Effects of loading and air bag bracing patterns on correlated relative air distribution inside refrigerated semi-trailers transporting fresh horticultural produce

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Hui, K.P.C., Vigneault, C., Sotocinal, S. A., de Castro, L.R. and Raghavan, G.S.V. 2008. **Effects of loading and air bag bracing patterns on correlated relative air distribution inside refrigerated semi-trailers transporting fresh horticultural produce**. Canadian Biosystems Engineering/Le génie des biosystèms au Canada **50**: 3.27–3.35. The objective of this research was to determine the effect of pallet loading and bracing patterns on air distribution inside refrigerated semi-trailers transporting fresh horticultural produce. The performance of air circulation systems was investigated in 20 trailers with mixed loads arranged in either centerline, offset or pinwheel patterns. In some tests, vinyl air bags were placed horizontally or vertically to brace every pair or every other pair of produce pallets. Pearson product-moment correlation coefficients were calculated based on temperature data, and were used as indices to represent the relative air distribution at different locations within semi-trailers. Pearson correlation coefficients and coefficients of determination were used to quantify the effects of pallet loading and bracing patterns on relative air distribution. Results obtained for the 20 field tests varied greatly within each category of loading and bracing patterns. Although no firm conclusions could be drawn, it was observed that arranging pallets in a pinwheel pattern tended to assist air circulation better than the offset pattern. Using air bags horizontally or not using air bags at all tended to promote better air circulation than using air bags vertically for bracing pallets inside refrigeration semi-trailers. **Keywords:** refrigeration transport, air circulation, Pearson correlation coefficient, loading pattern, bracing pattern, horticultural produce.

L'objectif de cette recherche était de déterminer l'effet du type de chargement de palettes et de l'utilisation de ballons stabilisateurs sur l'indice corrélé de la distribution de l'air à l'intérieur de semi-remorques réfrigérées transportant des produits horticoles frais. Les performances des systèmes de distribution de l'air ont été mesurées dans 20 semi-remorques transportant des charges de produits mélangés placées sur des palettes disposées en une ligne centrale, en quinconce ou en blocs circulaires. Des essais ont aussi été réalisés en plaçant horizontalement ou verticalement des ballons stabilisateurs en vinyle à chaque paire ou chaque deux paires de palettes. Les coefficients de corrélation de Pearson utilisant les moments de produit ont été calculés à partir des données de température recueillies, et utilisés comme indice d'uniformité de la distribution de l'air à différents endroits dans les semi-remorques. Les coefficients de Pearson et de détermination ont été utilisés pour quantifier les effets des types de chargement et de position des ballons stabilisateurs sur l'uniformité de la distribution relative de l'air. Les résultats obtenus à partir des 20 essais de transport ont considérablement varié selon les types de chargement des palettes et la position des ballons stabilisateurs. Bien qu'aucune conclusion ferme n'ait pu être tirée, il a été observé que la disposition des palettes en blocs circulaires a tendance à favoriser une meilleure circulation d'air par rapport au positionnement en quinconce. L'absence de ballons stabilisateurs ou l'utilisation de ces ballons placés horizontalement à l'intérieur des semi-remorques réfrigérées a eu tendance à favoriser la circulation de l'air par rapport à l'utilisation de ballons placés verticalement. **Mots clés:** transport réfrigéré, circulation de l'air, coefficient de corrélation de Pearson, modèle de chargement, stabilisateur de charge, produit horticole.

INTRODUCTION

Refrigerated semi-trailers are the most common vehicles used to transport fruits and vegetables in North America (Leblanc and Hui 2005). Produce is commonly shipped from producers to wholesalers, then to distributors and to retailers. Due to their perishable nature, fruits and vegetables must be maintained at optimum temperature and relative humidity during transport (Vigneault 2005). These conditions can be achieved by using refrigeration and air circulation systems that are capable of removing respiration heat from produce and heat transmitted from outside the vehicle (Hui et al. 2003).

Produce inside semi-trailers is not only a source of heat, it is also an obstruction to airflow. The packaging of produce and the subsequent arrangement of these packages inside the trailer affects the circulation of air, consequently affecting the efficiency of heat removal within the trailer. The availability of air channels and the airflow patterns change depending on the design of produce packaging, the arrangement of packages on the pallets, the type of external wrapping, the pallet loading pattern, and the use of bracing materials, or on a combination of these factors (Thompson and Brecht 2005).

In general, packages are loaded inside a semi-trailer as either a unitized load or a palletized load. A palletized load in a trailer may be composed of one single type of commodity (straight load) or several types of commodities (mixed load). In both cases, it is recommended that packages be arranged on pallets with their vent holes aligned along the direction of the airflow. The effectiveness of the vent holes in allowing air to remove respiration heat depends on how much air flows through the box of produce (de Castro et al. 2005). Plastic film wrapping and internal packaging materials such as liners, trays, wraps, dividers and pads may therefore be used as long as they do not limit air circulation through packages (Thompson et al. 2002).

The loading pattern of the pallets affects the airflow around and across the load, the load-inner walls contact, the load stability, and the shipment volume (Thompson et al. 2002). Produce pallets can be loaded in a sidewall, offset, pinwheel or centerline pattern by a forklift or pallet truck (Hui et al. 2002). In sidewall loading, produce pallets are aligned in two rows, with each row loaded closely against the left or right sidewall. This pattern creates an air channel between the two rows of produce. Pallets can be arranged with either their width or length facing the rear of the trailer, thus varying the amount of space of the middle air channel. In offset loading, pairs of pallets are arranged in a zigzag manner. Offset loading reduces produce-sidewall contact and provides better air circulation by creating alternating vertical channels around the load. In pinwheel loading, pallets are loaded in a set of four in a pinwheel fashion. Pinwheel loading provides more stability than offset loading but may create non-uniform vertical air circulation from the front to the rear of the trailer (Kasmire et al. 1996).

Finally, centerline loading eliminates all contact between the produce and the sidewalls. Although bracing is required to prevent side or backward shifting, this loading pattern enhances the removal of external and respiration heat, and eliminates the risk of warming or freezing caused by external environmental conditions, by isolating the load from wall surfaces (Thompson et al. 2002). It also creates wide air circulation channels on both sides of the load and near the rear doors, forming an insulating air jacket around the entire load. For this reason, Kasmire et al. (1996) recommend this loading pattern to protect highly perishable commodities such as strawberries, mushrooms and cut flowers during transport.

In addition to using various loading patterns, the transport industry also uses different bracing systems to secure their load. One type of bracing systems consists of large, inflated vinyl air bags which can be inserted between the load and sidewalls to minimize load shifting during transportation. It is reasonable to hypothesize that the use, positioning and orientation of these inflated air bags could have some effect on the air distribution inside the trailers.

The main problem associated with studying the effect of different setup on air distribution is being able to measure air velocity precisely (Alvarez and Flick 1999a, 1999b). Alvarez and Flick (1999a) utilized instrumented aluminum spheres to measure air distribution, and de Castro et al. (2003) applied plastic balls filled with water/agar-agar solution to simulate horticultural produce in a forced-air precooling system. However, these indirect measurement methods for air flow are applicable for large temperature difference only which is not the case in fruit and vegetable transportation. Also in the present transport study, data were collected under field conditions, while packers were working and there was a small time frame to allow instrumentation. The sensing device has to be wireless, compact, and easy to install and retrieve. On the other hand, it is much more precise and easier to collect temperature data if one can develop a method to correlate such data to air distribution. In statistical analysis, the Pearson product-moment correlation coefficient is used to study how closely one variable varies with another over time. By converting temperature data into Pearson correlation coefficient, it can be used as an index to examine air distribution surrounding the produce (Hui et al. 2006, 2008).

The Pearson correlation coefficient, denoted by r, is based on the covariance of two temperatures (the level that they vary together) and the variances of each individual temperature (Sokal and Rohlf 1969). This correlation coefficient can be used to describe how closely air temperature at one position in the load varies with the supply air temperature. By calculating the Pearson correlation coefficient at various locations, it is possible to quantify the distribution of air surrounding the load. Pearson correlation coefficient is calculated using Eq. 1.

$$r = \frac{S_{1,2}}{\sqrt{S_1^2 S_2^2}} = \frac{\sum(Y_1 - \overline{Y}_1)(Y_2 - \overline{Y}_2)}{\sqrt{\sum(Y_1 - \overline{Y}_1)^2 \sum(Y_2 - \overline{Y}_2)^2}} \quad (1)$$

where,
r = Pearson correlation coefficient of variables Y_1 and Y_2
S_1 = variance of variable Y_1
S_2 = variance of variable Y_2
$S_{1,2}$ = covariance between the variables Y_1 and Y_2
Y_1 = random variable 1
$\overline{Y}_1$ = mean of Y_1
Y_2 = random variable 2
$\overline{Y}_2$ = mean of Y_2

The magnitude of r varies from -1 to 1. A value of 1 indicates a perfect positive association between the two temperatures, i.e., air temperature at a point in the loading area increases linearly with the supply air temperature. A value of 0 indicates there is no association. A value of -1 indicates a perfectly negative association between the two temperatures, i.e., air temperature at a point decreases linearly with an increase in supply air temperature. Using this statistical method, it is logical to assume that the higher the value of the coefficient, the more air circulation is expected at such point. A negative value or a zero r-value suggests there was a blockage in the airflow, indicating that air circulation was poor at the specific location (Hui et al. 2006).

A review of the literature indicated that produce temperature can be affected by a wide variety of factors including accessories, produce packaging, package arrangement, and pallet loading pattern. However, little effort has been made to quantity the effects of these factors on the efficiency of the air circulation system during transport in semi-trailers. The objective of this research was to quantify the effect of loading pattern and bracing pattern of air bags on the distribution of air inside refrigerated semi-trailers, using Pearson correlation coefficient as method of analysis.

MATERIAL AND METHODS

Distribution centers

A total of 20 tests were conducted in semi-trailers transporting loads from the Provigo Inc. distribution centre in Longueuil (Quebec) to a Loeb Inc. distribution centre in London (Ontario), or to another Provigo distribution centre in Vanier (Quebec). Of these tests, 9 were performed on the Longueuil-London route (8-hour trip) and 11 were carried out on the Longueuil-Vanier route (3-hour trip). Each test was coded according to its destination (L for London, V for Vanier) and chronological occurrence as presented in Table 1.

Semi-trailers

Trailers with a nominal length of 14.63 or 16.15 m, equipped with various accessories and refrigeration systems were studied. The characteristics of each trailer are summarized in Table 1. Detailed descriptions of the various types of accessories are presented in Hui et al. (2006).

Loading pattern

Mixed loads including fruits, vegetables, fresh-cut produce, and a small amount of flowers, nuts and dairy products were palletized in the semi-trailers. The pallets may have contained a specific or several types of produce. Some pallets were wrapped in plastic film. In each trailer, 18 to 26 produce pallets were arranged in either centerline, offset or pinwheel patterns as listed in Table 1 and shown in Fig. 1.

Air bags

The loads arranged in pinwheel and centerline patterns were braced on both sides with vinyl air bags, provided by CenterLoad Shipping Technologies (San Leandro, CA). These $460 \times 1370 \times 0.25$ mm (width $\times$ length $\times$ thickness) air bags were placed either in horizontal (HA) or vertical (VA and FVA) patterns. In the HA and VA patterns, air bags were used to brace every other pair of pallets, as illustrated in Fig. 1. In the FVA shipments, air bags were used to brace every pair of pallets. Shipments without bracings were coded as NA in Table 1.

Temperature data loggers

Two types of data loggers were installed at the indoor shipping dock of the Longueuil distribution centre and retrieved at the indoor receiving dock in London or Vanier. One HOBO® H8 Pro RH/Temp Logger (Onset Computer Corporation, Bourne, MA) was used in each test to record the temperature and relative humidity of the supply air. Twenty-seven HOBO® H8 Temp/External Loggers (Onset Computer Corporation, Bourne, MA) were used to record air temperatures at various positions during the first three tests (L1, L8, L9). The 17 subsequent tests were equipped with fifteen temperature sensors. The loggers were programmed to collect data simultaneously, in one-minute sampling intervals.

Ideally, air temperatures should be measured on both sides of a load such as in the first three tests. However, in the subsequent tests, data loggers were used to monitor temperatures only on the right side of each load. The reason for using half the amount of data loggers was mostly logistical. The experiment was carried out within a limited time frame. During the experiment, the produce distributor was undergoing a restructuring process and there was a possibility of interruption of produce deliveries. It was necessary to schedule the field tests effectively by having them correspond to the delivery schedules. The reason for instrumenting the right side of the load rather than the left was that some of the trailers delivering produce to Vanier traveled in the afternoon and the sun would shine on the right side of the trailer. Since the majority of the London deliveries occurred at night, sunlight was not a consideration. The instrumentation on the right side of the load would represent the worst case if the sun has any effect on the air temperature surrounding the load. However, the air distribution would not be affected by the effect of solar radiation. Overall, using half the amount of data loggers allowed for the gathering of data in more trailers within the restricted time frame and limited budget.

Experimental procedure

At the shipping dock, six pallets (three pairs) were selected from each load for instrumentation for the preliminary tests (9 data loggers for each pair of pallets), and three pallets were selected for the main tests (5 data loggers per pallet). The selection of which pallets to be instrumented followed an order of preference that depended on pallet availability: pallets with only one produce item and the same type of produce from pallet to pallet; pallets with only one produce item, but with varying types of produce from pallet to pallet; and pallets with a variety of produce (mix-loaded pallets). The HOBO® H8 Temp/External Loggers were placed on the left (L), middle (M), and right (R) surfaces of the load for the first three tests, and only on the middle (M) and right (R) surfaces for the remaining tests (Fig. 2). The top (T), middle (M) and bottom (B) layers of these surfaces were instrumented according to the distances shown in Fig. 2.

Upon the arrival of the trailer at the loading dock, a HOBO® H8 Pro RH/Temp Logger was installed in the middle of the air duct when possible, or near the blower

Table 1. Trailer and load characteristics of each test.

Test no.	Trailer no.	Bulkhead & floor type**	Loading & bracing pattern***	Trailer nominal length (m)	Number of pallets	Trailer Precooled	Refrigeration system	Set point (°C)	Mode
L1	S96023	Frame^{D}	Pin NA	14.63	24	–	TK SB II di	3.3	–
L2	R33175	Frame^{F}	Pin NA	16.15	26	Yes	TK SB II di	3.3	–
L3	R33238	Frame^{F}	Pin NA	16.15	26	–	TK SB III Max+	3.3	–
L4	R33236	Frame^{F}	Pin NA	16.15	20^{Inc}	–	TK SB II	3.3	Auto
V1*	587569	Solid^{F}	Offset NA	16.15	24	No	TK SB III DE SR	8.9	Auto
V2	R33228	Frame^{F}	Offset NA	16.15	24	No	TK Super II Max+	8.9	Auto
V3*	587569	Solid^{F}	Offset NA	16.15	24	No	TK SB III DE SR	8.9	Auto
V4	R33176	Frame^{F}	Offset NA	16.15	24	Yes	TK SB II	1.1	Auto
V5	R83204	Frame^{D}	Center HA	14.63	22	No	TK SB III Max	8.9	Auto
V6	R33175	Frame^{F}	Center HA	16.15	22^{Inc}	No	TK SB III Max+	3.3	Auto
V7	R33177	Frame^{F}	Center HA	16.15	24	No	TK SB II	4.4	Cont.
V8	R33240	Frame^{F}	Center HA	16.15	24	No	TK SB III Max+	8.9	Auto
V9	912264	None^{D}	Pin VA	14.63	22^{Inc}	No	TK SB II di	8.9	Auto
L5	–	Solid^{D}	Pin VA	16.15	18^{Inc}	–	Carrier Phoenix Ultra	–	–
L6	R33174	Frame^{F}	Pin VA	16.15	22^{Inc}	–	TK SB II	10	Auto
V10	912264	None^{D}	Center VA	14.63	22	No	TK SB II di	8.9	Auto
V11	RT8307	Frame^{D}	Center VA	14.63	22	No	TK SB I 1200	8.9	–
L7	R33215	Frame^{D}	Pin FVA	16.15	24^{Inc}	–	Carrier	7.2	–
L8	R33229	Frame^{F}	Pin FVA	16.15	26	–	TK Super II Max+	3.3	–
L9	R33235	Frame^{F}	Pin FVA	16.15	26	–	Carrier Phoenix Ultra	3.3	–

*Multi-temperature trailer.
**^{F} = Flat floor, ^{D} = duct floor.
***Pin = Pinwheel, Center = centerline.
Inc = incomplete load.
– = information not available.

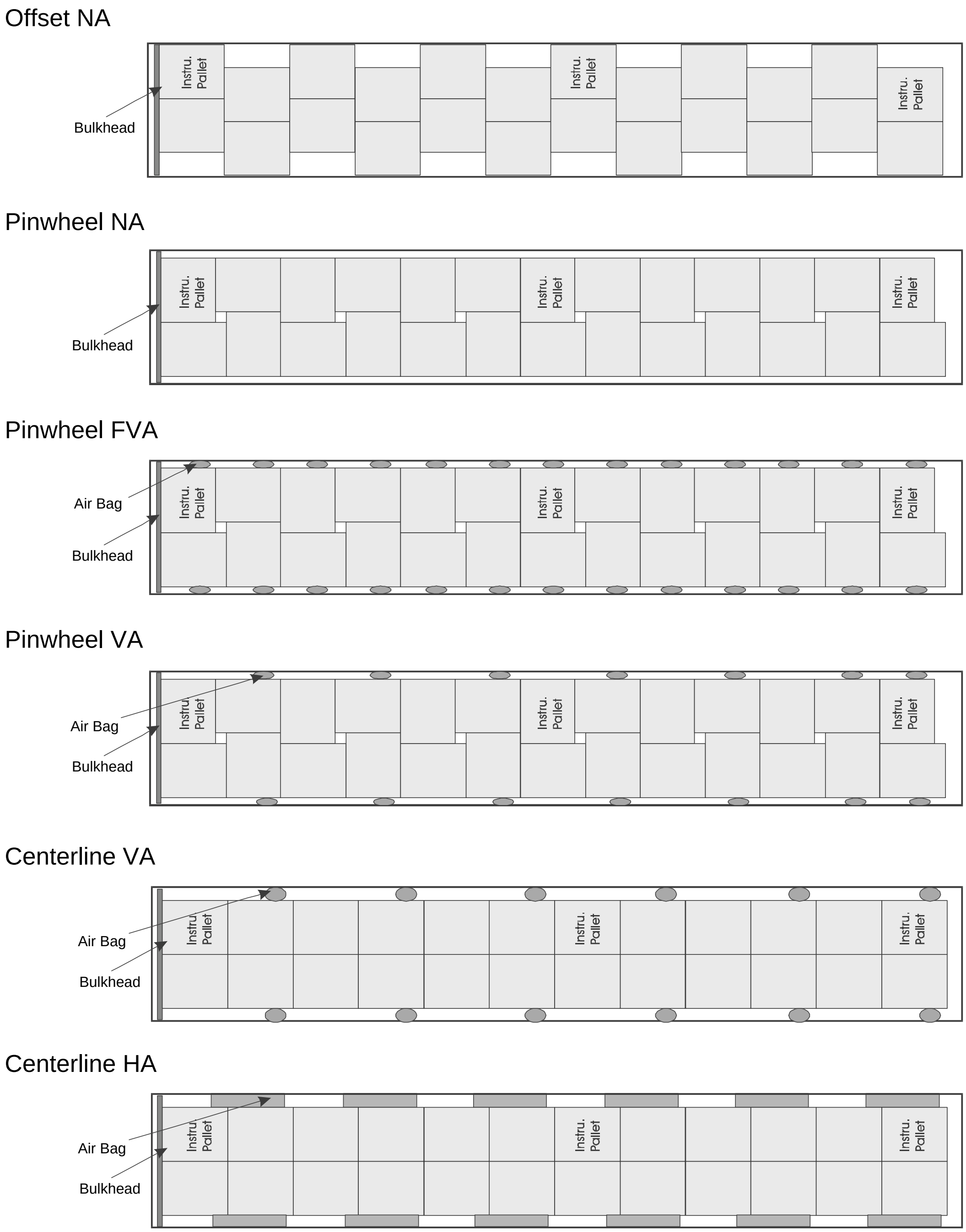

Fig. 1. The loading and bracing patterns used in the field tests. The actual locations of the instrumented pallets may vary depending on the number of produce pallets in the load and the length of the trailer.

discharge on the front wall. The instrumented pallets were then successively placed at the front, middle, and rear rows along the length of the load as illustrated in Fig. 1. All the instrumented pallets used in the last 17 tests were placed on the right side of the load. For the tests requiring bracing, a pair of pallets was loaded, air bags were then inserted between the produce and sidewall, and inflated with a portable device.

Data loggers were retrieved from the instrumented pallets as they were unloaded at the receiving dock in London or Vanier. The HOBO® H8 Pro RH/Temp Logger for the supply air was retrieved only after when the trailer was completely unloaded.

Since the refrigeration systems, set points, and operation modes were different among the tests, the Pearson product-moment correlation coefficient (r) was used as an index to compare airflow patterns (Hui et al. 2006) and to overcome the effect of system differences among the tests. The correlation coefficient was squared to obtain the coefficient of determination (r^2) (Steel and Torrie 1980). When expressed in percentage points, r^2 indicates the proportion of the total variation in air temperature

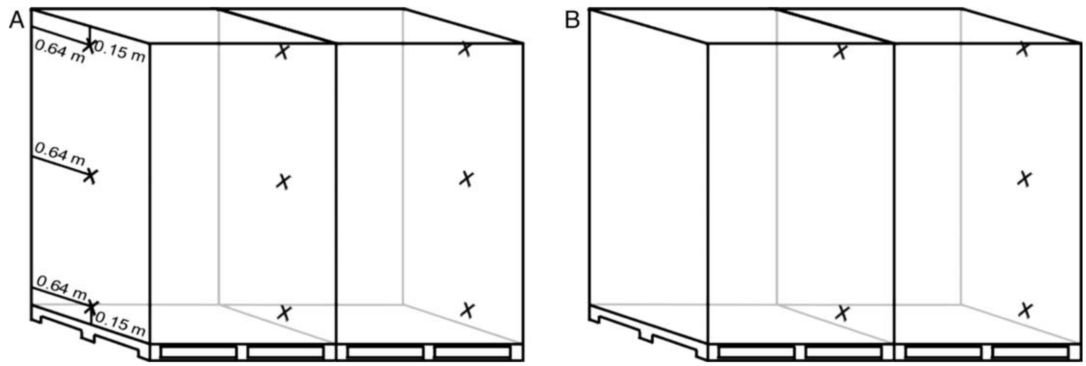

Fig. 2. Location of data loggers on produce pallets in the first 3 tests (2A) and the remaining 17 tests (2B).

around produce that was caused by variations in the temperature of supply air. The values of r, r^2, and their levels of significance were calculated using the SAS system for Windows, Release 6.12 (SAS Institute, Inc., Cary, NC).

RESULTS

Airflow pattern

In order to verify the airflow pattern, the Pearson product-moment correlation coefficient values (r) obtained in the tests were plotted graphically. Trailers used in tests L8 and L9 were loaded with different types of produce, but both had 26 pallets that were arranged in a pinwheel configuration and had air bag bracings at every pair of pallets (FVA) (Fig. 3). The two trailers also had similar floor and bulkhead configurations. Nonetheless, the trends of the Pearson coefficients did not follow similar patterns between the two graphs (Fig. 3, top and middle plots). These results suggested that the air distribution patterns in both trailers had few similarities. It was not possible to identify a general airflow pattern for these two tests, although they were conducted in similar field conditions.

Symmetry across the width

Results from the first three tests indicated a certain degree of symmetry in air distribution between the left and right sides of the load, as indicated in Fig. 3. In the pinwheel configuration with pallets arranged symmetrically, it would yield a similar airflow pattern around the right and left side of the load. However, the symmetrical distribution was present in some cases, but not in all (Fig. 3). For example, in test L1, the crosswise distribution was fully symmetrical at the rear of the load (indicated by the V-shape curves) as well as the front-top and front-bottom layers. However, in the middle of the trailer, the right side experienced more airflow than the left side.

Correlation coefficients across several planes

Table 2 summarizes the Pearson correlation coefficients (r) at the various sensing planes across the length, width, and height of the loads. For these correlation coefficients, air temperatures were grouped by plane and the average temperature at each plane was correlated to the temperature of supply air over time.

If one uses the same loading pattern in two similar trailers, it may be possible to determine the air flow pattern for that loading pattern. The multi-temperature trailer used in tests V1 and V3 was loaded with 24 pallets of produce arranged in an offset pattern without air bags. Use of the same trailer with similar loads resulted in similar air distribution for these tests. Both V1 and V3 presented better air distribution in the front, on the right, and on the top of the load. These areas had the highest values in Pearson correlation coefficients by plane, as indicated by the shaded values in Table 2.

Conversely, tests V2 and V4 were conducted in two trailers with similar internal configurations and loads; however, their air distribution patterns were not similar as indicated in Table 2. Test V2 had better air distribution at the rear, on the right and at mid-height of the load. In Test V4, it had better air distribution in the front, at mid-width and on the top of the load. The contractive conclusion drawn from the two sets of tests (V1 and V3, V2 and V4) is that it is not possible to obtain general air flow patterns for tests conducted in similar field conditions.

Overall correlation coefficients

In this analysis, a single correlation coefficient for each test was calculated to compare the loading and bracing patterns among tests. In each test, the overall correlation coefficient was obtained by correlating the average air temperature of the 15 points of measurement inside the trailer with the temperature of the supply air over time. The overall correlation coefficients were then squared to calculate the coefficient of determination (r^2) for the 20 tests. The r^2-values are summarized in Fig. 4. In this figure, the overall coefficients of determination are grouped by loading pattern and use of air bags: pinwheel NA, centerline HA, offset NA, pinwheel VA, pinwheel FVA and centerline VA.

Within the same category of load arrangement, the trailers may not have shared the same characteristics, as illustrated in Fig. 4. Trailers that were equipped with similar accessories and had the same nominal length shared the same letter (A to F). Tests L2, L3 and L4 were conducted in trailers with the same characteristics (A) and pallets arranged the same manner (pinwheel); however, their coefficients of determination varied from 36 to 76%. The same variability in results was observed

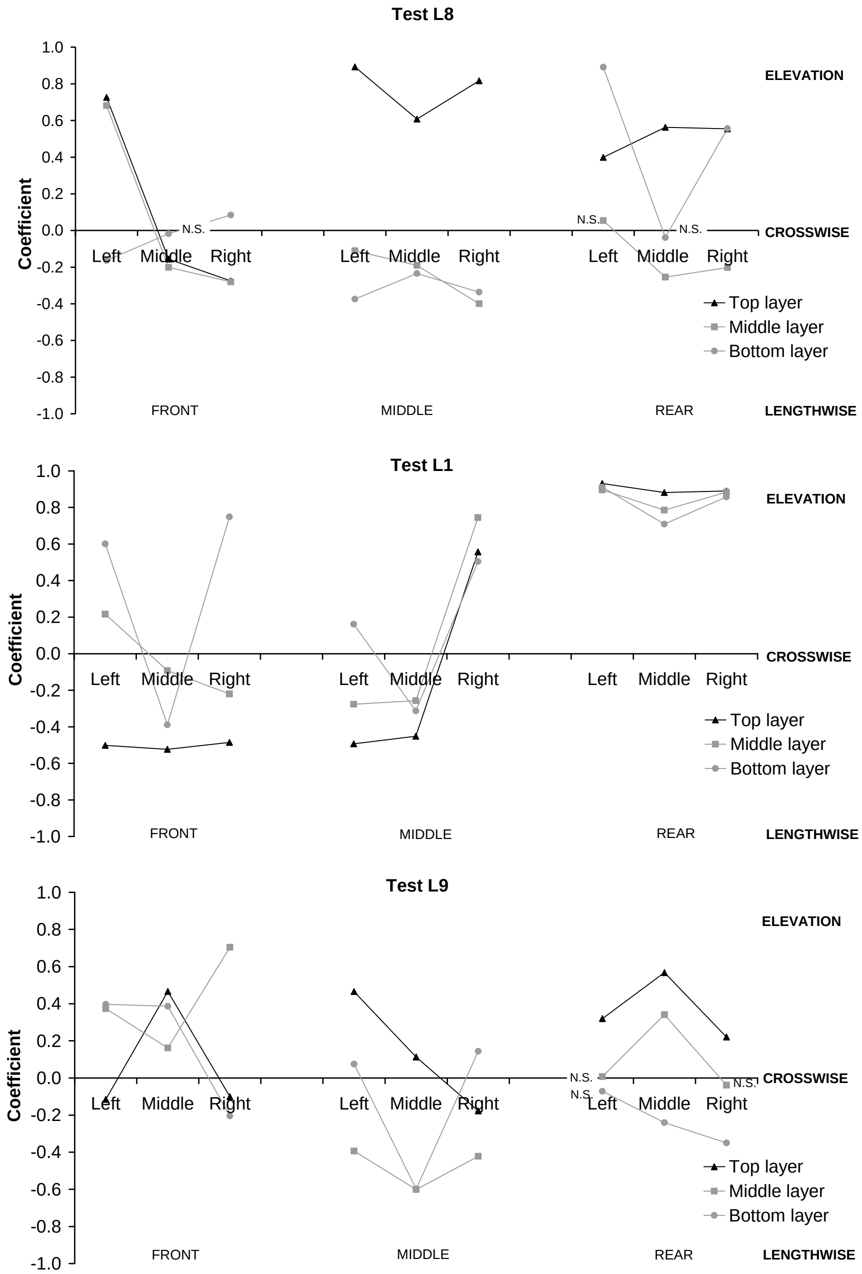

Fig. 3. Pearson correlation coefficients for the first three tests. All values are significant at $p = 0.10$, except those indicated by the letters NS (not significant).

for tests V7, V8 and V6, with the r^2-value ranging from 9 to 58%. The inconsistency of the results for tests conducted in similar conditions suggests the presence of irregular spacing between the load and the internal surfaces of the trailer, as well as within the palletized load itself.

Treating each test as an independent case and grouping them according to the loading pattern and use of air bags, Fig. 4 suggests several general trends. The pinwheel loading pattern tended to assist air circulation better than the offset pattern (pinwheel NA versus offset NA) with higher r^2 values. When air bags were used, arranging the load in a pinwheel NA, centerline HA, or offset NA pattern tended to assist air circulation more than the pinwheel VA, pinwheel FVA or centerline VA pattern. Bracing the load with air bags vertically (VA or FVA) resulted in a reduction in airflow, compared with bracing the load horizontally or not using any air bags. A physical explanation for such a finding is that air distribution inside a semi-trailer is mostly longitudinal, and placing air bags vertically between the load and the sidewalls creates an obstruction to airflow. Despite the general trends, the coefficients of determination varied greatly within each category (Fig. 4). The effect of loading pattern and the use of air bags was not dominant enough to override all other factors that influence air circulation (e.g. uniformity of

Table 2. Pearson correlation coefficients by plane. All values are significant at $p = 0.10$, except those indicated by the letters NS (not significant). Shaded values indicate planes with better air circulation.

	Lenghtwise			Crosswise		Elevation		
Test no.	Front	Middle	Rear	Middle	Right	Top	Middle	Bottom
L1	−0.25	0.20	0.96	−0.13	0.79	0.27	0.69	0.72
L2	0.83	0.91	0.87	0.87	0.87	0.90	0.86	0.75
L3	0.81	0.82	0.86	0.78	0.87	0.86	0.81	0.64
L4	0.72	0.47	0.46	0.57	0.60	0.64	0.59	0.34
V1	0.92	0.35	0.40	0.70	0.82	0.84	0.61	0.42
V2	0.16	0.46	0.89	0.57	0.81	0.79	0.82	0.53
V3	0.72	N.S.	N.S.	0.26	0.37	0.46	0.27	−0.18
V4	0.68	0.61	0.65	0.70	0.62	0.66	0.64	0.63
V5	0.94	0.84	0.79	0.58	0.94	0.87	0.90	0.84
V6	0.72	0.59	0.85	0.45	0.87	0.75	0.88	0.43
V7	N.S.	N.S.	0.50	−0.30	0.54	−0.26	0.52	0.60
V8	0.45	0.54	0.54	0.76	N.S.	0.67	N.S.	0.50
V9	−0.41	0.32	0.32	−0.17	0.20	0.27	N.S.	−0.25
L5	0.86	0.63	0.71	0.78	0.75	0.79	0.76	0.71
L6	0.44	0.45	0.35	0.29	0.50	0.59	0.40	0.16
V10	N.S.	N.S.	N.S.	−0.33	0.29	0.27	N.S.	−0.39
V11	0.21	0.22	0.22	0.23	0.21	0.23	0.18	0.24
L7	0.65	0.59	0.40	0.54	0.55	0.65	0.20	0.28
L8	−0.19	0.10	0.59	0.39	N.S.	0.65	−0.33	N.S.
L9	0.19	−0.25	N.S.	0.17	−0.17	0.30	−0.08	−0.21
Count	8/19	3/19	8/19	6/20	14/20	14/20	3/20	3/20
Ratio	42%	16%	42%	30%	70%	70%	15%	15%

spacing) and generate consistent results. With these data, it was not possible to confirm with certainty which type of loading or bracing pattern would best assist air circulation. Further tests using the same loading patterns are necessary to determine the effects of placing air bags horizontally versus not using any air bags.

CONCLUSION

The pinwheel loading pattern tended to assist air circulation better than the offset pattern (pinwheel NA versus offset NA). Placing air bags horizontally to brace the load or not using any air bags tended to assist air circulation better than bracing the load vertically (pinwheel NA, centerline HA and offset NA versus pinwheel VA, pinwheel FVA and centerline VA). The effect of loading pattern and the use of air bags was not dominant enough to override all other factors that influence air circulation (e.g., uniformity of spacing) and generate consistent results. The coefficients of determination varied greatly within each category of loading and bracing pattern;

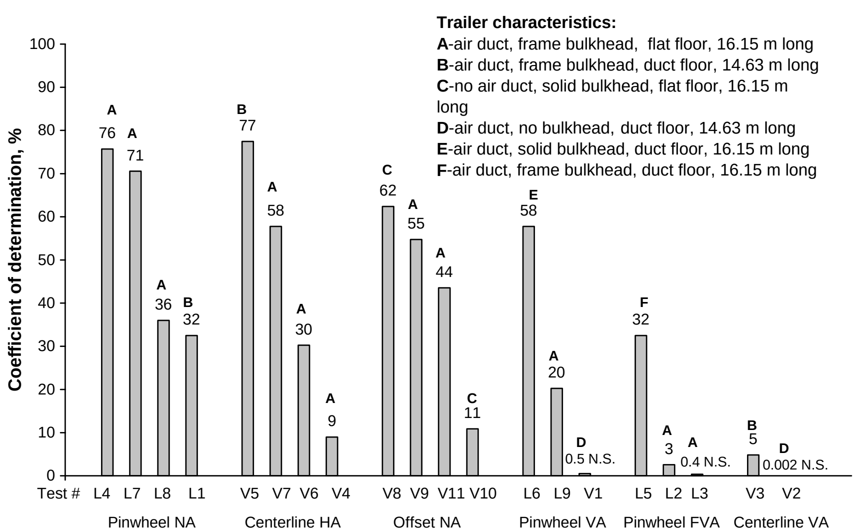

Fig. 4. Air distribution in semi-trailers, grouped according to loading pattern and use of air bags ($p = 0.10$).

therefore, it was not possible to confirm with certainty which type of loading or bracing pattern would contribute the best to air circulation. In addition, due to the variability of field conditions, a larger set of data will be needed if one wants to define the air distribution pattern in detail, for each category of loading and bracing patterns.

For packers, the choice of loading and bracing patterns was mostly a function of load volume, ease of loading and load stability, rather than of improving air circulation. This study demonstrates that loading and bracing patterns have an effect on air circulation, affecting the conditions to which produce is subjected during transport. Therefore, it is important for packers to load pallets in such a manner that facilitates and assists the circulation of air, especially for long-distance transportation.

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