Nutritional water productivity

An emerging approach for tackling malnutrition in South Africa

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What is malnutrition?

Malnutrition indicates a poor nutritional status.

Nutritional status is the physiological state of an individual, which results from:

• the relationship between nutrient intake and requirements, and

• the body’s ability to digest, absorb and use these nutrients.
Distinguish between malnutrition and under-nutrition:

**Malnutrition**
- deficiencies or excesses of specific nutrients, or
- diets lacking diversity (wrong kinds or proportions of foods).

**Under-nutrition**
- the outcome of insufficient food. caused primarily by an inadequate intake of energy from food.
In SA, and other developing countries, under- and over-nutrition occur simultaneously.

- **Over-nutrition**
- **Under-nutrition**
Micro-nutrient malnutrition

• Called “hidden hunger”, as effects often unnoticed for a long time.

• *Vitamin A, iron* and *zinc* are the core micronutrients of concern.

• Multiple signs are associated with hidden hunger:
  o *Vitamin A* deficiency may present as eye lesions.
  o Fatigue is typical of *iron* deficiency.
  o *Zinc* deficiency may result in skin changes.
Nutritional problems of South Africans can be summarised in terms of the following:

1. Energy and macronutrient (protein) status
2. Micronutrient malnutrition
3. Dietary diversity
4. Nutrient density
FOOD for Health

A healthy diet is:

- **Balanced** (in line with Food Based Dietary Guidelines).
- **Varied** (different foods are consumed from the various food groups).
- **Moderate** (to prevent over-nutrition).
Energy and macronutrient (protein) status

Energy:

• *Children*: Overall intakes are inadequate, but at the same time childhood obesity is increasing.
• *Adults*: Obesity common among women in rural areas.

Protein:

• Overall intakes adequate, but biological value (of mainly plant source protein) may be of concern.
Micro-nutrient status

Among 1-9 year old SA children:

- 64% have low serum retinol levels (low vit A status)
- 45% have low zinc status
- 28% are anaemic and 13 % have poor iron status.

Thus hidden hunger is a major cause of concern.

Source: National Food Consumption Survey – Fortification Baseline 2005
Dietary diversity

- Overall South Africans consume monotonous diets: their diets lack diversity
- Intake of fruit and vegetables is low
Nutrient density

• Nutrient density refers to amount of (micro)-nutrients relative to energy content (or volume) of the diet or of a food.

• Porridge (from maize meal) and bread are staples for many South Africans. Both have low micronutrient density.
Nutritional status is influenced by multiple and interrelated factors.

Poverty is the root cause of malnutrition.

In South Africa people in rural areas most affected.
Foods rich in PROTEIN

Animal source foods:
• Lean meat (mutton, goat, beef, pork)
• Poultry
• Eggs
• Milk
• Fish

Plant source foods:
• Legumes (dry beans, split peas, cowpeas, soya, groundnuts)
Foods rich in VITAMIN A

Animal source foods:
Lean meat, Poultry, Eggs
Milk and Fish

Plant source foods:
(contain pro-vit A, converted in human body to vit A)
Good sources include:
Yellow/orange vegetables
Dark green leafy vegetables
Yellow/orange fruit (excl citrus)
Foods rich in IRON

Animal source foods:
- Lean meat (mutton, goat, beef, pork, darker flesher cuts of poultry)
- Organ meat
- Egg yolks

Plant source foods - Fe not as bio-available as for animal sources:
- Dark green leafy vegetables
Foods rich in ZINC

Animal source foods such as:
  • Lean meat (mutton, goat, beef, pork, poultry)
  • Eggs

Plant source foods limited to:
  • Legumes, nuts and seeds
  • Whole grains
Human nutritionists / Crop scientists

Clearly an important topic
Can make a big contribution if we better nourish our people
Macro/micro-nutrient concentrations of unprocessed foods of importance in the diet of rural poor
Variation in nutritional value
Moisture %
Nutrients
Crop science – N, P, K etc
Human nutrition – Protein, energy, fat
WATER in food production

Water is essential for the agricultural production of plant and animal-source foods.
WATER in crop production

Crop water productivity - yield relative to water used to produce it

Water from rainfall – *green water*

Irrigation from surface or groundwater – *blue water*

Units: kg crop per m$^3$ or kg ha$^{-1}$ mm$^{-1}$
SOIL WATER BALANCE

\[ \Delta PAW = P + I - R - D - E - T \]

- Precipitation (P)
- interception (E)
- Transpiration (T)
- Runoff (R)
- Irrigation (I)
- Evaporation (E)
- Infiltration
- Change in Plant Available Water
- Roots
- Drainage (D)
Water productivity is influenced by multiple and interrelated factors.

**CLIMATE**

- Radiation
- Wind speed
- Temperature
- VPD
CROP factors affecting WP

• Photosynthetic mechanism - C3, C4 or CAM
• Harvest index - Fraction of DM consumed
• Composition - 1 g glucose →
  
  0.86 g cellulose / starch
  0.45 g protein
  0.36 g lipids (fats)

• Other factors limiting growth
  
  Nutrient deficiencies, plant diseases, weed and insect control, soil cultivation etc.
A general ranking of WUE of food crop types from most to least efficient:

1. from vegetables
2. to fruits
3. then to cereals,
4. oil crops and
5. lastly legumes.
Fresh and dry mass water productivities

![Graph showing WUE (kg ha\(^{-1}\) mm\(^{-1}\)) for various crops including Vegetables, Fruit, Cereals, and Legumes.]
<table>
<thead>
<tr>
<th>Product</th>
<th>Yield*</th>
<th>Water use</th>
<th>WUE*</th>
<th>Source</th>
<th>Locality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>t ha(^{-1})</td>
<td>mm</td>
<td>kg ha(^{-1})</td>
<td>mm(^{-1})</td>
<td></td>
</tr>
<tr>
<td>Butternut</td>
<td>16.4</td>
<td>370</td>
<td>44.3</td>
<td>Fanadzo (2009)</td>
<td>Fort Hare, SA</td>
</tr>
<tr>
<td>Carrots</td>
<td>67.4 - 103.6</td>
<td>-</td>
<td>19.4 - 28.3</td>
<td>Quezada et al. (2011)</td>
<td>Chile</td>
</tr>
<tr>
<td></td>
<td>57.6</td>
<td>390</td>
<td>148</td>
<td>Annandale &amp; Jovanovic (1999a; 1999b)</td>
<td>Roodeplaat, SA</td>
</tr>
<tr>
<td></td>
<td>30.3-64.7</td>
<td>201-493</td>
<td>131-148</td>
<td>Nortje (1988)</td>
<td>South Africa</td>
</tr>
<tr>
<td>Sweet potato</td>
<td>10.8-25.8</td>
<td>500</td>
<td>21.6 - 51.6</td>
<td>Beletse et al. (2011)</td>
<td>Roodeplaat</td>
</tr>
<tr>
<td></td>
<td>13-47</td>
<td>182-1400</td>
<td>33.4 - 71.1</td>
<td>Laurie et al. (2009)</td>
<td>South Africa</td>
</tr>
<tr>
<td></td>
<td>20.1-34.2</td>
<td>350-850</td>
<td>42.8 - 57.4</td>
<td>Gomes and Carr (2003)</td>
<td>Mozambique</td>
</tr>
<tr>
<td></td>
<td>40 - 55</td>
<td>400-500</td>
<td>70 - 130</td>
<td>Bok et al. (2000)</td>
<td>South Africa</td>
</tr>
<tr>
<td>Pumpkin</td>
<td>36 – 43</td>
<td>162</td>
<td>222 - 266</td>
<td>Zotarelli et al. (2008)</td>
<td>Florida, USA</td>
</tr>
</tbody>
</table>
WATER in livestock production

Animal-source foods - negligible amount used for drinking
Most used for production of feed
(considerations on plant water productivity apply)
Processing carcasses also depletes water.
Animal-source products are less water efficient than crop products.

Ranking from highest to lowest water productivity:

- Most productive: from milk and eggs, to chicken and pork, to small stock (sheep/goats), and lastly to beef.
Animal food products - WP

The diagram shows the amount of water (in kg product per m³ water) required for various animal food products. The products listed are Milk, Eggs, Chicken, Goat meat, Pork, Sheep, and Beef. Milk requires the highest amount of water, while Sheep and Beef require the least.
What is nutritional water productivity?

• This novel concept combines knowledge of the composition of foods in terms of nutrients (e.g. protein or vit A content) with knowledge of the water productivity of the food product.

• The result is an index for a given food which includes nutrient-based output per unit water use

• An example is μg β-carotene in spinach per m³ water used to produce this food.
A water productivity of 5.2 kg m\(^{-3}\) is reported from a study on sweet potato. Sweet potato has a nutrient content of:

- Energy: 4.5 MJ kg\(^{-1}\)
- Protein: 17 g kg\(^{-1}\)

Nutritional water productivity would thus be:

- Energy: 23.4 MJ m\(^{-3}\)
- Protein: 88 g m\(^{-3}\)

→ Per m\(^3\) water used, sweet potatoes yield 23.4 MJ of energy and 88 g protein.
Macro-nutrient WP - protein

Protein

mg kg\(^{-1}\)/g m\(^{-3}\)

NWP
Content

Beef  Eggs  Poultry  Cabbage  Carrots  Potatoes  Apple  Orange  Watermelon  Green beans  Groundnut  Soybean  Maize

Animal  Vegetables  Fruit  Legumes  Cereals
## Macro-nutrient NWP

<table>
<thead>
<tr>
<th>Product type</th>
<th>Energy (MJ m(^{-3}))</th>
<th>Protein (g m(^{-3}))</th>
<th>Fats (g m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal products</td>
<td>0.5-3.1</td>
<td>12-60</td>
<td>4-70</td>
</tr>
<tr>
<td>DGLV</td>
<td>1.1-32</td>
<td>17-608</td>
<td>1.9-76</td>
</tr>
<tr>
<td>Yellow or orange vegetables</td>
<td>5.3-24</td>
<td>35-152</td>
<td>2-19</td>
</tr>
<tr>
<td>Other vegetables</td>
<td>0.36-17</td>
<td>3-185</td>
<td>0.35-12</td>
</tr>
<tr>
<td>Fruit</td>
<td>9.2-15</td>
<td>31-42</td>
<td>5-10</td>
</tr>
<tr>
<td>Legumes</td>
<td>2.7-11</td>
<td>4.6-177</td>
<td>1-212</td>
</tr>
<tr>
<td>Grains</td>
<td>17.3</td>
<td>132</td>
<td>50</td>
</tr>
</tbody>
</table>
Micro-nutrient productivity - Zinc

Nutrient content

NWP
Micro-nutrient productivity - Fe

Nutrient content

NWP

Animal  Vegetables  Fruit  Legumes  Cereals

Beef  Pork  Chicken  Carrot  Pumpkin  Amaranthus  Apricot  Mango  Melon  Groundnuts  Peas, split  Soybeans, dried  Maize
Micro-nutrient productivity – Vit A

<table>
<thead>
<tr>
<th>Green leafy</th>
<th>Orange/yellow vegetables</th>
<th>Fruit</th>
<th>Legumes</th>
<th>Cereals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spinach</td>
<td>Swiss chard</td>
<td>Mango</td>
<td>Lentils</td>
<td>Maize</td>
</tr>
<tr>
<td>Of sweet potato</td>
<td>Pumpkin</td>
<td>Melon</td>
<td>Soybeans, dried</td>
<td></td>
</tr>
<tr>
<td>Pumpkin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melon</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lentils</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soybeans, dried</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## NWP – Fe and Vitamin A

<table>
<thead>
<tr>
<th>Product type</th>
<th>Iron (mg m(^{-3}))</th>
<th>Vitamin A (mg Re m(^{-3}))</th>
<th>β-carotene (mg m(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal products</td>
<td>1.3-18</td>
<td>0.01-1.3</td>
<td>0</td>
</tr>
<tr>
<td>Dark Green Leafy Vegetables</td>
<td>7.6-316</td>
<td>0.17-37</td>
<td>0.95-221</td>
</tr>
<tr>
<td>Yellow / orange vegetables</td>
<td>9-84</td>
<td>3-46</td>
<td>12-2226</td>
</tr>
<tr>
<td>Other vegetables</td>
<td>3-317</td>
<td>0.1-59</td>
<td>5-351</td>
</tr>
<tr>
<td>Fruits</td>
<td>10-21</td>
<td>0.5-6.1</td>
<td>2-37</td>
</tr>
<tr>
<td>Legumes</td>
<td>12-40</td>
<td>0.01-0.11</td>
<td>-</td>
</tr>
<tr>
<td>Grains</td>
<td>21</td>
<td>1.1</td>
<td>0</td>
</tr>
</tbody>
</table>
NWP can *promote production of nutritious foods* to help close nutrient gaps of vulnerable South Africans while, simultaneously, leaving a sustainable water footprint.

The concept of NWP must be *embedded in an understanding of eating habits* of the vulnerable groups targeted.

*Variety, balance* and *moderation* remain the pillars of healthy eating.
Reliable “water footprint” data is lacking for important food crops

Estimates of **NWP** should be made with a **single reliable data set** – so crop scientists measuring water balances and doing growth analyses of nutritionally important crops are encouraged to also **determine nutrient contents**

Need to **benchmark potential WUE’s and NWP’s** so we can identify limiting factors and strive for more efficient production
Acknowledgements

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Macro-nutrient WP - energy

The graph illustrates the energy content in kcal kg\(^{-1}\) of various food items, categorized into Animal, Vegetables, Fruit, Legumes, and Cereals. The chart uses blue bars for NWP and purple bars for content.
References


WATER in livestock production

Water inflows into the system are precipitation, surface water and groundwater. Water is used for biomass production, servicing and processing. Animal outputs are meat, milk, hides, manure, and wealth (Peden et al., 2009).
Example 2: Spinach

The water productivity of spinach is 3.2 kg / m³

Spinach has the following nutrient content per kg
   Energy: 1.3 MJ
   Protein: 27 g

The nutritional water productivity would thus be
   Energy: 4.1 MJ/m³
   Protein: 86 g/m³

→ Spinach yields 4.1 MJ of energy and 86 g of protein per cubic meter of water used.