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RESEARCH ARTICLE

The Diet of Free-Roaming Australian Central Bearded Dragons (*Pogona vitticeps*)

D.G.A.B. Oonincx,[1,2]* J.P. van Leeuwen,[3] W.H. Hendriks,[1] and A.F.B. van der Poel[1]

[1]*Wageningen Institute of Animal Sciences, Animal Nutrition Group, Wageningen University, Wageningen, The Netherlands*
[2]*Laboratory of Entomology, Department of Plant Sciences, Wageningen University, Wageningen, The Netherlands*
[3]*Biometris, Department of Plant Sciences, Wageningen University, Wageningen, The Netherlands*

The central bearded dragon (*Pogona vitticeps*) is one of the most popular pet lizards. However, little is known regarding their nutrient requirement, or their natural diet. Therefore, the stomach contents of 14 free-roaming *P. vitticeps* were determined by flushing. These stomach contents were described taxonomically, and analyzed for crude protein content as well as fatty acid content and composition. Most of the dry matter intake was in the form of animal material (61%) stemming from nine arthropod orders. The most abundant were alates of the termite *Drepanotermes sp.*, accounting for 95% of the total number of prey items and more than half of the total dry matter (DM) intake. Plant material contributed 16% of the total DM intake. The diets were high in crude protein (41–50% DM) and the total fatty acid content was 14–27% of the DM intake. The main fatty acid was C18:1n9c (51–56% of total fatty acids), and polyunsaturated fatty acids (n3 and n6) comprised 6–8% of the total fat intake. Our data suggest that *P. vitticeps* is an opportunistic predator, which exploits the seasonal availability of prey. Based on our data and other studies, a diet consisting of several insect species, supplemented with leafy vegetables, rich in n3 FA's, would best resemble the expected natural diet of *P. vitticeps*. Zoo Biol. 34:271–277, 2015. © 2015 Wiley Periodicals, Inc.

Keywords: agamid; Australia; lizard; stomach content

INTRODUCTION

The central bearded dragon (*Pogona vitticeps*) is an Australian agamid and one of the most frequently kept pet reptiles [Raiti, 2012]. Inappropriate husbandry conditions such as incorrect environmental temperatures or humidity, or inappropriate diets can lead to significant health problems [McWilliams, 2005; Wright, 2008; Köhler et al., 2013]. Bearded dragons are omnivorous and are, therefore, commonly provided with a variety of plant and insect species in captivity [Cooper and William, 2000]. The most common nutritional diseases in reptiles, including bearded dragons, are due to an inadequate vitamin D status or inappropriate intake of calcium or phosphorus [Kik and Beynen, 2003]. Several studies have focused on this aspect of *P. vitticeps* nutrition [Dralle et al., 2010; Oonincx et al., 2010, 2013], but not on macronutrient intake levels. In the absence of detailed information on nutrient requirements determined via empirical methods, one approach to ensure the nutrient requirement of captive animals is met, is to formulate diets which closely resemble the diet consumed by a population of healthy free living animals [Hendriks et al., 2000]. Limited information regarding the natural dietary constituents of *P. vitticeps* is available [MacMillen et al., 1989] and it is unknown to which extent the chemical composition of diets provided in captivity correspond to their natural diets. Therefore, we conducted a study to determine the natural diet of free-roaming *P. vitticeps* in New South Wales, Australia. We identified consumed dietary items and determined the protein and fat content of collected stomach contents.

Conflicts of interest: None.

*Correspondence to: D.G.A.B. Oonincx, Laboratory of Entomology, Department of Plant Sciences, Wageningen University, PO Box 8031, 6700 EH Wageningen, The Netherlands. E-mail: dennisoonincx@hotmail.com

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MATERIALS AND METHODS

Study Sites

All samples were collected in semi-arid New South Wales, between Broken Hill (S 31.91021°, E 141.48497°) and Cobar (S 31.71187°, E 144.15192°) in the summer of 2010 (January 28th–February 8th). A permit for scientific research was acquired at the NSW Department of Environment & Conservation (DEC) National Parks and Wildlife Service under the National Parks and Wildlife Act 1974, Section 132C. Additionally, a permit under the Animal Research Act was granted by the Animal Welfare Branch, NSW Department of Industry and Investment, Australia (license number S13043).

Sample Collection

Bearded dragons were captured by hand between 10:00 and 20:00, with half of them caught between 12:00 and 16:00. Gender was determined by visual inspection (hemipenal bulges and enlarged femoral pores in males), and body weight (BW) was measured using an extension spring (Pesola light, scale 500 g, accuracy 1 g, Pesola AG, Switzerland). Stomach content samples were taken as described by Legler [1977] and Legler and Sullivan [1979]. Immediately after sampling, all animals were released at the site of capture; none of the animals appeared to have been injured or otherwise harmed at that time. All stomach content samples were coded "PV" and numbered according to the chronological order in which the bearded dragons were found. Live locusts found near the location of the 14th bearded dragon (PV14), as well as samples of three plant species that looked similar to items found in the stomach contents, were collected. Obtained samples were immediately frozen in a mobile freezer (Engel Fridge, Engel, Australia) and shipped on dry ice to Wageningen University, Wageningen, The Netherlands.

Diet Composition

All samples were freeze-dried and the weight of the dry matter (DM) was recorded using a microbalance (CP2P, Sartorius AG Germany; accuracy 0.001–0.005 mg). When samples could not be placed in the microbalance due to size or volume, an analytical balance was used (ML54, New-Classic MF; accuracy 0.1 mg). Subsequently, contents were sorted as either plant material (PM), indigestible material (IM), or animal material (AM). The weight of PM and IM was determined per sample. Animal material, including intestinal parasites, was identified by consulting the CSIRO database [CSIRO, 2011] and information provided by Britton et al. (1970). Where possible, the Orthoptera, Isoptera, Scolopendromorpha, and Odonata were identified to the species level [Watson and Perry, 1981; Watson et al., 1989; Pocock, 1901; Tillyard, 1926; Ratcliffe et al., 1952; Watson, 1974; Watson and Abbey, 1993; Edgecombe, 2001; Australian Government, 2009; Fisher et al., 2011]. The number of prey animals was determined following Calver and Wooller [1982] where (1) each head counts as one insect, (2) each cephalothorax counts as one spider, and (3) four wings count as one dragonfly. Dietary items were grouped taxonomically and their weight was determined per sampled bearded dragon. After weight had been determined, volume (V) was estimated by means of the spheroid formula [Vitt and de Carvalho, 1995; Vitt et al., 1997; Durtsche, 2000].

$$V = \frac{4}{3} \cdot \pi \cdot \left(\frac{length}{2}\right) \cdot \left(\frac{width}{2}\right)^2$$

For the animal material, length and width of the specimen were determined with a dissecting microscope connected to a CMEX DC1300 USB camera. Pictures were taken of the complete individuals, and length and width were determined using ImageFocus (NewEra Software, Inc.; accuracy 0.001 mm). Large prey items such as Odonata, Arachnida, and PM, were measured by use of graph paper (in mm). Length was measured from the middle of the head to the caudal tip of the abdomen. Width of prey animals was measured directly behind the pronotum. For similar sized and shaped specimens, this procedure was followed for a minimum of ten percent of the complete individuals. The resulting average value was then used to calculate the total volume of these prey animals per sample. Food items without a spheroid shape, i.e., Hymenoptera and PM, were positioned as a whole in a spheroid shape, measured and total volume was calculated. The same procedure was applied to an unidentified Isoptera genus, due to large size variation between individuals. Fatty substances, which had a gelatinous appearance, were categorized as fat-like material (F), or as unidentified arthropod material (U) in case of non-identifiable body parts. Volume was not calculated, because it was not possible to position F and U into a spheroid shape.

Chemical Analysis

In order to obtain sufficient material for the chemical analysis, the stomach contents of samples were pooled as follows: PV01 with PV04 and PV05; PV06 with PV07, PV08, and PV09; and PV11 with PV14. The sample of PV13 was sufficient and analyzed *in duplo*; average values are reported. For PV02, PV03, PV10, and PV12, no stomach contents were extracted. Nitrogen (N) content of the stomach content samples, and of the collected locusts and three plant species, were determined according to Novozamsky et al. [1984]. Fatty acids were extracted according to Folch et al. [1957] and the fatty acid profile was determined according to Raes et al. [2001]. Crude protein (CP) content was calculated as N-content multiplied by 6.25. Total fatty acids (TFA) were calculated as the sum of all determined fatty acids.

RESULTS

Fourteen *P. vitticeps* were caught by hand, of which there were 13 adults (four females and nine males; Supplementary Table 1) weighing between 230 and 520 g and one sub adult male weighing 115 g (PV07). Stomach flushing was successful in 11 of the captured animals (not in PV02, PV10, and PV12). In one bearded dragon (PV03), which was sampled at 10:00, the stomach was empty except for an intestinal parasite. The same species of intestinal parasite was found in the stomach of PV08 and identified as *Abbreviata sp.* (Nematode: Physalopteridae) [Cremers, 2011]. No food items were found in PV03, so it was excluded from the tables.

In the 10 bearded dragons from which stomach contents were collected, prey items from nine arthropod orders were found. Seven orders belonged to Insecta, one to Scolopendramorpha, and one to Arachnida (Table 1). Isoptera were found in 80% of the sampled individuals, and accounted for 94.6% of the total number of prey items (1531 specimens). The Isoptera contributed over half of the total DM weight (52.8%; Table 1). Most of this (52.0%) was in the form of *Drepanotermes* alates (winged adults), most likely *D. perniger*. Hymenoptera, present in 70% of the sampled individuals, corresponded to 4.6% of the total number of ingested prey. The locust species found in the stomach of PV14 was the same as the collected locusts and identified as the Australian plague locust, *Chortoicetes terminifera* [Australian Government, 2009]. Most of the DM weight (61.0%) was comprised of AM, but also large amounts of F (20.6% of total DM) and PM (15.7% of total DM) were found. Furthermore, in 80% of the bearded dragons, IM in the form of grit, thread, or plastic was found, making up 2.3% of the total DM. Four percent of the DM weight was lost due to handling of the material during the determination process. The most voluminous food item was PM, corresponding to 54.4% of the total volume, followed by animal material (41.5%), mainly in the form of Isoptera (32.2%; Table 1). The four pooled stomach content samples had a CP content between 41 and 50% of the DM (Table 2). TFA content was between 14 and 27% of the DM. The main fatty acids (FAs) were C16:0 (~22% of TFA), C18:0 (~7% of TFA), C18:1n9c (50–55% of TFA), and C18:2n6c (5–7% of TFA). In all samples, small amounts of n3 (also known as ω-3) fatty acids were found (0.22–1.02% of TFA), mainly

TABLE 1. Number of prey items, volume and weight of food items found in the stomachs of free-roaming *Pogona vitticeps*

Food category	Number of prey items	Volume (cm^3)	Weight (g)
F			2.5 (20.6%)
U			0.1 (0.4%)
IM		6.28 (4.1%)	0.3 (2.3%)
PM		82.31 (54.4%)	1.9 (15.7%)
AM		62.76 (41.5%)	7.5 (61.0%)
Insecta	1529 (99.9%)	58.83 (38.9%)	7.3 (59.6%)
Isoptera	1449 (94.6%)	48.78 (32.2%)	6.5 (52.8%)
Termitidae	1329 (86.8%)	41.16 (27.2%)	6.8 (55.0%)
Drepanotermes	1329 (86.8%)	41.16 (27.2%)	6.8 (55.0%)
Alates	1140 (74.5%)	38.96 (25.7%)	6.4 (52.0%)
Soldiers	48 (3.1%)	4.59 (3.0%)	0.8 (6.4%)
Workers	262 (17.1%)	1.68 (1.1%)	0.3 (2.5%)
Unknown	120 (7.8%)	7.62 (5.0%)	0.1 (0.7%)
Soldiers	2 (0.1%)	0.02 (0.0%)	0.0 (0.0%)
Workers	118 (7.7%)	7.60 (5.0%)	0.1 (0.7%)
Hymenoptera	70 (4.6%)	6.92 (4.6%)	0.2 (1.8%)
Formicidae	56 (3.7%)	4.30 (2.8%)	0.1 (1.1%)
Myrmicinae	5 (0.3%)	0.06 (0.0%)	0.0 (0.1%)
Other	14 (0.9%)	2.62 (1.7%)	0.1 (0.7%)
Diptera	4 (0.3%)	0.07 (0.0%)	0.0 (0.1%)
Brachycera	3 (0.2%)	0.04 (0.0%)	0.0 (0.0%)
Nematocera	1 (0.1%)	0.03 (0.0%)	0.0 (0.0%)
Odonata	1 (0.1%)	2.64 (1.7%)	0.2 (1.4%)
Gomphidae	1 (0.1%)	2.64 (1.7%)	0.2 (1.4%)
Orthoptera	2 (0.1%)	0.21 (0.1%)	0.1 (0.5%)
Acrididae	1 (0.1%)	0.17 (0.1%)	0.1 (0.4%)
Chortoicetes	1 (0.1%)	0.17 (0.1%)	0.1 (0.4%)
C. terminifera	1 (0.1%)	0.17 (0.1%)	0.1 (0.4%)
Coleoptera	2 (0.1%)	0.13 (0.1%)	0.0 (0.2%)
Lepidoptera	1 (0.1%)	0.09 (0.1%)	0.0 (0.1%)
Scolopendromorpha	1 (0.1%)	1.89 (1.2%)	0.2 (1.3%)
Otostigmus	1 (0.1%)	1.89 (1.2%)	0.2 (1.3%)
Arachnida	1 (0.1%)	2.04 (1.3%)	0.0 (0.1%)
Araneae	1 (0.1%)	2.04 (1.3%)	0.0 (0.1%)
TOTAL	1531	151.35	12.28

F, fat-like material; U, unidentified; IM, indigestible material; PM, Plant material; and AM, Animal.

TABLE 2. Crude protein (CP), and total fatty acids (TFA) on a dry matter (DM) basis, and fatty acid profile (as a percentage of total fatty acids) of pooled stomach contents of free-roaming *Pogona vitticeps* (PV), as well as collected locusts (*Chortoicetes terminifera*) and three unidentified plant species resembling plant material found in the stomachs collected at site of capture

	CP (%DM)	TFA (%DM)	C13:0	C14:0	AI-C16:0	C16:0	AI-C17:0	C16:1	C17:0	C18:0	C18:1n9c	C18:2n6c	C18:3n3	Total n3	Total n6	n6/n3
PV (1, 4 & 5)	42.31	23.79	2.55	1.44	0.00	22.58	0.47	1.91	0.31	7.32	54.06	5.14	0.61	0.61	5.16	8.4
PV (6,7, 8 & 9)	49.75	27.24	2.22	1.31	0.00	21.61	0.43	1.89	0.29	7.22	55.65	5.89	0.22	0.22	5.95	27.4
PV (11 & 14)	50.25	14.00	4.29	1.97	0.02	21.95	0.51	1.58	0.25	7.19	51.23	7.04	1.02	1.09	7.15	6.6
PV (13)	41.13	23.94	2.54	1.49	0.01	21.00	0.44	1.80	0.37	7.81	54.59	5.86	0.43	0.51	5.91	11.8
C. terminifera	68.75	13.13	4.55	2.04	0.00	27.84	0.15	1.47	0.42	7.64	26.60	11.10	16.98	16.99	11.10	0.7
Plant 1 (PV14)	24.25	3.30	18.03	0.61	1.49	15.96	1.47	0.39	0.11	2.79	4.98	9.97	41.15	41.20	10.23	0.2
Plant 2	26.69	2.54	23.57	0.71	2.16	18.62	1.44	0.54	0.28	1.62	9.03	11.54	27.47	27.70	11.68	0.4
Plant 3	20.31	1.86	32.31	1.56	1.44	13.88	1.08	0.40	3.29	1.60	5.28	8.29	24.02	24.02	9.06	0.4

consisting of C18:3n3. However, in the pooled sample of PV11 and PV14, and in PV13, trace amounts of eicosapentaenoic acid (C20:5n3; 0.02-0.03% of TFA) and docosahexaenoic acid (C22:6n3; 0.05-0.07% of TFA) were also found (data not shown). The CP, TFA, and FA profiles of the *C. terminifera* and of the three unidentified plant species closely resembling the plants found in the stomach of PV14, are detailed in Table 2.

DISCUSSION

Although we sampled a limited number of bearded dragons, for only a short period, we found a high diversity of prey items, indicating *P. vitticeps* is an opportunistic predator. The diet of our *P. vitticeps* contained a large proportion of AM. This is similar to the diet described for *Pogona minor* (AM = 80.7% of total volume; [Pianka, 1986]), but in contrast with data on adult *P. vitticeps* (AM = 4.3–32.4% of DM weight; [MacMillen et al., 1989]). The latter study sampled in September, December, and February, and their highest value for AM was distorted by the consumption of a lizard (*Ctenophorus nuchalis*) by one of the *P. vitticeps*. Seasonal differences in prey availability affect dietary composition and diversity, especially in arid zone lizards [James, 1991; Pough et al., 2001]. Regarding number of prey, volume, and DM weight, Isoptera, and especially *Drepanotermes* alates, were the most important dietary item in our study. Workers of *Drepanotermes* are present throughout the year, whereas *Drepanotermes* alates are only seasonally available after rainfall [Abensperg-Traun, 1994; Palmer, 2010]. Our fieldwork was conducted between the 28th of January and the 8th of February 2010, while the first rain came at the 2nd of February [Australian Government, 2011]. No *Drepanotermes* alates were present in our first samples (Supplementary Table 1), while after the onset of the summer rains, all samples, except for one, did contain alates. Generally, rains cause an increase in prey abundance, but especially so for Isoptera alates [James, 1991], which form the main dietary component of nearly every lizard after heavy summer rains, even for species that normally do not consume termites [Pianka, 1986]. *Drepanotermes* alates are high in protein and fat and easily caught. Predators are expected to prefer the most profitable prey, therefore, their temporary abundance during our sampling period likely influenced our results [Schoener, 1971]. Similarly, the diet of the Australian agamid *Ctenophorus isolepis*, was reported to consist of 6.6% termites (by volume); however, half of this was found directly after the termites started swarming and it was based on 5% ($n = 511$) of the collected specimens [Pianka, 1971]. A later publication by the same author [Pianka, 1986] in which a larger number of lizards were sampled ($n = 1357$), reported 13.5% of the volume to consist of Isoptera. This indicates that even with a high number of samples, large variations in dietary constituents can occur. For the North-American Teiid *Cnemidophorus tigris*, large seasonal dietary variation has been described, especially for

TABLE 3. Crude protein (CP), crude fat (CF) and fatty acid (FA) composition (as a % of total fatty acids)* of a selection of commercially available insects

	CP (%DM)	CF (%DM)	C 14:0	C 16:0	C 16:1	C 18:0	C 18:1n9c	C 18:2n6c	C 18:3n3	Total n3	Total n6	n6/n3
Acheta domesticus	69.70	16.50	0.61	23.93	0.96	9.72	21.41	39.16	0.37	0.61	39.37	6471.59
Tenebrio molitor	58.50	26.60	3.69	15.79	2.16	2.73	40.27	33.53	0.00	0.00	33.59	N/A
Schistocerca gregaria (Penultimate)	65.50	17.60	2.00	24.26	1.31	7.80	36.18	16.68	9.49	9.53	16.78	176.00
Locusta migratoria (Penultimate)	65.20	16.20	1.67	22.36	0.84	9.04	29.07	22.22	12.34	12.38	22.37	180.67
Schistocerca gregaria (Adult)	61.10	27.40	1.80	27.20	1.47	5.70	44.33	17.74	0.00	0.02	17.97	84684.52
Locusta migratoria (Adult)	63.10	22.60	1.94	27.30	1.37	7.77	39.36	20.23	0.00	0.03	20.38	68505.45

*Only FAs contributing >1% to the sum of FAs are reported.

the seasonally abundant Orthoptera (4–46% by volume; [Pianka, 1970]) and Isoptera (33–55% by volume; [Pianka, 1970]). Nine arthropod orders, including the major Australian arthropod orders (Isoptera, Hymenoptera, and Orthoptera; [Pianka, 1986]), were represented in our samples. In the diet of the closely related *Pogona minor*, 12 Arthropod orders were found [Pianka, 1986] and MacMillen et al. [1989] reported 3–5 arthropod orders, one vertebrate, and 3–7 plant families, in adult *P. vitticeps*, depending on the sampling period. Whereas we found one Lepidopteran specimen (1.3% of volume), none were found in the stomach contents of *P. minor* [Pianka, 1986]. Our samples came from several locations (maximum distance between samples was 270 km), while MacMillen et al. [1989] sampled along a 50 km tract along one highway. Hence, the higher dietary diversity found in our study, might be due to spatial differences in prey availability [Pianka, 1986]. Strong influences of sampling location are known for the North American Teiid *Cnemidophorus tigris*. Depending on the sampling location 46–88% of consumed prey items were Isoptera and 0.6–10.7% of consumed prey items were Orthoptera [Pianka, 1970].

The presence of IM in our samples, consisting of grit, thread, or plastic can be suggestive of an automatic feeding mechanism triggered by movement [Tyler, 1960]. A similar mechanism was described for the North American lizard *Phrynosoma douglasii*, in which large amounts of pebbles (13% of items) were found. This was explained by the wind blowing the pebbles in motion, eliciting a feeding response [Lahti and Beck, 2008]. Grit found in the stomach content of our *P. vitticeps*, appeared to be degraded pieces of bone, which could have aided in their dietary calcium intake. Pieces of bone have also been found in the stomachs of two species of the Australian skink genus *Tiliqua* [Shea, 2006], whereas MacMillen et al. [1989] did not find IM in their *P. vitticeps*.

Assuming a similar digestibility, we can relate our field data to captive diets, based on compositional data. Although variable, as a rule of thumb insects have a CP content of approximately 60% DM [Finke and Oonincx, 2013]. The CP content of the stomach contents was consistent with a largely insectivorous diet supplemented with plant material. A large part of these samples consisted of *Drepanotermes* alates. In four species of African termites, the alates had a CP content of 34–40% DM, and a fat content of 45–47% DM [Kinyuru et al., 2013]. These alates contained large proportions of C18:1 (42–50% of TFA), C16:0 (26–38% of TFA), and C18:2 (5–18% of TFA). A similar trend was found in our stomach content samples (Table 2). Polyunsaturated fatty acids (PUFA's) are considered beneficial in human health, and a n6/n3 ratio <5 is recommended [Kouba and Mourot, 2011]. In the Australian lizards *C. nuchalis* and *Trachydosaurus rugosus*, differences in dietary FA composition influenced thermoregulatory behavior; a higher PUFA intake (C18:2

n6c), resulted in a lower selected body temperature [Geiser et al., 1992; Geiser and Learmonth, 1994]. In *C. nuchalis* the n6/n3 ratio of fat deposits followed the dietary n6/n3 ratio and a similar, but smaller effect, was found for muscle tissue [Geiser and Learmonth, 1994]. In our samples, the n6/n3 ratio was highly variable (6.6–27.4) as was the case for the n6/n3 ratio in alates (5.8–57.7) in Kinyuru et al. [2013]. In the plant and *Chortoicetes terminifera* samples the PUFA content was higher and the n6/n3 ratio was considerably lower (0.2–0.7). Both *Drepanotermes* alates and *C. terminifera* are seasonally abundant [Farrow, 1979; James, 1991]. Hence, during an outbreak of *C. terminifera* the diet of *P. vitticeps* would likely have a high CP and a low TFA content, as well as a low n6/n3 ratio (Table 2). During periods in which arthropods are less abundant, the *P. vitticeps* diet might well consist of mostly plants, as suggested by MacMillen et al. [1989]; and have a lower CP and TFA content and a low n6/n3 ratio.

The captive diet of *P. vitticeps* can include a large variety of plant species [Minch, 2008; Köhler et al., 2013]. However, the number of commercially available insect species is more limited. Commonly used insects are House crickets (*Acheta domesticus*), Yellow mealworms (*Tenebrio molitor*), and locusts (*Schistocerca gregaria* and *Locusta migratoria*) [Finke, 2002; Oonincx and van der Poel, 2011]. Samples of these species taken during a dietary study were analyzed for CP, crude fat (CF) [Oonincx et al., 2010], and for FA composition (Unpublished data; Table 3). All species and instars were rich sources of CP and CF. The two locust species were similar in composition, although there were large differences between development stages; in adults C18:3n3 was absent, while this was 9.5–12.4% of TFA in penultimate locusts. Consequently, their n6/n3 ratios differed greatly. The composition of penultimate stage locusts is most similar to *C. terminifera* and the composition of *Drepanotermes* alates is most similar to Yellow mealworms (Tables 2 and 3). House crickets are a good source of CP, and n6 PUFA's [Oonincx et al., 2010]. A varied diet comprised of these insect species, combined with a large contribution of leafy vegetables, rich in n3 FA's, would closely resemble the expected natural diet of *P. vitticeps*. Similar studies are needed to elucidate the natural diet of *P. vitticeps*, accounting for temporal, spatial, and potentially ontogenetic variation. These studies should include chemical analysis of dietary items, specifically concerning Ca, P, vitamin A,D, E, carotenoids, [Finke and Oonincx, 2013], and possibly PUFAs. Furthermore, studies on adapting the chemical composition of feeder insects to mimic the composition of insects consumed in the wild should be conducted.

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