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Research article

Reducing dust and allergen exposure in bakeries

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Abstract: Bakers have a continuing high incidence of occupational allergic asthma. In factory bakeries they are exposed not only to flour dust containing allergens, but also improvers whose ingredients enhance the strength and workability of the dough and its speed of rising. Improvers are flour-based but can contain added soya, fungal or bacterial enzymes that are also allergenic, as well as vegetable oil, calcium sulphate/silicate and organic esters. This study investigated the dustiness of the components used in factory bakeries and whether altering improver ingredients could reduce dust and allergen exposure. A standardised rotating drum test was employed on the individual components, as well as a representative improver and three practicable improver modifications by decreasing calcium sulphate, calcium silicate or increasing oil content. Levels of dust, the allergens wheat flour amylase inhibitor (WAAI) and soya trypsin inhibitor (STI) were measured in the generated inhalable, thoracic and respirable sized fractions. A "scooping and pouring" workplace simulation was also performed. Initial tests showed that dustiness of several wheat flours was relatively low, and even lower for soya flour, but increased in combination with some other improver components. All three improver modifications generally reduced levels of dust, STI and WAAI, but increasing oil content significantly decreased dust and STI in comparison to the standard improver and those improvers with reduced calcium silicate or sulphate. The simulation demonstrated that increased oil content reduced inhalable levels of gravimetric dust, STI and WAAI. Changing improver formulation, such as increasing oil content of flour by a small amount, may represent a simple, practical method of reducing bakery workers' exposure to dust and allergens where improvers are used. It may be a useful adjunct to engineering control, changes to work practices and appropriate training in reducing the risk to bakers' respiratory health.

Keywords: allergen; bakers; exposure reduction; dustiness; flour dust

1. Introduction

Bakers have historically had high incidence rates of occupational asthma [1,2]. Recent Great Britain statistics suggest that flour/grain exposure remains one of the top two causes of occupational asthma and that the average rate of reported cases of asthma in the period 2006–2015 was 45 per 100,000 per year for bakers and flour confectioners [3].

Bakeries are potentially dusty workplaces and it is often assumed that any airborne dust is a simple consequence of all flour being the same intrinsically "dusty material", and the poor health outcomes are a consequence of this dust reaching the respiratory system of workers. Certainly wheat flour contains a number of endogenous allergens [4], including wheat flour alpha amylase inhibitor (WAAI) [5,6]. A number of studies have looked at the prevalence of allergic symptoms and sensitisation by means of specific IgE measurements or skin prick tests [7,8]. But there also are different types of wheat flour that are employed for different bakery commodities or as filler flours as opposed to higher quality bread making flours. Flours from different cereals (e.g., wheat, rye, soya etc.) may also be used in various products. All flours may not have the same intrinsic dustiness or allergen content.

To improve the quality and the processing of dough in industrial bakeries, flour is often supplemented with additives, including enzymes such as fungal alpha-amylase (FAA) that aids the conversion of starch to sugars to aid the dough rising. Such enzymes of fungal or bacterial origin are known to be potent allergens, causing sensitisation and IgE mediated symptoms to the ocular, nasal and respiratory systems, amongst bakery workers [7,9,10,11]. Such extrinsic enzymes are added via an "improver" that consists of several agents that are mixed into the bulk flour to improve the quality of the bread. Agents in improvers include "binders" such as soya flour and soya oil that themselves contain known respiratory sensitisers [12]. Improvers also include emulsifier mixes and "bulking agents" e.g., calcium sulphate or calcium carbonate that help blend fatty materials into the mix and also fulfil the role of calcium dietary supplementation. Ascorbic acid (vitamin C) is also added for reasons of dietary supplementation. A typical emulsifier mix consists of diacetyltartaric acid esters of mono and diglycerides together with a "free flow agent" to help prevent machinery clogging, in the UK calcium silicate as 5% of the emulsifier mix is generally employed. The constituents of a typical UK improver and their concentrations are shown in Table 1.

Table 1. A general description of typical UK bakery improvers.

Nature/purpose of additive	Examples	%
Bulk material	Wheat flour	31.96
Binder	Soya flour	20
Binder	Rapeseed oil	2
Enzyme additives to improve dough/bread characteristics	Fungal alpha amylase that releases sugars from starch, aiding fermentation	0.044
Other additives	Ascorbic acid	1
Bulking agents	Calcium carbonate or calcium sulphate, also used as calcium supplementation	25
Emulsifier mixture including free flow agents	Organic esters	19
	Calcium silicate as free flow or anticaking agent	1

Traditionally, bakery workers' exposure to flour has been reduced by promotion of control measures such as local exhaust ventilation (LEV), appropriate cleaning techniques, use of respiratory protective equipment (RPE), safety and awareness training and adjustments to working practices. UK workplace exposure limits (WEL) for flour dust have been established since 2001 at 10 mg/m^3 (8 hour time-weighted average) and 30 mg/m^3 for short-term 15 minute exposures. However, evidence from the UK suggest that despite these measures, bakery workers continue to be sensitised to flour dust and extrinsic enzyme levels with new cases of asthma occurring [3,7,13]. Interestingly Van Tongeren [14] has failed to find a temporal reduction in UK atmospheric flour dust levels over the period 1985–2003.

An initiative from within the industry had suggested a strategy of reducing exposure to the flour improver, which contains several allergens, as an effective approach for preventing new cases of sensitisation [15]. While improvers are available as pastes or liquid so likely to reduce inhalation exposure, mixing the improver as a dry powder has been regarded within the industry as the most effective way to ensure thorough dispersion throughout the flour.

Dustiness of flour or improver mixes can be measured in the laboratory by a number of techniques, but it is a relative term and the measurements obtained are dependent on the apparatus used, properties of the chemical tested, the influence of environmental conditions and the dust fractions measured. The European standard EN15051 was produced as a means of providing standardisation in the measurement of the dustiness of bulk materials [16]. This standard establishes reference test methods that classify the dustiness in terms of health-related particle size fractions of the bulk material. One of the laboratory methods uses a rotating drum with longitudinal vanes to lift the material under test and let it fall, producing a dust cloud. Air is drawn through the drum and the airborne dust is collected on two size selective foams and finally onto a filter. From appropriate weighings, dustiness values for the three health-related size fractions (respirable, thoracic and inhalable) are determined, giving a measure of the propensity of the dust to become airborne and the nature of the size of the dust particles and their likely deposition sites in the respiratory system. The inhalable fraction represents particles that can only enter the respiratory system as far as the larynx, the thoracic fraction where the particles are small enough to pass by the larynx into the tracheal and bronchial regions and the respirable fraction where the particles are small enough to penetrate into the deepest regions of the lung.

We have also extended this rotating drum test to include the extractions and measurement of relevant specific proteins, thus giving some idea of the aerolysation of allergens in produced dust. While initial work suggested that the measurement of fungal alpha amylase (FAA) in these laboratory studies would be problematic because of the low added levels involved, we could measure WAAI and also soya kunitz trypsin inhibitor (STI) a proven respiratory allergen in soya flour that is often a component of bakery improvers [17,18,19]. While WAAI and STI are both endogenous proteins causing significant sensitisation in bakers, it should be noted that they are not the only allergens found in wheat or soya flour. However, we believe that WAAI and STI may serve as useful surrogate measures for endogenous allergens. Also FFA, as an added enzyme to flour, may have different particle characteristics to endogenous allergens with regard to its ability to aerolyse. For this reason, we caution about over-interpretation of the results.

This paper describes some initial studies using the standardised rotating drum method to explore the dustiness of various flours and the ingredients, in various combinations, of bakery improvers. Subsequently we looked at improver ingredients that could lead to a reduction in dustiness, and may represent a simple, practical and cost-effective method of reducing exposure to dust and allergens in bakeries. This paper reports these laboratory studies examining combinations of improver ingredients to identify which generates the least airborne dust with the lowest allergen content by monitoring WAAI and STI.

2. Materials and Method

Materials for testing in this study were supplied by Association of Bakery Ingredient Manufacturers (ABIM) These samples were supplied colour coded so that analysis of the samples could be undertaken blind to their composition. The composition of the ABIM prepared material was only supplied after analyses were completed.

The study consisted of three elements:

(a) dustiness testing of three flour samples and the single components used within bakery improvers, with subsequent combinations of improver components with a flour sample.

(b) based on the outcomes of the first element, a number of practicable bakery improvers were formulated by ABIM that might reduce dustiness and liberation of allergens. Three potential ways of decreasing the dustiness were investigated, by increasing the amount of vegetable oil in the improver, by decreasing the calcium sulphate in the improver, and decreasing the amount of the free flow agent calcium silicate within the emulsifier. Seven improver mixtures were prepared by ABIM to reflect these manipulations in improver constituents and supplied colour coded; Red (R), Orange (O), Green (G), Black (Ba), Blue (Bu), White (W) and Yellow (Y).

(c) a single user test was also performed to study how these improvers behaved when handled manually and whether the dustiness testing results were replicated in a task simulation.

2.1. Rotating drum dustiness testing

Dustiness of materials were tested using the standardised rotating drum dustiness methodology, one of two methods defined within a European standard [16].

For the drum dustiness testing, essentially 35 ml of material was placed into a drum that rotated at 4 rpm with longitudinal vanes to lift and drop the dust and hence produce a dust cloud. Air was drawn through the drum at 38 L/min and entrained dust was collected onto a three stage sampler consisting of in series two, size selective metal foams, 20 pores per inch, 80 pores per inch and finally a glass fibre filter (GF/A) 80 mm in diameter. All components of the sampler are preconditioned and preweighed prior to use. After collection of dust on the individual foams and GF/A filter, gravimetric analysis allowed calculation of dust levels associated with the inhalable, thoracic and respirable health-related fractions.

Each dustiness test was performed in triplicate for statistical analysis. Calculation of the three health related fractions was as follows:

Inhalable fraction:

Weight on (20 ppi + 80 ppi foams + GF/A filter)/weight of material added to drum

Thoracic fraction:

Weight on (80 ppi foam + GF/A filter)/weight of material added to drum

Respirable fraction:

Weight on GF/A filter/weight of material added to drum

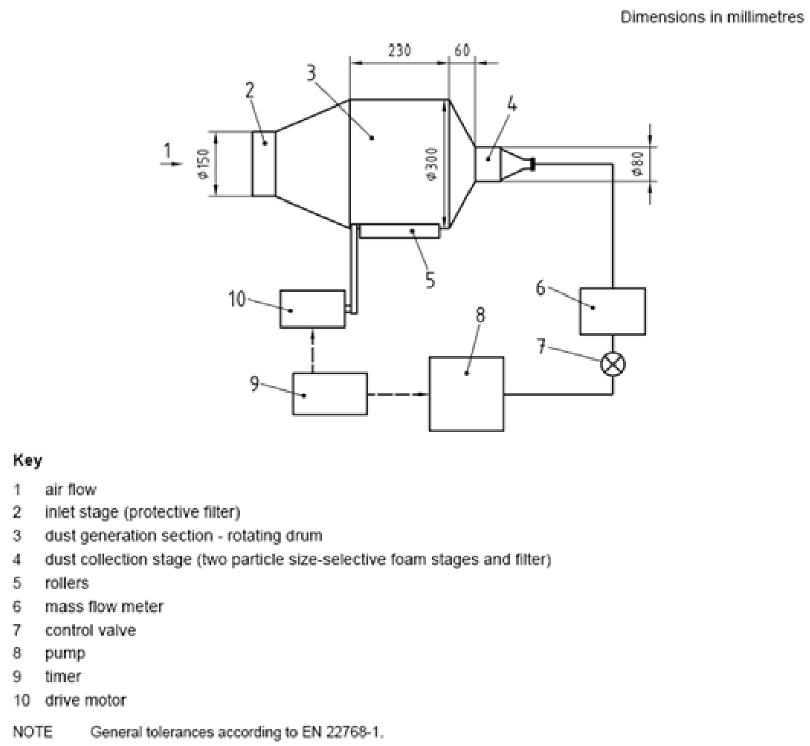

Figure 1. Schematic diagram of rotating drum test apparatus taken from [16].

Dustiness mass fractions is expressed as mg/kg. EN15051 also gives a dustiness classification, see Table 2.

Table 2. Dustiness classification (mg/kg) for rotating drum test according to EN 15051:2006.

Category	Inhalable dustiness mass fraction	Thoracic dustiness mass fraction	Respirable dustiness mass fraction
Very low	<200	<40	<10
Low	200–1000	40–200	10–50
Moderate	>1000–5000	>200–1000	>50–250
High	>5000	>1000	>250

We have extended this standardised gravimetric based dustiness test, where appropriate, to the amounts of allergens found in the three sized fractions, by extracting identified allergens from the foams, GFA filters and the bulk material. The two foams are extracted with 60 ml of phosphate buffer containing 0.1% Tween 20; while the GF/A filter is extracted with 15 ml of the same buffer. The bulk materials are extracted at 10% w/v with this extraction buffer. Extracts are mixed on a roller for two hours, and then filtered through a 0.45 µm filter, centrifuged and supernatants stored at –20 °C until analysis for the allergens. STI and WFA were measured as described later.

Calculations for the three fractions are performed as above relating the amount of allergens extracted from the respective foams/filters with the amount of material added to the drum.

2.2. Workplace simulation

Based on an observed bakery visit and discussion with Association of Bakery Ingredient Manufacturers, a repeated scooping and pouring activity was undertaken, standardised on a cycle of 20 scoops/pours per minute over 45 minutes. The activity was performed under still air conditions in an exposure chamber, grounded to reduce the effects of electrostatic charge on the aerosol, and where the improver was handled through use of the chamber's glove ports. Measurement of airborne dust levels was carried out using conical inhalable samplers (CIS-Casella Ltd) operating at a flow rate of 3.5 liters/min to measure the inhalable fraction and PGP10 cyclones samplers (GSM, GmbH) operating at a flow rate of 10 liters/min to measure the respirable fraction. Glass fibre filters were used in these samplers for gravimetric analysis and then extracted for specific allergens. A Microdust real-time dust monitor (Casella CEL) was also employed to give an indication of temporal dust fluctuations. The samplers were placed at heights typical of an operator's breathing zone.

2.3. Allergen and protein measurement

WAAI was measured using a non-competitive sandwich immunoassay [5]; STI was also measured using a non-competitive immunoassay using a commercially available polyclonal antisera (Chemicon Ab 1239) [20,21]. Quality control samples were included to monitor the "inter" and "intra" assay performance for these immunoassays.

The calculated lower limits of quantitation (LLOQ) in the dustiness testing fractions were 4 ng and 2 ng in the respirable fraction for WAAI and STI respectively; 18 ng and 8 ng for the thoracic fraction and 32 ng and 14 ng for the inhalable fraction. These calculations of LLOQ were based on analysis of individual methods using the software ProQuant (QIVX). The between batch analytical precisions of the WAAI and STI assays were 13% and 14% respectively, based on their routine use over the last two years.

The levels of WAAI and STI were also measured in duplicate extractions of each bulk improver using 10% w/v of the extraction buffer, with subsequent filtration through a 0.45 μm filter and centrifugation before analysis.

3. Results

3.1. Dustiness of single components and in combination

The results of the dustiness tests (Table 3) suggest that "flour" is not an intrinsically dusty material when compared with the EN 15051 classification (Table 2). Interestingly the bread making flour gave more inhalable dust than the two "filler" flours. However, flour is by its nature used in large quantities in bakeries and some of the activities in handling large quantities of flour have tended to be energetic leading to dust production.

It is noticeable in Table 3 that soya flour is less dusty than wheat flour, and that some of the other individual components of bakery improvers are considerably dustier than flour and are of smaller particle size (see the increased thoracic and respirable dustiness values). The components of improvers are employed in much smaller quantities than bread making flour (see Table 1) and usually added as single improver mix. Although more safely added as a paste, improver mix is still often added as a powder as it is considered to distribute more homogeneously throughout the flour.

Table 3. Dustiness test results on flour and single components of improver. Coefficients of variation of triplicate measurements shown in brackets.

	Inhalable (mg/kg)	Thoracic (mg/kg)	Respirable (mg/kg)
Wheat Flour 1 (filler)	133 (6.1)	63 (5.9)	26 (9.3)
Wheat Flour 2 (filler)	169 (7.1)	34 (6.7)	4 (6.1)
Wheat Flour 3 (bread making)	339 (5.4)	83 (7.8)	23 (8.5)
Soya flour	86 (7.0)	29 (6.6)	5 (5.7)
Calcium carbonate	317 (1.1)	166 (3.4)	39 (5.6)
Calcium sulphate	456 (7.9)	224 (8.8)	67 (5.7)
Emulsifier	6850 (3.3)	2389 (5.3)	592 (6.3)
Calcium silicate	3827 (1.8)	1001 (3.2)	76 (1.5)

We then tested to see if combinations of the single components influenced the dustiness of a representative flour sample (Table 4). The additions were at the concentrations found in a representative UK improver.

Table 4. Dustiness and WAAI allergen test results from combinations of flour and individual improver components in drum dustiness testing, Coefficients of variation of triplicates shown in brackets.

Ingredient combination	Dustiness			WAAI		
	Inhal (mg/kg)	Thor (mg/kg)	Resp (mg/kg)	Inh (µg/kg)	Thor (µg /kg)	Resp (µg/kg)
Wheat flour (100%)	327 (12)	74 (4)	3 (12.1)	13 (31.7)	5 (49.6)	<1 (34.9)
Wheat flour (75%) + Calcium sulphate (25%)	2073 (4.6)	701 (2.7)	38 (7.8)	332 (4.3)	119 (3.1)	9 (12.7)
Wheat flour (80%) + Emulsifier (20%)	3910 (6.3)	1013 (0.5)	71 (5.2)	1231 (31.7)	602 (55.8)	110 (14.8)
Wheat flour (98%) + Calcium silicate (2%)	7086 (5.7)	2145 (5.8)	270 (8.4)	4399 (10.4)	1528 (17.1)	20 (11.4)
Wheat flour (99%) + Calcium silicate (1%)	1452 (2.3)	455 (4.5)	38 (3.5)	319 (12.7)	200 (34.4)	15.3 (96.8)
Wheat flour (99.4%) + Calcium silicate (0.6%)	772 (1.7)	234 (7.6)	18 (4.6)	265 (16.3)	125.4 (16.8)	6 (97.1)

The data in Table 4 highlights that the addition of emulsifier, calcium sulphate or even a very small percentage of calcium silicate considerably increased the dustiness, including the smaller respirable sized particles. Addition of calcium silicate showed a dose-dependent increase. For example, the addition of 2% calcium silicate changes the flour from a low dustiness material to a high dusty material in all three particle size fractions. The amounts of calcium sulphate and emulsifier added reflect those found in a typical bakery improver mix, as does the 1% silicate addition. WAAI was quantified in the aerolysed inhalable fractions for the flour sample and the combinations. The levels of aerolysed allergen largely follow the dustiness measurements. The addition of emulsifier, calcium suphate and calcium silicate all significantly increased the levels of aerolysed wheat flour allergen, including for the smaller thoracic and respirable sized particles.

3.2. Dustiness and generation of allergens from seven modified improvers

The characteristics of the seven modified improvers developed for dustiness testing are described in Table 5. All these improvers also contain 1% ascorbic acid, 0.044% fungal alpha amylase and 20% soya flour. The Table also includes the measured levels of extractable WAAI, STI and moisture in these improvers. It is noted that although the improvers contained a higher percentage of wheat flour than the 20% of soya flour in all improvers, measurements suggested roughly 10-fold more extractable STI in comparison to WAAI per unit weight of improver. There is a relative constant level of extractable STI (0.103–0.246%) and WAAI (0.012–0.024%) from these improvers.

Table 5. Seven modified bakery improvers.

	Data supplied with improvers					Measured		
	Improver Descriptor	Wheat flour %	$CaSO_4$ %	Emulsifier %	Oil %	STI %	WAAI %	Moisture %*
R	Control: typical improver	32	25	20% with 5% Ca_2SiO_4	2	0.196	0.017	9.4
O	As R but no emulsifier.	52	25	None	2	0.246	0.024	11.5
G	As R but no $CaSO_4$	57	None	20% with 5% Ca_2SiO_4	2	0.103	0.013	8.6
Ba	As R but minimum Ca_2SiO_4	32	25	20% with 3% Ca_2SiO_4	2	0.155	0.013	9.7
Bu	As R but minimum $CaSO_4$	52	5	20% with 5% Ca_2SiO_4	2	0.117	0.018	8.9
W	As R but maximum oil	30	25	20% with 5% Ca_2SiO_4	4	0.213	0.012	8.9
Y	With all changes in Ba, Bu & W	50	5	20% with 3% Ca_2SiO_4	4	0.114	0.023	7.9

The letter codes refer to the improvers identified by colour as supplied by ABIM and measured blind to their contents

Table 6. Results from dustiness testing on the seven improvers.

	Dustiness (mg/kg bulk)			STI (μg/kg bulk)			WAAI (μg/kg bulk)		
	Inh	Thor	Resp	Inh	Thor	Resp	Inh	Thor	Resp
R	467 (2.4)	86 (3.5)	5 (5.4)	107 (30.2)	143 (15.8)	7.7 (25.9)	14.5 (58.9)	4.6 (51.0)	1.2 (56.8)
O	93 (5.5)	35 (5.1)	3 (0.5)	58.1 (8.2)	8.0 (44.3)	1.3 (70.7)	3.9 (49.5)	1.3 (51.2)	0.2 (32.7)
G	55 (9.3)	13 (5.6)	3 (8.1)	195 (13.8)	33 (27.3)	1.0 (24.0)	1.8 (9.9)	1.0 (16.8)	0.2 (1.0)
Ba	148 (2.0)	31 (6.6)	4 (6.0)	318 (1.4)	39 (4.3)	4.1 (42.3)	2.9 (86.8)	0.8 (1.1)	0.2 (6.5)
Bu	99 (2.4)	18 (3.9)	2 (0.5)	316 (38.2)	29.1 (45.4)	4.7 (33.3)	2.5 (35.5)	1.5 (57.4)	0.3 (63.1)
W	22 (3.0)	97 (7.7)	1 (0.3)	22 (32.0)	2 (15.9)	0.4 (51.4)	2.3 (30.0)	1.2 (55.5)	0.5 (63.0)
Y	34 (4.2)	11 (3.7)	27 (11.1)	5 (25.9)	1 (71.3)	0.3 (55.5)	2.6 (66.9)	0.9 (12.6)	0.2 (48.2)

Letter codes in this table refer to the colour-coded improvers supplied by ABIM. They are described in Table 5.

Results from the triplicate dustiness testing expressed per unit weight of each of the modified improvers are shown in Table 6. For the WAAI measurements, one, or in a very limited number of cases two of the triplicates were below the LLOQ. In these cases the mean and (coefficient of variation) has been derived by substituting 50% of the LLOQ for these results.

For the gravimetric dustiness and STI specific allergen measurement, the results allow statistical comparison across improvers and health related size fractions. Using the Kruskal-Wallis test there were significant differences ($p < 0.05$) between the improvers for dustiness and STI. In order of decreasing dustiness the results show:

Dust (Inhalable) R > Ba > Bu > O > G > Y > W (overall $p = 0.0034$)
Dust (Thoracic) R > O ≈ Ba > O ≈ G > B2 > G > Y > W (overall $p = 0.0036$)
Dust (Respirable) R ≈ Ba ≈ O > G > Bu ≈ Y > W (overall $p = 0.0079$)
STI (Inhalable) R > Ba ≈ Bu > G > O > W > Y (overall $p = 0.0034$)
STI (Thoracic) R > Ba ≈ Bu ≈ G > 0 ≈ W > Y (overall $p = 0.0048$)
STI (Respirable) Ba ≈ Bu > G ≈ O ≈ R > W ≈ Y (overall $p = 0.0110$)

where > reflects significant differences between improvers at the $p < 0.05$ level and p values are for the overall Kruskal-Wallis test, expressed per unit weight.

Of the three practicable modified improvers (Ba, Bu and W), W with the increased oil showed consistently and significantly decreased dustiness and aerosolization of STI across all three health fractions, and invariably lower than the other two practicable modifications (Ba & Bu). However, both Ba and Bu improvers showed significantly decreased dustiness and STI aerosolisation over R in the inhalation and thoracic fractions.

A similar Krusal-Wallis test for the WAAI suggested overall p values between 0.13 and 0.17, indicating no significant differences. However, the number of individual replicates falling below the limit of detection for WAAI assay and the general low levels of WAAI close to the LLOQ makes formal statistical comparison inappropriate. However, qualitatively the data suggests that the experimental improvers led to lower levels for airborne allergen WAAI in comparison with the typical improver (R), albeit not clearly for the respirable fraction.

Increasing the oil to the maximum amount (W) in comparison with the standard improver (R) gave average dustiness reductions by approximately 20, 10 and 5-fold in the inhalable, thoracic and respirable fractions respectively. Similar comparisons for the specific allergens showed reductions of 53-fold; 75-fold and 3-fold for STI and for WAAI 7-fold and 3-fold reductions for inhalable and thoracic fractions with no apparent reduction for the respirable fraction.

3.3. Workplace simulation

The user testing was performed on the typical improver (R) and the three practically possible improvers, namely extra oil (W), reduced calcium sulphate content (Bu) and the sample with the reduced calcium silicate in emulsifier (Ba). The user test results include the inhalable and respirable dust concentrations measured gravimetrically and using the Microdust real time monitor results. The user tests produced lower concentrations of airborne dust than the drum dustiness tests, and so the respirable fraction, using the PGP10 sampler, was too low to be accurately measured by gravimetric analysis. The Microdust monitor gave a more reliable measure of the respirable dust levels and so these results were used for the analysis, although they are likely to differ from the true levels of respirable dust due to the nature of instrument calibration. The inhalable concentrations and Microdust respirable concentrations are reported in Table 7.

Table 7. Measurements from user tests.

Code	Gravimetric (mg/m^3)	Microdust (mg/m^3)	STI (ng/m^3)		WAAI (ng/m^3)	
	Inhalable	Respirable	Inhalable	Respirable	Inhalable	Respirable.
R	60.4	2.9	115,569	16	3,843	ND
Ba	55.9	2.3	146,946	122	4,940	ND
Bu	30.7	2.2	116,940	45	2,971	ND
W	9.1	0.4	25,118	13	867	ND

Although this user test was only undertaken once, it suggests that the experimental improver with increased oil content (W) made a considerable reduction of airborne dust of around 7-fold for both respirable and inhalable fractions, with little effect for the two other practicable modified improvers (Ba & Bu). The specific allergens measured in the extracts of respirable fractions were close to, or at the limit of detection for the immunoassays, limiting their comparative value. However, the inhalable fractions of specific allergens also show around a 5-fold reduction in their levels for improver (W) in comparison with the typical improver (R). Thus the user test tends to support the outcomes from the drum dustiness testing, although suggesting that increased oil was significantly better than minimising either calcium silicate or calcium sulphate. However the lack of repeat user testing precludes any statistical analysis of the differences between the different modified improvers.

4. Discussion

Manipulation of the ingredients of bakery improvers appears to have significant effects on their dustiness and at least two allergens that may become airborne and inhaled by bakery operatives. Both these allergens have been reported as causing sensitisation in bakery workers.

The addition to flour of inorganic calcium compounds, as well as the organic emulsifier increased dustiness, including allergens within the dust.

Three individual modifications for improver have been investigated that may be feasible and help reduce the dustiness of bakery improvers and exposure to allergens. These were (a) adding extra oil to improver to the maximum of 4% (W), (b) reducing the amount of calcium sulphate in improver to the minimum of 5% (Bu) and (c) reducing the amount of calcium silicate within the emulsifier mix to 3% or 0.6% in the overall improver (Ba). The main findings can be summarised as follows: The modification of increased oil was consistent in both the drum dustiness testing and user test in causing large decreases in inhalable airborne levels of dust and two major allergens implicated in bakeries [12,22]. The two other practical modifications of reducing either calcium silicate or sulphate in improver showed real reductions in airborne levels of dust, STI and apparently in WAAI from drum dustiness testing, but not as great as that shown by increasing the oil and with no apparent effect in the user test.

Interestingly the modified improver where all three practical modifications are combined (Y), showed no clear evidence of an additive reduction in dust or allergen levels.

Out of the improver modifications investigated to decrease dustiness, the addition of extra oil may be the easiest to implement. However, adding extra oil could affect other features of the improver such as the ease of improver blending, the quality and taste of the product, dough mixing times, and the industry are generally under pressure to reduce the fat content of food. Other issues for consideration would be the increased cost of such a modification and whether it would work in the real world or could possibly cause other health problems such as dermatitis.

Reducing the concentration of calcium sulphate or calcium silicate appeared to reduce dustiness and airborne allergens in the dustiness testing experiments. These modifications do not have the cost implications of increasing the oil content, but their positive effects on dust levels were not clearly substantiated by the user testing or caused the magnitude of reduction found in dust and STI levels. Since the use of free flow agents, such as calcium silicate, is widespread in mechanised mixing of food, further work on manipulating free-flow agents and the potential effect on the dustiness of materials containing allergens may be warranted.

A possible reason for the differences between results in the standard dustiness drum test and the user test may be due to the amount of energy imparted by these two procedures. The standard drum dustiness test applies a constant uniform rotational energy, whereas the user test reproduces a specific work activity, namely scooping and pouring tasks. As constituted our user test may be better correlated with the drop method of dustiness testing, as opposed to rotating drum dustiness testing, both standardized methods being contained in EN15051 [16]. However, it is also likely that improvers may be handled or manipulated in bakeries in a number of ways, with a range of factors influencing aerosolisation.

The user test investigated the behaviour of these agents in a single realistic specific handling scenario with the results reported in units that are comparable to those used in occupational hygiene surveys (Table 4). However, the user test was performed once only involving repetitive tasks for a limited time period and therefore its variability is unknown. Thus these results cannot be taken as representative of likely exposures across the industry. Taking these limitations into account, the data from both dustiness testing and a user simulation suggest that only the addition of extra oil consistently reduced exposure to improver dust and allergens, but this needs confirmation either in further realistic simulations or workplace studies.

5. Conclusion

This study has shown that the addition of some inorganic calcium salts and organic ingredients of bakery improvers can significantly increase the potential dustiness of flour and at least two airborne allergens. There is the potential for reducing the very real risk of allergic asthma in bakery workers by decreasing the dustiness of bakery improvers through altering their ingredients, as well as through engineering control measures and staff training.

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Conflict of Interest

All authors declare that no conflicts of interest in this paper.

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