SEPARATE PRINT 58

Plant Research and Development

A Biannual Collection
of Recent German Contributions Concerning
Development through Plant Research

Volume 3

Edited in Conjunction with
Numerous Members of German Universities
and Research Institutions by the
Institute for Scientific Co-operation

THE NUTRITIVE VALUE OF PLANT PRODUCTS AND THE USE OF FERTILIZERS

by

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The quality of plant products is determined by the purpose for which they are used. The intelligent and controlled use of mineral fertilizers can increase yields, i. e. produce more ear-bearing stalks per sq. m and more fully formed grains per ear. The amount of valuable components can also be increased, thus improving the quality. In the final analysis these ingredients determine the nutritive value or nutritional/physiological quality of a plant product.

The ingredients of plants are of varying importance for human nutrition. They can, for example, be energy suppliers (chiefly carbohydrates and fats) or essential nutrients (e. g. certain amino acids, unsaturated fatty acids, vitamins) on which the body relies as it cannot synthesize them itself. An adequate supply of certain minerals or trace elements is also vital for the electrolytic functioning of the body.

While the pattern or formation plan of these ingredients in plants is largely determined genetically, their proportions can be altered to a greater or smaller extent by many factors, e. g. plant variety, climate, soil fertility, growing and harvesting methods, etc. These factors also include mineral fertilizers, which are particularly advantageous in that they can be used according to need. It is true that it is precisely this possibility which has given rise to the generally unjustified objection to mineral fertilizers on the grounds that they are used just to make money. In some places, this indispensable aid to production has even been stamped as a biocide.

The present contribution was given as a speech in September 1973 during the annual meeting of the Association of German Agricultural Experiment and Research Stations in Regensburg.

It would be totally mistaking matters and greatly over-estimating the possibilities of mineral fertilizers to believe that such measures – however extreme – could suddenly produce in cultivated plants anything other than genetically predetermined substances or even substances damaging to health. However, the proportion of ingredients which increase nutritive value (e. g. certain proteins, vitamins, etc.) and reduce nutritive value (crude fibre content, nitrate, oxalic acid, etc.) can be favourably influenced by the moderate use of fertilizers. The danger of causing a deterioration in nutritive value as a result of breakdowns or the careless use of fertilizers is very slight. In any case, most of our soils have a high buffering and filtering capacity which, partly without realizing it, and partly on purpose, we often make use of to carelessly pollute the environment.

Actual nutritive value is, however, not only the result of various production factors and conditions (for it is very seldom that food is consumed directly out of the field or garden) but is often greatly impaired in transit, by storage, preservation measures, preparation and cooking. As a rule, substances just containing calories (such as starch, sugar, etc.) hardly suffer any loss of quality, whereas biotic ingredients, such as vitamins (e. g. B complex, vitamin C), certain important minerals (Ca, Fe, etc.) and essential amino acids and unsaturated fatty acids, are very seriously affected.

The following paragraphs attempt to quantify these factors affecting nutritive value by means of some examples and to show the results of various experiments.

Bread-making cereals: Wheat

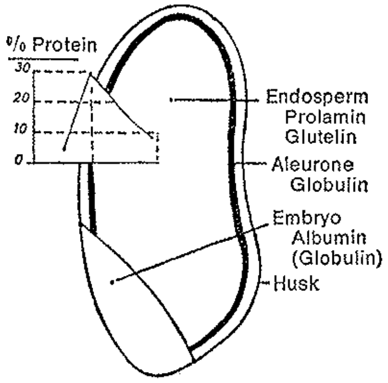
The wheat grain consists of 69 % carbohydrates, 12 % protein and 2 % ash (Table 1).

Vitamin E and the B complex vitamins as well as the minerals Ca, Fe, Zn, and Na are important.

Table 1 – *Breakdown of the wheat grain (according to Souci/Fachmann/Kraut)*

Main ingredients	ϕ %	Vitamins	ppm	Minerals	ppm
Carbohydrates	69.3	Carotene	2.3	Ca	437
Protein	11.7	Vitamin E	32	Fe	33
Fats	2.0	Vitamin B complex	73	Zn	100
Minerals	1.8			Na	78
				K	5000
				Mg	1700

The *starch* is pure energy and – topographically speaking – is distributed over the whole endosperm from the aleurone layer inwards. The *protein*, however, is present in various forms or – methodically speaking – fractions, whose topographical distribution within the grain and biological value vary greatly (Fig. 1).



Weight %	Protein content %	% of total protein	Lysine content %
82	8–14	– 75	0.8 2.4
7	30	– 13	3.4
3	26	– 6	6
8	– 10 (5–20)	– 6	

Figure 1 – *Protein distribution in the wheat grain (according to G. Michael)*

It can be seen from Michael's [6] diagram that the protein percentage increases from the centre outwards. There is only 8–14 % protein in the endosperm (prolamin and glutelin), although this in fact accounts for ¾ of the total protein in the grain. However, the protein content of the aleurone layer (globulin) and embryo (albumin and globulin) amounts to 26–30 %, even though it makes up scarcely 20 % of the total protein content. Then there is the husk which is 6 % protein.

The *minerals* are found mainly in the husk and vitamins B and E chiefly in the embryo.

Optimum growing and fertilizing methods produce an equally increasing grain formation and starch storage. It is well known that the protein content can be considerably increased (by about 2–4 %) by the proper use of nitrogenous fertilizers (above all late fertilizing). However, this mainly increases the reserve proteins, glutelin and prolamin, as Ewald [1] shows (Fig. 2). Glutelin and particularly prolamin are, however, of little value from the nutritional/physiological point of view. The limiting amino acid here is mainly the lysine, which amounts to 0.8–2.4 % in the endosperm and 3.4–6 % in the aleurone layer and embryo (see Fig. 1).

Cereal protein, therefore, is made up chiefly of endosperm protein which is not biologically complete and requires supplementing in the diet either

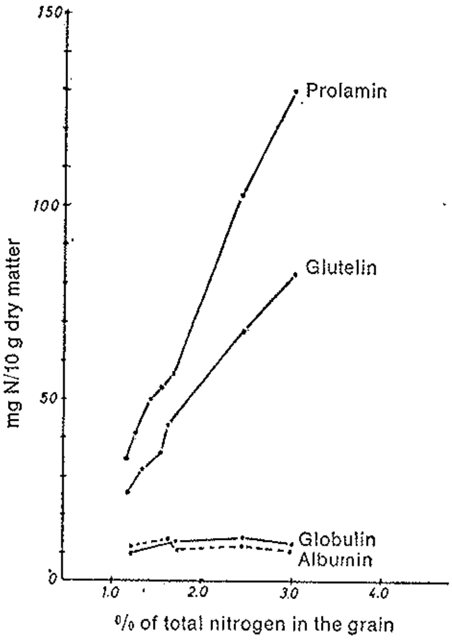


Figure 2 – *Nitrogen fractions in the wheat grain (Heines Koga variety) in relation to the overall nitrogen content (according to Ewald)*

by relatively high value vegetable protein or by animal protein (milk, meat, fish, etc.).

Cereal products also provide an important source of complex B vitamins, the percentage of which can be considerably improved by the heavy use of nitrogen (Table 2), as Pfuetzer and collaborators [8] show.

Let us assume that a farmer has applied his mineral fertilizer according

Table 2 – *The effect of nitrogenous fertilizers on the vitamin* B_1 *content of oat grain (according to Pfuetzer/Pfaff/Roth)*

Fertilizer (g N/sample)	Yield g dry matter/sample	Crude protein % in dry matter	Vitamin B_1 ppm in dry matter
without N	7	9.5	2.5
0.2	16	7.6	2.8
0.5	32	7.3	3.3
1.2	51	8.9	4.4
1.7	60	10.7	5.1
2.4	59	13.3	6.5

to the most up-to-date scientific knowledge and, as a result, produced wheat grain with the highest possible percentage of nutritive ingredients. The grain is then milled and processed, for example, either into whole wheat meal or into the usual 550 or 405 type meals. The current per caput consumption of wheat meal amounts on average to about 140 g per day. This, however, varies in nutritional/physiological value according to the degree of milling, as Menden [5] shows (Table 3).

Table 3 – *Bread quality – nutritional/physiological value*

	Ingredients in 140 g of wheat			% of daily requirement	
	Whole wheat	Meal type 550	Meal type 405	Whole wheat	Meal type 405
Protein	16 g	15 g	15 g	23	20
Calcium	61 mg	22 mg	21 mg	8	3
Iron	4.6	2.0	2.0	46	20
Thiamine	0.7	0.2	0.08	56	6
Riboflavin	0.2	0.1	0.04	12	2
Niacin	7.2	0.7	1.0	38	5
Calories	508	518	515	20	20

While whole wheat meal and the 550 and 405 meal types have roughly the same calorie content, there is 10–15 % less protein in the latter. It is, however, mainly the biologically valuable albumin and globulin contained in the outer parts of the grain which are lost and which it is extraordinarily difficult to improve by the use of fertilizers. In addition, there are calcium, iron, thiamine and riboflavin losses of 50–65 % and a niacin loss of as much as 90 %.

The actual nutritive value of bread is, therefore, not determined by the farmer but by the consumer depending on whether he prefers brown bread, which is of high biological value, or eats white bread and leaves the biologically valuable ingredients of the embryo and husk as bran for good cattle feeding.

Potatoes

Figure 3 shows the components of the potato and their topographical distribution.

The potato is known to have a high water content. Starch accounts for by far the largest proportion of the dry matter, followed by crude protein and ash in varying amounts according to variety.

Sugar
Average content: 0.5 %
Variation range: 0.1–5.0 %

Starch
14.0 %
9.0–25.0 %

Crude fibre
0.7 %
0.4–1.0 %

Amino acids
Average content: 0.8 %
Variation range: 0.7–1.2 %

Organic acids
Average content: 2.0 %
Variation range: 1.0–3.0 %

Rose end
Vascular system in pith
Eye
Cortex layer with vascular system
Cortex cells
Husk (Epidermis)
Ring of vascular bundles (Phloem, xylem)
Pith layer
Heel end
Anatomical structure of the potato
(Longitudinal section)

Protein
2.0 %
1.2–2.5 %

Fats
0.2 %
0.1–0.4 %

Minerals and trace elements
Average content: 0.6 %
Variation range: 0.3–1.0 %

Vitamins
0.02 %
0.004–0.03 %

Enzymes, growth substances … and solanin
% difficult to determine

Contents in % of the fresh matter

Figure 3 – *Distribution of the ingredients determining the quality of the potato tuber (according to K. Mueller)*

As Mueller's diagram shows, the starch is found mainly at the centre of the potato tuber. The biologically valuable ingredients, on the other hand, such as free amino acids, protein, minerals and lipides, are found in more or less large amounts on the outside or round the vascular bundle zone.

3/4 of potato protein consists of tuberin (Table 4), which is an easily soluble, biologically valuable globulin (with a value ratio of approx. 90 : 100 compared with egg protein) and some albumin. The percentage of biologically low value reserve proteins amounts in total to only about 7–8 %.

Table 4 – *Analysis of the protein in the "Ella" potato variety (according to Lindner/Jaschik/Korpaczy)*

Tuberin (easily soluble globulin)	76.4 %
Globulin II (not easily soluble)	1.4 %
Albumin	4.0 %
Prolamin	1.8 %
Glutelin	5.5 %

Amongst the essential amino acids in potato protein, the lysine content, which amounts to about 10 % of the total amino acid content (Table 5), is strikingly high compared with other equally important amino acids from the biological point of view, such as tryptophan, alanin, arginin, methionin, prolin, etc.

Table 5 – *Essential amino acids in potato protein*

Author	Lindner & collab.	Mulder & Bakema	Hegsted	Hughes	Reissig	Schuphan & Postel
	g/100 g protein				g/100 g crude protein	
Valine	5.60	6.7	5.34	8.0	6.38	5.4
Leucine	9.87	16.5	4.98	11.1	10.68	6.2
Isoleucine	2.52	—	4.38	6.8	10.68	7.0
Phenylalanine	4.80	5.2	4.42	6.2	4.35	4.4
Tryptophan	1.85	1.9	1.07	1.8	1.13	1.4
Threonine	6.50	6.2	3.94	5.7	3.59	4.0
Methionine	1.95	2.4	1.25	2.8	2.01	1.6
Lysine	10.05	4.2	5.33	8.3	5.00	6.0

Potato protein, therefore, is an ideal supplement to cereal protein and, with a ratio of $^2/_3$ potato protein : $^1/_3$ animal protein, it has a better utilization than egg protein, as Kofranyi [3] has recently shown.

In addition, the potato has a considerable mineral and vitamin content. The daily requirement of Ca, P, Fe, vitamin $B_1 + B_2$, nicotinic acid and, above all, vitamin C can be covered to a considerable extent, depending on the amount of potato consumed. Apart from just providing calories, therefore, the potato is an important source of minerals and vitamins.

Now what effect do mineral fertilizers have on the ingredients of the potato?

Optimum use of nitrogen, phosphate and potassium leads to larger and fuller tuber formation. Potassium increases the starch content (Table 6).

Table 6 – *The use of potassium fertilizers on potatoes (according to Baden)*

Fertilizer pure nutrients kg/ha	Tubers dt/ha	Starch (%)
PN without K_2O	144	12.4
PN + 50 K_2O	158	13.0
PN + 100 K_2O	194	13.8
PN + 150 K_2O	189	14.4
PN + 200 K_2O	217	15.1

Nitrogenous fertilizers can almost double the crude protein content (Table 7). In general, therefore, considerable quality improvements can be achieved by using fertilizers.

Let us again assume that a potato has optimum ingredients – precisely what the nutritional physiologist would wish for. What then are the ways in which the *quality is lost* up to the point when the potato is served cooked on the table?

Table 7 – *Effect of nitrogenous fertilizers on the yield and crude protein content of potatoes (according to Kaempf)*

Variety Yield Crude protein content		kg N/ha			
		0	40	80	120
Maritta:	Tubers (dt/ha)	300	365	447	441
	Crude protein (% in dry matter)	6.8	6.2	7.3	9.6
Eva:	Tubers (dt/ha)	377	489	540	545
	Crude protein (% in dry matter)	5.3	6.3	7.7	9.2
Carmen:	Tubers (dt/ha)	287	349	396	445
	Crude protein (% in dry matter)	6.2	7.3	8.4	10.1

Table 8 – *% Starch loss and sugar increase in potatoes (Heida) from November to April according to storage temperature (according to Fischnich)*

Temperature	Starch loss	Sugar increase
1 °C	50	743
4 °C	16	122
7 °C	9	5
18 °C	33	40

Variety: Heida ⌀ 1957/58 and 1958/59;
Starch and sugar content when put into store = 100

Too high or too low storage *temperatures* accelerate the breakdown of the starch and the increase in sugar content and alter the taste (Table 8). The optimum storage temperature, therefore, lies within relatively narrow limits.

Skin losses depend on the potato variety, i. e. on the shape, size, depth of the eyes, skin thickness, etc. Careful removal of the skin only causes a 2 % loss of substance, peeling with a kitchen knife on the other hand produces a 10–12 % loss and machine peeling in large kitchens a 15–40 % loss (Table 9). It is above all the outer parts which are affected, i. e. the area between the skin and the ring of vascular bundles, which means big losses of minerals (Fe, Ca, P), Vitamin B, high value protein and essential amino acids.

Table 9 – *Total losses (peeling and trimming) in % from potatoes when using various peeling methods (according to M. E. Highlands)*

Potato variety	Peeling methods Carborundum peeling method	Steam method	Leaching method	Comb. steam & leaching method
Katahdin	22	20	18	18
Kennebec	28	20	19	15
Busset Burbank	35	22	26	21

Considerable vitamin C losses also occur as a result of excessive *cooking and steaming*, ranging from 5–30 % depending on the method used and amounting to as much as 50 % in the production of fried potatoes (Table 10).

Table 10 – *Vitamin C losses resulting from various ways of preparing potatoes (Belf, 1965 Annual Report)*

Preparation method	Total vitamin C losses in % Cooking	Steaming
Peeled potatoes	32	33
Unpeeled potatoes (potatoes in their jackets)	11	13

These figures speak for themselves as they show that poor storage, preparation and cooking can destroy a lot of what has been strenuously achieved by means of the optimum use of fertilizers.

Vegetables

The *nutritional/physiological value of fruit and vegetables* to man lies not so much in their energy content as in the vitamins and minerals they provide.

However, they also have a considerable protein content, 60–80 % of which is of high nutritional/physiological value. The protein, carotene and vitamin B content can be greatly improved by using nitrogenous fertilizers (Table 11).

Table 11 – *Effect of nitrogenous fertilizers on the carotene and vitamin B content of spinach (according to Pfuetzer/Pfaff/Roth)*

Fertilizer (kg/ha)	Yield dt dry mat./ha	N °/o in dry mat.	Carotene	Vitamin B_1	Vitamin B_2
				mg/100 g dry mat.	
without N	8	2.3	32	0.08	0.6
30 N	13	3.0	43	0.09	1.0
60 N	15	4.2	51	0.15	1.5
90 N	18	4.8	53	0.38	1.95
150 N	22	5.2	58	0.39	1.83

Habben [2] recently obtained the same results with carrots. Vitamin C behaves in the same way as a result, above all, of heavy potassium treatment (Table 12), as Wolf [9] and Ott [7] have shown. The sucrose content of carrots also increases, improving both nutritive value and taste.

These and other examples show that the valuable ingredients of green and root vegetables can be considerably improved by the proper use of fertilizers. However, it is precisely these valuable ingredients from the nutritional/physiological point of view which suffer heavily from storage, preservation methods and cooking. Blanching, for example, washes out 20–25 °/o of those ingredients which dissolve in water. It is calculated that about 30–50 °/o of vitamins are generally lost in the cooking (Table 13).

It can be seen that the losses from fresh spinach, especially in large kitchens, are higher than in the case of frozen spinach. It is well known that the quality of warmed up spinach can be severely impaired as a result of bacterial nitrite formation. The best vegetable quality, therefore, can be very seriously damaged by improper storage and cooking.

Fruit

However, it is not only storage and cooking which affect nutritive value. The ingredients determining the nutritive value of the different varieties can also vary greatly.

It is currently estimated that man needs about 70–100 mg of vitamin C a day. This is the equivalent of about 2 oranges or lemons or 2 Ontario or v. Berlepsch apples, but of about 10–15 Golden Delicious or Morgenduft apples (Table 14). The vitamin C content of apples, therefore, varies greatly [Matzner, 4].

The last two varieties, however, account for by far the greatest proportion of apples consumed today in our country.

An exact knowledge of the nutritive value of plant products should not

Table 12 – *Effect of potassium fertilizers on the vitamin C content*

Potassium fertilizer	(according to Wolf) Carrots	Celery	(according to Ott) White cabbage
	Vitamin C (mg/100 g fresh substance)		
O	7.2	7.8	18
K_1	7.4	9.1	21
K_2	9.6	10.0	30

Table 13 – *Vitamin losses resulting from cooking fresh and frozen spinach (according to Cremer and collaborators)*

	% Loss Fresh Large kitchen	Small kitchen	Frozen Large kitchen	Small kitchen
Vitamin C	90	75	50	25
Vitamin B_1	57	50	30	20
Riboflavin	65	50	40	27

Table 14 – *The vitamin C content in apples (according to Matzner)*

Variety	Vitamin C mg/100 g fresh subst.	Variety	Vitamin C mg/100 g fresh subst.
Freiherr v. Berlepsch	25	Golden Delicious	7
Ontario	25	Landsberger Renette	4
Schöner von Boskoop	16	Rote Sternrenette	3
James Grieve	13	Morgenduft	4

limit the consumer's free choice. It is merely suggested that a physiologically low value foodstuff – which, however, may be no less liked for this reason – must be made up for by other high value products.

We worked on the basis that the formation of ingredients according to variety is determined genetically and that it is possible to obtain high yields and good quality, i. e. to produce products of high nutritional/physiological value, by means of the optimum use of fertilizers. We concentrated less on the energy suppliers than on the essential ingredients. Breakdowns and negligence occur everywhere as well as in the use of fertilizers. However, just as the motor industry cannot be held responsible for the traffic offences or negligence of individual drivers, fertilizer manufacturers or agricultural advisors cannot be blamed if individual farmers use fertilizers foolishly. These cases are rare but should not be ignored.

The examples given have shown that the quality of an optimum plant product, as far as composition is concerned, can be seriously affected by transport, technological processing, preparation and cooking and that these losses can often eliminate a lot of the improvements achieved by the careful use of fertilizers.

The time has come for us to go beyond the present practice of qualifying plant products according to externally visible and measurable criteria and to start assessing their nutritive value according to specific ingredients.

What conclusions arise from this study?

1. In order to guarantee our nutritional basis as well as a high nutritive value in plant products, we must continue to insist on optimum use of mineral fertilizers in accordance with scientific knowledge.
2. The consumer can exert considerable influence by considered judgement and conscious choice on the growing of high value and wholesome plant products. Such an influence, however, presupposes an accurate basic knowledge of nutrition.
3. Knowledge of these basic facts of human nutrition and the nutritional/physiological assessment of plant products is admittedly still totally insufficient in consumer circles today and must be promoted by means of systematic explanation and instruction from school age onwards.

In this way, prejudices can be overcome, wishful thinking and assumptions objectively examined in the light of scientifically incontestable facts and real progress made.

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Tübingen, Landhausstr. 18
Federal Republic of Germany

Printed by Buchdruckerei Eugen Göbel, Tübingen