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The importance of calcium in relation to phosphorus, especially in folivorous reptiles

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The green iguana (*Iguana iguana*) is being employed for this presentation because it is paradigmatic of a large, showy, intelligent (for a triune-brained reptile), rapidly growing, folivorous lizard taxon that is displayed in many zoological collections. Green iguanas are very favoured by the pet trade (approximately one million are imported into the USA annually, and nearly an equal number are imported into and distributed to the UK, continental Europe, and Asia). Even with trade, green iguanas are still relatively non-endangered over much of their range because captive breeding is often effective. Loss of habitat, however, still threatens some native populations.

Green iguanas are easy animals to husband and treat because they are relatively large and can be handled with minimal physical restraint by experienced personnel, blood samples can be readily obtained without deleterious consequences, and an ever-increasing body of data that documents the normal physiological chemistry values of both healthy and sick iguanas is being accumulated. With proper nutrition and husbandry, green iguanas grow to mature size (although not always full sexual maturity) under captive conditions in about 2–2·5 years; in the wild, adult size and sexual maturity requires an additional 1–2 years (Rodda, 1992). Nutritionally-adequate and readily-acceptable food usually can be grown locally or obtained at most greengrocers' fresh vegetable counters (an important consideration when animals are being kept in captivity). Some iguanas tolerate less than ideal diets, often sustaining only modest permanent injury if the harmful diet is corrected before skeletal growth has ceased.

Growing iguanas require a well-balanced diet that contains adequate Ca without concomitant excessive P (the reasons for this are complex), but simply stated, Ca is essential for the following physiological processes:

growth and maintenance of the skeleton and teeth;
skeletal, and smooth- and heart-muscle contractions;
nerve-impulse conduction to and from the brain and spinal cord;
blood coagulation;
cellular movements.

METABOLIC BONE DISEASE CAUSED BY EXCESSIVE PHOSPHORUS: INADEQUATE CALCIUM

When a diet contains too much P relative to Ca, the body makes every effort to re-establish a normal Ca : P value by removing Ca from blood plasma, then from existing calcified tissues, particularly bone. Unless Ca is replaced, the tissue stores from which the Ca is extracted soon become markedly altered.

Previously called 'fibrous osteodystrophy', this important disorder of Ca, P, and Mg metabolism has long been recognized as a major medical problem in zoo animals in general, and green iguanas specifically (Wallach & Hoessle, 1968). For instance, monkeys fed on a diet unbalanced in its mineral content soon develop skeletal deformities; owners of monkeys and some zoo personnel used to call this condition 'cage paralysis' and 'rubber jaw'. Similarly, carnivores, especially felines, fed on diets consisting mostly or entirely of muscle meat rapidly lose bone mass and, as a result, suffer multiple skeletal fractures; this nutrition-related disease was once erroneously called 'osteogenesis imperfecta', which is a heritable disorder observed in many species (including man).

Fortunately, much has been learned about nutrition in the last 30 years. As a consequence of experience gained through observation and experimentation, the diets fed to a diverse number of species have improved immensely and, as a result, many mineral- and vitamin-related disorders are seldom seen today. Sadly, this is not necessarily true with the diets fed to captive green iguanas. Mainly, this is because of ignorance, albeit innocent in intent. One of the more common sources for husbandry information regarding iguanas is the petshop salesperson. If that petshop salesperson is well trained, experienced, and reads pertinent resource materials, then the customer is likely to be given factual and accurate information; however, if the clerk is inexperienced and told only to sell whatever is over-represented in the shop's inventory, the likely result is misinformation that can foster one or more nutritional disorders occurring in the purchased pet.

Once a significant imbalance in Ca and P occurs, small glands in the iguana's neck (parathyroids; represented as an anterior pair and a posterior pair) are stimulated to secrete a hormone that causes Ca stored in the bones to be removed, the Ca then becomes incorporated in the blood plasma and tissue fluids, and finally Ca is lost in urine. If this loss of Ca is not controlled and the Ca that was lost is not replaced, the result is a condition called metabolic bone disease (for example, see Frye, 1981). The early signs of this disorder are limbs which gradually swell and, particularly, jaw bones which become markedly shortened and markedly bowed. What at first may appear to be chubby limbs really are severely softened bones and wasted muscle tissue. When the limb bones are thus affected, there may be additional swelling and lameness. In extreme cases, fine muscular twitching, spasms and, eventually, paralysis and death can occur. If the affected bones are subjected to stressful forces (that otherwise would be of no consequence to a normal skeleton), they may fracture or collapse. When the vertebrae that comprise the spine are affected, they may collapse and, in doing so, compress the spinal cord. If the mandibles (lower jaw bones) are affected, they tend to become not only diffusely swollen, they also become bowed outward. This is because the tongue is attached to the inner aspect of the centremost portion of the lower jawbone and the force of the muscular tongue's backward pull causes the lower jaw to assume a bowed shape. This is not to suggest that the upper jaw and skull are not equally soft; however, because there is nothing exerting tension on the upper jaw, it does not tend to become as deformed as the lower jaw.

Metabolic bone disease usually can be linked to diets consisting primarily of: head lettuce, carrots, squash and cucumbers; melons, grapes, bananas and other fruit; some greens such as spinach (*Spinacia oleracea*; which, although it contains an adequate $Ca:PO_4$ value, also contains oxalic acid with reacts with Ca to form calcium oxalate, a relatively insoluble salt); and invertebrates such as mealworms (*Tenebrio molitor*) and crickets (*Acheta domestica*). Each of these items is rich in available P, but very deficient in gross or available Ca (Table 1; Frye, 1995). Not only will Ca be lost to an iguana's bones if it eats spinach frequently, but excessive calcium oxalate crystals can damage the kidneys sufficiently to cause uremia and death from renal failure.

Table 1. *Vegetables and fruits with an undesirable calcium : phosphorus value* (From Frye, 1995)

Vegetable	Ca (mg/240 ml)	P (mg/240 ml)	Ca : PO_4
Bananas	7	22	1 : 3·10
Broccoli flowerets	85	140	1 : 1·65
Brussels sprouts	36	161	1 : 4·48
Maize	16	206	1 : 12·90
Cucumber	10	21	1 : 2·10
Grapes	19	35	1 : 1·80
Lettuce (iceberg)	17	40	1 : 2·40
Mushrooms	19	131	1 : 6·90
Tomatoes	11	29	1 : 2·60

METABOLIC BONE DISEASE CAUSED BY INSUFFICIENT CHOLECALCIFEROL ('RICKETS')

> *'There is a disease of infants... having scarcely as yet gotten a proper name in Latin, called the rickets; wherein the head waxeth too great, whilst the legs and lower parts wane too little.'* Thomas Fuller (1608–1661) *Good Thoughts in Worse Times*

In rickets, another form of metabolic bone disease characterized by osteomalacia and failure of cartilaginous anlages to mineralize, the available dietary Ca may or may not be sufficient, but there is a dietary or environmental (lack of sunlight or source of suitable u.v. light) deficiency of cholecalciferol. Either preformed vitamin D is not present in the food, or the iguana is not exposed to u.v. irradiation of suitable wavelength. The end result, reduced intestinal absorption of Ca, is the same in both cases.

During the 17th to early 20th centuries, many children who worked in the mines and factories of pre-industrial and post-industrial England and Wales suffered from rickets because, among other factors, they were usually underground or indoors during the daylight hours and, thus, were not exposed to sunlight. Therefore, these children were unable to absorb sufficient Ca from their diet to meet their bodies' requirements for normal bone growth and maintenance. The fact that their diets also may have been deficient and the air was often foggy and smoke-polluted only exacerbated the situation. Of course, many adults worked under similar environmental conditions, but because their bone growth had already ceased, the effects on their skeletons were not as profound.

Bone is a dynamic tissue; it is in almost constant 'turnover'. Small amounts are removed every day and small amounts are formed and added every day. Under conditions of inadequate Ca absorption from the large intestine, which requires cholecalciferol, the bones may be affected, and eventually they become thinner and weaker. Once a threshold is reached, these weakened bones may actually become grossly thicker, but not necessarily stronger.

Rather than forming bone substance by the orderly mineralization of cartilage 'templates' at the ends of growing bones, the bones of individuals who are suffering from rickets tend to undergo a variable degree of cartilage overgrowth (hypertrophy and hyperplasia). Such bones remain very poorly mineralized and, thus, are soft. One characteristic of rickets is the formation of swellings termed 'rachitic rosettes' at the junctions where the bony ribs join the cartilaginous ribs. These structures are rounded swellings that can be seen as the iguana's rib-cage expands during each breath. In addition, the ends of the limb bones may be greatly thickened or buttressed, and the bone next to

adjacent joints may become broadly flared. Both of these anatomical (and pathological) alterations are examples of the body's attempt to strengthen grossly weakened bony tissue. Radiographs of affected bones reveal soft-tissue swellings that constitute the rachitic rosettes. These radiographs exhibit little or no evidence of osseous mineralization. The outer layers of bone also exhibit marked thinning. Fractures, particularly of the vertebral spine, pelvis, and/or long-bones, also occur frequently.

THE ROLE OF CHOLECALCIFEROL

The lack of sufficient cholecalciferol is an important factor in inducing rickets. Iguanas are heliothermic reptiles and, in order to thermoregulate and increase their body temperature, they bask in sunlight. The u.v. light in sunlight is used in the synthesis of cholecalciferol. Unfortunately, not all cages housing captive iguanas are furnished with artificial illumination which possesses the u.v. spectrum necessary to facilitate the biosynthesis of this vitally important vitamin. This can be remedied because a variety of full-spectrum (with at least a chromatic index of 90 or better) lighting devices that promote conversion of the intermediate metabolite pre-vitamin D molecule to the active cholecalciferol are now available.

Fortunately, most forms of metabolic bone disease are treatable. Even if the bony deformities at first appear to be profound, many previously affected iguanas return to normal over a period of several months following effective treatment.

PATHOLOGICAL MINERALIZATION CAUSED BY EXCESSIVE CHOLECALCIFEROL COMBINED WITH EXCESSIVE CALCIUM

Cholecalciferol is required by iguanas (and many other animals) to aid in the absorption of soluble calcium salts from the digested food in the large intestine.

A diet containing too much cholecalciferol and too much Ca can initiate changes in an iguana's skeleton and soft tissues. There are some in the nutrition community who believe firmly that reptiles do not absorb ingested cholecalciferol. As a comparative pathologist who has examined literally thousands of histological sections from captive reptiles (including many iguanas) that had been fed dog, cat, and monkey food, and has identified lesions in soft tissues that are unambiguously consistent with those induced experimentally with oral-dosed cholecalciferol, I must respectfully differ with those nutritionists. The evidence is compellingly persuasive. The first published case of hypercholecalciferolaemia in an iguana was by Schuchman & Taylor (1970); interestingly, their case involved a pet iguana whose owner supplemented the iguana's diet with sources of oral cholecalciferol.

Almost invariably, this disorder of soft-tissue mineralization is induced by the feeding of artificial dietary items that contain supplementary forms of cholecalciferol.

The problem is that with ingestion of too much preformed (as opposed to endogenously-synthesized) cholecalciferol, there is absorption of excessive Ca. This results in an abnormally-high blood Ca level which promotes the deposition of calcium salts into normally pliant and elastic tissues in which calcium hydroxyapatite, an insoluble mineral, is not normally found. Thus, the clinical signs of hypercholecalciferolaemia (induced when sources of preformed cholecalciferol are fed to excess) are referable to which organs are involved: the heart muscle, aorta and other large muscular arteries (calcinosis cordis, heart failure, arteriosclerosis); pulmonary airways involving the trachea, bronchi, and lungs (pulmonary hypertension, respiratory dyspnoea); oesophagus, stomach, and intestines (dysphagia, inhibited peristalsis, chronic indigestion, constipation); kidneys,

ureters, and urinary bladder (renal failure, uraemia, calcinosis urocysticus); genital tract, particularly the oviducts and vasa deferentiae (egg retention, multiple reproductive dysfunctions); skin (calcinosis cutis); spleen (calcinosis muscularis, arteriosclerosis, splenic infarction); brain, and spinal cord (arteriosclerosis, parenchymatous and meningeal calcinosis).

Some authorities recommend feeding dog or cat food or monkey biscuits to iguanas. There is no arguing that many iguanas find these commercial diets that have been formulated for dogs, cat, and primates highly palatable, and prefer to eat them rather than leafy green vegetables (which are a more natural diet for them). However, these items have not been formulated for iguanas and, in my opinion, should not be fed to them, because they contain too much preformed cholecalciferol.

The simple ingestion of too much Ca without a concomitant increase in cholecalciferol usually does not cause a problem, and only results in excessive Ca being passed in the faeces with little absorption taking place.

When the cause for hypercalcaemia is due to nutritional overload, the affected iguana should be treated. Fortunately, an effective treatment for too much Ca in the blood plasma and soft tissues has been developed (Frye *et al.* 1991; Frye, 1996*a*) and the deleterious effects of this condition can be reversed. Since this is an entirely preventable disorder, attention must be paid to what is fed to green iguanas and other folivorous lizards.

EGG RESORPTION AS RELATED TO BLOOD CALCIUM LEVELS

The eggs of iguana are occasionally resorbed before they can be laid (Frye, 1995). This is a natural means for recycling vital protein, and fat- and Ca-laden yolk. During the time of yolk and shell deposition, the female iguana's blood Ca level is significantly elevated, but this high level is transient and tends to be self-limiting. Similarly, during the time when her eggs are resorbed, the female's blood Ca rises substantially above normal levels. An adult male iguana or non-gravid female green iguana possesses a normal blood Ca concentration of approximately 104–136 mg/l. In some instances, gravid female green iguanas have been found to possess blood Ca levels in excess of 900 mg/l. Other females which resorbed their eggs had blood Ca levels as high as 1510 mg/l. Within a few weeks, all these enormously high levels had returned to within normal limits without remedial treatment or other intervention.

These findings demonstrate the ability of iguanas to mobilize Ca from, and sequester Ca in, their skeletal stores. Before female iguanas are treated medically for hypercalcaemia, they should be evaluated carefully to ascertain whether they are either producing eggs or resorbing them.

FEEDING GREEN IGUANAS

Whenever possible, the food fed to green iguanas should contain a Ca : P value of at least 2 : 1 (Table 2). As long as too much supplemented preformed cholecalciferol is not fed, any mild excess of Ca will be excreted in the iguanas' faeces.

When fed on a proper leafy diet (Table 3), supplementation with vitamin–mineral products is, in my opinion, usually unnecessary. Also, feeding a more 'natural' diet results in steady growth and development without metabolic bone disease, soft-tissue mineralization, and some of the secondary diet-related disorders such as constipation, diarrhoea, and intestinal gas that some diets rich in less complex carbohydrate sources often promote,

Table 2. *Vegetables with a desirable calcium : phosphorus value* (From Frye, 1995)

Vegetable	Ca (mg/240 ml)	P (mg/240 ml)	Ca : PO_4
Beet greens	188	80	2·35 : 1
Broccoli leaves	349	89	3·92 : 1
Broccoli stems	111	47	2·36 : 1
Cabbage, green (outer leaves)	429	72	5·95 : 1
Cabbage, Chinese	400	72	5·56 : 1
Chard	300	100	3·00 : 1
Collard greens	414	150	2·76 : 1
Dandelion greens	168	70	2·40 : 1
Endive	104	39	2·66 : 1
Kale	390	134	2·91 : 1
Kohlrabi	390	120	3·25 : 1
Mustard greens	582	168	3·46 : 1
Turnip greens	694	98	7·08 : 1
Watercress	53	15	3·53 : 1

For comparison purposes: broccoli flowerets contain 85 mg Ca and 140 mg P yielding a Ca : PO_4 value of 0·41 : 1; broccoli leaves contain 349 mg Ca and 89 mg P, yielding a Ca : PO_4 value of 3·92 : 1. Thus, parts of the same plant can be widely diverse with respect to their nutritional content.

Table 3. *An ideal diet for green iguanas* (Iguana iguana)

Large amounts	Smaller amounts	Treats
Tender, chopped mustard	Thawed, frozen mixed vegetables	Occasionally tofu soyabean curd
Collard	Grated yellow, orange, green squash	Hard-cooked egg-white
Kale	Mixed bean, pea, lentil and edible seed sprouts	Steamed brown rice
Bok choi	Water-moistened ground lucerne pellets	Multi-grain 'kashi' mash
Napa cabbage	Rose petals (from rose plants that have not had pesticides applied to them)	Multi-grain bread
Turnip greens	Fresh fruit (pitted stone fruits, ripe papayas, mangoes, kiwi fruit, figs, shredded apples)	Cooked unseasoned whole-grain pasta (without cheese)
Broccoli leaves		
Mulberry leaves		
Hibiscus leaves and blossoms		
Fresh dandelion and nasturtium leaves and blossoms		
Cilantro		
Escarole		
Endive		

particularly for the first few days or weeks after they are introduced into the iguanas' ration.

Iguanas can discern the colours red, yellow, orange, and green; therefore, this information should be used to prepare diets that are visually attractive.

Generally, iguanas are fed free-choice several times weekly. Young iguanas, because they are growing rapidly, need to be fed more often whereas mature iguanas can be maintained on a three to four times per week feeding schedule:

hatchlings measuring from approximately 85 mm snout-to-vent length (SVL) should be fed daily;

yearlings measuring approximately 175 mm SVL should be fed at least five times weekly; adult green iguanas (3 years old and older) measuring approximately 350 mm SVL usually should be fed three or four times weekly. It should be noted that gravid female iguanas usually refuse to feed during the time that they are carrying intra-oviductal ova (Rodda, 1992; Frye, 1995).

The frequency of feeding also depends on the activity level of the iguanas, their reproductive status, average ambient temperature, and the nutritive density or quality of the diet. The effect of the reproductive status on the appetite and nutritional requirements of mature iguanas must be considered also, because these factors can greatly influence the requirement(s) for macro- and micronutrients.

The quality of the foodstuffs is important when determining the amount of food to be fed. For example, a diet consisting of high-water-content foods, such as melons and ripe fresh fruits, contains less cellulose and other nutrients than a diet whose identical weight consists of fresh green leaves or grain-rich bread.

Factors influencing the differences in nutritional quality of foodstuffs are:

water (moisture) content;
energy content (kJ) per unit dry weight;
mineral content expressed on a dry weight basis;
relative content of minerals (for example, Ca : P : Mg);
ability of the energy content of the food to be efficiently assimilated.

For example, iceberg head lettuce has a low amount of Ca but a high amount of P (Table 1); therefore, the desired relative amounts of Ca and P of iceberg head lettuce are reversed and, if iceberg lettuce is fed excessively to an iguana, metabolic disturbances are likely to develop. Also, because of its very high water content, extremely large amounts of lettuce must be consumed in order to obtain even minimal amounts of nutritional value.

Food items that consist primarily of easily digested and assimilated simple carbohydrates (sugars) tend to foster obesity, fermentation, and excessive intestinal gas production (Frye, 1995).

Better-quality foodstuffs characteristically are composed of complex carbohydrates, especially cellulose, which must be processed by the micro-organisms residing in the digestive tract (especially in the iguana's sacculated colon).

Iguanas will acquire a taste for almost any food offered constantly regardless of its nutritional value or even if it has detrimental qualities (as do iceberg lettuce, Brussels sprouts, maize, grapes, and soaked primate chow; Frye, 1995). If an iguana is already eating poor or specific nutrient-deficient foods, a transition to a healthier diet should be made by mixing a little of the usual 'poor' food with the new 'good' food so that the iguana will eat its meal, and gradually reduce the amount of the former diet until it is totally replaced by the proper foods.

Although iguanas have strong jaws and many teeth, they do not actually chew their food before swallowing it; rather, pieces of leafy vegetation are secured and bitten from a larger portion before swallowing them. If two or more iguanas are housed together, it is better to place the food in more than one plate, bowl, or pile because this will help avoid disputes over favoured food items. Another option is to prepare a thoroughly combined mixture or salad of foods, which eliminates waste of vitamin supplements (if provided) and ensures that each 'bite' is complete. This is advantageous and convenient if two or more iguanas, or a large group of iguanas varying in size, are being fed. After preparing several meals, the amount of food required becomes evident.

Iguanas should be fed between 11.00 and 14.00 hours because they eat most heartily after being warmed up by basking in radiant energy (Frye, 1995). Also, they then have time in the afternoon to digest their meal. The intestinal bacteria and protozoa responsible for digestion of fibrous plant matter before nutrient absorption operate optimally at temperatures of approximately 29–35 °. It is helpful to provide a warm area where the lizards can bask for 1–2 h after they have been fed so that each meal is properly digested and assimilated.

The gastrointestinal organs of green iguanas are adapted to process a diet consisting mainly of nutritive plant fibre (see Appendix), much in the manner of foregut fermenting ruminants; however, rather than accomplishing this fermentation in a multi-chambered rumen complex, it occurs in the iguana's hindgut, in a sacculated colon.

Some captive iguanas will accept, and may prefer or even become habituated to, aberrant, abnormal diets consisting of animal protein in the form of insects, arachnids and other small invertebrates, small eggs, and rodents such as mice and small rats (Frye, 1995). None of these food items is suitable for an iguana's alimentary tract. Many iguanas may remain outwardly healthy and exhibit no signs of clinical disease caused by their unnatural diets. Others develop and eventually display signs consistent with metabolic bone disease.

In their native habitats, green iguanas generally confine their diet to vegetable matter in the form of leaves, blossoms, tendrils, and soft fruits. Although young green iguanas often eagerly eat insects and arachnids, they are adapted morphologically to a diet composed mainly of plant material (Troyer, 1982, 1983, 1984*a*,*b*,*c*). There is a greater need for protein while young iguanas grow and develop rapidly during the first 1–2 years of their life, and although invertebrates or other small animals can augment this protein requirement, plant sources alone can provide sufficient nutrition for orderly growth and development to proceed. When iguanas become adults, their nutritional needs are mainly directed toward maintenance, and a diet composed of relatively high Ca : low P leafy vegetables fulfills this requirement (Table 2).

Many iguana keepers give their pets soft fruits such as kiwi, strawberries, melons, pitted stone fruits (apricots, peaches, nectarines, plums), figs, etc. These items add variety and flavour to the diet, and are acceptable in small quantities as treats or special 'goodies'. However, most fruits contain more P than Ca, and some have so much readily-fermentable sugar that they promote excessive gas production which can cause bloat and distress to iguanas unaccustomed to eating them.

Some keepers feed their iguanas commercial dog, cat, or primate chow. In my opinion, this is unwise from several standpoints:

these products were formulated for canines, felines, and primates, not for iguanas which anatomically are different from dogs, cats, and monkeys;

many, if not most, of these commercial diets contain substantially more preformed vitamin A and cholecalciferol than are required by iguanas. (An appropriate diet composed of green leafy vegetables contains adequate β-carotene from which vitamin A can be converted biologically; with appropriate u.v. radiation, iguanas can synthesize their own cholecalciferol.)

If dog, cat, or primate chow is included in the diet, it should not exceed 50 g/kg total ration.

BRASSICA PLANTS

One of the best sources of Ca that also contains acceptable amounts of P is the Brassicas (Table 4). This singular group of vegetables is remarkable because its members are so

dissimilar in their appearance: cabbage, kale, broccoli, mustard greens, rutabaga, and kohlrabi are all members of this nutritious family of vegetables.

The Ca content of vegetables comprising the family *Brassicaceae* varies widely, not only between plants within the genus, but also within the same plants, depending on which part of the edible plant is analysed (Table 4). For example, broccoli leaves are substantially richer in Ca than both the stems and flowerets, even though the parts may be separated from each other on the same stalk by only a few centimetres or less; and turnip greens are one of richest leafy sources of Ca, but the bulbous turnip roots contain only a very modest amount of this essential mineral.

Because the stiff stem-like leaf veins of some of these leafy varieties are fibrous, they should either be eliminated by trimming the leaves or cut into short bite-size lengths before feeding to iguanas.

Although eating excessive amounts of some members of the family *Brassicaceae*, such as white head cabbage, could predispose to or even induce a thyroid hormone deficiency because they contain isothiocyanate compounds (which are natural goitrogens and are capable of inhibiting the production of thyroid hormone by the thyroid gland), in practice, it is a problem only when they are eaten excessively while simultaneously excluding other nutritious foods. If in doubt about excessive consumption, a partial or full tablet of dried kelp can be added occasionally to the ration. This source of soluble iodine is harmless (unless massive numbers of tablets are given to an iguana over a brief period of time).

ADDITIONAL SOURCES OF NUTRITIONAL GREEN FORAGE

Other nutritious greens include dandelion leaves and blossoms, escarole, endive, and mulberry and hibiscus leaves and blossoms. Where available in Central America, the indigenous Jacoté tree is cultivated for its leaves and fruits which are fed almost exclusively to breeding colonies of green iguanas (Frye, 1996*b*). Without exception, the leaves of these plants are excellent sources of Ca and nutrient fibre and do not contain high levels of P or oxalic acid.

Table 4. *Some nutritious members of the Brassica family of plants* (From Frye, 1995)

Common name	Latin name	$Ca:PO_4$
Broccoli, cauliflower, broccoflower,	*B. oleracea* var. botrytis	1·49 : 1
Flowerets		0·61 : 1
Leaves		3·91 : 1
Cabbage varieties:		
Chinese (pe-tsai; napa)	*B. oleracea* var. pekinensis	5·55 : 1
Head, green leaves	*B. oleracea* var. capitata	5·96 : 1
Head, white leaves		1·35 : 1
Kale, borecole	*B. oleracea* var. acephala	2·90 : 1
Kohlrabi	*B. oleracea* var. gonggylodes	3·25 : 1
Mustard varieties:		
Abyssinian	*B. carinata*	3·65 : 1
Black	*B. nigra*	3·54 : 1
Chinese (pak-choi)	*B. c. chinensis*	3·62 : 1
Field	*B. campestris*	3·48 : 1
Indian (brown)	*B. juncea*	3·48 : 1
White	*B. alba* (*B. hirta*)	3·54 : 1
Wild (charlock)	*B. kaber* (*B. arvensis*)	3·78 : 1
Rutabaga	*B. rapa*	1·32 : 1
Turnip greens	*B. c. rapifera*	4·24 : 1

Commonly-grown ornamental garden plants and houseplants, especially hibiscus, nasturtium, eugenia, and the ubiquitous wandering Jew (*Zebrina pendula*) and golden pothos (*Epipremnum aureum*) are also suitable as nutritious forage sources and are avidly eaten by green iguanas.

ARTIFICIAL COMMERCIAL DIETS

During the past 4 years, several artificial diets have been developed and marketed for feeding the green iguana. Most of these products claim that they are 'complete', i.e. nothing but these and water need be fed. Many, however, contain far more protein and preformed vitamin A and cholecalciferol than are necessary for proper nutrition of the green iguana.

In an attempt to assess the value of four of these commercial diets, we conducted a feeding trial in which groups of juvenile green iguanas were fed nothing but the test diets and fresh water to ascertain how they would grow and develop (Hamdoun & Frye, 1995). We were unaware of another study, then unpublished, that closely paralleled our study (Donoghue, 1994). Two of the diets that we evaluated appeared to provide the growing iguanas with sufficient nutrients; one did not provide sufficient nutrients and, on humane considerations, had to be discontinued; the formula of the last diet in the group appeared to contain sufficient nutrients, but it was so unpalatable that the iguanas refused to eat it. The two that were palatable and were proven to provide adequate nutrients to support normal growth were Nutri'Guana (Feather Gourmet, Sacramento, CA 95827, USA) and Pretty Pets Iguana Diet (Pretty Bird International, Stacy, MN 55079, USA). Other commercially-prepared iguana diets have been formulated since our study was published.

It has now been shown conclusively that when fed on a diet in which the only source of protein is nutritious, fibrous plant protein, green iguanas thrive, grow to maturity, and reproduce without developing metabolic bone disease, abnormal mineralization of soft tissues, or visceral gout.

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Appendix. *Selected vitamin, mineral and protein contents of fruit and vegetables sometimes included in the diet of green iguanas* (Iguana iguana)

		Vitamins				Minerals			Other
Food	Measure	A (μg)	Thiamin (mg)	Riboflavin (mg)	C (mg)	Ca (mg)	P (mg)	Fe (mg)	Protein (g)
Apple	1 small	27	0·360	0·050	6	7	12	0·3	0
Apricot*	3 med	2250	0·033	0·100	4	13	24	0·6	1
Asparagus	8 stks	330	0·360	0·065	20	21	40	1·0	2
Aubergine (Eggplant)	1/2 cup	21	0·042	0·036	10	11	31	0·5	1
Avocado	1/2 med	150	0·120	0·137	9	44	42	6·3	2
Banana	1 med	90	0·045	0·087	10	8	28	0·6	1
Beans, green‡	3/4 cup	285	0·060	0·100	8	55	50	1·1	2
Beet greens‡	1/2 cup	6600	0·100	0·500	50	94	40	3·2	2
Beets	1/2 cup	15	0·041	0·037	8	28	42	2·8	2
Blackberries	3/4 cup	90	0·025	0·030	3	32	32	0·9	0
Blueberries	3/4 cup	11	0·045	0·031	11	25	20	0·9	0
Broccoli: Flower	3/4 cup	1950	0·120	0·350	65	64	105	1·3	2
Leaf	3/4 cup	9000	0·120	0·687	90	262	67	2·3	3
Stem	3/4 cup	600	–	0·187	–	83	35	1·1	2
Brussels sprouts	3/4 cup	120	0·180	0·090	130	27	121	2·1	4
Cabbage:‡	1 cup	0	0·780	0·075	50	46	34	2·0	2
§	1 cup	48	0·090	0·150	50	429	72	2·8	2
‖	1 cup	1500	0·036	0·462	50	400	72	2·5	2
Cantaloupe	1/2 small	270	0·090	0·100	50	32	30	0·5	1
Carrots¶	1/2 cup	1350	0·070	0·075	5	45	41	0·6	1
Cauliflower	3/4 cup	3	0·085	0·090	75	122	60	0·9	2
Celery:**	4 stks	6	0·030	0·015	5	78	46	0·5	1
Green	4 stks	192	0·030	0·045	7	98	46	0·8	1
Root	1/2 cup	–	–	–	2	47	71	0·8	3
Chard, leaves‡	1/2 cup	4500	0·450	0·165	37	150	50	3·1	2
Cherries*	12 lrg	78	0·051	–	12	19	30	0·4	1
Collards‡	1/2 cup	1890	0·130	–	70	207	75	3·4	3
Corn on cob	1 med	258	0·209	0·055	8	8	103	0·4	3
Cucumber	1 med	11	0·060	0·054	12	10	21	0·3	1
Dandelion, green‡	1/2 cup	6000	0·190	0·270	100	84	35	0·6	3
Endive	10 stks	4500	0·058	0·072	20	104	39	1·2	1
Grapefruit	1/2 med	6	0·070	0·060	45	21	20	0·2	0
Grapes	1 small bunch	8	0·030	0·024	3	19	35	0·7	1
Guava	1	60	0·156	0·105	125	15	16	3·0	1
Honeydew melon	1/4 med	30	–	–	90	–	–	–	0
Huckleberry	1/2 cup	30	0·045	0·021	8	25	20	0·2	1
Kale‡	1/2 cup	6000	0·189	0·570	96	195	67	2·5	4
Kohlrabi	1/2 cup	–	0·030	0·120	50	195	60	0·7	2
Leeks	1/2 cup	6	0·150	–	24	58	56	0·6	2
Lettuce: Green	10 leaves	600	0·075	0·150	7	49	28	1·5	1
White	1/4 head	38	0·051	0·062	5	17	40	0·5	1
Mushrooms‡‡	3/4 cup	0	0·160	0·070	2	14	98	0·7	4
Mustard greens	1/2 cup	3300	0·138	0·450	126	291	84	9·1	2
Okra	1/2 cup	132	0·126	–	17	72	62	2·1	2
Onions, fresh	4 med	18	0·042	0·125	7	41	47	0·4	1
Orange	1 med	57	0·090	0·075	50	44	18	0·4	0
Parsley	1/2 cup	2400	0·057	–	70	23	15	9·6	20
Parsnips‡‡	1/2 cup	30	0·120	–	40	60	76	1·7	2
Peaches: White	3 halves*	30	0·025	0·065	6	10	19	0·2	1
Yellow	1 lrg*	300	0·025	0·065	9	10	19	0·3	1
Pear	1 med	5	0·030	0·060	4	15	18	0·3	0
Peas, fresh‡	1/2 cup	450	0·390	0·250	20	28	127	0·2	7
Persimmon‡‡	1 lrg	480	–	–	40	22	21	0·2	2
Pineapple§§	2/3	9	0·100	0·025	38	8	26	0·2	0
Plums	3 med	39	0·120	0·056	5	20	27	0·5	1

continued

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Appendix (*continued*)

Food	Measure	Vitamins				Minerals			Other
		A (μg)	Thiamin (mg)	Riboflavin (mg)	C (mg)	Ca (mg)	P (mg)	Fe (mg)	Protein (g)
Potato: Sweet	1 med	1080	0·155	0·150	25	19	45	0·9	3
White	1 med	0	0·220	0·075	33	13	53	1·5	3
Yam	1 med	1500	0·180	0·360	6	44	50	1·1	2
Pumpkin	1/2 cup	750	0·056	0·057	8	23	50	0·9	1
Radishes	15 lrg	0	0·030	0·054	25	21	29	0·9	1
Raspberries	1/2 cup	78	0·021	–	30	41	38	0·8	1
Rutabaga	3/4 cup	8	0·075	0·120	26	74	56	0·7	1
Spinach‡	1/2 cup	3300	0·090	0·312	30	78	46	2·5	2
Squash: Hubbard	1/2 cup	1200	0·050	0·075	3	19	15	0·5	1
Summer	1/2 cup	300	0·040	0·050	3	18	15	0·3	1
Strawberries	1/2 cup	30	0·025	–	50	34	28	0·6	1
Tangerine	2 med	90	0·120	0·054	48	42	17	0·2	1
Tofu soyabean cake	120 g	0	0·070	0·010	0	150	150	2·3	86
Tomatoes	1 med	450	0·100	0·050	25	11	29	0·4	1
Turnips‡	1/2 cup	0	0·062	0·062	22	56	47	0·5	1
Turnip greens	1/2 cup	3300	0·060	0·045	130	347	49	3·4	2
Watercress	3/4 cup	375	0·030	0·090	15	40	11	0·8	0
Watermelon	1 med sl	135	0·180	0·084	22	33	9	0·6	0

stks, stalks; lrg, large; med, medium; sl, slice; cup, 237 ml (8 oz).
* Pitted.
† Cooked.
‡ Inside white leaves.
§ Outside green leaves.
‖ Chinese.
¶ Diced.
** Bleached.
†† Domestic.
‡‡ Japanese.
§§ Fresh.

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