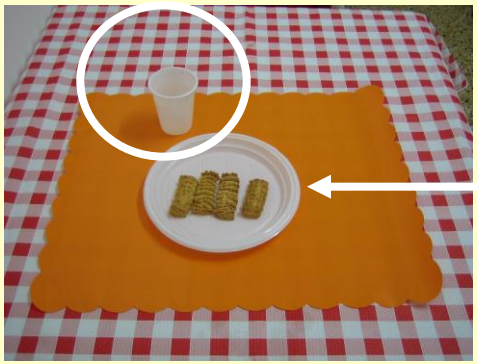
272-434 kcal (mean=353 kcal)

Defining the preloads

Small preload

(Normal consumption)

150 kcal

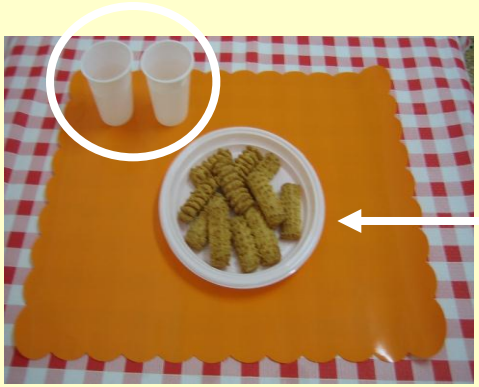


4

Large preload

(Over consumption)

450 kcal

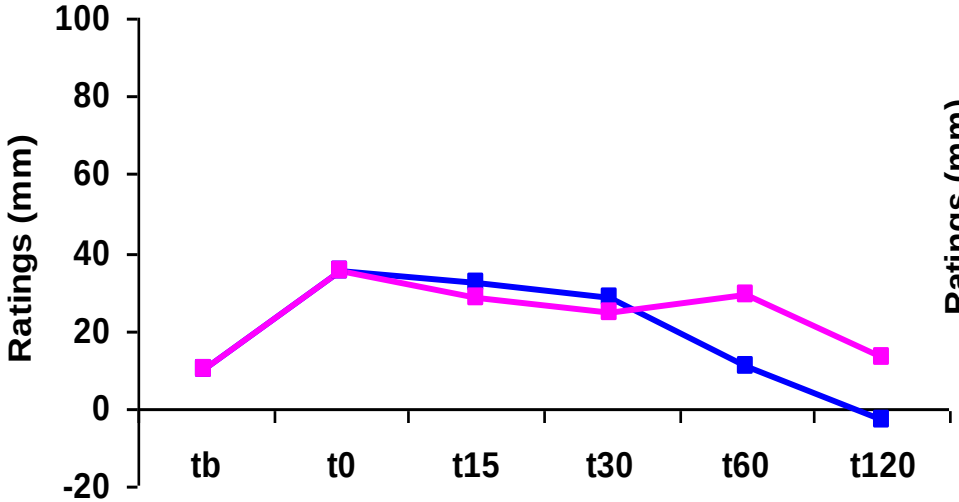


12

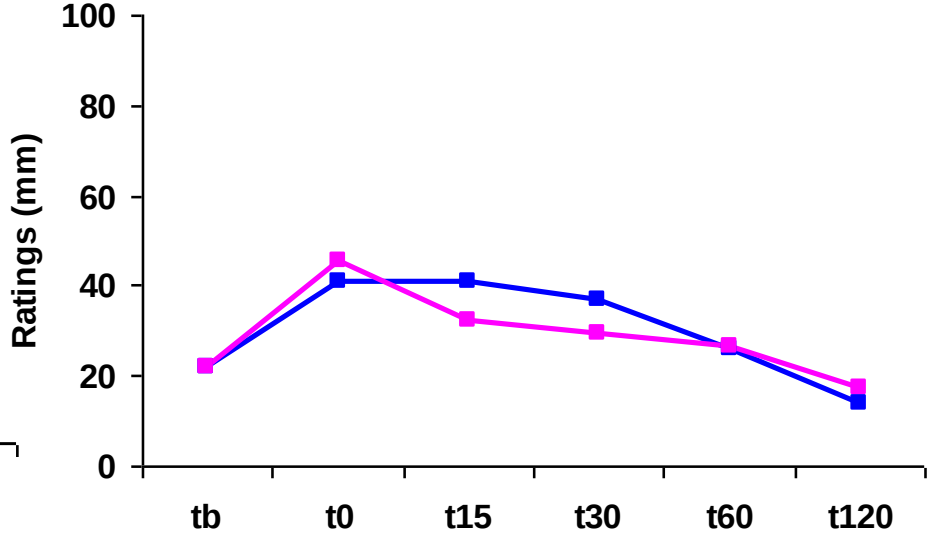
Dietary fibre intake

DFB	5 g	15 g
CB	3 g	9 g

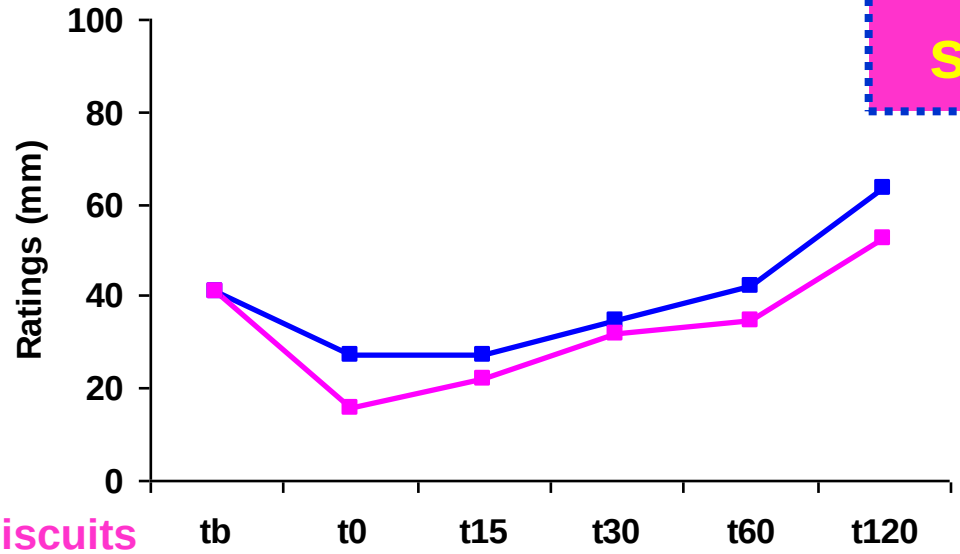
Satiety



Fullness



Hunger

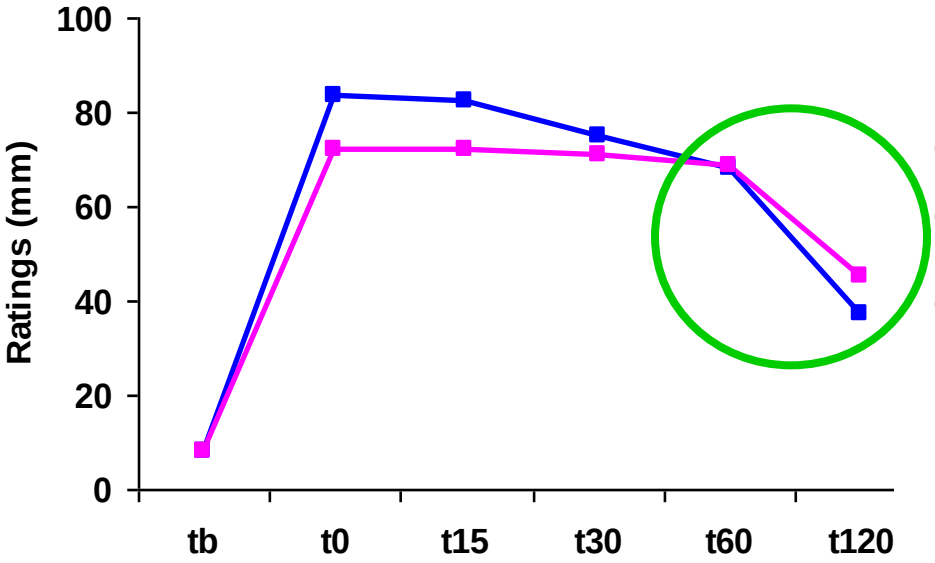


For small preload

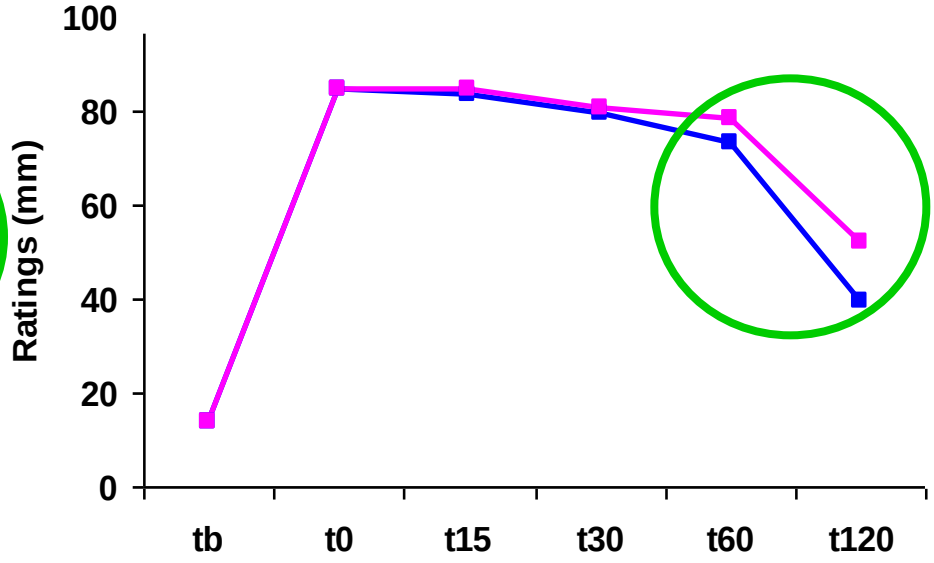
Control biscuits

Dietary fibre-rich biscuits

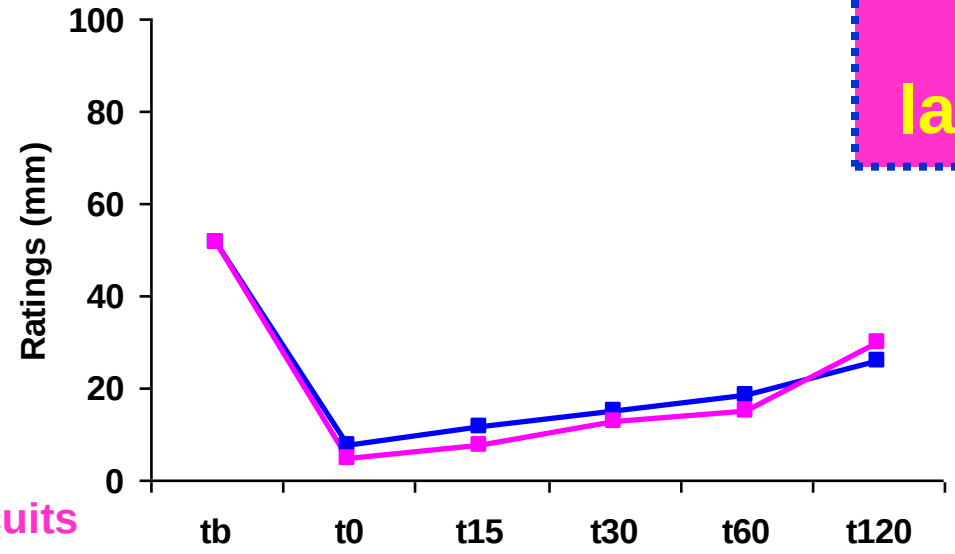
Satiety



Fullness



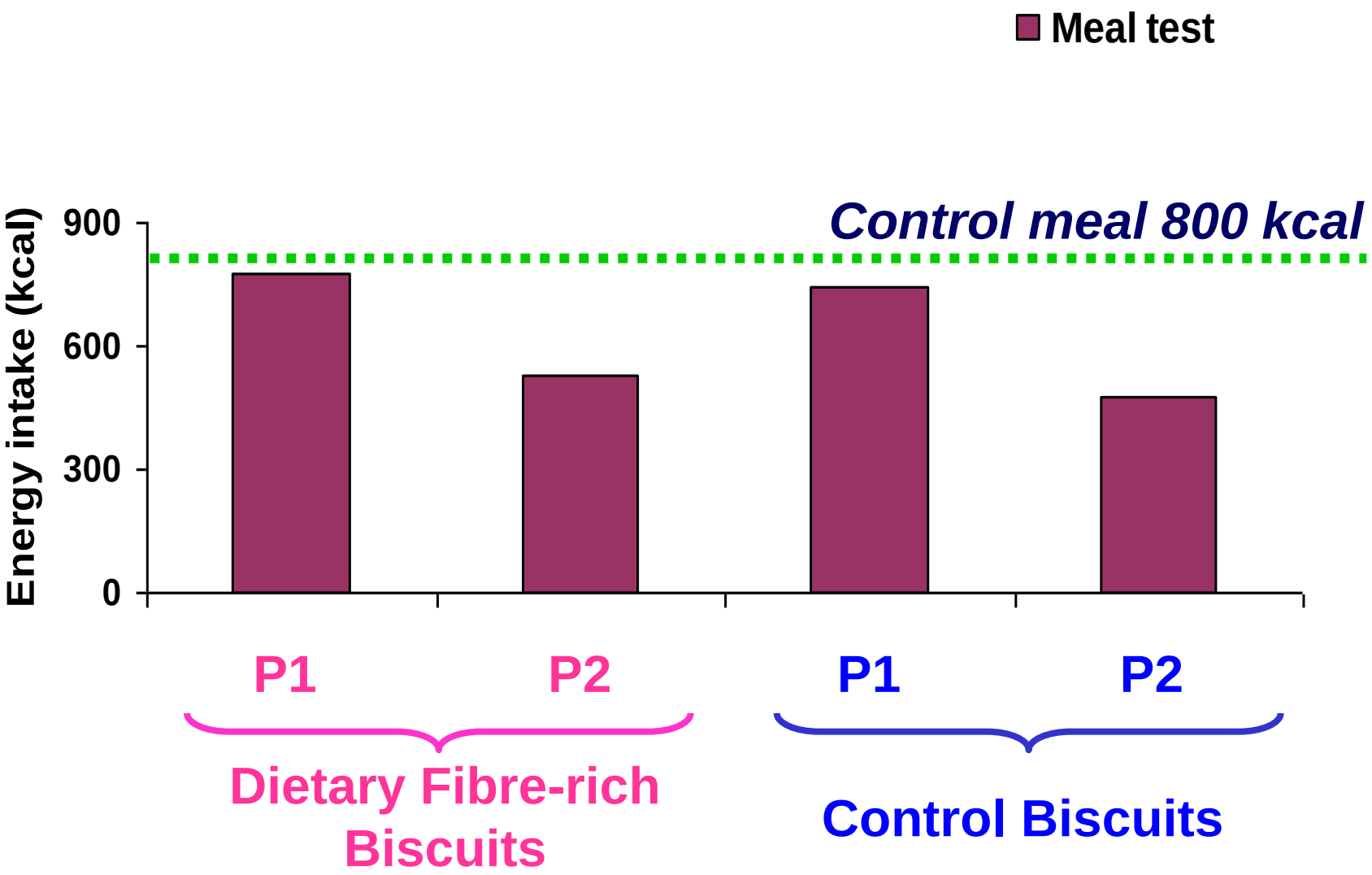
Hunger



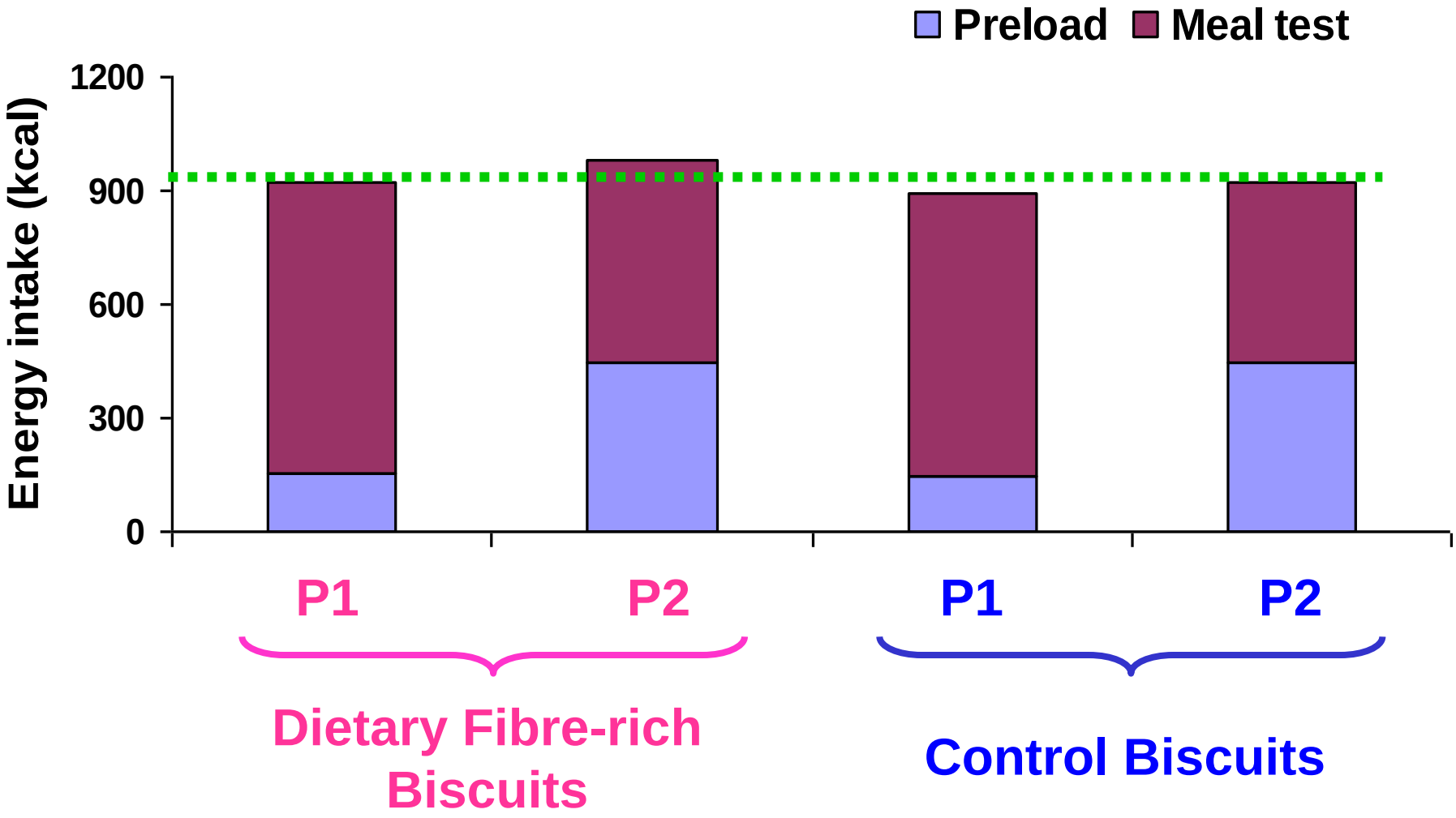
For large preload

Control biscuits

Dietary fibre-rich biscuits

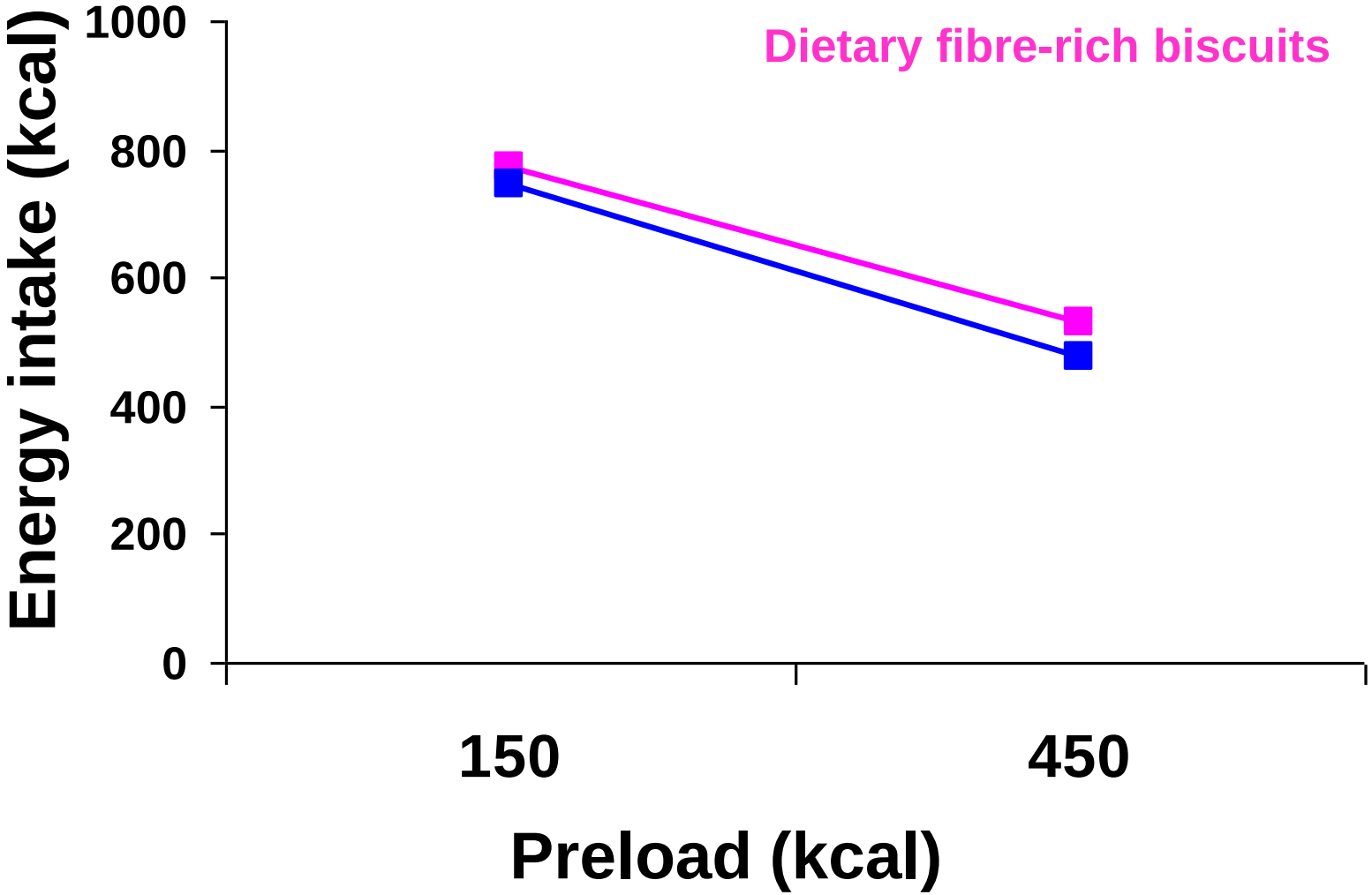

Meal test
Control meal 800 kcal
Energy intake (kcal)
900
600
300
0
P1
P2
P1
P2
Dietary Fibre-rich Biscuits
Control Biscuits

Energy intakes



Satiating efficiency index *(Kissileff)*

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



The reasons of contraddictions:

- **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)**

Appetite xxx (2009) xxx xxx

Contents lists available at ScienceDirect

Appetite

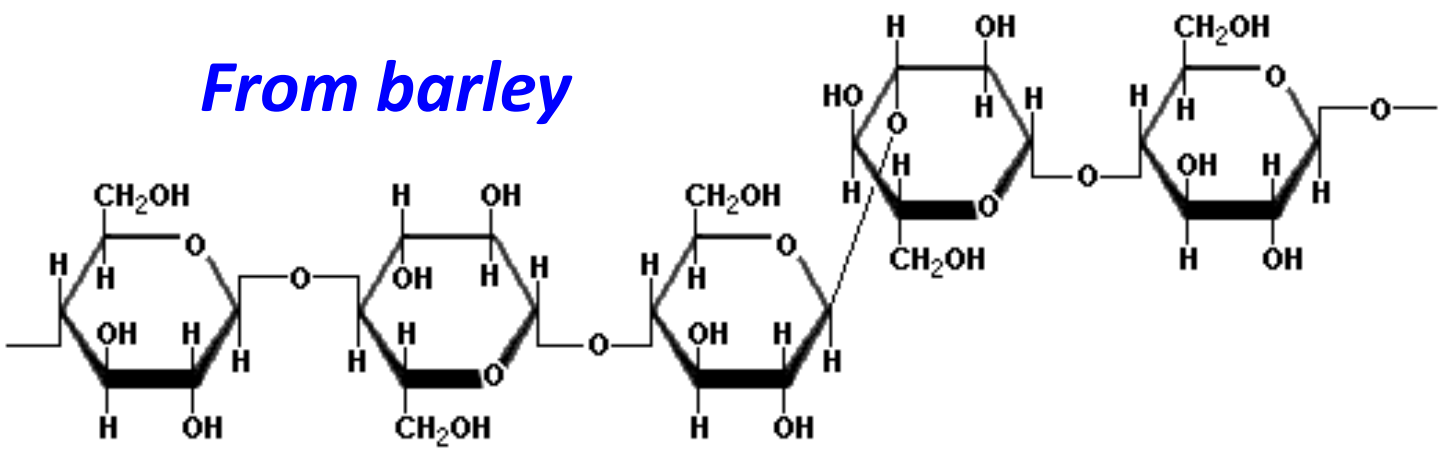
journal homepage: www.elsevier.com/locate/appet

β-Glucan-enriched bread reduces energy intake and modifies plasma ghrelin and peptide YY concentrations in the short term

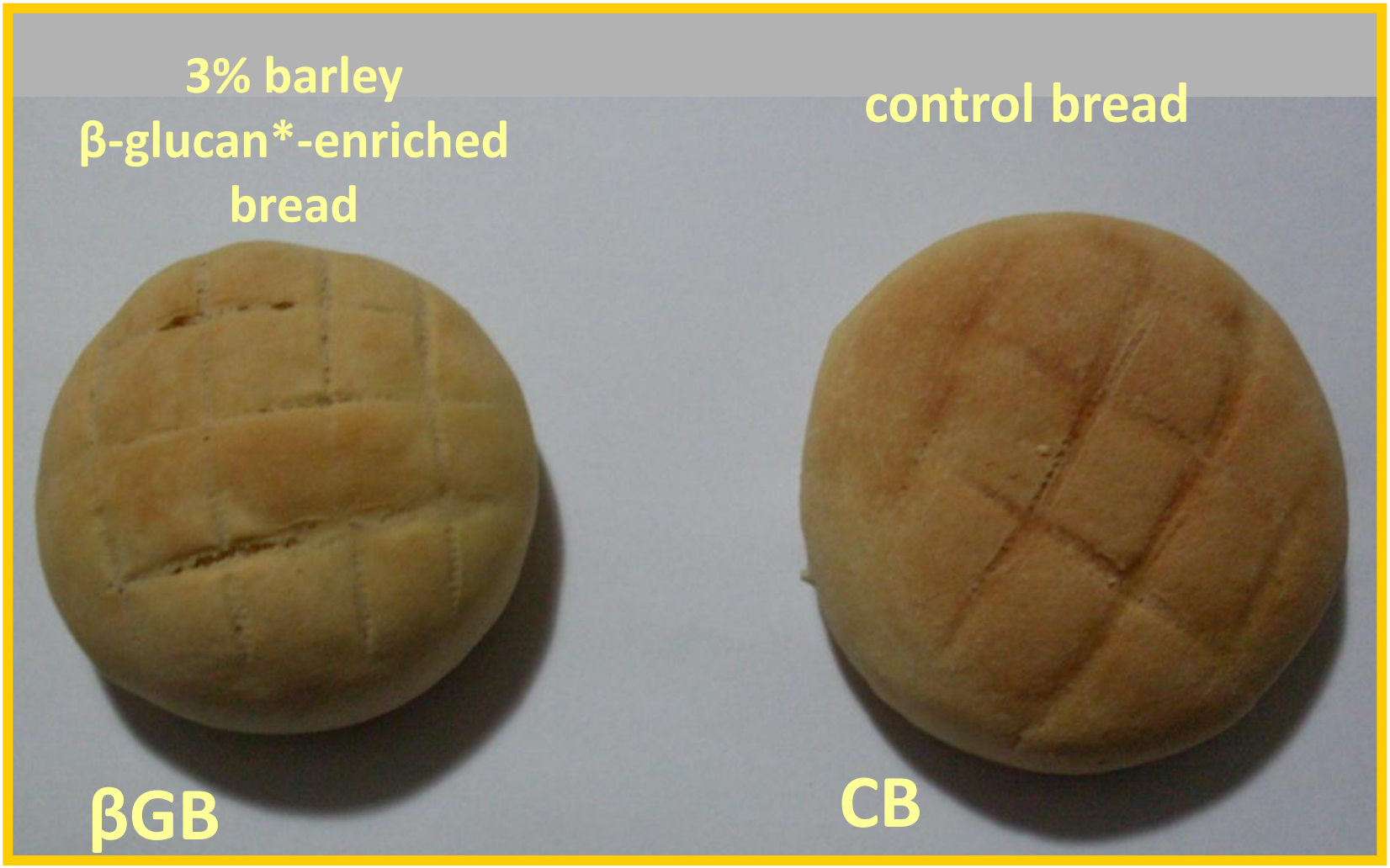
Paola Vitaglione*, Roberta Barone Lumaga, Antonio Stanzione, Luca Scalfi, Vincenzo Fogliano

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

From barley



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/m^2
- Each subject partecipated 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

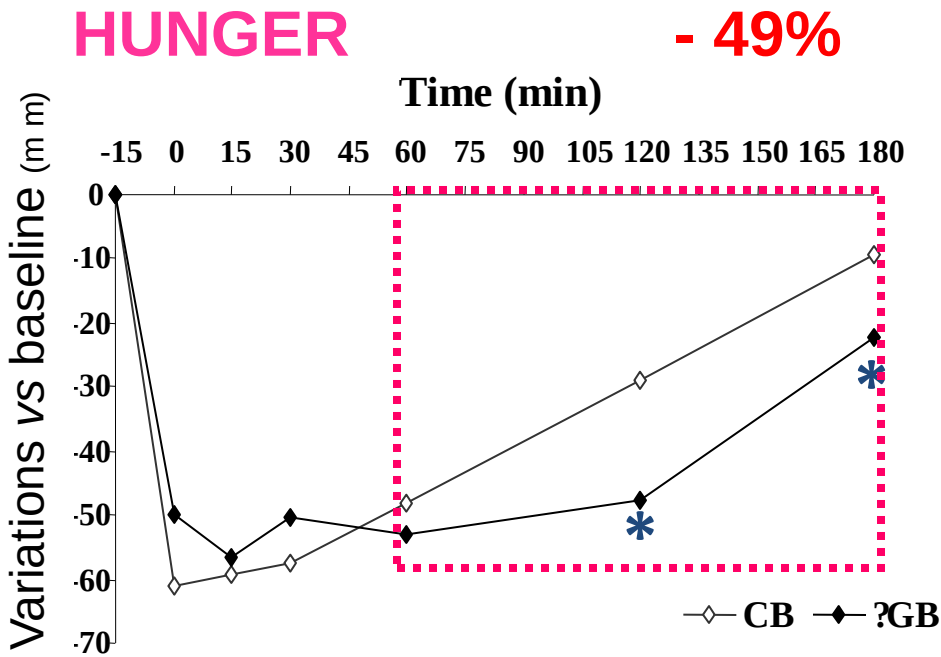
- **From 0900 to 1200:**
  Subjects filled out some questionnaires (VAS for appetite ratings)
- **At 12.00:**
  Subjects were invited to have a lunch *ad libitum*

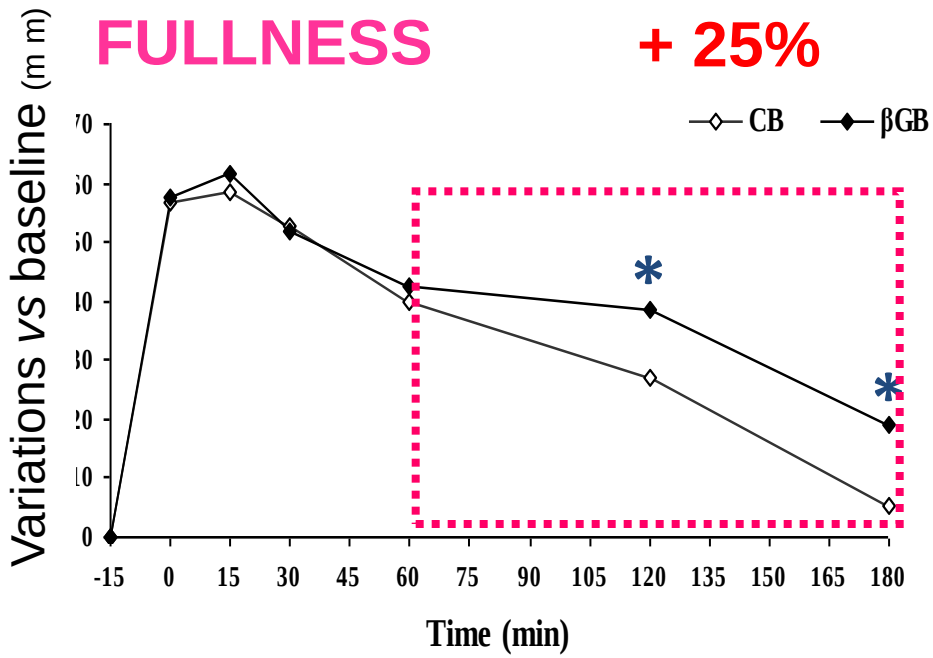
Protocol 2

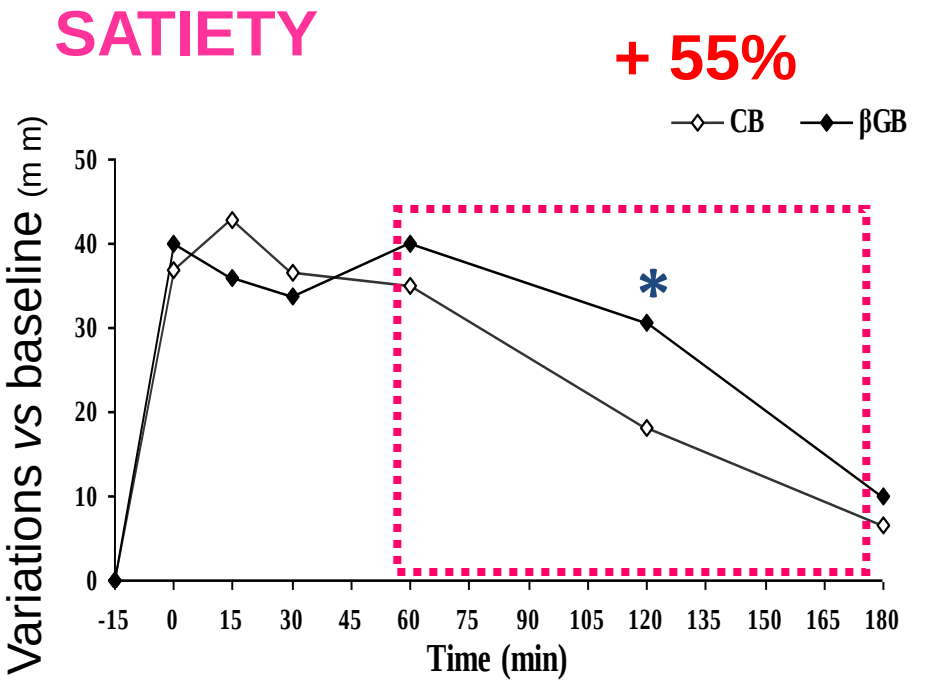
- **From 0900 to 1200: Subjects were submitted to blood drawings to determine glucose and satiety-related hormone concentrations (ghrelin, PYY and insulin)**

RESULTS

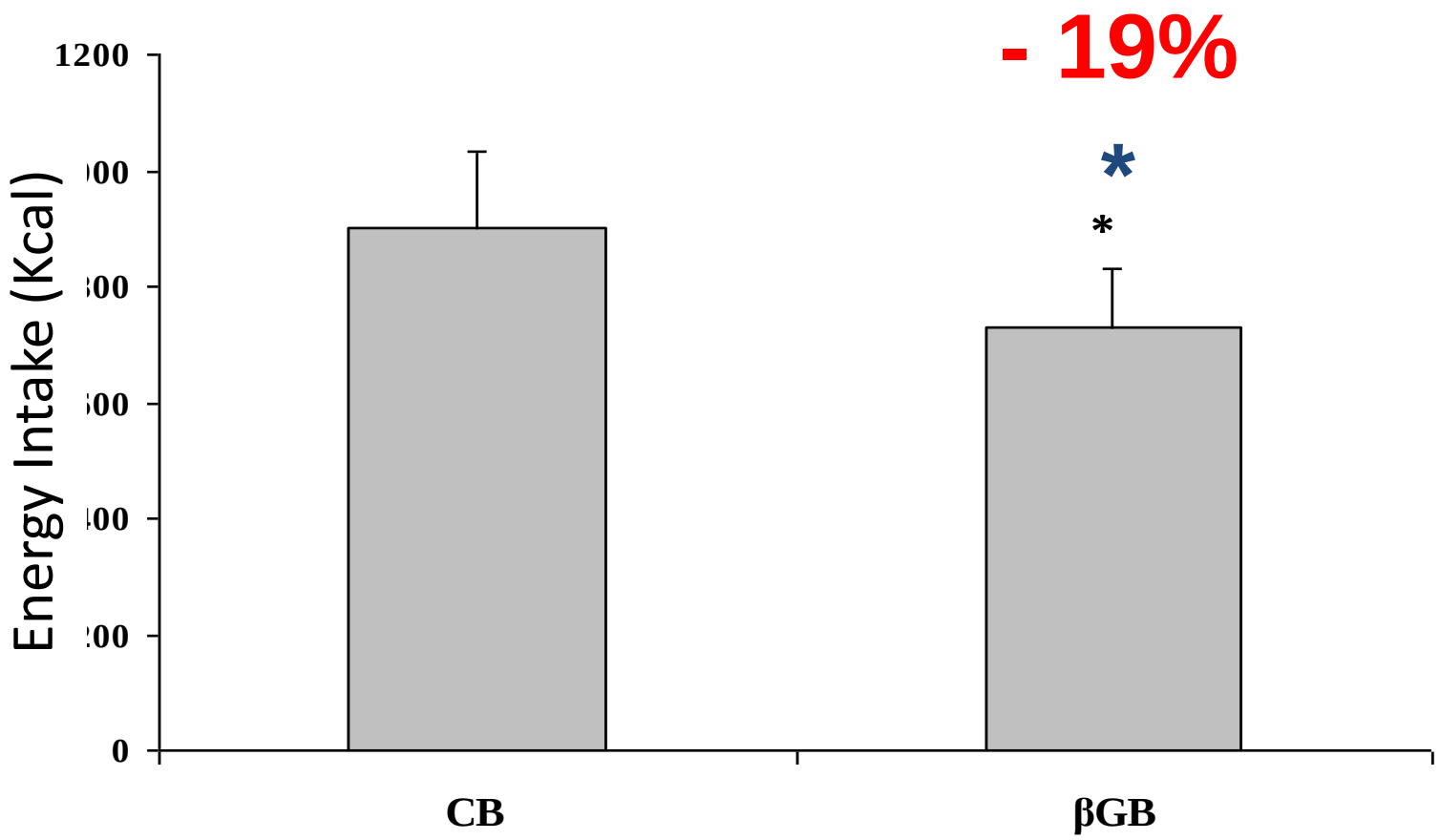
Subjective appetite ratings (VAS)



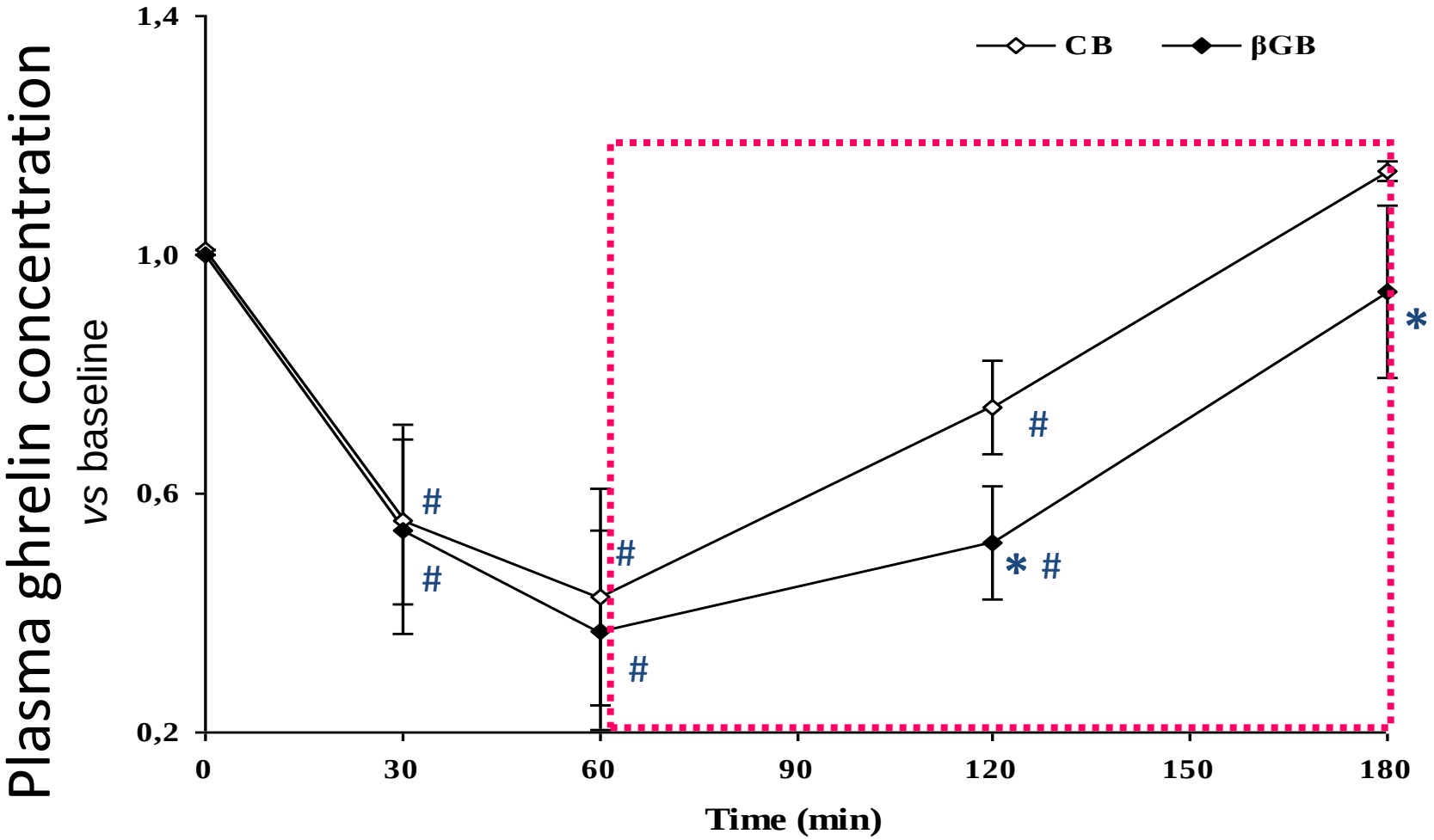




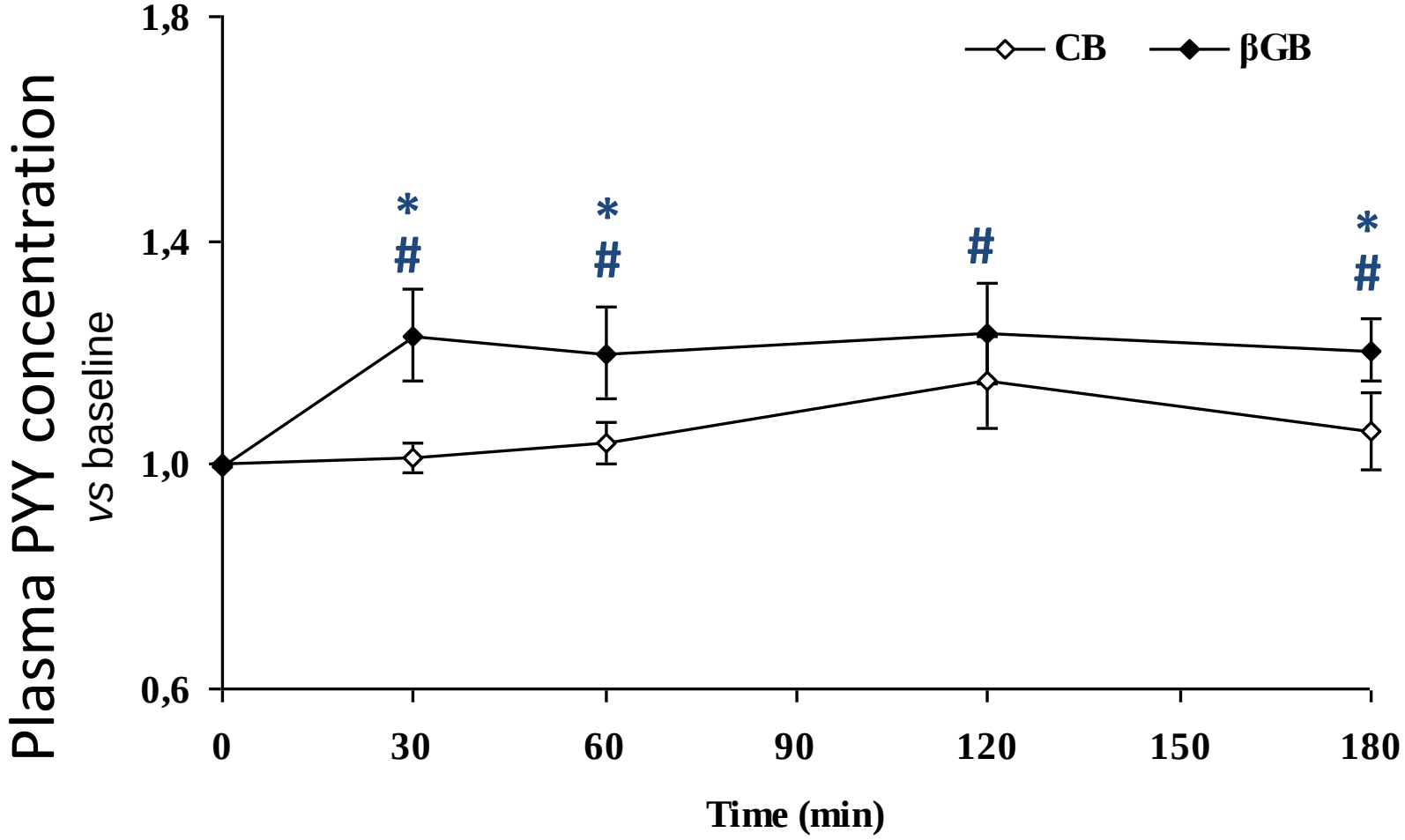
Energy intake at lunch



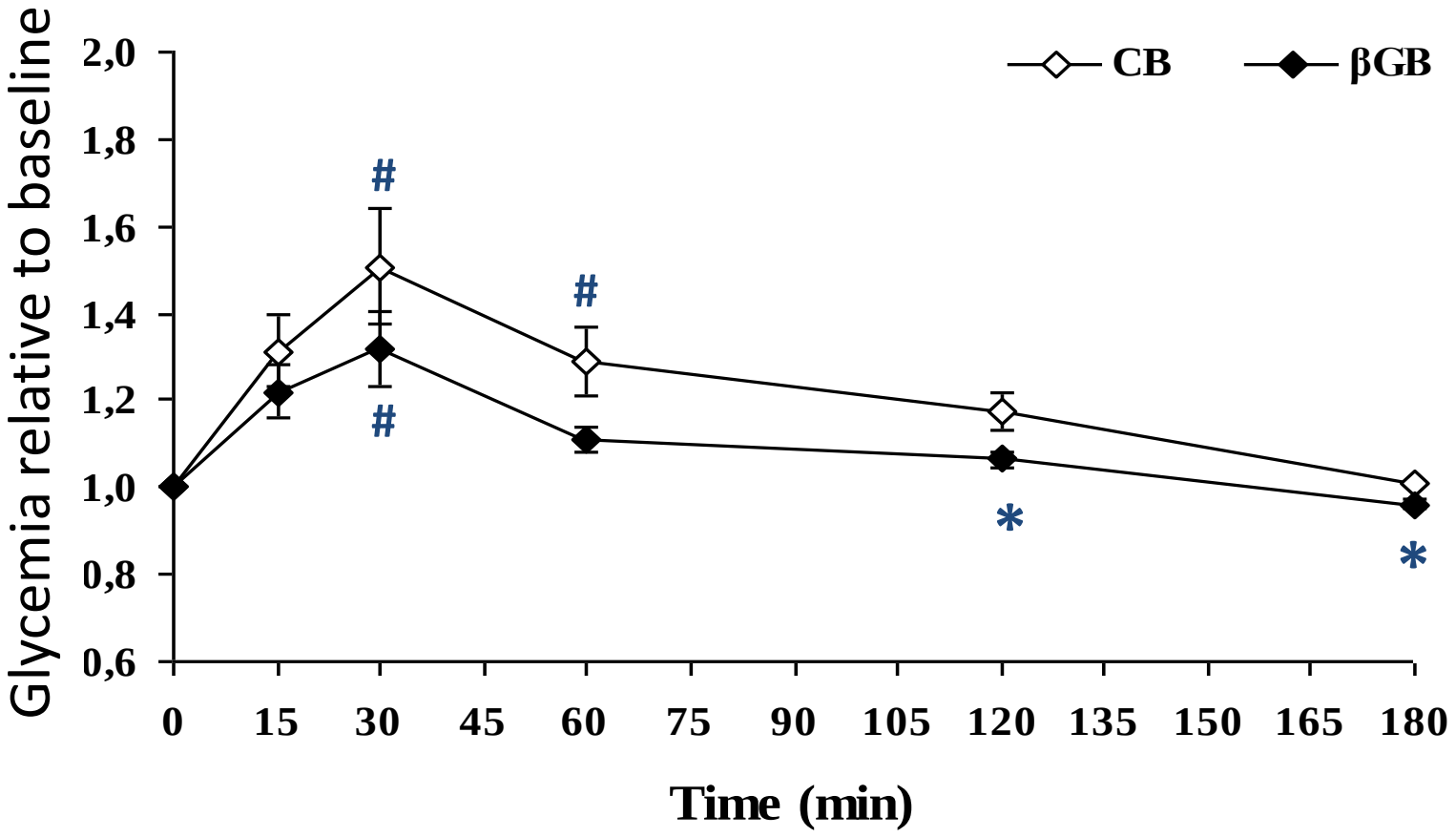
Blood analyses
ghrelin



Blood analyses
PYY



Biochemical analyses
Glycaemia



Conclusions

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

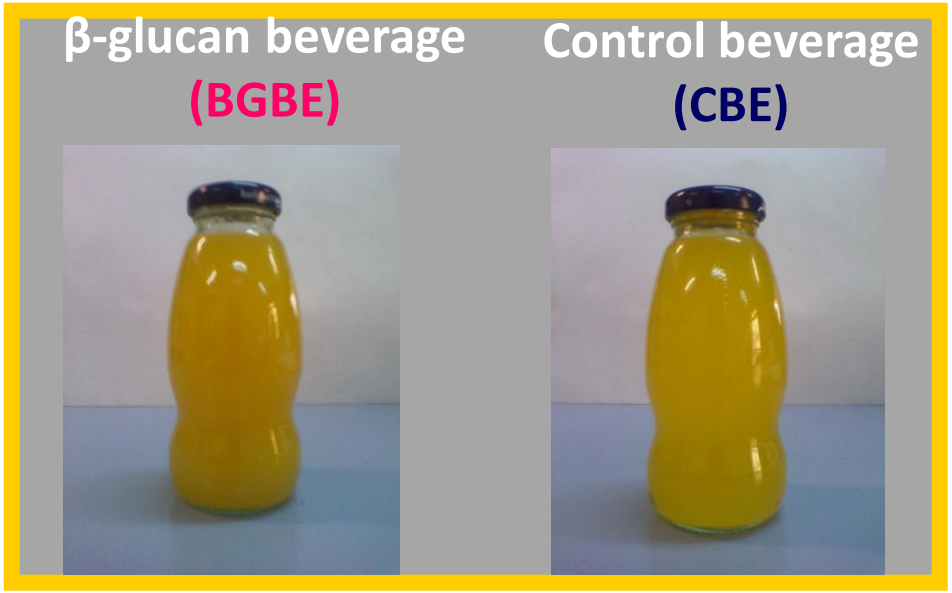
- the ability of barley β-glucans to modulate appetite sensations and to reduce energy intake;
- the potential role exerted by ghrelin and PYY in determining a short term satiety effect by β-glucans independent from insulin.

Food & Function

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,[a] Danilo Azzali,[b] Vincenzo Fogliano,[a] Luca Scalfi[a] and Paola Vitaglione*[a]

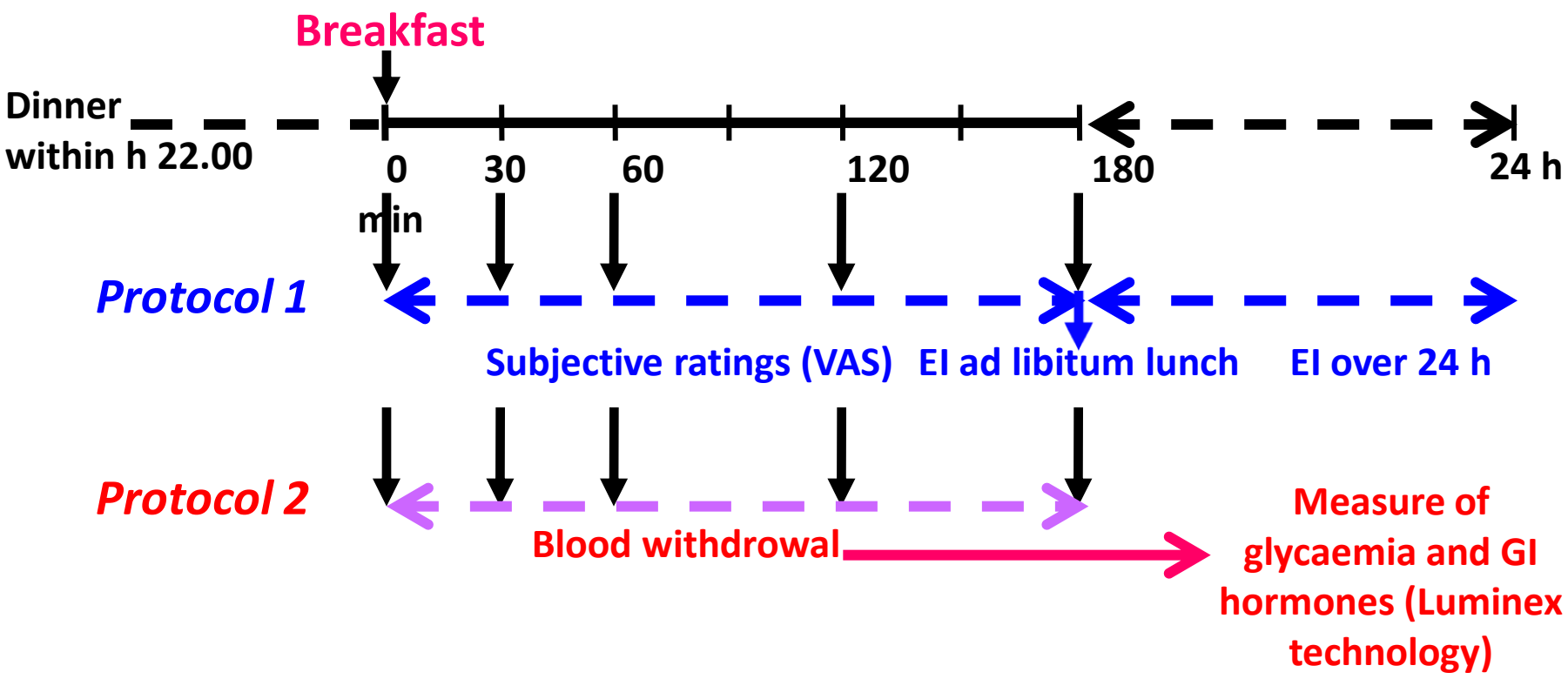
Food Funct., 2012, **3**, 67

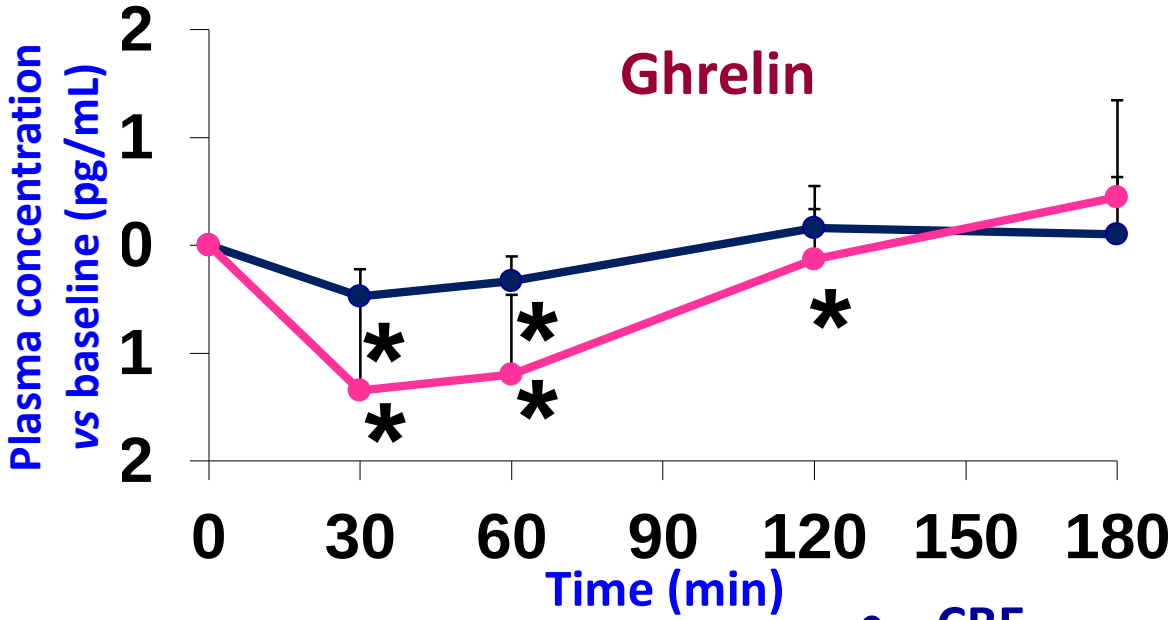


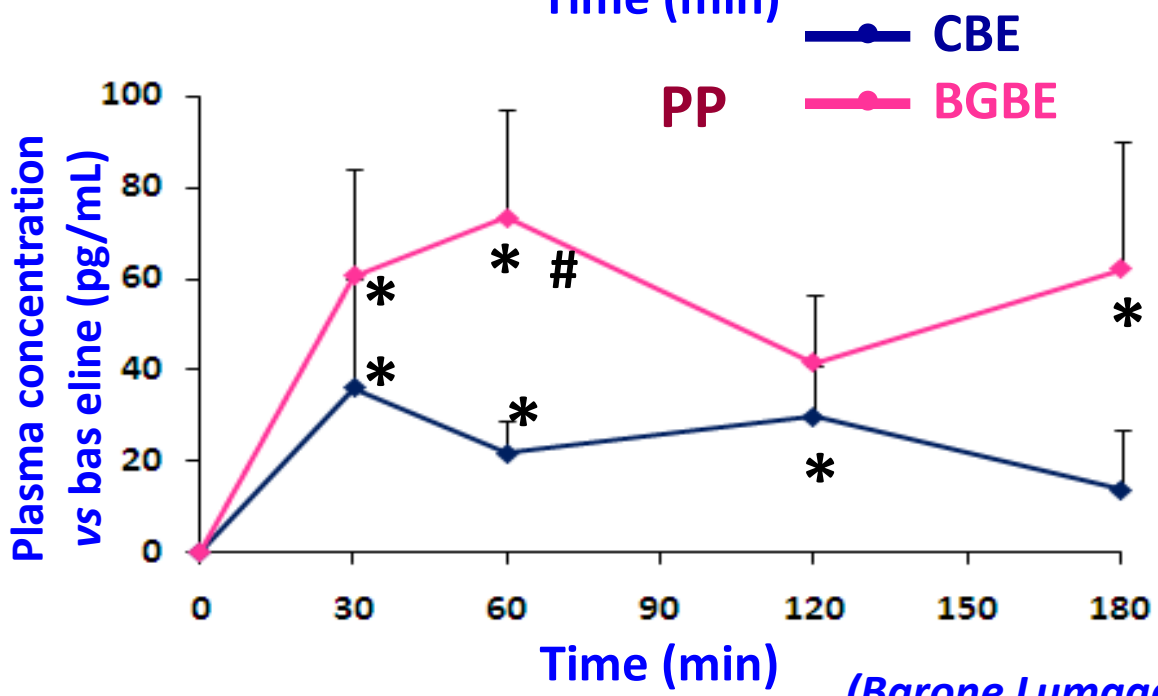
(Barone Lumaga et al., Food & Function, 2011)

	BGBE	CBE
Portion volume (mL)	250	250
Proteins (g)	0.2	---
Fats (g)	0.3	---
Carbohydrates (g)	34.5	37.3
Total dietary fibre (g)	3.00	---
β-glucans (g)	3.00	---
Energy density (kcal)	147.5	149.2

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

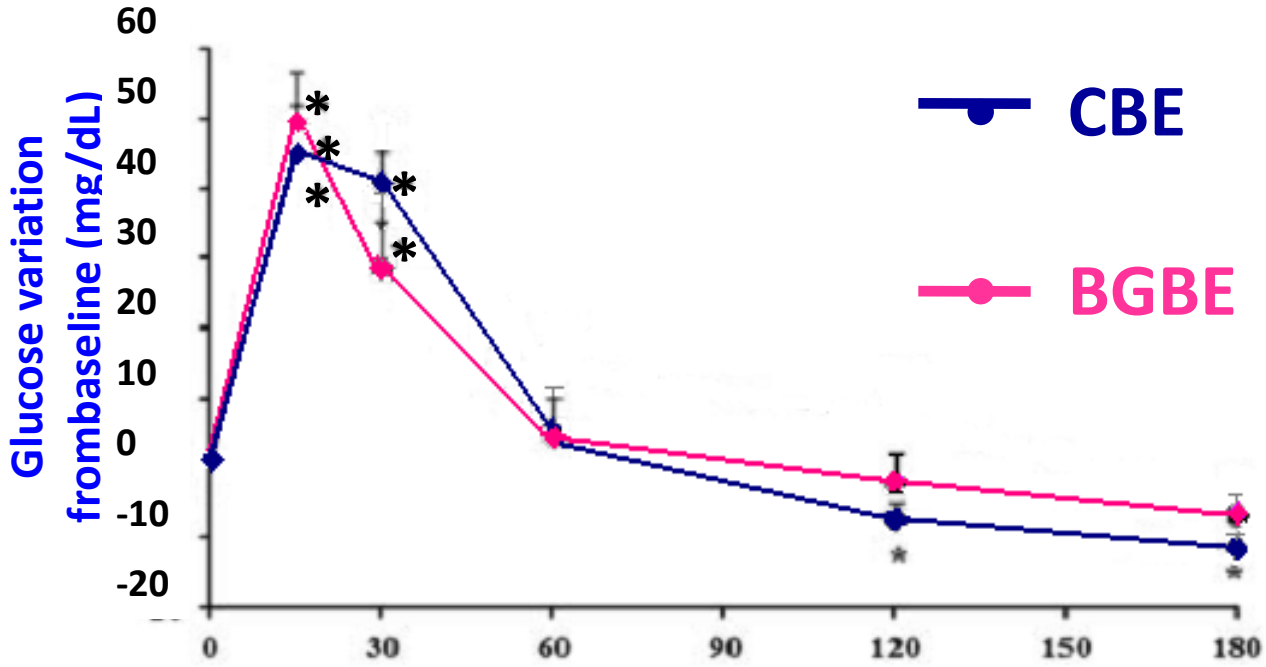
Pancreatic polypeptide (PP) response was significantly higher after BGE than CBE, independently from insulin response.

***: $p < 0.05$ 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



BGBE=
β-glucan beverage
CBE=
control beverage

*: p<0.05 *vs* baseline

#: p<0.05 *vs* CBE

ENERGY INTAKES

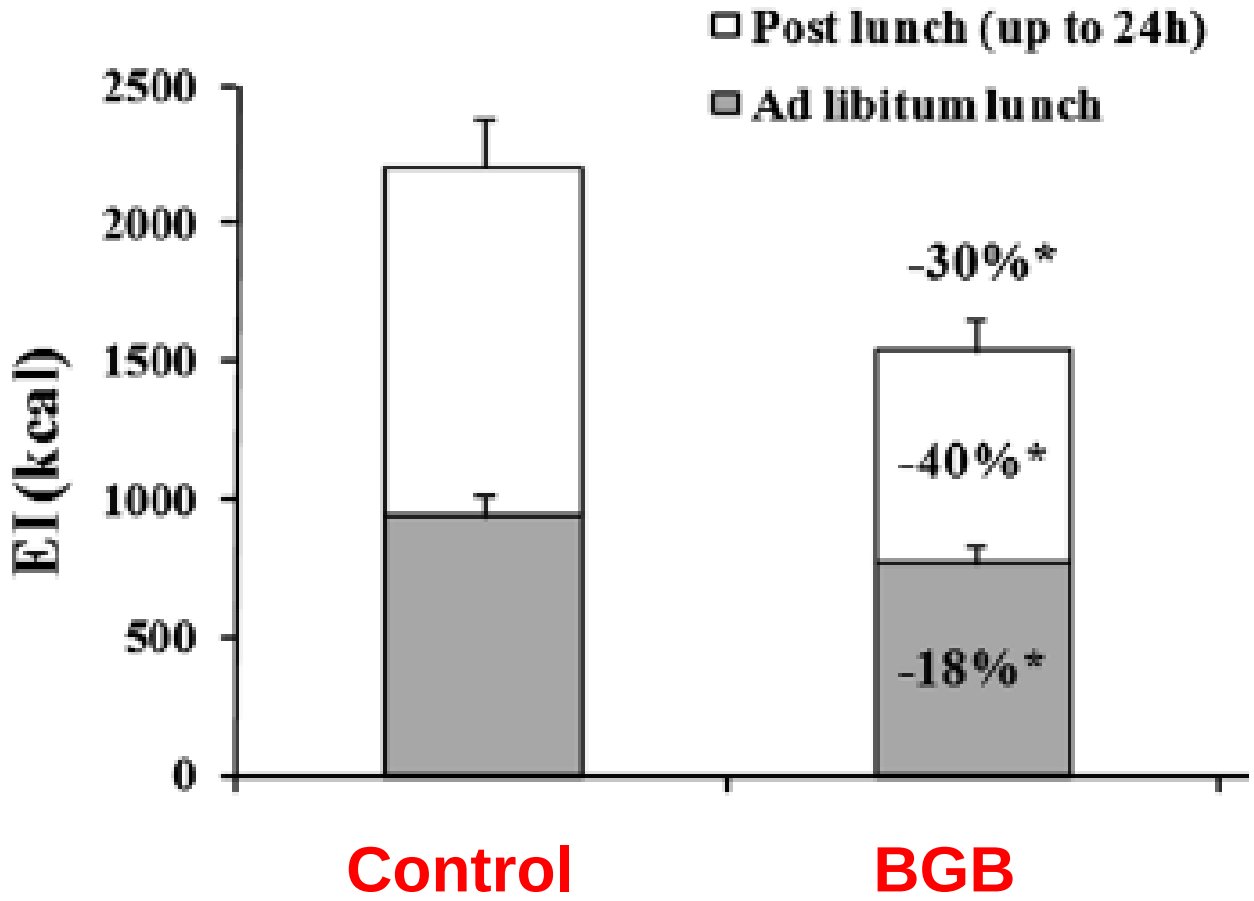


Fig. 2 Energy intakes (kcal) measured at *ad libitum* lunch, post-lunch and over the all experiment day upon consumption of each beverage. *: $p < 0.05$ *vs.* meal 1.

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.

Meal replacements

European Food Safety Authority

EFSA Journal 2010; 8(2):1466

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[1]

The food that is the subject of the health claims is "meal replacement for weight control", which is defined in Directive 96/8/EC[5] 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.

ID	Food or Food constituent	Health Relationship	Proposed wording
1417	Meal replacement for weight control (as defined in Directive 96/8/EC energy restricted diets for weight reduction)	Safe, effective & healthy weight loss. Greater weight loss than with conventional calorie counting	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
	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		

	Food or Food constituent	Health Relationship	Proposed wording
1418	Meal replacement for weight control (as defined in Directive 96/8/EC energy restricted diets for weight reduction)	Maintenance of weight loss	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 maintenace
	Conditions of use - Replace one meal a day as a weight maintenance strategy/to keep the weight off		