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A mixed-methods approach to elucidate SARS-CoV-2 transmission routes and clustering in outbreaks in native workers and labour migrants in the fruit and vegetable packaging industry in South Holland, the Netherlands, May to July 2020

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ABSTRACT

Objectives: To obtain insight into SARS-CoV-2 clustering and transmission routes during outbreaks in the predominantly migrant workforce of the fruit and vegetable packaging industry of South Holland, the Netherlands, May to July 2020.
Design: This mixed-methods study applied direct observation and interviews, epidemiologic investigation, source and contact data analysis and whole-genome sequencing.
Results: We detected 46 SARS-CoV-2 cases and 4 outbreaks with a proportional representation of labour migrant and native workers in 6 unrelated facilities. Complete viral genome sequences revealed at least 3 clusters of native workers and labour migrants, 2 within and 1 between facilities. On-site inspections found adequate implementation of preventative measures to which both native workers and labour migrants showed suboptimal adherence. Being a labour migrant was associated with living in shared housing, but not with more contacts or different sources.
Conclusions: The fruit and vegetable packaging industry gave the impression of sufficient preparedness and control. Suboptimal adherence to the facilities' preventative guidelines could have facilitated work floor transmission. Community and household transmission are likely to have contributed to outbreaks. We encourage further research into risk factors for transmission in labour migrants and application of these insights into targeted public health policy.

Introduction

SARS-CoV-2 is currently causing a pandemic of COVID-19 that has severely affected the Netherlands (RIVM, 2021a). Outbreaks have occurred in the food manufacturing and processing industry, an essential industry that offers limited possibilities to work from home and where physical distancing may be hampered by the nature of assembly-line work (Dyal et al., 2020; Rubenstein et al., 2020; Steinberg et al., 2020; Waltenburg et al., 2020). Although most countries established travel bans early in the pandemic to prevent importation of new cases, exemptions have been made for critical personnel, including labour migrants who have a key role in the food industry (OECD, 2020; FAO, 2020). In the Netherlands, 400 000 labour migrants from Central and Eastern Europe fill 5% of all jobs, the majority in the logistics sector, followed by agri- and horticulture and the food industry (Heyma et al., 2018). The demographic, social, cultural and economic dynamics of migrant

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workforces may be associated with increased transmission risk and barriers to effective prevention and control of COVID-19 (OECD, 2020; FAO, 2020). For example, on-call contracts and inadequate medical leave and disability policies may incentivise working while experiencing symptoms, while community transmission may be increased by shared housing and by socialising with co-workers (Dyal et al., 2020; Rubenstein et al., 2020; Steinberg et al., 2020; Waltenburg et al., 2020). Moreover, mixed cultural and language backgrounds may raise barriers to educating and training employees on safety and health information (OECD, 2020; FAO, 2020). Large outbreaks in the meat processing industry (Reuben, 2020) raised concerns about possible increased risks in other sectors of the food industry, such as fruit and vegetable processing, which share many risk factors related to SARS-CoV-2 outbreaks.

On 5 June 2020, the public health service of Rotterdam-Rijnmond (PHS-RR) received a positive SARS-CoV-2 test result from a Bulgarian woman working in a fruit and vegetable packaging facility. Similar to infected workers at meat processing plants, she claimed to have had around 100 close work floor contacts on the days between the onset of symptoms (19 May) and the positive test result (5 June). The possible public health threat of this case and the food industry's general history of vulnerability to SARS-CoV-2 outbreaks urged the PHS-RR to conduct an on-site inspection and risk assessment the next working day. Following the notification of more COVID-19 cases in a total of 6 fruit and vegetable packaging facilities in 2 neighbouring PHS regions in the province of South Holland, an outbreak management team was established consisting of communicable disease physicians and nurses, a communication expert, a manager and a management assistant to represent the PHS-RR, the PHS of the Hague (PHS-HA) and South Holland South (PHS-SHS). Collectively referred to as the PHS, this team initiated an in-depth mixed methods investigation of transmission routes and clustering in workers in the fruit and vegetable packaging industry in the 3 PHS regions. Here, we describe the outcomes of this investigation and provide recommendations for SARS-CoV-2 control in vulnerable industries and workforces.

Methods

Epidemiological investigation

A case was defined as an individual testing positive for SARS-CoV-2 RNA in nose and throat swabs by reverse transcription polymerase chain reaction (RT-PCR), who worked in a fruit and vegetable packaging facility and was reported to the PHS between 5 June 2020 (when the first case was reported) and 13 August 2020 (the point at which no new cases had been reported for 2 incubation periods, or 28 days, since the last case report). A line list of cases and epidemiological curve were made. We defined an outbreak as 2 or more cases that could be epidemiologically linked, with a maximum of 14 days between onset of illness. Attack rate per facility was defined as the percentage of detected symptomatic and asymptomatic cases among the total number of workers and was calculated if a facility had an outbreak.

Virus detection and whole-genome sequencing

Subjects with self-reported symptoms were tested upon their own initiative. In addition, 15 asymptomatic contacts of an index case at Facility B were selected for pre-emptive testing to obtain insight into asymptomatic work floor transmission. SARS-CoV-2 detection was done by RT-PCR (Corman et al., 2020) as described previously (Oude Munnink et al., 2020). A random selection of one-third of specimens with a viral load below a cycle threshold value of 32 was sequenced to obtain insight into clustering between cases that met the case definition. Complete genome sequences were determined through a SARS-CoV-2-specific, amplicon-based sequence method using Nanopore sequencing (Oude Munnink et al., 2020). Sequences were compared with all available Dutch sequences in the national sequence database by maximum likelihood (ML) analysis using IQ-TREE (Nguyen et al., 2015), to assess clustering with cases that did not meet the case definition and obtain insight on transmission outside the facilities. A cut-off of a maximum of 2 nucleotide differences was used to define clusters.

Source and contact interview data collection and analysis

As part of regular COVID-19 control measures, PHS-trained staff conduct a structured source and contact tracing interview by telephone with every notified case. During this interview, socio-demographic data (gender, date of birth, nationality, living situation), source and contact information (presumed source of infection, household contacts, other close contacts) and data on disease discourse that gives insight into guideline adherence (date of symptom onset, date of testing, last working day) is collected and stored in the PHS patient file. Unfortunately, the data is not always complete due to subjects being unable or unwilling to disclose information to the interviewer. Using IBM SPSS version 22, descriptive and analytical statistics were performed to examine differences in these variables between native workers and labour migrants. We used Mann–Whitney U test for continuous variables and Fisher's Exact test for dichotomous and categorical variables to allow for a small sample size. A P-value less than 0.05 was considered statistically significant. If values were missing, percentages were calculated based on the total of the existing values.

Medical ethical clearance

Outbreak investigations of notifiable diseases such as COVID-19 and the collection and storage of data of an index case in the PHS medical record upon notification of such a disease are the legal tasks of the PHS as described under the Public Health Act (Wettenbank, 2021). Scientific research in which data is obtained by studying medical records does not fall under the Dutch Medical Scientific Research with Humans Act and does not require separate medical ethical clearance (Ministry of Health, Welfare and Sport, 2020). The conduct of this study was approved by the senior communicable disease physician of PHS-RR, who is also the last author of this paper.

Qualitative research

The PHS made an announced visit to facilities with an outbreak (Facility A-D). A technical hygienist, accredited by the Netherlands Institute for Accreditation in Healthcare (NIAZ, 2021) as an internal auditor, conducted the on-site inspection following a list of 6 COVID-19 prevention and control topics: distancing, hygiene, face masks, screening, isolation and quarantine, and information. On the day and the site of observation, the PHS met with the facility's management for an unstructured group interview on the COVID-19 prevention and control topics mentioned above. At Facility A and D, the manager of their primary employment agency (agency X and Z) was part of the group interview. Every member of the PHS team recorded the interview by making notations per topic. We obtained and analysed the facilities' internal COVID-19 prevention guidelines and information material. Data of observations, records and interviews, was fused and categorized under the above-mentioned topics. We processed the data into an infection prevention report, provided to each facility, that summarized performance on these

topics and the overall impression of COVID-19 prevention and control.

Results

Epidemiological findings

A total of 46 confirmed COVID-19 cases related to 6 fruit and vegetable packaging facilities (A to F) were reported to the PHS, with dates of onset of disease between 19 May and 23 July 2020 (Table 1; Figures 1 and 2). One facility was located in the South Holland South region, 2 in The Hague area, and 3 in the Rotterdam area. The number of daily workers averaged 150 (Facility F) to 800 (Facility A), of whom about a quarter were native office, kitchen or technical staff and three quarters were migrant assembly-line workers, cleaners or drivers. Native workers made up 24% of detected cases, while 76% were labour migrants with an Eastern or Central European nationality. Facility A-D had an outbreak, Facility E and F had 1 case each. The average attack rate per facility was 3.2% of the total workforce, ranging from 1.6% (Facility C) to 4.2% (Facility A).

Findings from source and contact data analysis

Being a SARS-CoV-2 positive labour migrant was significantly associated with younger age (P = 0.001) and more often living in shared housing (P = 0.008) (Table 2). Native workers and labour migrants did not significantly differ in number of contacts and indicated source of infection. Almost one-third of labour migrants and no native workers lived with a co-worker that had become infected in these outbreaks. Further analysis of those with infected housemates revealed a significant positive association with working at Facility A (P = 0.003). Guideline adherence was suboptimal in migrant and native workers and not different between groups. Ninety percent of native workers and 81% of labour migrants had worked while symptomatic for a median number of 1.5 and 1.0 days, respectively. Testing delay was a median of 3.5 days in both groups.

Findings from whole-genome sequencing

A random selection of 15 of the 46 RT-PCR-positive specimens (33%) with a sufficiently high viral load was sequenced, which

Table 1
Line-list of confirmed COVID-19 cases in order of date of onset of illness, with gender, age, nationality, facility and job type in the fruit and vegetable packaging industry in South Holland, The Netherlands, between 19 May and 23 July 2020.

Case	Onset of illness	Gender	Age	Nationality	Facility	Job type
1	19-5-2020	Female	31	Bulgarian	Facility B	Assembly-line worker
2	22-5-2020	Female	54	Dutch	Facility E	Assembly-line worker
3	26-5-2020	Female	52	Eastern-European	Facility D	Assembly-line worker
4	28-5-2020	Female	53	Rumanian	Facility B	Assembly-line worker
5	29-5-2020	Male	26	Bulgarian	Facility B	Assembly-line worker
6	29-5-2020	Female	29	Polish	Facility D	Cleaner
7	2-6-2020	Male	46	Dutch	Facility B	Management
8	2-6-2020	Female	24	Polish	Facility F	Assembly-line worker
9	5-6-2020	Female	61	Dutch	Facility C	Kitchen staff
10	6-6-2020	Male	29	Polish	Facility D	Driver
11	8-6-2020	Male	28	Dutch	Facility B	Technical staff
12	8-6-2020	Female	52	Dutch	Facility C	Kitchen staff
13	9-6-2020	Female	30	Polish	Facility D	Assembly-line worker
14	10-6-2020	Female	¥	Dutch	Facility C	Kitchen staff
15	10-6-2020	Female	53	Polish	Facility D	Assembly-line worker
16	12-6-2020	Male	50	Dutch	Facility C	Warehouse
17	12-6-2020[a]	Male	25	Polish	Facility B	Assembly-line worker
18	13-6-2020	Male	51	Dutch	Facility A	Management
19	13-6-2020	Male	28	Polish	Facility B	Assembly-line worker
20	18-6-2020	Female	41	Greek	Facility A	¥
21	25-6-2020	Male	43	Dutch	Facility A	Technical staff
22	30-6-2020	Male	45	Dutch	Facility A	Management
23	30-6-2020	Male	27	Latvian	Facility A	Assembly-line worker
24	2-7-2020	Female	37	Latvian	Facility A	Assembly-line worker
25	3-7-2020	Female	27	Latvian	Facility A	Assembly-line worker
26	5-7-2020	Female	23	Moldavian	Facility A	Assembly-line worker
27	7-7-2020	Female	36	Greek	Facility A	¥
28	8-7-2020	Male	24	Moldavian	Facility A	Assembly-line worker
29	9-7-2020	Female	37	Rumanian	Facility A	Assembly-line worker
30	10-7-2020	Female	20	Lithuanian	Facility A	Assembly-line worker
31	10-7-2020	Female	34	Polish	Facility A	Assembly-line worker
32	10-7-2020	Female	31	Polish	Facility A	Assembly-line worker
33	12-7-2020	Female	24	Eastern-European	Facility A	Assembly-line worker
34	12-7-2020	Female	26	Rumanian	Facility A	Assembly-line worker
35	12-7-2020	Male	39	¥	Facility A	¥
36	13-7-2020	Male	41	Dutch	Facility A	Office job
37	13-7-2020	Male	32	Rumanian	Facility A	Kitchen staff
38	14-7-2020	Female	26	Polish	Facility A	Assembly-line worker
39	16-7-2020	Female	60	Bulgarian	Facility A	Assembly-line worker
40	17-7-2020	Male	45	Bulgarian	Facility A	Assembly-line worker, driver
41	18-7-2020	Male	24	Lithuanian	Facility A	Assembly-line worker
42	19-7-2020	Female	21	Latvian	Facility A	Assembly-line worker
43	20-7-2020	Female	50	Bulgarian	Facility A	¥
44	20-7-2020	Male	31	Eastern-European	Facility A	Assembly-line worker
45	22-7-2020	Male	45	Bulgarian	Facility A	Assembly-line worker, driver
46	23-7-2020	Male	27	Bulgarian	Facility A	Assembly-line worker

[a] For the one asymptomatic case, testing date was entered as date of onset of illness, ¥ = Missing data.

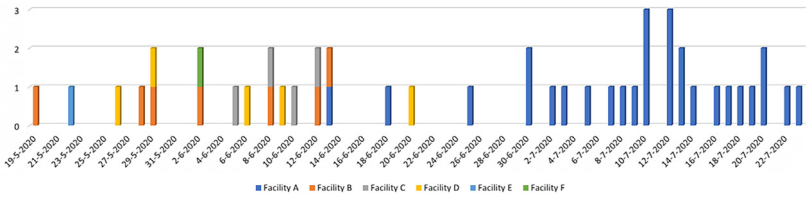

Figure 1. Epidemic curve with dates of onset of illness of confirmed COVID-19 cases per facility in SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry in South Holland, The Netherlands, between 19 May and 23 July 2020. For the one asymptomatic case, testing date was entered as date of onset of illness.

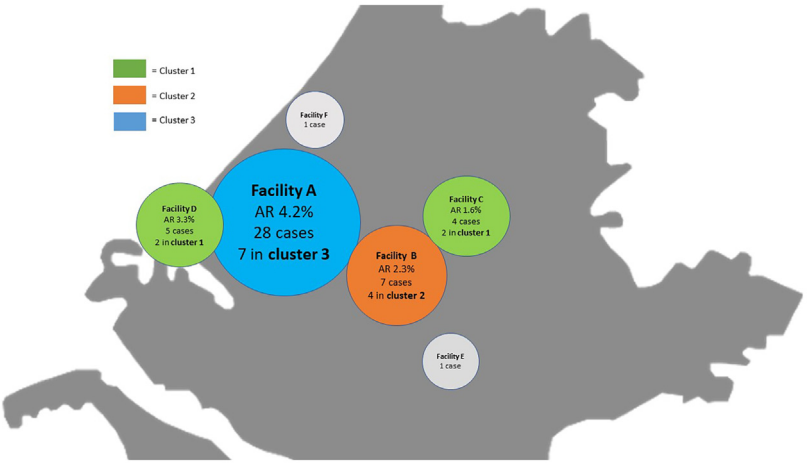

Figure 2. Geographical overview of the size of the outbreaks, attack rates, and cluster size and relationships between the affected facilities of SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry in South Holland, The Netherlands, between 19 May and 23 July 2020. Cluster 1 is green; Cluster 2 is orange; Cluster 3 is blue.

Table 2
Data from source and contact tracing interviews with COVID-19 confirmed workers in the fruit and vegetable packaging industry in South Holland, The Netherlands, between 19 May and 23 July 2020[a].

	Total (n = 46)	Native workers (n = 11)	Labour migrants (n = 35)	*P*
Socio-demographic characteristics				
Gender, female, no. (%)	26 (57%)	4 (36%)	22 (63%)	0.169
Age, years (mean; median (range))	36; 32 (20-61)	47; 48 (28–61)	33; 30 (20–60)	**0.001**
Living situation[b], no. (%)				
Non-shared housing	29 (66)	11 (100%)	18 (55%)	**0.008**
Shared housing	15 (34%))	0 (0%)	15 (45%)	**0.008**
Source and contact variables				
Source of infection as indicated by index, no. (%)				
Work floor	24 (53%)	7 (70%)	17 (49%)	0.296
Home	4 (8,9%)	0 (0%)	4 (11%)	0.561
Unknown source	16 (36%)	3 (30%)	13 (37%)	
Other	1 (2,2%)	0 (0%)	1 (2,9%)	
Household contacts[c], no. (mean; median (range))	2.6; 2.0 (0–13)	2.7; 2.5 (1–5)	2.5; 2 (0–13)	0.447
Other close contacts[d], no. (mean; median (range))	6.5; 2.0 (0–100)	3.1; 2.0 (0–12)	7.6; 1.5 (0–100)	0.782
Sharing a household with an infected co-worker, no. (%)	11 (24%)	0 (0%)	11 (31%)	0.089
Guideline adherence variables				
Worked while experiencing symptoms, no. (%)	34 (83%)	9 (90%)	25 (81%)	0.660
Days worked with symptoms[e], days (mean; median (range))	1.8; 1.0 (0–7)	2; 1.5 (0–5)	1.7; 1.0 (0–7)	0.314
Testing delay[f], days (mean; median (range))	4.7; 3.5 (1–15)	4.5; 3.5 (1–14)	4.7; 3.5 (1–15)	0.858

[a] Valid percentage is shown in case of missing values.
[b] Living situation was categorized non-shared housing (i.e., living single or in a family household with partner and/or children) and shared housing (living with family and unrelated housemates like in-laws, co-workers or friends, or with only unrelated housemates, like housing shared with co-workers organised by the employment agency).
[c] A household contact is defined as a person who lives in the same setting as the index case during his/her infectious period (RIVM, 2021b).
[d] A close contact is defined as a person who has contact with the index case during his/her infectious period for over 15 min at less than 1.5 meters distance (RIVM, 2021b). Other close contacts resemble all close contacts that are not household contacts, which includes colleagues.
[e] Last working day was defined as the last working day at the facility before the day of testing (this workday can follow or precede symptom onset). Days worked with symptoms was defined as the number of days between the last working day and the day of symptoms onset. If the last working day and day of symptom onset were the same, we checked the medical record to see if the person had worked that day with symptoms, which was always the case, and counted this as one day worked with symptoms.
[f] Testing delay was defined as the number of days between the day of onset of symptoms and the day of testing. If the day of onset of symptoms and the day of testing was the same day, this did not count as one day of delayed testing.

resulted in 13 complete genome sequences. Analysis indicated that 12 of these cases had sequences belonging to 3 different clusters while 1 was a unique sequence. Comparison to a national sequence database yielded 2 more cases that fitted the case definition with matching genomes in Cluster 3, resulting in a total of 14 cases that belonged to 3 sequence clusters: 4 to Cluster 1, 3 to Cluster 2, and 7 to Cluster 3 (Figures 2–5; Table 3) plus the 1 unique sequence. Comparison to the national database revealed an additional 2 sequences with matching genomes in Cluster 1, 1 in Cluster 2 and 1 in Cluster 3, that did not fit the case definition.

Cluster 1 included 4 employees working for Facility C (The Hague area) and D (Rotterdam area). The 2 cases at Facility C were native kitchen staff with 3 days between the onset of symptoms in each case. The first case had worked 5 days with symptoms, which makes work floor transmission plausible. The 2 cases at Facility D were a cleaner, who had worked 7 days while symptomatic, and an assembly-line worker whose symptoms started to develop 11 days after the cleaner's symptoms. They had different job types, but work floor transmission is possible during breaks. There was no reported link between Facility C and D outside of the work floor. The cleaner lived in a form of shared housing but did not have a housemate who was a case in this investigation. Sequences from the national database of 2 cases that did not fit the case definition were also part of Cluster 1. One was an Eastern European office worker at the employment agency X that staffs facility A, C and D, who lived in a family setting in the Rotterdam area and denied work floor or community contact with workers from Facility C or D during his incubation time or infectious period. The other was a person who did not have any affiliation with the fruit and vegetable packaging industry but did have social ties through work and family with people of Eastern European origin and lived in the Rotterdam area.

Cluster 2 comprised 2 assembly-line workers and a technician, all working at Facility B (Rotterdam area), who each lived in a separate family setting. The first case, who developed symptoms on 28 May, was an assembly-line worker who worked 7 days while symptomatic. During machine maintenance, he could have transmitted the virus to the technician, who developed symptoms on 8 June. During work or breaks, he could have infected the other assembly-line worker, who tested positive on 12 June. The other sequence matching with Cluster 2 belonged to a case that did not fit the case definition, did not have an affiliation with the fruit and vegetable packaging industry or with people of Eastern European origin and lived in the Rotterdam area.

Cluster 3 included 7 people at Facility A (The Hague area). On the basis of incubation time and working while being infectious, work floor transmission could link the cases. The first 3 cases were native workers, 2 with office jobs and 1 technician, each living in a separate family setting. The other 4 were labour migrants, of which 3 were assembly-line workers in separate shared housing and 1 kitchen worker in a family setting. Transmission from technical or office staff to an assembly-line worker could have happened during maintenance, supervision, or possibly breaks. The sequence from the national database matching with Cluster 3 belonged to a case that did not fit the case definition but had a family association with people of Eastern European origin, had travelled to Eastern Europe in his incubation period and lived in the Rotterdam area.

Qualitative findings

Facilities were geographically and otherwise unrelated and did not exchange staff. Facilities were usually 8–18 °C, depending on the type of fruit or vegetables, and used both mechanical and fresh-air ventilation with zero or partial recirculation. Inside the

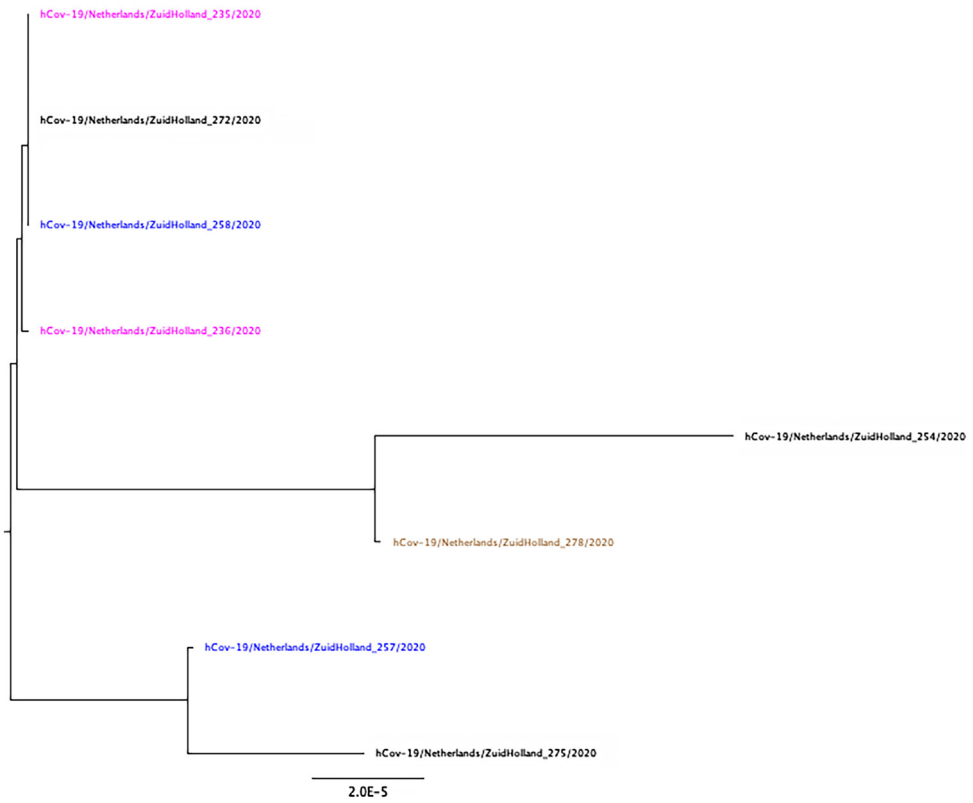

Figure 3. Phylogenetic tree of Cluster 1 with clusters of confirmed COVID-19 cases detected after viral-genome sequencing in SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry, South Holland, The Netherlands, between 19 May and 23 July 2020. Facility C is magenta; Facility D is blue; Employment agency X is brown.

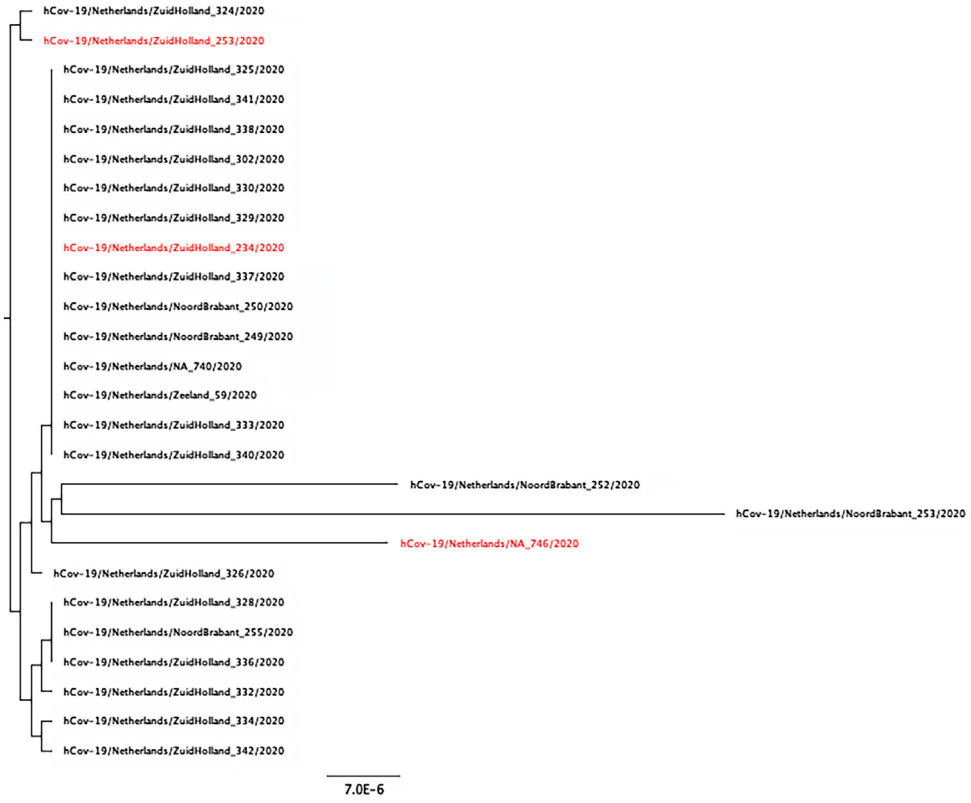

Figure 4. Phylogenetic tree with Cluster 2 of confirmed COVID-19 cases detected after viral-genome sequencing in SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry, South Holland, The Netherlands, between 19 May and 23 July 2020. Facility B is red.

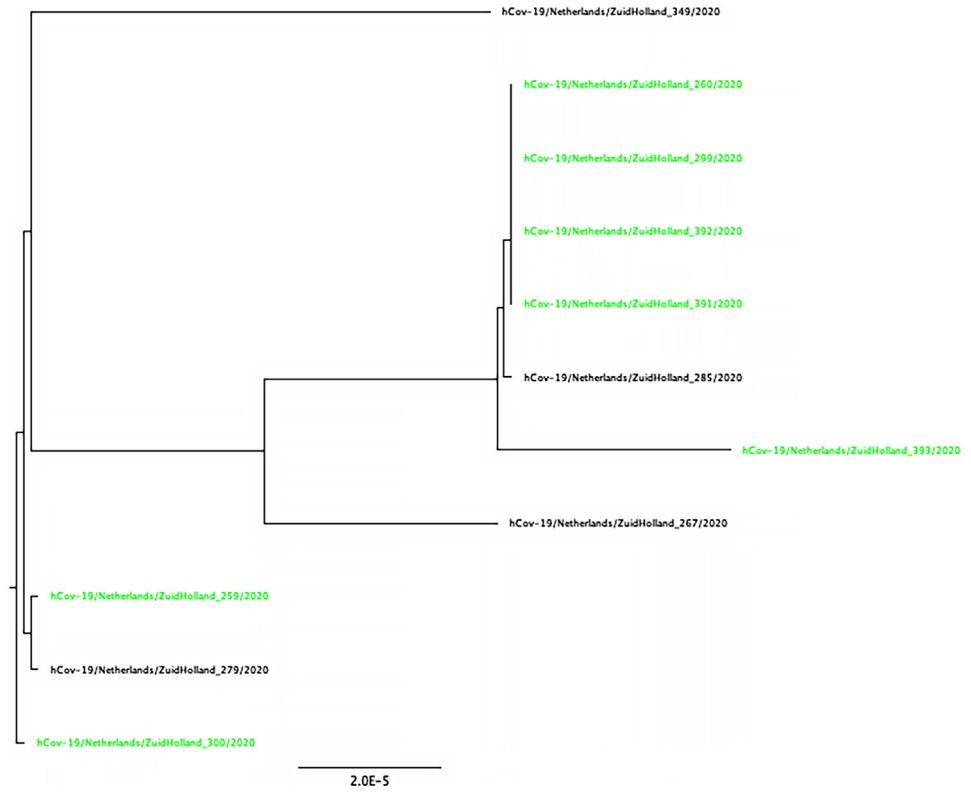

Figure 5. Phylogenetic tree with Cluster 3 of confirmed COVID-19 cases detected after viral-genome sequencing in SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry, South Holland, The Netherlands, between 19 May and 23 July 2020. Facility A is green.

Table 3
Characteristics of confirmed COVID-19 cases within clusters detected after viral-genome sequencing in SARS-CoV-2 outbreaks in the fruit and vegetable packaging industry, South Holland, The Netherlands, between 19 May and 23 July 2020.

Cluster	Workforce	Date of onset of illness	Job type	Days worked with symptoms	Facility	Living situation	Source of infection as indicated by index
1	Labour migrant	29-5-2020	Cleaner	7	Facility D	Shared housing	Unknown
	Native worker	5-6-2020	Kitchen staff	5	Facility C	Family	Work
	Native worker	8-6-2020	Kitchen staff	3	Facility C	Family	Work
	Labour migrant	9-6-2020	Assembly-line worker	Missing	Facility D	Family	Work
2	Labour migrant	28-5-2020	Assembly-line worker	7	Facility B	Family	Unknown
	Native worker	8-6-2020	Technical staff	1	Facility B	Family	Unknown
	Labour migrant	NA[a]	Assembly-line worker	NA[b]	Facility B	Family	Work
3	Native worker	13-6-2020	Office job	0	Facility A	Family	Unknown
	Native worker	25-6-2020	Technical staff	1	Facility A	Family	Work
	Native worker	30-6-2020	Office job	2	Facility A	Family	Unknown
	Labour migrant	3-7-2020	Assembly-line worker	0	Facility A	Shared housing	Home
	Labour migrant	10-7-2020	Assembly-line worker	1	Facility A	Shared housing	Work
	Labour migrant	13-7-2020	Kitchen staff	1	Facility A	Family	Unknown
	Labour migrant	19-7-2020	Assembly-line worker	2	Facility A	Shared housing	Unknown

NA = not applicable.
[a] Asymptomatic.
[b] Worked until day of testing 12-06-2020.

facilities, we observed that assembly-line work was performed by labour migrants only. Interactions between native and migrant staff occurred during supervision and technical support and possibly during lunch breaks, although we were unable to observe lunch breaks. At the offices, distancing was enforced by separating or blocking desks and one-way walking lanes. Since the production line set-up hampered physical distancing (1.5 meters) rules, plexiglass barriers were installed between workers or entire production lines were closed (Table 4). Physical distancing in lunch and smoke areas was enforced by using one-way walking lanes, dispersing tables, removing seats, and blocking sections of tables and benches, or these areas were closed to create outdoor break areas. Nevertheless, at least once at each facility, we observed groups of 5 to 10 labour migrants who kept less than 1.5 meters from each other for over 15 min without any personal protection such as face masks. This behaviour mainly occurred during cigarette breaks and while entering, exiting or moving around the facilities. In organized transportation to and from work, social distancing was enforced by using more vehicles to carry fewer passengers and installing plexiglass barriers and sometimes face masks were mandatory. Three employment agencies (X, Y and Z, all located in The Hague area) are responsible for placement of labour migrants and provide housing and transportation for a proportion of labour migrants. Employment agency X, which provided shared housing for facilities A, C and D, claimed to have reduced tenants from 2 to 4, although we could not observe this. COVID-19 prevention guidelines and health and safety information were communicated at all facilities by posters, leaflets, letters, and emails in all native languages of the workers. At all facilities we observed the use of latex gloves and increased disinfection of high-touch surfaces. Hand hygiene was encouraged by providing materials and instructions for hand disinfection, although some disinfectants did not meet efficacy standards (e.g., 70% alcohol). Face masks were not mandatory inside facilities as they were not mandatory in covered spaces at the time (RIVM, 2021c). Most facilities had implemented symptom and temperature screenings upon entering vehicles and/or the premises. One facility demanded a negative test result from workers and their close contact co-workers upon resumption of work after they had experienced symptoms. The manager of employment agency X, responsible for placement of the highest number of labour migrants, stated that they did not withhold wages when workers are ill or quarantined. However, we could not confirm this. All facilities claimed that the measures we observed were implemented at the beginning of the COVID-19 epidemic in the Netherlands, March 2020, but this could only be confirmed for Facility A.

Discussion

To our knowledge, this is the first in-depth mixed methods study that applied qualitative, epidemiologic and molecular methods with source and contact data analysis to elucidate clustering and transmission routes of SARS-CoV-2 in outbreaks in workers in the fruit and vegetable packaging industry.

Whole-genome sequencing revealed at least 3 potential transmission clusters, of which 2 clusters occurred within a facility. From observation and contact and source data analysis, we learned that both native and migrant workers continued working while being symptomatic and delayed testing. In addition, we observed labour migrants in close unprotected contact with each other when they were away from the production lines, which could have enabled transmission inside the facilities. Our findings are in contrast to reports of larger outbreaks in the meat industry, which are thought to result from crowding on the production line combined with sharing of housing and transportation, incentives to work while symptomatic (Dyal et al., 2020), plus environmental conditions that may facilitate viral transmission (Günther et al., 2020). The fruit and vegetable packaging facilities visited, apart from implementing measurements adequately, were well ventilated and less cooled than meat-processing facilities and working while symptomatic occurred in labour migrants and native workers equally.

Whole-genome sequencing revealed 1 cluster that consisted of sequences from 2 separate facilities that were not epidemiologically linked. Work floor transmission, to which 3/4 workers in this cluster attributed their infection, is therefore not plausible between facilities. Additionally, multiple identical sequences were found in patients not epidemiologically linked to the facilities but to people of Eastern-European origin. These findings suggest that our investigation did not encompass all work floor relations and that some infections could be attributable to community transmission.

Although migrant and native workers do not differ in number of household and indicated sources of infection, being a labour migrant was significantly associated with living in shared housing. Having a housemate that was infected in these outbreaks was significantly associated with working at Facility A, which had the highest attack rate (4.2%), the highest number of cases (N = 28) and

Table 4
COVID-19 prevention and control measures in four fruit and vegetable packaging facilities with a SARS-CoV-2 outbreak between 19 May and 23 July 2020 and the 2 employment agencies they cooperate with in South Holland, The Netherlands.

Facility/employment agency combination	Distancing	Hand hygiene and disinfection	Face masks	Screening	Isolation and quarantine	Information
Facility A cooperating with employment agency X and Z	Plexiglass barriers in production lines and transportation	Provision of hand alcohol, efficacy not observed	Mandatory in vehicles (not on premises)	Symptom and temperature screening	Negative test result mandatory of worker and close contact co-workers upon resumption of work after experiencing symptoms	Posters, leaflets, letters, and emails in all languages with and up-to-date guidelines on COVID-19 preventive measures
	Designated places for workers at production lines	Disinfection of high touch surfaces by cleaning staff at least once daily				
	Physical distancing measures in restaurant					
	Reduction of tenants from four to two				Continuation of salary payment during isolation or quarantine	Enforcing a working culture of shared responsibility for prevention
Facility B cooperating with employment agency Z	Plexiglass barriers in production lines and transportation	Provision of hand alcohol that did not always meet efficacy standards (e.g., 70% alcohol)	Not mandatory in vehicles or premises	Symptom and temperature screening	Promotion of isolation and quarantine according to guidelines	Posters, leaflets, letters, and emails in all languages with and up-to-date guidelines on COVID-19 preventive measures
	Physical distancing measures in restaurant	Disinfection of high touch surfaces by cleaning staff at least once daily				
Facility C cooperating with employment agency X and Z	Plexiglass barriers in production lines and transportation	Provision of hand alcohol that did not always meet efficacy standards (e.g., 70% alcohol)	Mandatory in vehicles (not on premises)	No screening	Promotion of isolation and quarantine according to guidelines	Posters, leaflets, letters, and emails in all languages with and up-to-date guidelines on COVID-19 preventive measures
	Closed indoor restaurant, created outdoor break area					
	Reduction of tenants from four to two	Disinfection of high touch surfaces by cleaning staff at least once daily			Continuation of salary payment during isolation or quarantine	Direct communication through speeches of the management to workers about COVID-19 prevention
Facility D cooperating with employment agency X	Plexiglass barriers in production lines and transportation	Provision of hand alcohol that did not always meet efficacy standards (e.g., 70% alcohol)	Mandatory in vehicles (not on premises)	Symptom and temperature screening	Promotion of isolation and quarantine according to guidelines	Posters, leaflets, letters, and emails in all languages with and up-to-date guidelines on COVID-19 preventive measures
	Physical distancing measures in restaurant	Disinfection of high touch surfaces by cleaning staff at least once daily			Continuation of salary payment during isolation or quarantine	
	Adjusted break- and worktimes					
	Closed smoking area, created outdoor smoking area					
	Reduction of tenants from four to two					

the highest number of labour migrants employed (N = 800), yet also gave the overall impression of most adequate prevention measures and very good control. The high attack rate at this facility might be accounted for by household transmission with introduction onto the work floor, on top of work floor transmission. This hypothesis, however, should be taken with caution since when a worker lives with colleagues, it is difficult to trace the actual source of infection back to either work or home.

A limitation of this study is that testing was dependant on self-reporting of complaints. Therefore, the reported data on SARS-CoV-2 infections likely underestimates the actual prevalence due to missed symptomatic and asymptomatic cases. In previous investigations of SARS-CoV-2 outbreaks, the proportion of asymptomatic and pre-symptomatic SARS-CoV-2 infections ranged from 19% to 88% (Lalani et al., 2021; Oran and Topol, 2020), while it was 12% in a report from the US meat industry (Steinberg et al., 2020) and 11% in an outbreak in the fruit industry in a part of the Netherlands beyond our investigation (Santen van, 2020). If proactive facility-wide testing had been initiated in all facilities, this would most likely reveal asymptomatic cases that have now gone unrecognized. A second limitation is that only a selection of samples was sequenced, so additional transmission clusters could have been missed. Moreover, the number of mutations in the SARS-CoV-2 genome is still relatively limited, making it challenging to draw conclusions on transmission solely based on sequence information. Identical or near-identical sequences have been shown to circulate in diverse geographical areas or settings. Finally, source- and contact-tracing interviews were not followed by further patient contact, which might have elucidated relationships between cases, especially in Cluster 1. Other than their living situation, we lacked data on risk factors for transmission outside the work floor, such as transportation from and to work and having a housemate who tested positive for SARS-CoV-2 but was not involved in this outbreak investigation. Inspection of housing would also have been beneficial to obtain complete insight into household transmission.

We conclude that the fruit and vegetable processing industry gave the impression of sufficient preparedness and control. Outbreaks with low attack rates with a proportional representation of native workers and labour migrants lasted for 2 months, despite timely and adequate implementation of COVID-19 preventative measures. We observed suboptimal adherence to the facilities' preventative guidelines in migrant and native workers, which could have facilitated work floor transmission. Community transmission contributed to at least 1 outbreak. Household transmission due to shared housing and introduction onto the work floor could have contributed to a higher attack rate of the outbreak in 1 facility.

We encourage a mixed-method approach to outbreak investigation for optimal insight into transmission routes and clustering. We recommend further research into SARS-CoV-2 transmission in labour migrants and application of these insights into public health policy targeted at infection prevention in this group and the companies that are responsible for procuring their employment and housing.

Conflict of interest

None declared.

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Ethical approval

Separate medical ethical clearance not mandatory.

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