DRUMMOND FOOD SCIENCE ADVISORY LTD

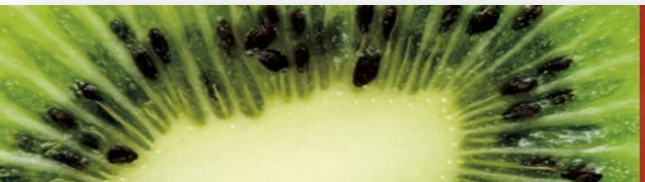
KIWIFRUIT AND DIGESTIVE FUNCTION

Lynley N Drummond

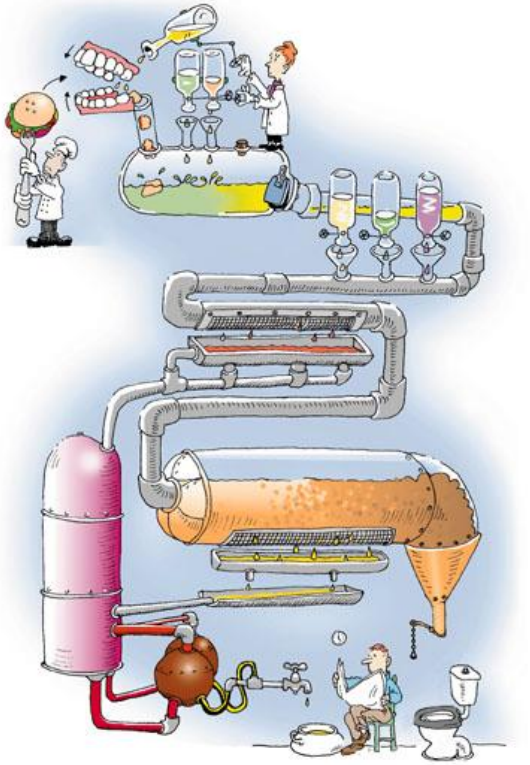
How do we determine the effects on digestive function?

- Promotion of digestion
- Beneficial effects

- Effect on relief of poor digestion
- Ability to relieve
- Digestive dysfunction



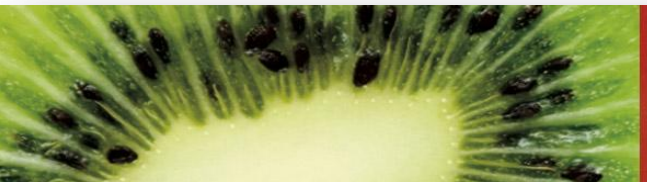
Digestive Dysfunction



A major consequence of life-style, aging & chronic disease e.g. diabetes

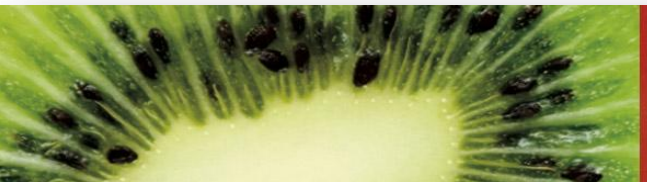
- Indigestion
- Gastric reflux
- Nausea
- Bloating
- Vomiting
- Abdominal discomfort
- Constipation
- Gastroparesis
  - Delayed gastric emptying
- Treatment options limited
  - Dietary modification
  - Pharmacological intervention

- Food / dietary solution: How can kiwi contribute?

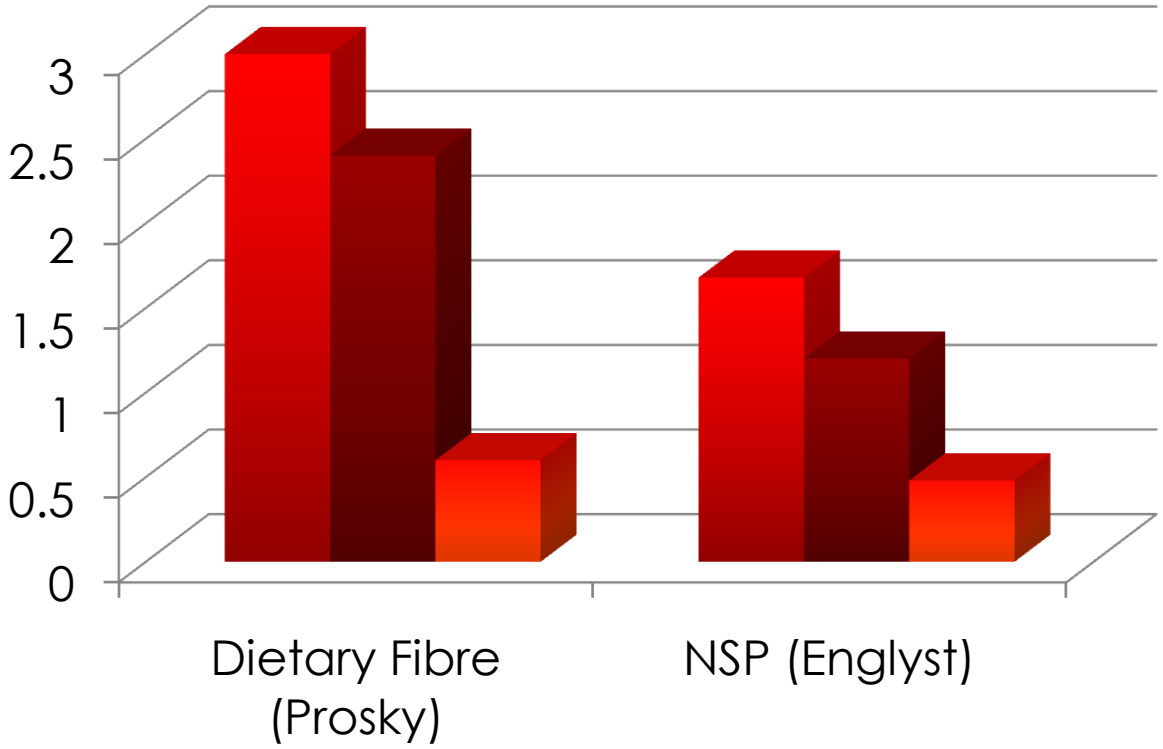


Can one food influence digestion ?

- What components of the food have the potential to be effective for addressing digestive function?
- What is the potential mode(s) of action throughout the entire GI tract?



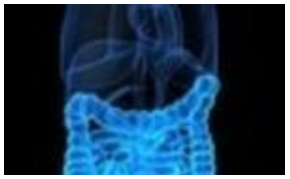
Fibre Content of Kiwi

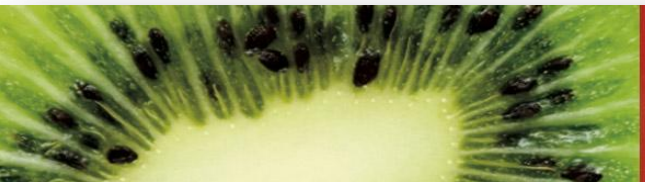


NSP: Non-starch polysaccharides

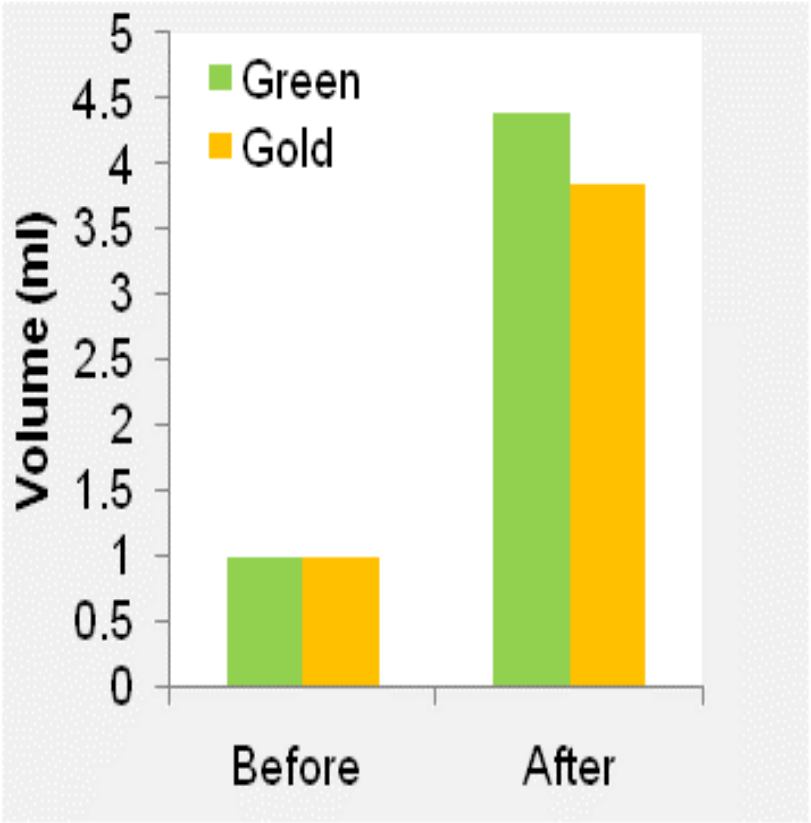
How does the fibre behave during digestion?

- Using a gastric digestion model we looked at the behaviour of the fibre during digestion
  - Swelling
  - Viscosity
  - Glucose diffusion
  - Mixing



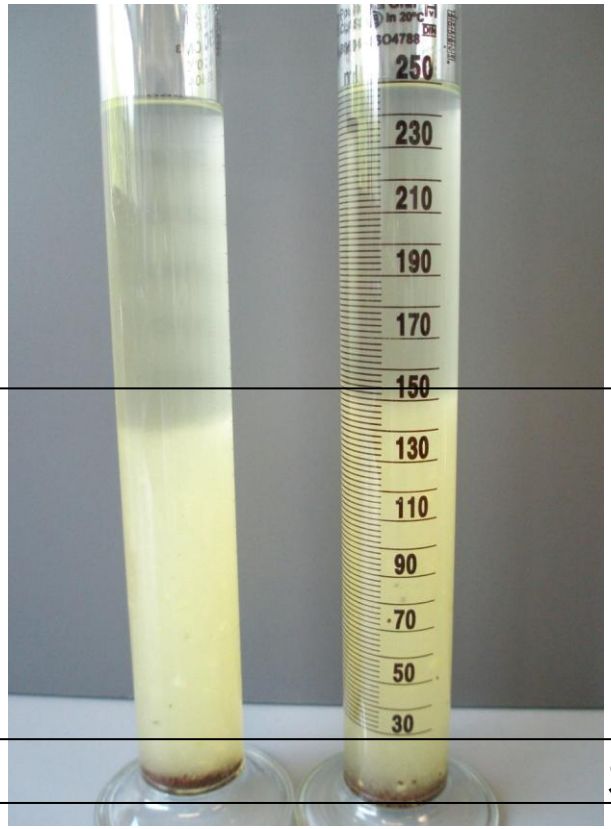


Fibre swells significantly during digestion



Post digestion volume per unit of pulp digested

Fibre swells significantly during digestion



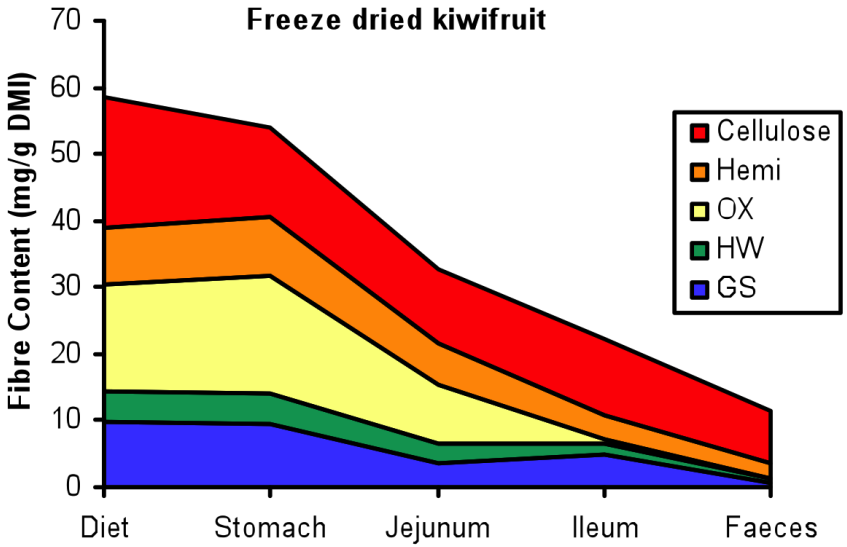
Post digestion

Starting vol = 30 ml pulp

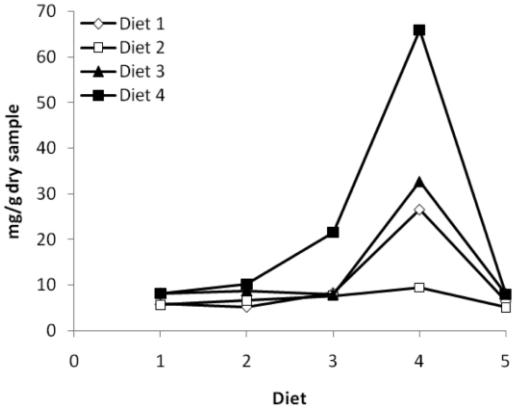
- Kiwi fibre has the capacity to substantially reduce the rate of diffusion of glucose.
- Kiwi undigested remnants have a substantial capacity to reduce both mixing and diffusion
- Kiwi fibre has a more than additive effect when added to medium with some background viscosity, such as would occur in the gut.
  - Kiwi fibre probably increases the resistance of digesta to mixing.
- During digestion kiwi has a substantial capacity to swell beyond it's volume in the fresh fruit. This will influence the digestive processes significantly
  - Recent work suggests an influence on the absorption of nutrients.

Fate of Kiwi NSP in the GI Tract

Disappearance of kiwi NSP fractions throughout the gastrointestinal tract of the growing pig



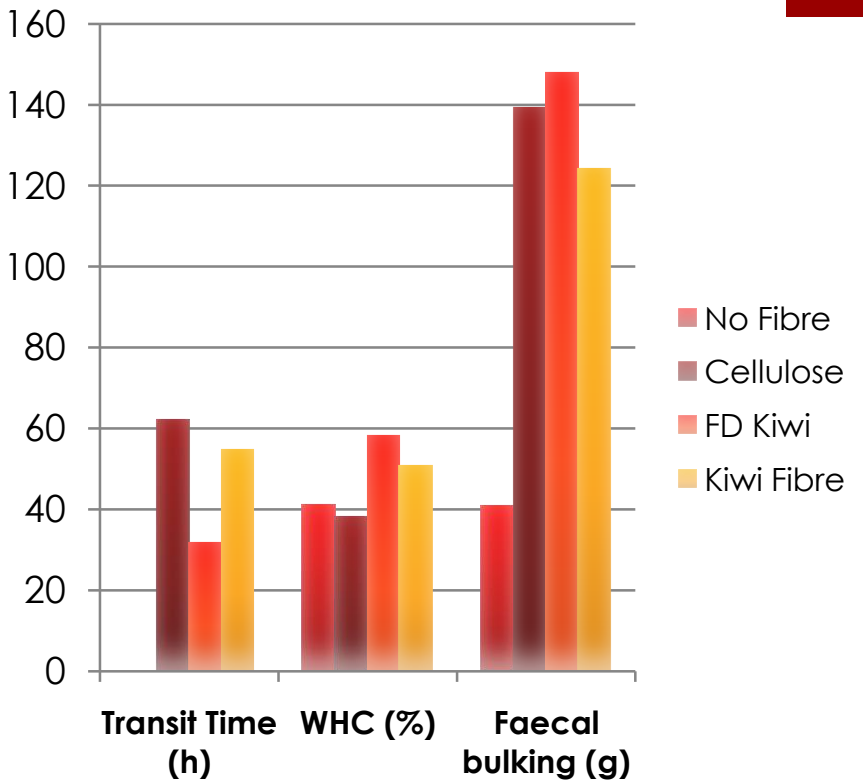
Change in gut-soluble NSP as a proportion of dry matter with passage of diet through the gut



1, diet; 2, stomach; 3, jejunum; 4, ileum; 5, faeces.
Diet 1, control; diet 2, cellulose; diet 3 kiwi; diet 4, kiwi fibre.

Fate of Kiwi NSP in the GI Tract

- Concentration of pectic fractions in the ileum
  - Extends region of digestion along the ileum
  - Reduces rate of absorption of nutrients
    - Glucose absorption
      - Glycaemic repsonse
      - Delays onset of hunger (satiety)
    - Lipid absorption
      - Reduces post-prandial lipaemia (CVD risk)
    - Bile acid resorption (in terminal ileum)
      - Reduces plasma cholesterol



Fate of Kiwi NSP in the GI Tract

- Sharp decline in pectic fractions in faeces
  - Used as fermentable substrate for colonic microflora
- Accumulation of cellulose-type fractions
  - Increases in faecal bulking & water holding capacity
- Reduction in GI transit time

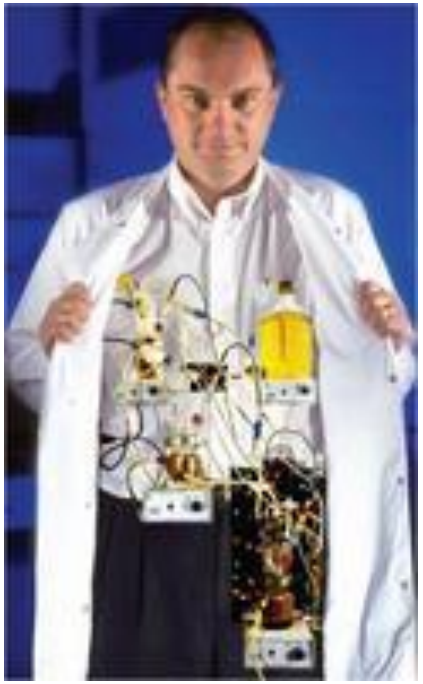
The full effect of the differences observed between feeding groups cannot be attributed to the fibre content alone.

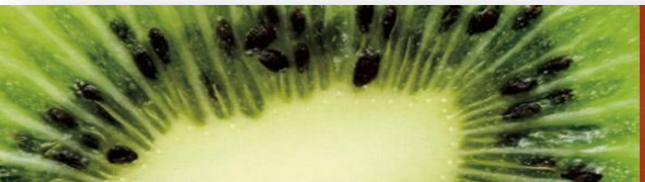
Further Effects of Kiwi in the GI Tract

- Recent work confirms:
  - Significant adaptation of the gut to kiwi in the diet short & long term)
    - Can affect nutrient uptake (weight management)
  - Enhanced microbial fermentation
    - Increased butyric acid production
    - Changes in microbial populations
  - Prebiotic potential
  - Modulation of gut-mediated immune function

Can dietary enzymes aid digestion & reduce measures of digestive dysfunction?

- ***ACTINIDIN***
  - A unique enzyme in *Actinidia deliciosa* var. Hayward (Green Kiwi)
  - Cysteine protease
    - Known industrial applications (meat tenderising, protein hydrolysis processes)
    - OTC digestive enzyme supplements





Kiwi – the natural digestive aid?

- Potential function of actinidin in digestion
  - Breaks down protein
    - Improved digestion of protein
    - Better absorption
    - Digestive comfort
- Anecdotal evidence it assists digestion
  - No evidence in literature

Tested the assumption on a range of different food proteins using a laboratory models of digestion

- *Gastric (stomach)*
- *Ileal (small intestine)*

Improving Digestion – a research strategy

LITERATURE REVIEW: The Role of Kiwifruit Proteases in the Digestion and Uptake of Dietary Proteins and Amino Acids

In vitro gastric digestion models evaluating the effects of kiwi on the breakdown of different food proteins

In vivo gastric digestion models (animal models)

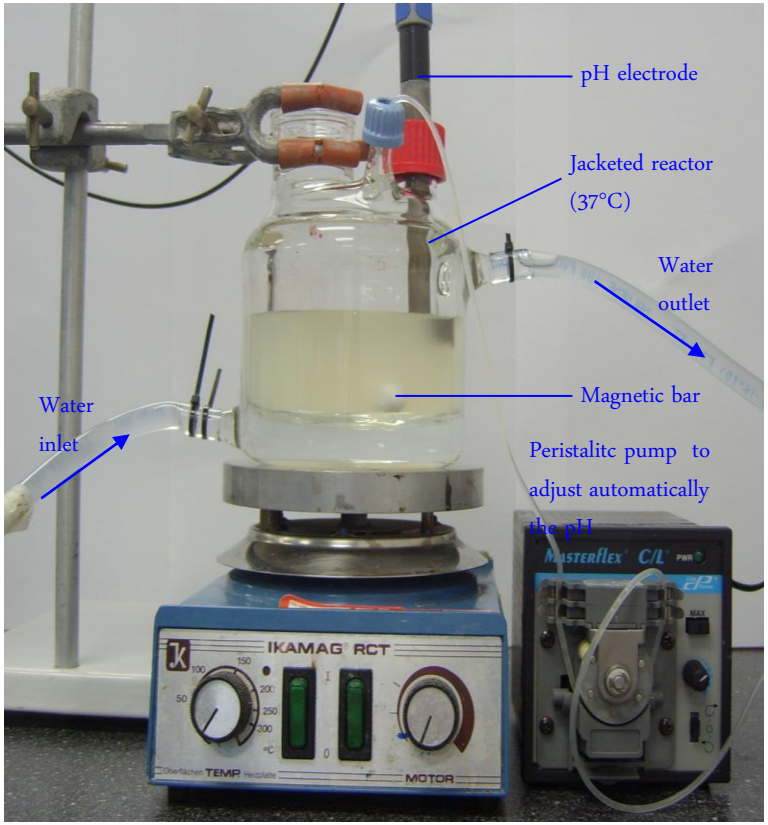
In vivo gastric digestion models (human ileostomates)

Gastric perfusion

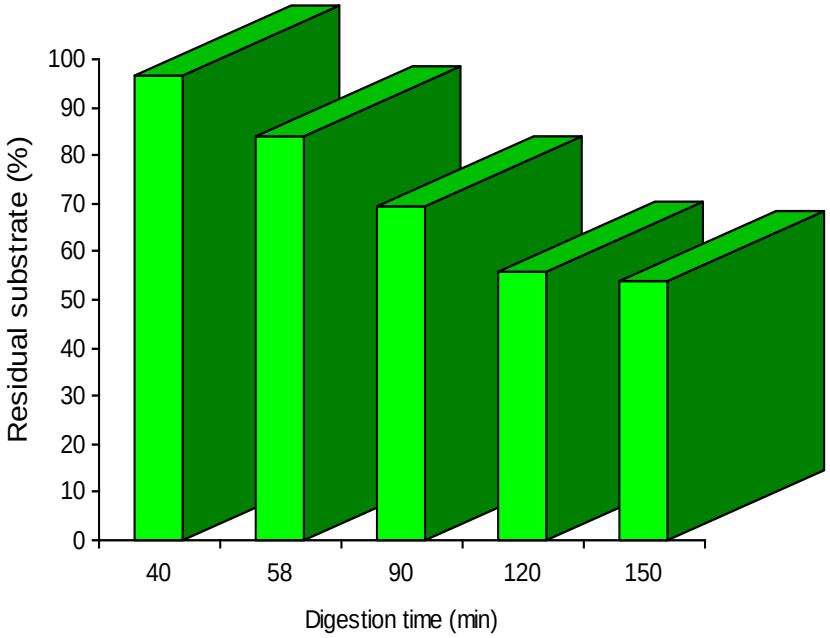
Scintigraphy studies

In vitro protein digestion reactor

- **Stage 1 :** Gastric
  - Simulated juice with Pepsin
  - pH = 2
  - Temp: 37°C
  - Duration: first 30 min
- **Stage 2 :** Ileal
  - Intestinal simulated juice
  - With Pancreatin,
  - pH = 8
  - Temp: 37°C
  - Duration: next 120 min



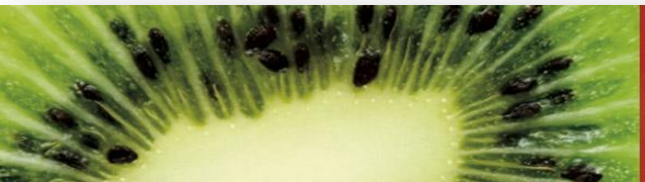
Improving Protein Digestion -I



In vitro digestion of Na-caseinate using kiwi extract alone (no pepsin/pancreatin) under simulated gastric (first 30 min) and intestinal conditions (next 120 min): using RP-HPLC

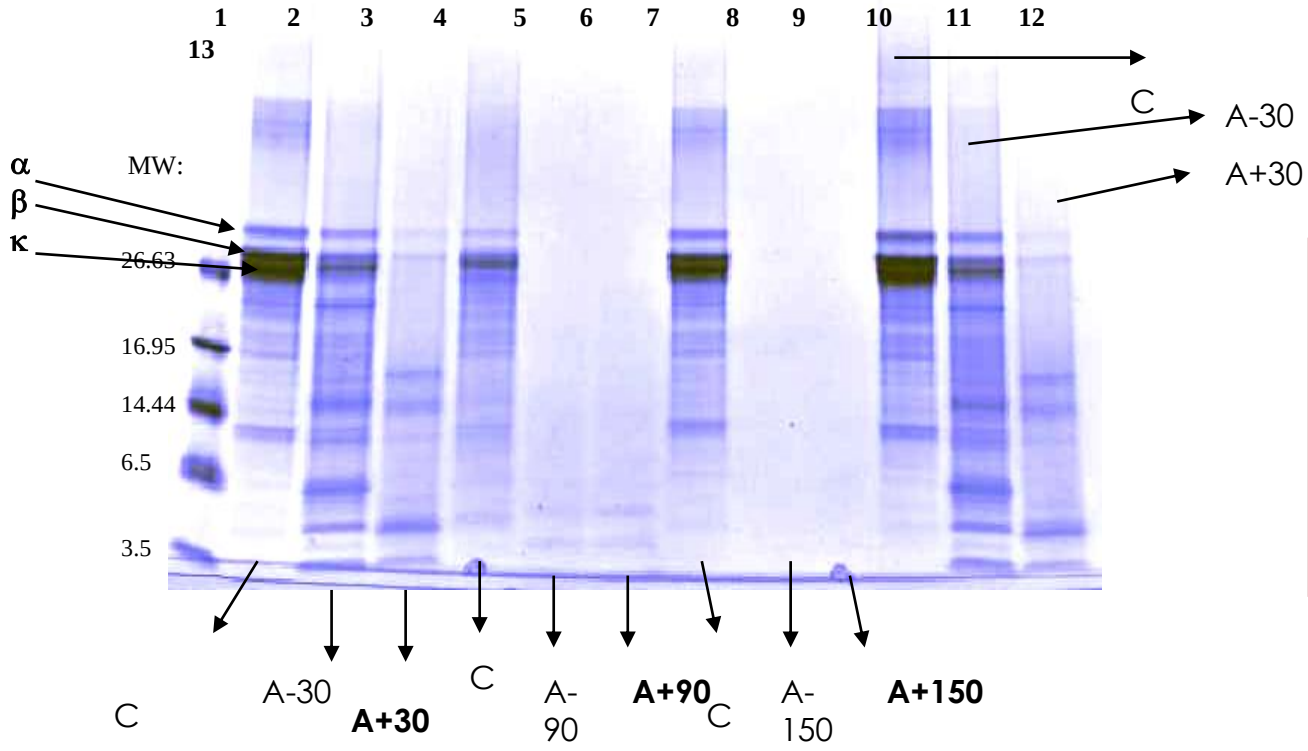
Kiwi extract alone can digest approx. 45 % of sodium caseinate within 150 minutes

Like the digestive enzymes, actinidin is active at very low pH



Improving Protein Digestion - I

In vitro gastric digestion of a milk protein

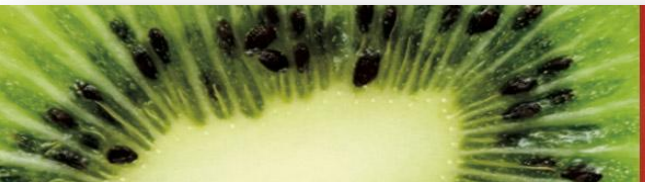


C= Control

A- = No actinidin

A+ = In the presence of actinidin

30, 90 and 150 are the digestion times



Improving Protein Digestion - I

Actinidin Enhances Gastric Protein Digestion as Assessed Using an *In Vitro* Gastric Digestion Model

Lovedeep Kaur†, Shane M Rutherfurd†, Paul J Moughan†,Lynley Drummond‡ and Mike J Boland†*

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Journal of Agricultural and Food Chemistry 2010 *58(8), 5068-5073*

Actinidin Enhances Protein Digestion in the Small Intestine as Assessed Using an *In Vitro* Digestion Model

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Journal of Agricultural and Food Chemistry 2010 *58(8), 5074-5080*

Improving Digestion II
In vivo Study

- *Study Design*
  - Male Sprague-Dawley rats
  - Fed 1 of 6 protein diets (whey, beef muscle, gelatin, soy, wheat, zein)
  - - Actinidin control diet : GOLD kiwi
  - + Actinidin control diet : Green kiwi and actinidin to supplement to specific level
  - Stomach and small intestine contents analysed for protein digestion

Improving Digestion II
In vivo Study

- Similar measures were made to the *in vitro* study

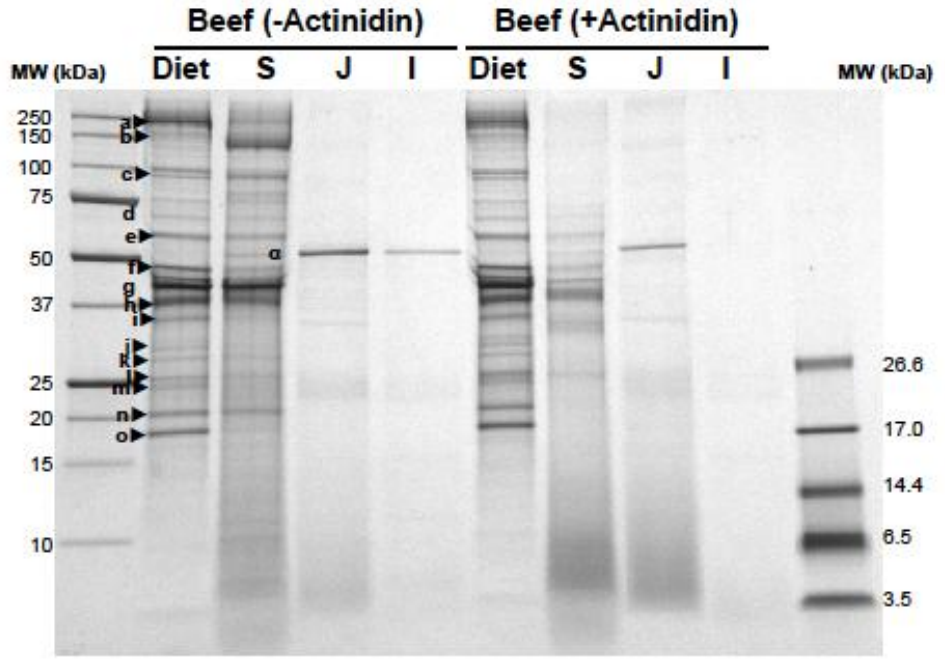


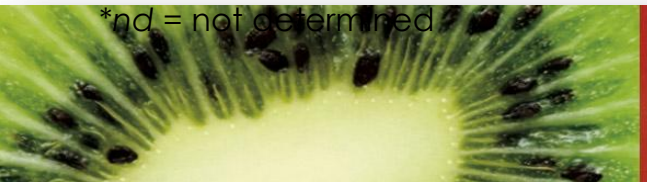
Figure 5. SDS-PAGE analysis of a beef muscle-based diet and stomach chyme (S), jejunal digesta (J) and ileal digesta (I) of selected rats fed the beef muscle-based diet. *The amount of sample loaded in each lane was normalized based on the concentration of titanium dioxide (indigestible marker). The protein bands were identified as follows: a) myosin-heavy chain, b) β-actinin, c) α-actinin, d) 68 kDa protein, e) desmin, f) 45 kDa protein, g) actin, h) tropomyosin-β chain, i) tropomyosin-α-chain, j) 32 kDa protein, k) 29 kDa protein, l) 25 kDa protein, m) myosin-light chain, n) troponin I, o) myosin-light chain, α) α-amylase.*

Improving Digestion II
In vivo Study

- Similar patterns of enhanced protein digestion were observed in both studies

Food Protein	GASTRIC		ILEAL	
	In vitro	*In vivo*	*In vitro*	*In vivo*
Whey	-	-	+	+/-
Zein	*nd**	-	+	-
Soy	+	+	-	-
Beef muscle	+	+	-	+/-
Gelatin	-	+	-	-
Wheat	+	+	+	+/-

**nd* = not determined

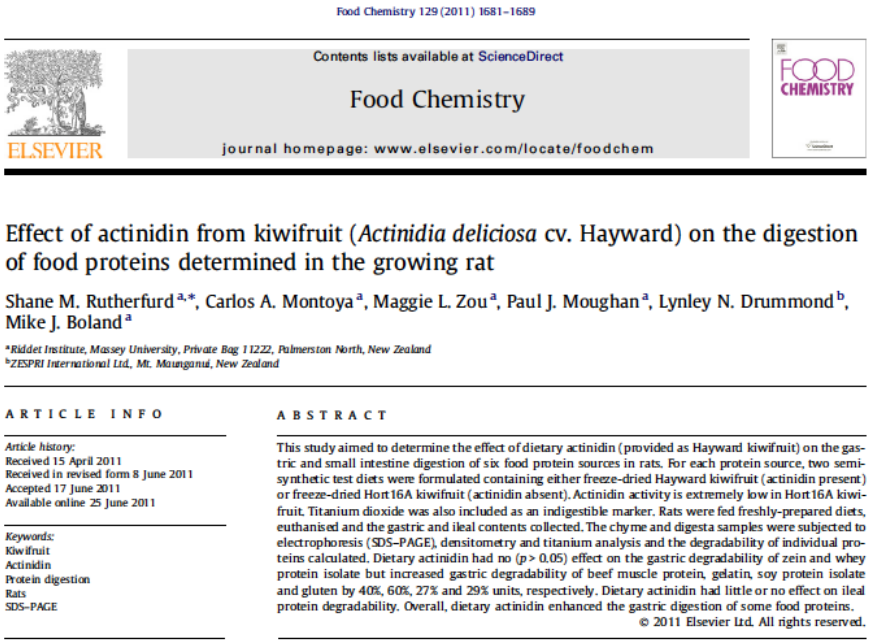


Improving Protein Digestion - II

Effect of actinidin from kiwifruit (*Actinidia deliciosa cv*. Hayward) on the digestion of food proteins determined in the growing rat.

Rutherfurd, S. M., Montoya, C. A., Zou, M. L., Moughan, P. J., Drummond, L. N., & Boland, M. J.

Food Chemistry 2011: *124(4), 1681-1689*



Food Chemistry 129 (2011) 1681–1689

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Effect of actinidin from kiwifruit (*Actinidia deliciosa* cv. Hayward) on the digestion of food proteins determined in the growing rat

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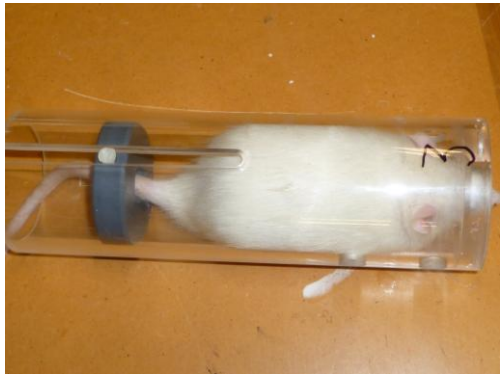
ABSTRACT

This study aimed to determine the effect of dietary actinidin (provided as Hayward kiwifruit) on the gastric and small intestine digestion of six food protein sources in rats. For each protein source, two semi-synthetic test diets were formulated containing either freeze-dried Hayward kiwifruit (actinidin present) or freeze-dried Hort16A kiwifruit (actinidin absent). Actinidin activity is extremely low in Hort16A kiwifruit. Titanium dioxide was also included as an indigestible marker. Rats were fed freshly-prepared diets, euthanised and the gastric and ileal contents collected. The chyme and digesta samples were subjected to electrophoresis (SDS-PAGE), densitometry and titanium analysis and the degradability of individual proteins calculated. Dietary actinidin had no ($p > 0.05$) effect on the gastric degradability of zein and whey protein isolate but increased gastric degradability of beef muscle protein, gelatin, soy protein isolate and gluten by 40%, 60%, 27% and 29% units, respectively. Dietary actinidin had little or no effect on ileal protein degradability. Overall, dietary actinidin enhanced the gastric digestion of some food proteins.

Improving Digestion II
In vivo Study



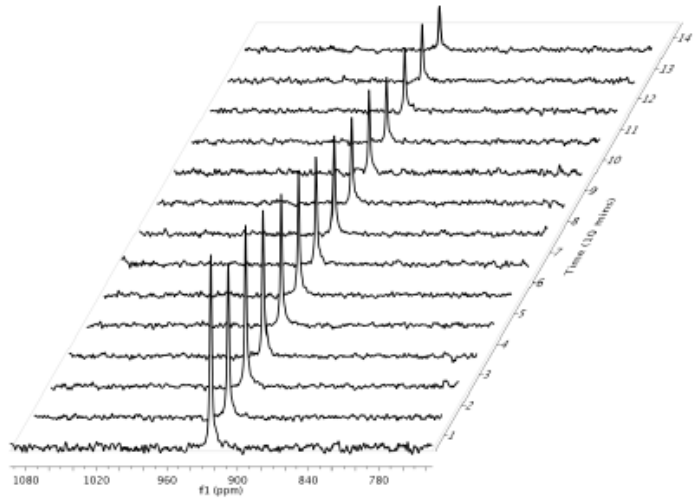
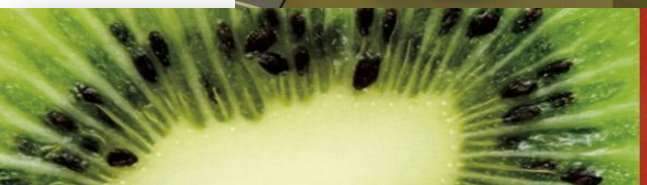


Figure 8 The ^{27}Al peak in the stomach chyme of a selected rat fed a beef muscle-based diet supplemented with Hayward kiwifruit determined using MRS.

Using an NMR ^{27}Al isotope model the gastric emptying rates (GER) were measured *in vivo*

- beef muscle
- soy protein
- wheat proteins



Improving Digestion II
In vivo Study

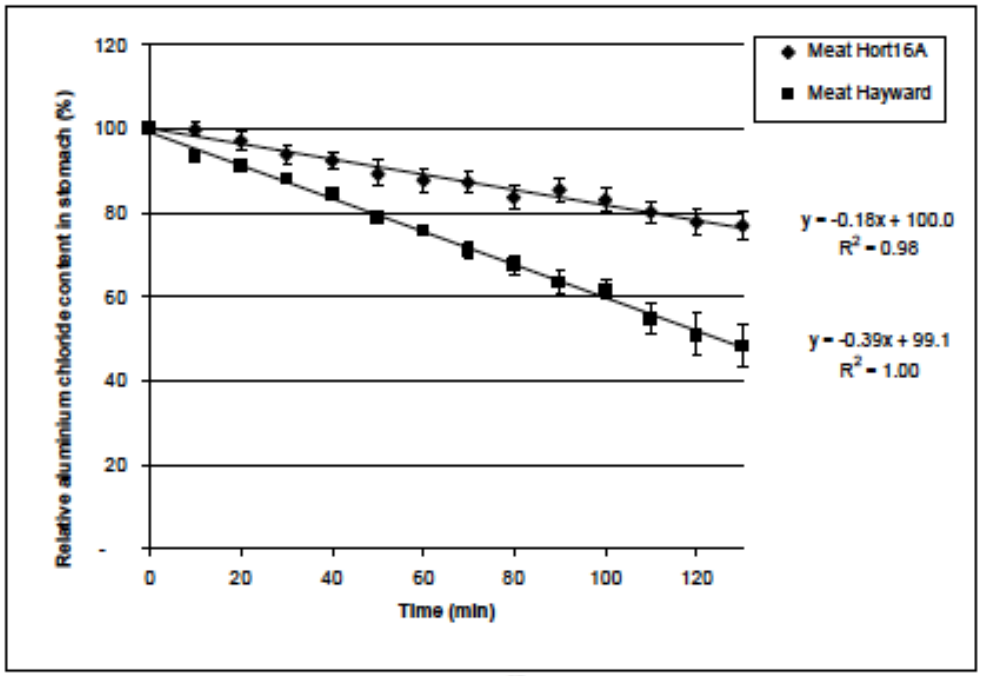
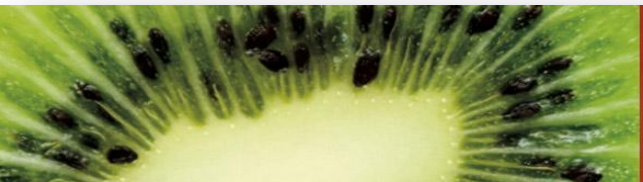


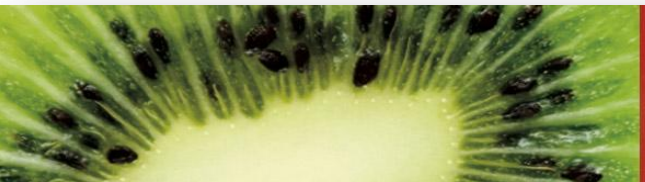
Figure 11. Mean (±SEM) relative gastric ^{27}Al content of rats fed the beef muscle protein-based diets supplemented with either Hort16A kiwifruit or Hayward kiwifruit.
The equation for the regression line for each protein source is shown next to the regression line. The absolute slope is the stomach emptying rate (units are % ^{27}Al per min).
n=6 for the both beef muscle protein-based diets.

The green kiwi (actinidin) diet increased the GER significantly



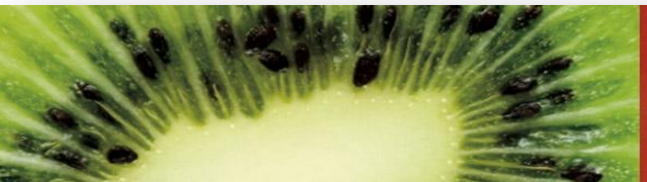
Improving Digestion II
In vivo Study

- *In vivo* study demonstrated 2 mechanisms of green kiwi associated with improved digestion
  - Enhanced protein breakdown
    - *Stomach*
    - *Small intestine*
  - Increased gastric emptying rate



Does actinidin affect the digestion of other dietary food proteins?

- Using the 2-stage *in vitro* model we studied a range of typical dietary proteins:
  - **Fish (Hoki & tuna)**
  - **Chicken**
  - **Yoghurt**
  - **Cottage cheese**
  - Egg
  - Pork
  - Tofu/bean curd
- Actinidin consistently enhanced protein digestion



Constipation – a common GI motility disorder

- Prevalence rates vary around the world (4-28%)
  - Most recent reviews estimate 12%-19%
  - More prevalent in women and older adults
- Decreases health-related quality of life in otherwise healthy people & those with other disease conditions
  - Often is unreported
- Significant financial burden in health costs
  - Estimates in the US suggest
    - constipation is the cause of 2.5million physician visits annually & >USD400million for laxatives
    - USD2752 per patient treated

Constipation Therapies

- Diet & lifestyle
- Laxatives
  - Bulk forming e.g. psyllium
  - Emolients e.g. mineral oil
  - Osmotic agents e.g. salts and lactulose
  - Stimulants e.g. anthraquinones
- Serotonergic agents
  - 5-HT4 receptor agonists
- Chloride channel activators

Is there a possible food solution?

- Diet & lifestyle
- Total dietary modification
  - Can be difficult
- Simple addition of a fruit to the diet
  - May offer a realistic option

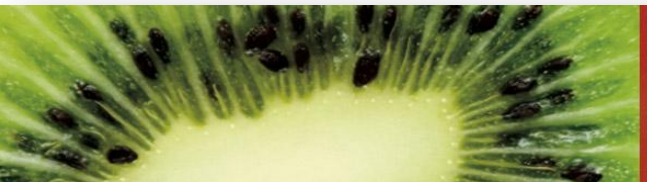
Anecdotal evidence for the effectiveness of kiwi

Kiwi & Laxation in the Elderly (NZ)

- Cross-over design (1 week baseline, 3 weeks per period)
- N=38 (13 men & 25 women) >60 years
- 1 kiwi per 30kg body weight (2-3 kiwi)
- Daily diaries included measures of
  - Frequency of defaecation
  - Stool consistency
  - Stool volume
  - Ease of defaecation

- Significant improvements in all measures

Rush, E. C., Patel, M., Plank, L. D., & Ferguson, L. R. (2002). Kiwifruit promotes laxation in the elderly. *Asia Pacific Journal of Clinical Nutrition, 11(2), 164-168.*

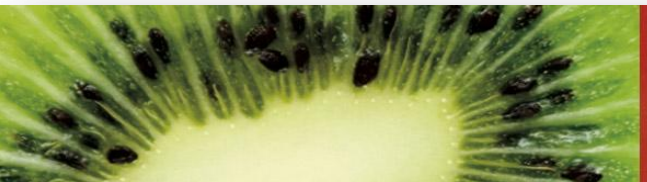


Kiwi Relieve Constipation in Chinese Patients (Hong Kong)

- Case control trial (2 week baseline, 4 week intervention)
- N = 53 (33 constipated 20 healthy)
- 2 kiwi per day (1 morning, 1 evening)
- Measures of frequency (CSBM), stool form (Bristol Stoll Scale), straining, bothersomeness, satisfaction of bowel habit & laxative use
- Measures of anorectal physiology (transit time, sensation etc)

- Significant changes in bothersomeness, satisfaction, laxative use & several measures of anoretal physiology in constipated patients

Chan, A. O. O., Leung, G., Tong, T., & Wong, N. Y. H. (2007). Increasing dietary fiber intake in terms of kiwifruit improves constipation in Chinese patients. *World Journal of Gastroenterology, 13(35), 4771-4775.*.

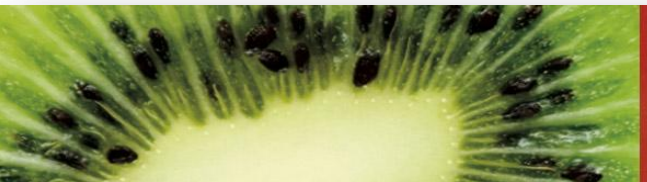


The Effect of Consuming Kiwis on Constipation in Adults (EU)

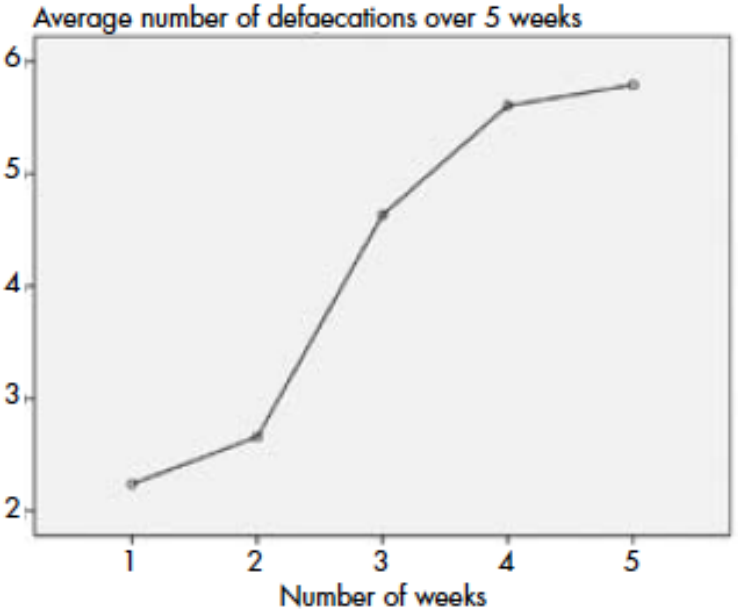
- Repeated measures (baseline 2 weeks, kiwi intervention 3 weeks (3 kiwi per day))
- N= 38 (20-70 years) constipated patients (Rome III criteria)
- Daily dairies for 5 weeks
  - Stool frequency
  - Stool consistency (Bristol Stool Scale)
  - Stool volume
  - Ease of defaecation
  - Use of laxatives
  - Food habits

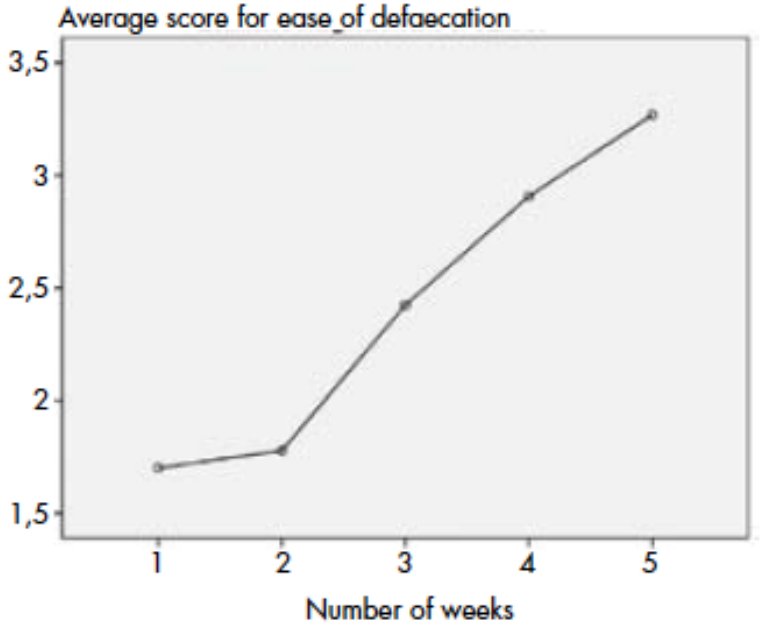
- Weekly evaluation of satisfaction over the week

Prof. M. Hiele (Gastroenterology Dept., Catholic University of Leuven, Belgium)



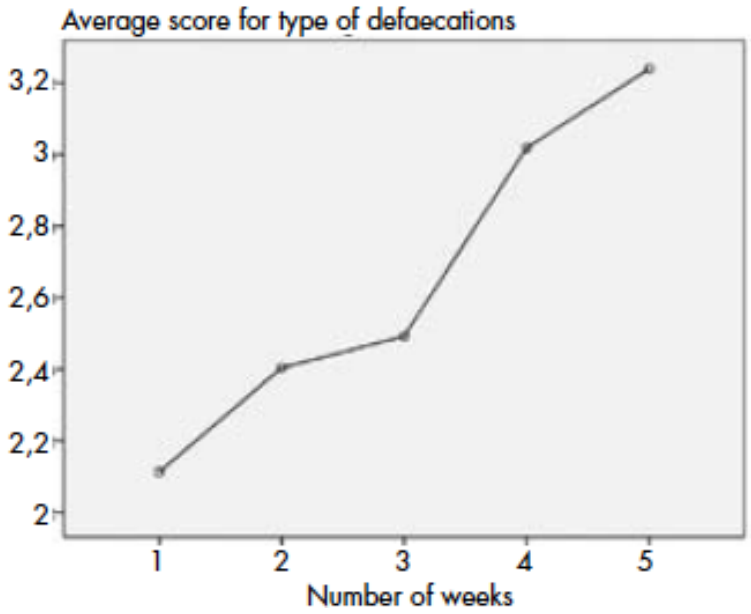
Changes in Bowel Habits

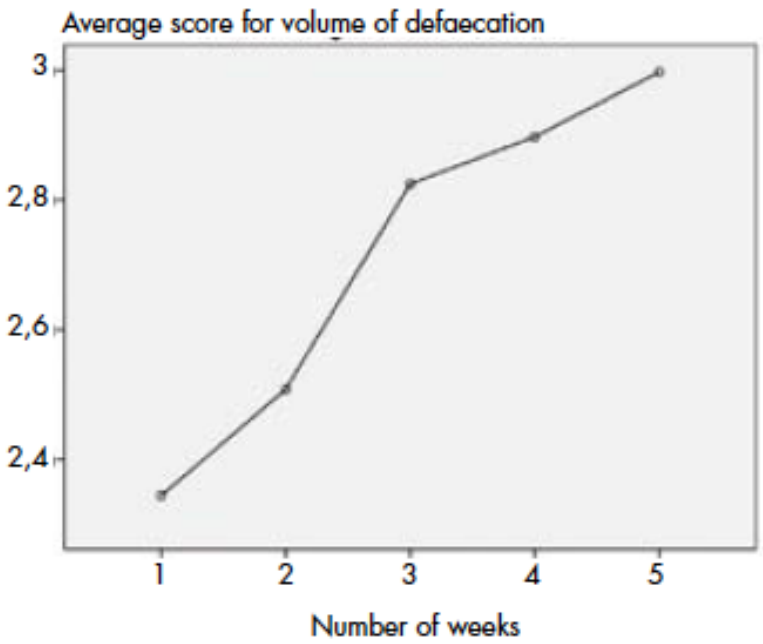




Significant improvements in both stool frequency and ease of daefaction following consumption of kiwi

Changes in Stool Characteristics





Significant improvements in both stool consistency and volume following consumption of kiwi

Conclusions

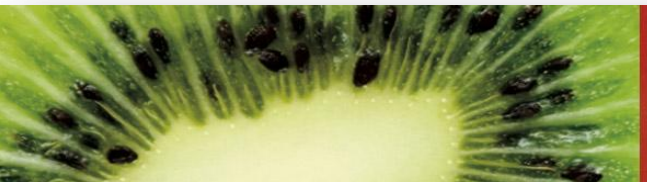
- Chronic constipation may be relieved by consuming 3 kiwi per day
- Other findings:
  - Patients reported a significant reduction in the bloated feeling after consumption of kiwi began
  - Patient satisfaction scores improved significantly with consumption of kiwi
  - No effect of age, gender or BMI was observed
  - Improvements continued to be recorded over the period of kiwi consumption

Potential Mode of Action of Kiwi in Constipated Patients

- The fibre in kiwi has an important role as
  - A faecal bulking agent
    - Water-holding capacity
    - Swelling
  - Viscosity effects may enhance laxation
- However the fibre alone does not account for the observed laxative effects
- Kiwi enzymes may enhance transit times
- Other components in kiwi may have effects on mucosa and GI motility

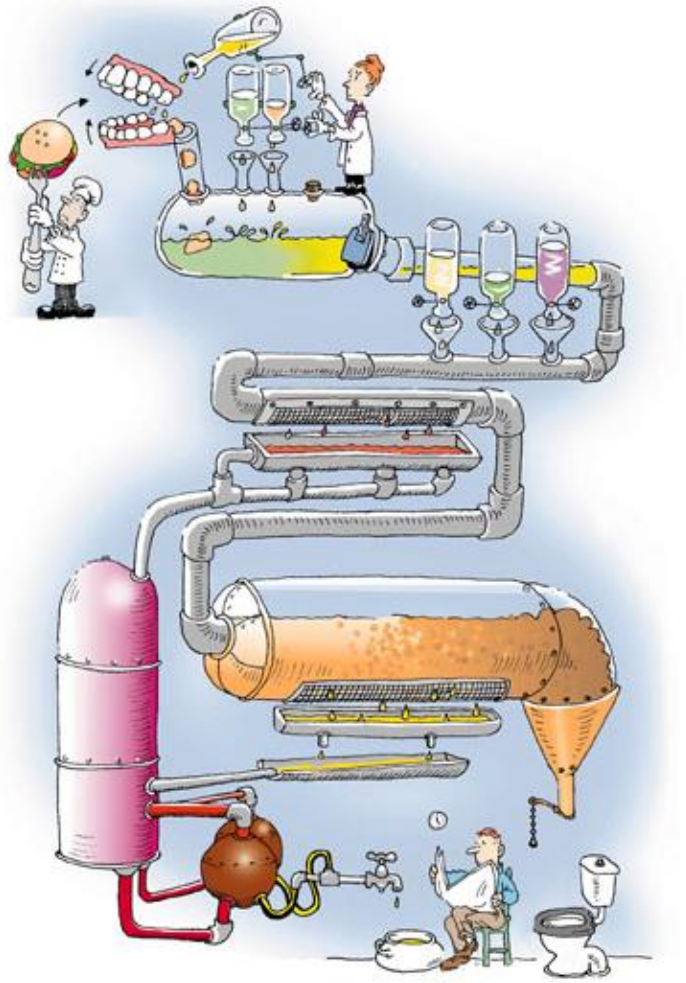
What does all this mean?

- Kiwi are a natural digestive aid
  - They are the digestion fruit
    - Suitable for healthy individuals to promote digestion & gut health benefits
    - Suitable for those with digestive dysfunction



Kiwi are effective throughout the GI tract

- Multifunctional effects for various digestive functions
  - Protein digestion
  - Fibre digestion & effects
  - Motility / regularity
- Multiple targets within the GI tract
  - Stomach
  - Intestines
  - Colon



November 10

Thank you

Discussion