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Brewer's Yeast, *Saccharomyces cerevisiae*, Enhances Attraction of Two Invasive Yellowjackets (Hymenoptera: Vespidae) to Dried Fruit and Fruit Powder

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Abstract

The German yellowjacket, *Vespula germanica* F., and common yellowjacket, *Vespula vulgaris* L. (Hymenoptera: Vespidae), are pests of significant economic, environmental, and medical importance in many countries. There is a need for the development and improvement of attractive baits that can be deployed in traps to capture and kill these wasps in areas where they are a problem. Yellowjackets are known to feed on fermenting fruit, but this resource is seldom considered as a bait due to its ephemeral nature and its potential attractiveness to nontarget species. We analyzed the headspace volatiles of dried fruit and fruit powder baits with and without Brewer's yeast, *Saccharomyces cerevisiae*, using gas chromatography–mass spectrometry, and we field tested these baits for their attractiveness to yellowjackets in Argentina. The addition of yeast to dried fruit and fruit powder changed the volatile compositions, increasing the number of alcohols and acids and decreasing the number of aldehydes. Dried fruit and fruit powder baits on their own were hardly attractive to yellowjackets, but the addition of yeast improved their attractiveness by 9- to 50-fold and surpassed the attractiveness of a commercial heptyl butyrate-based wasp lure. We suggest that further research be done to test additional varieties and species of yeasts. A dried fruit or fruit powder bait in combination with yeast could become a useful tool in the management of yellowjackets.

Key words: *Vespula*, Brewer's yeast, *Saccharomyces*, fermenting fruit, trap bait

Yellowjackets in the genus *Vespula* (Hymenoptera: Vespidae) are significant nuisance pests due to their aggressive nest-defense behavior, their painful sting, and their tendency to frequent urban and agricultural areas (Akre et al. 1980, de Jong 1990, Beggs et al. 2011). They are also pests of the beekeeping industry, as they can attack honey bee hives to feed on honey and bee larvae (Clapperton et al. 1989, de Jong 1990). They frequently sting humans, causing thousands of hospital visits every year (Langley et al. 2014), and they also cause life-threatening anaphylactic shock in some people (Bonay et al. 1997, Faux et al. 1997, Vetter et al. 1999). Yellowjackets build cryptic underground or aerial nests and, in late summer, build up high population levels. Their presence, especially in invaded areas, has adversely impacted logging and agricultural productivity and has resulted in school and recreational park closures in some instances (Akre et al. 1980).

The common yellowjacket, *Vespula vulgaris* L., and German yellowjacket, *Vespula germanica* F., are native to Europe but have become invasive in many countries, including some with no native yellowjackets such as New Zealand and Argentina (Beggs et al. 2011). In New Zealand, *V. vulgaris* competes with endemic bird species for honeydew resources in beech forests and has also greatly reduced populations of several native arthropods (Beggs 2001). In Argentina, both *V. vulgaris* and *V. germanica* are invasive (Willink 1980, Masciocchi et al. 2010), have rapidly spread across the country (Masciocchi and Corley 2013), and have become prevalent nuisance pests.

Many synthetic chemical lures have been developed and deployed in traps to capture and kill social wasps (MacDonald et al. 1973; Landolt 1998, 2000; Day and Jeanne 2001; El-Sayed et al. 2009; Rust and Su 2012). These traps can alleviate the impact of yellowjacket pests by reducing local populations and by diverting foraging wasps away from humans (Davis et al. 1973, Rust and Su 2012). However, these lures are not equally attractive to all species, and no operational synthetic lure has been developed specifically for *V. germanica* and *V. vulgaris*. Although a blend of isobutanol and acetic acid attracts *V. germanica* (Landolt 1998, Day and Jeanne 2001), this lure does not appear to work for all populations (El-Sayed et al. 2009; Babcock and Borden, unpubl. obs.), suggesting that yellowjackets may respond to lures differently in different geographical locations. Yellowjackets are generalist scavengers on both carbohydrate and protein resources and are known to feed on overripe fruit (Akre et al. 1980, Edwards 1980, Matsuura and Yamane 1990). While yellowjackets utilize both visual and olfactory cues to locate carbohydrate resources, olfaction is the more important sensory mode (Hendrichs et al. 1994, Moreyra et al. 2006). Several studies have considered volatiles from fruit and sugar resources as attractants for yellowjackets (McGovern et al. 1970, Landolt 1998, Day and Jeanne 2001, Dvořák and Landolt 2006, Brown et al. 2014, Landolt and Zhang 2016), but many of these lures are attractive only to a few species (Landolt et al. 2005, El-Sayed et al. 2009). This suggests that synthetic chemical lures may not accurately represent the full spectrum and dynamics of volatile production in ripening fruit. Fresh fruit as an attractant is limited by its rapid spoilage (Day and Jeanne 2001) and its potential to attract nontarget species (Spurr 1996); however, dried fruit and freeze-dried fruit powders may produce the same volatiles as fresh fruit and can be stored for long periods without spoiling. Prior to this study, these materials have never been considered for use as operational wasp attractants.

Yellowjackets are typically observed feeding on overripe and fermenting fruits (Edwards 1980, Matsuura and Yamane 1990). Fruits like pear may become more attractive as they age (Day and Jeanne 2001), and a recent study suggests that fermented apple pieces in syrup is attractive to wasps (Dvořák and Landolt 2006). Fermentation involves the breakdown of fruits by microorganisms such as bacteria and yeasts, which metabolize fruit constituents and alter the chemical composition (Ubeda and Briones 2000, Pino et al. 2010, Pielech-Przybylska et al. 2016). Microorganisms can produce volatiles that play a role in attracting insects to food resources (Davis et al. 2013). For example, vinegar flies, *Drosophila melanogaster* (Meigen), exploit volatiles from the yeast *Saccharomyces cerevisiae* to locate suitable fermenting fruits (Becher et al. 2012). In a recent study, *V. germanica* and the western yellowjacket, *Vespula pensylvanica* (Saussure), were attracted to an epiphytic fungus isolated from the surface of apples (Davis et al. 2012), providing evidence that microbial cues affect foraging decisions.

Our objectives were to test the hypotheses that dried fruit and fruit powders are attractive to *V. vulgaris* and *V. germanica* and that adding Brewer's yeast, *S. cerevisiae,* to these fruit sources will change their headspace volatiles and enhance their attractiveness.

Materials and Methods

Fruit Baits

Dried fruit baits were made from dried apples (Real Canadian Superstore, Coquitlam, BC, Canada) and dried bananas (Thrifty Foods, Coquitlam, BC, Canada) ground into small pieces (approximately 0.5 cm^2) using a food processor. The two fruits were mixed together in equal proportions by weight, and 25 g of this mixture were placed into a teabag (6 × 8 cm; Finum Slim Tea Filter, Riensch & Held GmbH & Co. KG, Hamburg, Germany) to which sodium lauryl sulfate (2.5 g) was added to reduce water surface tension. Dried fruit plus yeast baits were made by adding 2.5 g of Brewer's yeast (Danstar Belle Saison Beer Yeast, Lallemand Inc., Montreal, QC, Canada) to the above mixture. Teabags were folded shut and secured using a single metal staple.

Fruit powder baits were made from freeze-dried apple powder (Drum Dried Northern Spy Apple Powder, Firehouse Pantry, Brookville, OH) and freeze-dried banana, strawberry, and raspberry powder (Just Tomatoes, Etc., Westley, CA) mixed together in equal proportions by weight. Aliquots of this mixture (25 g) were placed in teabags as above, and 2.5 g of sodium lauryl sulfate were added. Fruit powder plus yeast baits were made by adding 2.5 g of Brewer's yeast to the above mixture. Teabags were folded shut and secured as above.

Headspace Volatile Analyses

For each of the four teabag baits, headspace volatiles were captured and analyzed. A single teabag bait was submerged in 500 ml of water in a 600-ml beaker, which was placed into a clean Pyrex glass aeration chamber (340 mm high × 125 mm wide). An air pump (A.O. Smith, Tipp City, OH) drew charcoal-filtered air at 0.5 liter/min through the aeration chamber and then through a glass tube containing 0.2 g of Porapak-Q (50–80 mesh). Aerations were run for 24 h, after which volatiles were desorbed from Porapak-Q with 2 ml of a 50:50 mixture of pentane and ether. The extracts were then concentrated to a volume of 500 µl.

Aliquots (2 µl) of Porapak-Q extracts were analyzed using a Varian 3800 gas chromatograph (GC) coupled to a Saturn 2000 Ion Trap mass spectrometer (MS) (Agilent Technologies Inc., Santa Clara, CA). The GC-MS was fitted with a DB-5 GC-MS column (30 m × 0.25 mm internal diameter) and operated in full-scan electron impact mode. Helium was used as the carrier gas at a flow rate of 35 cm/s, with the following temperature program: 50°C (held for 5 min), then 10°C/min until 280°C (held for 36 min). The injector was set at 250°C and the transfer line at 280°C. The foreline pressure was 52.4 kPa. Sample volatiles were identified and quantified by comparing their retention times and mass spectra with those of authentic standards.

Field Experiments

Two field experiments were run concurrently at different sites near San Carlos de Bariloche, Argentina from 2–4 March, 2016. Experiment 1 (N = 12 replicates) was conducted at a sheep and cattle farm, and Experiment 2 (N = 8 replicates) was conducted in an urban nature reserve. Both experiments were set up in a randomized complete block design, with the blocking factor as different sections of the field site. Experimental baits were immersed in 500 ml of water inside plastic bag-style wasp traps (Scotts Canada Ltd., Delta, BC, Canada), with two offset entry ports to discourage escape. There was no incubation period for any bait prior to the onset of Experiments 1 and 2. Traps were hung ≥5 m apart approximately 1 m above ground from bush and tree branches using white cotton string. Traps were left in the field for 48 h before being collected. The contents of each trap were poured through a strainer and captured yellowjackets were counted and identified to species using characteristic markings on their head and abdomen (Akre et al. 1980, Masciocchi et al. 2010).

Experiment 1 tested the attractiveness of dried fruit with and without Brewer's yeast. The treatments were: 1) dried fruit teabag bait, 2) dried fruit plus yeast teabag bait, 3) heptyl butyrate-based lure (50-ml emulsifiable concentrate, 77.4 % = 0.81 g/lure heptyl butyrate in 450-ml water; Scotts Canada Ltd., Delta, BC, Canada), and 4) water control. Because heptyl butyrate is attractive to several yellowjacket species (MacDonald et al. 1973, Landolt et al. 2005, El-Sayed et al. 2009), treatment 3) was used as a positive control. Treatment 4) consisted of 500-ml water and 2.5 g of sodium lauryl sulfate and was used as a negative control.

Experiment 2 tested the attractiveness of fruit powder with and without Brewer's yeast using methodology as described for Experiment 1. The treatments were: 1) fruit powder teabag bait, 2) fruit powder plus yeast teabag bait, 3) heptyl butyrate-based lure, and 4) water control.

Data from Experiments 1 and 2 were transformed by $\log_{10}(x + 1)$ and analyzed using JMP 12 (SAS Institute Inc., Cary, NC). The mean numbers of yellowjackets captured per trap were compared among treatments using a one-way randomized block analysis of variance and Tukey's honest significant difference test for pairwise comparisons of means. In all cases, $\alpha = 0.05$.

Results

Headspace Volatile Analyses

The headspace volatiles identified by GC-MS and their relative abundance in blends emanating from dried fruit teabags with and without yeast (Fig. 1) and fruit powder teabags with and without yeast (Fig. 2) are summarized in Table 1. Volatile compositions of all four baits differed. In general, the presence of yeast increased the number of alcohols and carboxylic acids. 2-Methylbutyric acid, isobutyric acid, and 2-phenylethyl alcohol emanated only from baits containing yeast. The presence of yeast also appeared to reduce the number of aldehydes and to increase the relative abundance of isoamyl acetate (1.33 and 1.43 times in the dried fruit bait and fruit powder bait, respectively). Dodecyl alcohol emanated from all the baits and was likely a derivative of the sodium lauryl sulfate surfactant.

Field Experiments

In Experiment 1, there was a significant difference among treatment means for both *V. vulgaris* ($F_{3,33} = 79.47$; $P < 0.0001$) and *V. germanica* ($F_{3,33} = 43.76$; $P < 0.0001$) (Fig. 3). For both species, traps baited with dried fruit plus yeast captured significantly more yellowjackets than traps baited with dried fruit and water controls. For *V. vulgaris* (but not *V. germanica*), traps baited with dried fruit plus yeast captured significantly fewer yellowjackets than traps with the heptyl butyrate lure ($P_{V. vulgaris} = 0.005$; $P_{V. germanica} = 0.984$). For both species, captures in traps baited with dried fruit alone did not differ from those in water control traps ($P_{V. vulgaris} = 0.740$; $P_{V. germanica} = 0.577$) and were significantly lower than in traps baited with the heptyl butyrate lure ($P < 0.0001$ for both species).

In Experiment 2, there was also a significant difference among the treatment means for both *V. vulgaris* ($F_{3,21} = 46.16$; $P < 0.0001$) and *V. germanica* ($F_{3,21} = 45.37$; $P < 0.0001$) (Fig. 4). For both species, traps baited with fruit powder plus yeast captured significantly more yellowjackets than traps baited with fruit powder, the heptyl butyrate–based lure or water ($P < 0.0001$ for each of the six pairwise comparisons). Traps baited with fruit powder alone captured significantly more *V. germanica* than water control traps ($P < 0.001$), but these treatments did not differ significantly in the number of *V. vulgaris* captured ($P = 0.069$). For both species, captures in traps baited with fruit powder did not differ from those in traps baited with the heptyl butyrate-based lure ($P_{V. vulgaris} = 0.279$; $P_{V. germanica} = 0.962$).

Traps baited with dried fruit and fruit powder teabags with and without yeast captured low numbers of vinegar flies and earwigs. Traps baited with fruit powder plus yeast also captured a total of three *Polistes* paper wasps. No honey bees or other hymenopteran insects were captured in either of the two experiments.

Discussion

The addition of yeast had a significant effect on the volatile blends emanating from dried fruit and fruit powder. Isobutyric acid, 2-methylbutyric acid, and 2-phenylethyl alcohol were present in headspace volatile blends of dried fruit and fruit powder only when yeast was added, and furfuryl alcohol was produced when yeast was added to fruit powder. This is expected because yeast metabolism

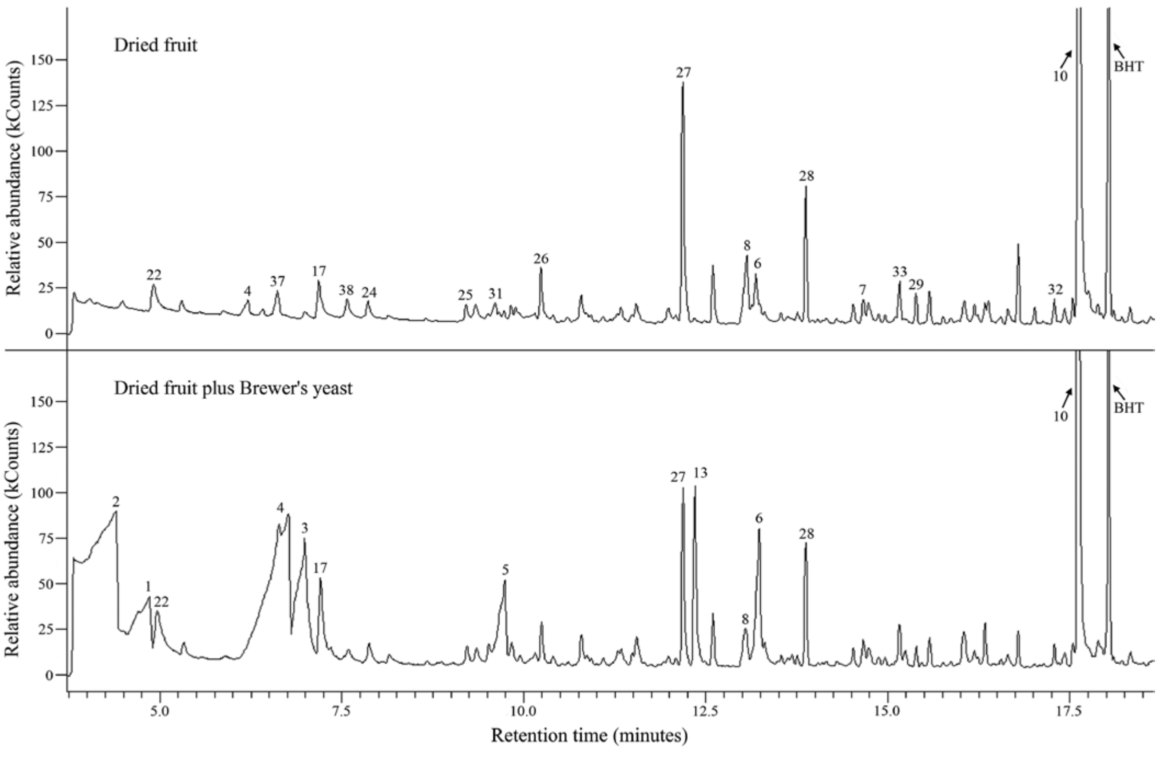

Fig. 1. Total ion chromatograms of odorants originating from dried fruit baits with and without Brewer's yeast. Numbers above or next to odorants (peaks) correspond to those listed in Table 1. BHT = butylated hydroxytoluene (an antioxidant in the solvent). Note particularly the increase in relative abundance of poorly chromatographing acids (numbers 1, 2, 3, 4, and 5; see Table 1) when yeast is present.

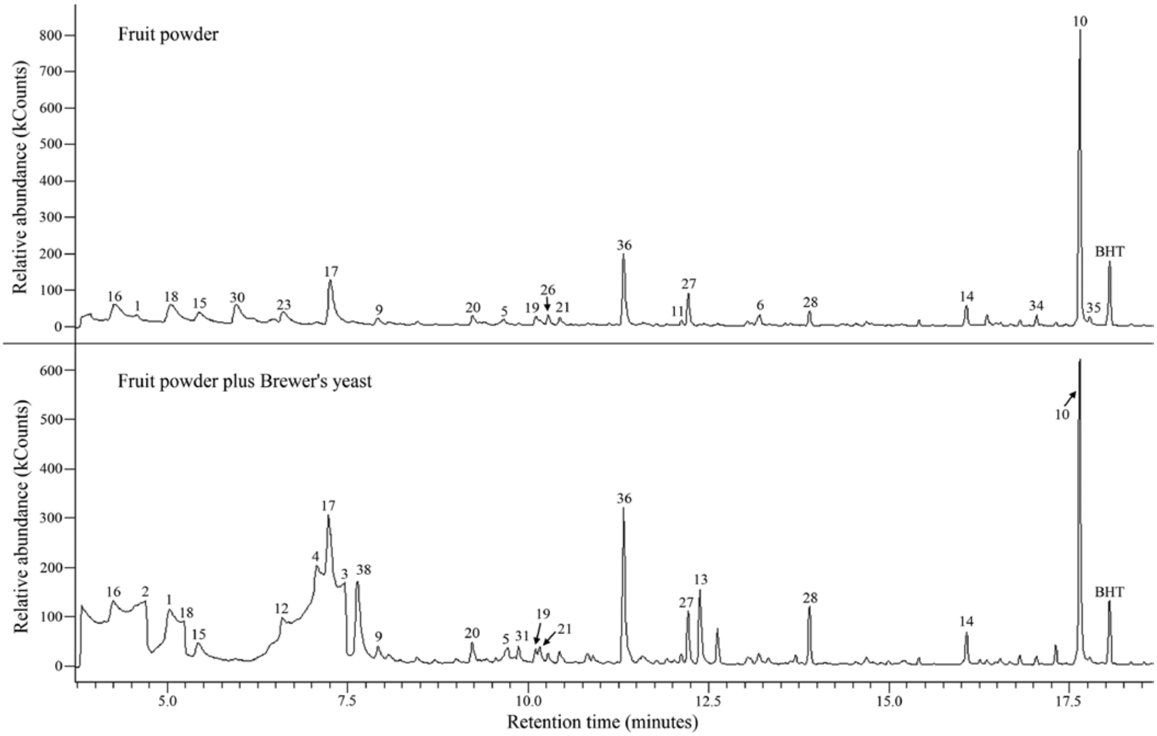

Fig. 2. Total ion chromatograms of odorants originating from fruit powder baits with and without Brewer's yeast. Numbers above or next to odorants (peaks) correspond to those listed in Table 1. BHT = butylated hydroxytoluene (an antioxidant in the solvent). Note particularly the increase in relative abundance of poorly chromatographing acids (numbers 1, 2, 3, and 4; see Table 1) when yeast is present.

produces higher alcohols during fruit fermentation (Palanca et al. 2013). Surprisingly, the esters in headspace volatile blends of fruit compositions did not change when yeast was added. Yeast fermentation typically produces esters from the metabolism of carboxylic acids and alcohols (Palanca et al. 2013, Golonka et al. 2014). It is possible that the dried fruit and fruit powder, unlike fresh fruit, do not contain the specific precursors necessary for ester formation. *S. cerevisiae* possesses several aldehyde dehydrogenases and reductases, which convert aldehydes to carboxylic acids such as acetic acid (Liu and Moon 2009, Datta et al. 2017). This explains the smaller number of aldehydes and the larger number of carboxylic acids in headspace volatile blends of dried fruit mixtures containing yeast. In particular, furfural is a known inhibitor of microbial fermentation, as it damages cell membranes and DNA, inhibits enzymatic activity, and prevents DNA and RNA synthesis (Liu and Moon 2009). Furfural is present in the fruit powder volatile blend but is absent when yeast is added; this is indicative of aldehyde reductase activity.

Neither dried fruit nor fruit powder was very attractive on its own to yellowjackets. Fruit powder alone attracted only a few yellowjackets, but it performed on par with the heptyl butyrate-based lure for both species (Fig. 4). In comparison, the dried fruit bait attracted significantly fewer yellowjackets than the heptyl butyrate lure (Fig. 3). These data in combination suggest that fruit powder is more attractive to yellowjackets than dried fruit. This phenomenon could be explained by the greater number of esters emanating from fruit powder than from dried fruit. Esters are fruity or floral fruit odorants, and many are known as yellowjacket attractants (Davis et al. 1967, 1968; McGovern et al. 1970; Landolt 1998). Butyl butyrate, an ester present in our fruit powder bait, but not in our dried fruit bait, is a known attractant for *V. vulgaris* (El-Sayed et al. 2009) and other species such as the western yellowjacket, *V. pensylvanica* (Landolt 1998). Two additional esters, ethyl hexanoate and isoamyl acetate, are reported as attractants for *V. vulgaris* (Brown et al. 2014) and both were present in the fruit powder volatile blend. Isoamyl acetate was also found in dried fruit volatiles but in much lower concentrations. The fruit powder volatile blend contained isobutyl acetate, which is formed by the esterification of isobutanol and acetic acid. These two latter odorants are strong attractants for *V. germanica* (Landolt 1998, Day and Jeanne 2001), suggesting that the corresponding ester may also be attractive. Furthermore, our fruit powder volatile blend included raspberries and strawberries, which were not present in the dried fruit composition. Raspberries emit esters such as butyl acetate and ethyl hexanoate (Aprea et al. 2015) that we observed only in the fruit powder volatile blend, and strawberries contain 4-hydroxy-2,5-dimethyl-3-furanone (Williams et al. 2005); some of these odorants may have played a role in the differential attractiveness of dried fruit and fruit powder.

The presence of Brewer's yeast in the dried fruit and fruit powder compositions resulted in a 9- to 50-fold increase in bait attractiveness relative to the dried fruit and fruit powder alone. For both species of yellowjackets, the fruit powder plus yeast bait was also significantly more attractive than the heptyl butyrate-based lure. Heptyl butyrate is a widely used attractant for yellowjackets (MacDonald et al. 1973, Landolt et al. 2005, El-Sayed et al. 2009, Landolt and Zhang 2016).

By-catches of nontarget insects were minimal. Small numbers of vinegar flies and earwigs were captured in traps with dried fruit and fruit powder, regardless of the presence of yeast, and the eight traps baited with fruit powder plus yeast captured a total of three *Polistes* paper wasps. No bees or any other Hymenoptera were captured, even though they were present in both field sites. Therefore, there is apparently minimal potential for traps baited with dried fruit or fruit powder plus yeast to have an adverse effect on beneficial species in this geographical area.

Table 1. Compositions of headspace volatile blends emanating from teabags containing dried fruit and fruit powder, with and without Brewer's yeast

Compounds	No.	Dried fruit	Dried fruit + yeast	Fruit powder	Fruit powder + yeast
Carboxylic acids					
Butyric acid	1		5.3	1.8	3.9
Isobutyric acid	2		12.8		7.2
2-Methyl butyric acid	3		8.4		9.8
3-Methyl butyric acid	4	1.0	17.1		14.4
Hexanoic acid	5		5.0	1.3	0.9
Octanoic acid	6	1.0	5.1	1.6	
Nonanoic acid	7	0.5			
Benzoic acid	8	2.7	1.6		
Alcohols					
2-Heptanol	9			1.2	0.4
Dodecyl alcohol	10	66.7	30.2	25.5	8.8
Linalool	11			0.5	
Furfuryl alcohol	12				5.6
2-Phenylethyl alcohol	13		4.3		2.4
Eugenol	14			2.1	1.0
Esters					
Butyl acetate	15			4.1	1.2
Isobutyl acetate	16			6.6	3.7
Isoamyl acetate	17	1.8	2.4	12.4	17.7
Ethyl butyrate	18			7.5	4.1
Butyl butyrate	19			1.7	0.3
Butyl isobutyrate	20			1.5	0.8
Ethyl hexanoate	21			1.1	0.4
Aldehydes					
Hexanal	22	1.8	1.8		
(*E*)-2-Hexenal	23			3.9	
Heptanal	24	0.8			
(*E*)-2-Heptenal	25	0.5			
Octanal	26	1.7		1.3	
Nonanal	27	7.6	3.8	3.4	1.6
Cecanal	28	3.5	2.2	1.4	1.6
Undecanal	29	0.8			
Furfural	30			6.4	
Ketones					
Sulcatone	31	0.3			0.7
Geranyl acetone	32	0.6			
2-Undecanone	33	0.9			
α-Ionone	34			0.8	
β-Ionone	35			0.8	
4-Hydroxy-2,5-dimethyl-3-furanone	36			8.6	5.8
Others					
Hydrogen peroxide	37	1.1			
Styrene	38	1.0			6.7

The percentage of each volatile identified by GC-MS in a specific blend is shown. Numbers correspond with compounds identified in Figs. 1 and 2. Total percentages of all odorants may be less than 100% due to GC column bleed compounds and to several unknown odorants (all less than 2%).

The distinctively different headspace volatile blends originating from dried fruit and fruit powder with and without yeast are consistent with reports that fruit fermentation by yeasts results in the production of higher alcohols and esters (Palanca et al. 2013, Golonka et al. 2014) and the reduction of aldehydes to carboxylic acids (Liu and Moon 2009, Datta et al. 2017). One higher alcohol, 2-phenylethyl alcohol, originated only from baits containing yeast. This alcohol alone is weakly attractive to yellowjackets (Davis et al. 2012) and may have contributed to the attractiveness of fruit plus yeast baits. Several carboxylic acids such as isobutyric acid, 2-methylbutyric acid, and 3-methylbutyric acid were present in headspace volatile blends only when yeast was part of the fruit composition. These acids may be attractive semiochemicals for yellowjackets. Fewer aldehydes were generated from compositions containing yeast, suggesting that aldehydes may be yellowjacket repellants that are removed by the yeast. The role of Brewer's yeast in attracting yellowjackets suggests that, like other insects (Becher et al. 2012, Davis et al. 2013), yellowjackets may use microbe-produced volatiles to locate fermenting fruit. It is also possible that yeasts may be mutualistic symbionts of yellowjackets. Recent studies indicate that *S. cerevisiae* uses social wasps as vectors, overwintering sites (Stefanini et al. 2012), and sexual reproduction sites (Stefanini et al. 2016). In turn, yellowjackets may receive nutrients in the form of metabolic by-products, e.g., amino acids (Hansen et al. 2011), from

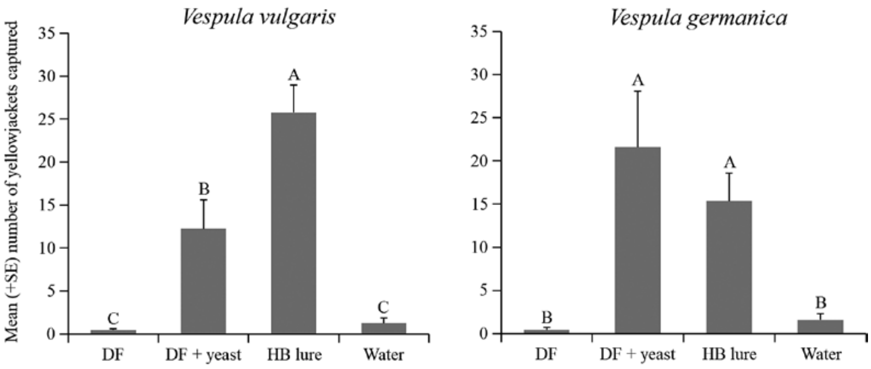

Fig. 3. Mean numbers of *V. vulgaris* and *V. germanica* captured per trap in Experiment 1 (N = 12) that was run at a sheep and cattle farm near San Carlos de Bariloche (Argentina) and tested teabags containing dried fruit (DF) with and without Brewer's yeast. Traps baited with a heptyl butyrate (HB)-based lure or filled with water were used as positive and negative controls, respectively. Bars labeled with the same letter are not significantly different (Tukey's honest significant difference test, $P < 0.05$).

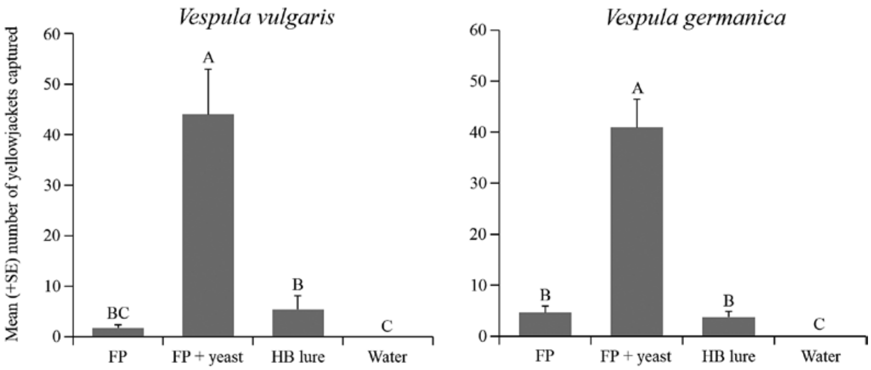

Fig. 4. Mean numbers of *V. vulgaris* and *V. germanica* captured per trap in Experiment 2 (N = 8) that was run at an urban nature reserve near San Carlos de Bariloche (Argentina) and tested fruit powder teabags (FP) with and without Brewer's yeast. Traps baited with a heptyl butyrate (HB)-based lure or filled with water were used as positive and negative controls, respectively. Bars labeled with the same letter are not significantly different (Tukey's honest significant difference test, $P < 0.05$).

endosymbiotic yeasts, as shown in many insect–microbe associations (Douglas 1989). Thus, orientation to yeast-produced volatiles may be an adaptive trait for yellowjackets. The recent discovery (Ibarra Jimenez et al. 2017) that the digestive tracts of five species of North American yellowjackets harbor several species of yeasts (particularly species in the genera *Lachancea* and *Hanseniaspora* but not *S. cerevisiae*) suggests that these potential symbionts may produce a composition of volatiles that is even more attractive than those produced by *S. cerevisiae* on a fruit powder substrate.

In conclusion, our data suggest that fruit powder plus yeast shows potential for use as an operational yellowjacket bait. The bait may be improved further by using different fruits or varieties and species of yeasts.

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