Comparison of energy use and GHG emissions when cooking roast chicken: Electric pressure cooker/air fryer vs conventional oven

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Abstract

This study compares the energy use and GHG emission of cooking chicken using different electrical appliances. The aim was to compare the energy consumption of a conventional electric oven with that of two electric cooking devices that the manufacturer believes to be highly energy efficient using two different chicken-based recipes. One recipe was used for comparing the energy consumption of an electric oven with that of an electric pressure cooker and another was used to compare it with an air fryer. The energy used was measured directly through an electricity meter for the pressure cooker and air fryer, while manufacturer information on energy consumption combined with timing of preheating and cooking steps were combined to calculate this for the oven. The temperature of the chicken before and after cooking were measured, to ensure the chicken was cooked under equivalent conditions. We calculated the GHG emissions in all cases by following the GHG emission reporting methodology and conversion factors described by Department of Business, Energy and Industrial Strategy. The results were normalised by the amount of raw chicken used to make fair comparisons. In the case of the first chicken recipe, we found that the pressure cooker used on average 0.57 kWh per kg of raw chicken vs 3.05 kWh required by the electric oven, resulting in a footprint of 131 g CO_2eq./kg raw chicken vs 704 g CO_2eq./kg raw chicken. This indicates that the energy efficient devices required 81% less energy and fewer emissions compared with roasting the chicken in the oven. For the second recipe, the air fryer consumed on average 0.44 kWh per kg of raw chicken vs 2.74 kWh when cooked in the electric oven. This gives a footprint of 102 g CO_2eq./kg raw chicken when cooking with the air fryer compared with 634 g CO_2eq./kg raw chicken in the oven; this represents on average 84% less energy and lower emissions. These results provide direct evidence that cooking with these alternative appliances is far more energy efficient, making them cheaper to run in the household and with lower GHG emissions.

Background

Households around the world are increasingly concerned about their energy consumption given the rising costs of electricity and gas. The impact on climate change of the food choices they make is also of growing concern.

Instant Brands commissioned an independent cooking comparison to test their belief that cooking with their devices would result in significant energy savings and reduce GHG emissions compared with cooking in the conventional ovens, as commonly used in Europe.

The work was informed by the evidence collected by the Modern Energy Cooking Services Programme[1] that established the high energy efficiency of electric pressure cookers along with being economical for cooking a range of East African dishes (Batchelor et al 2019).

In addition, a recent study estimated that the impact to climate change of cooking practices in the UK could account for up to 61% of the total impacts of the farm to fork of foods (Frankowska et al 2020), while in other countries this understanding is still under development (Reynolds et al 2020a,b).

Study Methodology and Design

We carried out the study using the principles and good practice of the Controlled Cooking Test[2] (CCT) method developed in 2004 for the Household Energy and Healthy Programme of the Shell Foundation.

The approach and key principles were:

- Cooking comparison should be of genuine recipes that could be cooked in the target context and carried out by household cooks using normal equipment
- As far as possible conditions and approach should be standardised across multiple cooking episodes – minimum of three – keeping sources of variation, such as the cook, as minimal as possible.
- Energy use of the Instant Brands products would be measured directly using energy meters,
- Energy use of the conventional oven would be determined by timing oven usage and using manufacturers information about power and energy consumption – with calculations following methodology of studies in the field.
- Objectively defined end-points of the cooking would be used to ensure the processes being compared are equivalent.

Cooking

We carried out the comparison using two different roast chicken recipes, repeating each three times in both the Instant Brands devices and in a conventional oven.

[1] https://mecs.org.uk

[2] https://cleancooking.org/binary-data/DOCUMENT/file/000/000/80-1.pdf

The cooking using the Instant Brands products all took place in the same domestic kitchen, with the same cook. The only equipment supplied by Instant Brands were the two cooking devices:

- Vortex Plus 6-in-1 Air Fryer with ClearCook & OdourErase[3] (used for Cajun Chicken)
- Pro Crisp 8L Multi Pressure Cooker and Air Fryer[4] (used for Rosemary and Parmesan Chicken)

See Appendix for the recipes and instructions followed.

The cooking of the chicken using the oven took place in a different, but similar, domestic kitchen, again with the same cook throughout. The domestic oven used for cooking the two chicken recipes was an electric oven of 2400W - Manual Lamona LAM3210[5]. In all cases, the chickens were purchased from supermarkets and consumed and enjoyed by families.

We sought to measure and control:

- Weight of chicken (from sales packaging)
- Welfare of chicken (selected free-range)
- Feeding of chicken (selected corn-fed)
- Pots used to cook chicken in (keeping the same ones for each repetition of each recipe)
- Temperature of the chicken before and after cooking were measured, to ensure equivalence and that the chicken was cooked through before ending the monitoring (domestic cooking thermometer)
- Starting temperature of the Instant Brand cooking devices – in all cases the cooking started with the devices at room temperature (i.e., not having recently been heated for previous dish)
- Oven temperature at start and at each stage (domestic oven thermometer)
- Cooking time - for the oven, preheating and cooking steps were timed (timer)
- Energy consumption of the Instant Brand devices (Nevsetpo monitor plug power, electricity usage meter[6])

We also made informal, subjective notes and observations about the cooking experience and the final products and took photos at various points during the process.

Energy consumption & Greenhouse gas (GHG) emissions

Energy consumption of the oven was calculated following Frankowska et al (2020) using manufacturer information on energy consumption, the reported rated power and measured cooking times.

Energy was normalised with the weight of each raw chicken to account for weight difference as we did not find 12 chickens with exactly the same weight.

[3] https://instantbrands.co.uk/shop-all-products/vortex-plus-6in1-airfryer-clearcook-odourerase/

[4] https://instantbrands.co.uk/shop-all-products/pro-crisp-8l-multi-pressure-cooker-air-fryer/

[5] https://manuall.co.uk/lamona-lam3210-oven/

[6] Brand new meter from https://www.amazon.co.uk/gp/product/B07H1ZFVFM/ref=ppx_yo_dt_b_asin_title_o04_s00?ie=UTF8&th=1

GHG emissions associated with the energy use were calculated following GHG emission reporting methodology under Scope 2 described by Department of Business, Energy and Industrial Strategy (BEIS) (2021), which considers the indirect emissions associated to the energy usage; the conversion factors used were those recommended by BEIS (2022).

Results

The data collected and the calculations on which the comparisons were made are given in Table 1 and Table 2. We present the energy comparison graphically in Figure 1 and the carbon footprint in Figure 2, showing clearly the substantial difference between the two cooking modes, found across both recipes.

Results are shown per kg of raw chicken.. The results are first presented for the energy consumption and then for the GHG emissions associated to cooking.

Energy Consumption

In the case of the Parmesan chicken recipe, the electric pressure cooker used on average 0.56 kWh per kg of raw chicken, which represents 19% of the energy required by the oven; this would mean a household would use 81% less energy compared with roasting the chicken in the oven (see Figure 1). The findings across all cooking instances were very consistent with the net energy saving only ranging between the extremes of 4 to 4.7 times when compared with the electric oven (Table 1).

Similarly, in the case of the Cajun chicken, the air fryer consumed on average 0.44 kWh per kg of raw chicken; this is equivalent to 16% the energy used by the oven; hence it represents on average 84% less energy than the consumed when cooking in the oven for the same recipe (see Figure 1). The net energy saving of the air fryer only ranged between 4.7 to 5.7 times when compared to an electric oven for the same recipe (see Table 1).

Subjectively, we felt both modes of cooking delivered an equivalent and very acceptable result in appearance, aroma and flavour. The Parmesan chicken recipe involved more stages, for both forms of cooking and switching the chicken between the EPC and the air fryer arrangement resulted in some damage to the chicken which affected its appearance, on completion.

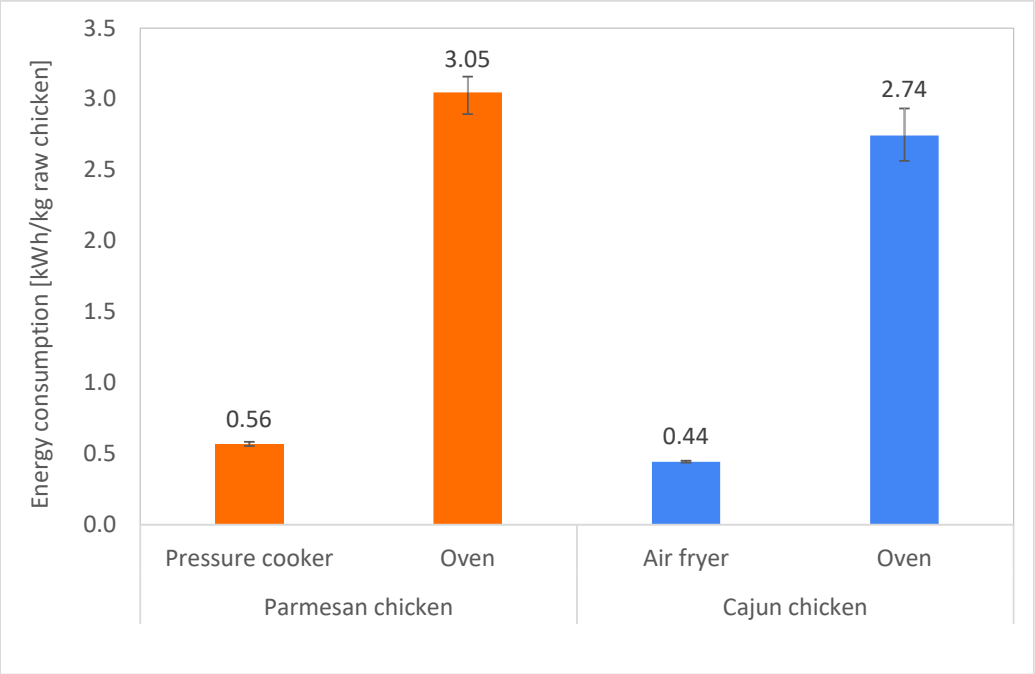

Figure 1 Comparison of energy consumption between pressure cooker and air fryer against electric oven using two chicken-based recipes; results are presented per kg of raw chicken. Solid bars show mean values, while error bars represent maximum and minim values from the tests

Table 1 Raw data recorded and calculations of energy use.

								Comparison against oven [%]			Saving [times]			Net Saving [times]		
Recipe	**Appliance**	**Weight of chicken [kg]**	**Total Energy [kWh][7]**	**Total Energy [kWh/kg raw chicken]**	**Mean [kWh/kg]**	**Max [kWh/kg]**	**Min [kWh/kg]**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Parmesan chicken	Pressure cooker	1.350	0.748	0.554	0.565	0.584	0.554	19%	20%	18%	5.4	5.0	5.7	4.4	4.0	4.7
	Pressure cooker	1.350	0.751	0.556												
	Pressure cooker	1.350	0.788	0.584												
	Oven	1.360	4.200	3.088	3.047	3.159	2.894									
	Oven	1.410	4.080	2.894												
	Oven	1.380	4.360	3.159												
Cajun Chicken	Air fryer	1.650	0.727	0.441	0.443	0.451	0.436	16%	18%	15%	6.2	5.7	6.7	5.2	4.7	5.7
	Air fryer	1.628	0.735	0.451												
	Air fryer	1.600	0.698	0.436												
	Oven	1.560	4.000	2.564	2.744	2.935	2.564									
	Oven	1.610	4.400	2.733												
	Oven	1.540	4.520	2.935												

[7] Total energy consumption was calculated following Frankowska et al. (2020), using the timing of the oven cooking, which includes preheating the oven and cooking time, and the manufacturer information. The oven used is a Lamona 3210 with a power of 2400W

GHG emissions of cooking

In this study, we focused on the GHG emissions associated to the energy required for cooking two chicken-based recipes using air fryer, pressure cooker and electric oven. The GHG emissions are directly correlated with the energy consumption as all were powered by electricity and we assume an equivalent proportion of the electricity was generated renewably.

As seen in Figure 2, the GHG emissions of using the electric pressure cooker for cooking the Parmesan chicken recipe is estimated at 131 g CO_2eq./kg raw chicken while for the electric oven, this is estimated at 704 g CO_2eq./kg raw chicken, representing 81% lower emissions. From the evidence of this study, using the pressure cooker instead of the electric oven to cook Parmesan chicken could avoid releasing up to 82% of the GHG emissions associated to the oven usage (see Table 2).

Similarly, the GHG emissions of using the air fryer for cooking Cajun chicken is calculated at 102 g CO_2eq./kg raw chicken while for the same recipe using the electric oven represents 634 g CO_2eq./kg raw chicken, which represents 84% lower emissions (see Figure 2). Table 2 shows that using the air fryer to cook Cajun chicken instead of the oven would have net savings of up to 85% of the emissions associated to the oven usage.

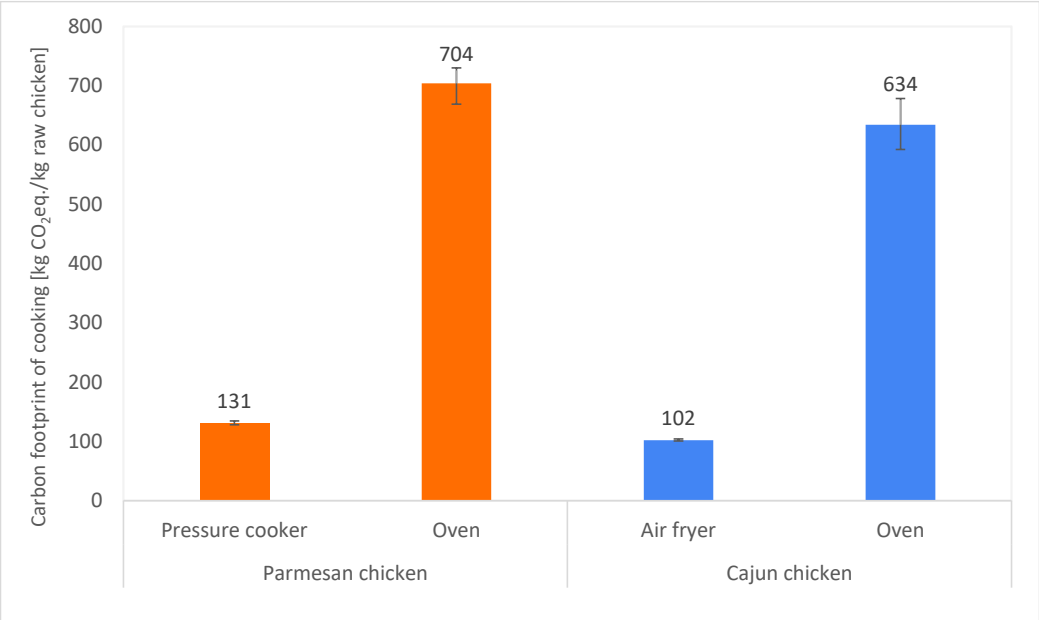

Figure 2 Comparison of the GHG emission associated with the energy used by a pressure cooker and an air fryer against an electric oven when cooking two chicken-based recipes; results are presented per kg of raw chicken. Solid bars show mean values, while error bars represent maximum and minim values from the tests.

Table 2 Summary of the calculations of GHG emissions

					Comparison against oven [%]			Saving [times]			Net Saving [times]		
Recipe	**Appliance**	**Total Energy [kWh/kg raw chicken]**	**Carbon footprint[8] [kg CO_2eq/kg raw chicken]**	**Mean [kg CO_2eq/kg raw chicken]**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**
Parmesan chicken	Pressure cooker	0.554	128.1	130.5	19%	20%	18%	5.4	5	5.7	4.4	4	4.7
	Pressure cooker	0.556	128.6										
	Pressure cooker	0.584	134.9										
	Oven	3.088	713.8	704.2									
	Oven	2.894	668.8										
	Oven	3.159	730.2										
Cajun Chicken	Air fryer	0.441	101.8	102.3	16%	18%	15%	6.2	5.7	6.7	5.2	4.7	5.7
	Air fryer	0.451	104.3										
	Air fryer	0.436	100.8										
	Oven	2.564	592.6	634.2									
	Oven	2.733	631.6										
	Oven	2.935	678.4										

[8] For calculations, GHG reporting conversion factor of 2021 of the UK electric grid was used (BEIS, 2022)

To contextualise these findings, it is important to help the consumers with tangible comparisons so that they can understand how the GHG emissions associated with their cooking choices sit alongside those of other activities. From previous public engagement activities in this field[9], a good example is to compare the emissions of this study to driving a car in the UK.

Considering that the emissions associated with driving an average car in the UK are estimated at 155 g CO_2eq per km, and assuming a speed of 40mph (64.4 kph), it can be estimated that the emissions associated with cooking in the electric oven for this study (704 & 634 g CO_2eq/kg raw chicken) are equivalent to driving a car for around 4 minutes (3.8-4.2 min), as seen in Figure 3. If now they are compared with the emissions from pressure cooker and air fryer, it can be seen that the emissions associated to their energy used for cooking in this study (102 and 131 g CO_2eq/kg raw chicken) are equivalent to less than a minute driving (see Figure 3).

Using this approach, if we consider that an average chicken weights 1.5 kg, it can be inferred that cooking one chicken in an electric oven will be equivalent to driving for around 6 minutes (6.3 - 5.7min), while cooking a chicken in a pressure cooker or in an air fryer will be comparable to the emissions of driving a car for just one minute (1.2 and 09 minutes, respectively).

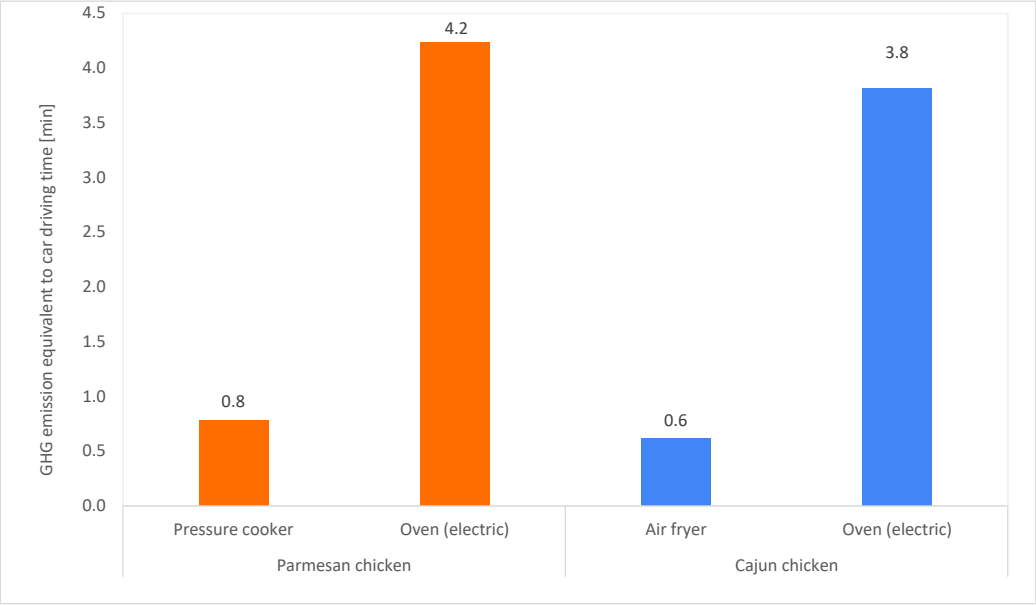

Figure 3 GHG emission equivalent to driving time on a car for the appliances studied. For comparison, data of emissions of an average car in the UK equivalent to 155 g CO_2eq per km, and assuming a speed of 40mph (64.4 kph); data use in engagement material[9]

[9] Games and activities carried out by Take a Bite out of climate change https://www.takeabitecc.org/flashcards.html

It is also important to understand how the emissions associated with cooking sit alongside the GHG emissions associated with all other stages and contributors to food production. As seen in Figure 4, the GHG emissions associated with cooking represent between 1% and 8% of the total impacts associated with the production of chicken.

For the pressure cooker and the air fryer, the results estimated in this study are lower than those found by Frankowska et al. (2020) (1% vs 4% for slow cooker based on raw chicken), however in the case of electric oven, the results of this study are far lower (8% vs 33%). The reasons for these variations are clear; first, Frankowska' s study used self-reported data compared with the measured data of this study, in addition to the assumptions taken for the portion sizes.
Second, in relation to other calculation steps, these studies use different carbon intensity for the UK electricity (e.g., 2019 vs 2021), different fuels for the oven (e.g., mix of electricity and natural gas vs electricity only), different rated power for the appliances, and finally different cooking times reported.

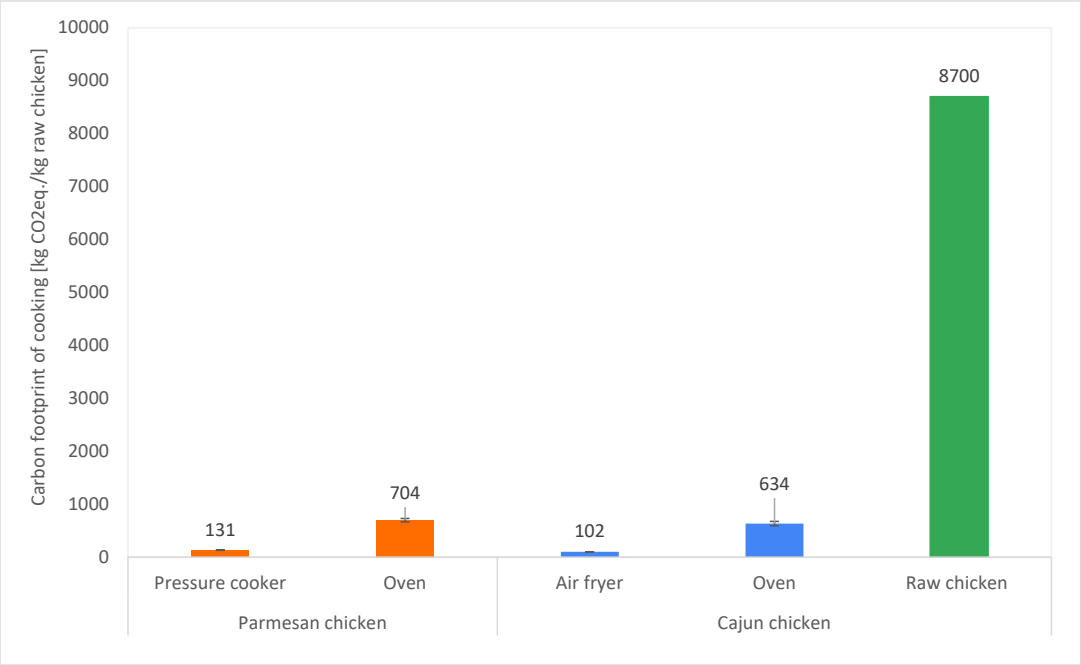

Figure 4 Comparison of the impacts associated to cooking versus the full impacts of raw chicken (pre-consumption: including rearing, processing, distribution and retail); data for chicken was sourced from Poore & Nemecek (2018).

Discussion

These findings showed conclusively that the two Instant Brands devices can consume much less energy than an electric oven when cooking roast chicken. Similarly, the carbon footprint associated to the use of electricity for cooking in the UK with the Instant Brands appliances is also much lower than with an electric oven. The findings provide a good representation of the different energy usage of the appliances studied, and their potential savings in terms of energy and GHG emissions.

Future extrapolations of these results need to consider differences in rated power of the appliances, the energy source (e.g., electric vs gas oven), country of origin, and the user cooking practices, including time, recipes, etc.

We have not replicated the comparison with a selection of domestic ovens, and we would expect some variation in the energy demand for different oven manufacturers and models, and fuel use. Further work would enable us to compare these findings with what is known about the different ovens used in most European households and to extend our conclusions with confidence.

Finally, in terms of calculations, for the Instant Brand appliances, direct meter readers were used, however for the oven, installing meters were not possible due to the testing set up (e.g., existing domestic kitchen). Hence, cooking steps were timed, and temperatures recorded, and the oven reported rated power was used for calculating the energy use. The accuracy of both methods for estimating energy used need to be further explored in future studies.

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Appendix

A1. Oven recipe for Cajun chicken

INGREDIENTS
1.6 kg whole free range chicken
2 tbsp cajun spice
Salt & pepper
Cooking spray oil

INSTRUCTIONS
1. Take chicken out of the fridge 1 hour before cooking to allow it to come to room temperature. Temperature in room should be between 20-22℃.
2. Heat oven to 190ºC/fan 170ºC/gas 5.
3. Pat dry the chicken and combine the cajun spices with the salt and pepper, then rub the spices all over the chicken
4. Spray the chicken with cooking spray then place the whole chicken in the oven.
5. Cook for 1 hour, turning the chicken halfway through cooking.
6. Turn the chicken over again so that it is breast-side up and cook for a further 20 minutes.
7. When the cooking program has finished, use a meat thermometer to check the internal temperature of the chicken is at 75°C. If it isn't quite to temperature, put it back in the oven for another 10-15 minutes.
8. Let the roast chicken rest for 5-10 minutes before serving.

A2. Oven recipe for rosemary and parmesan chicken

INGREDIENTS
2 lemons
3 tsp salt plus more to taste
3 tsp black pepper
2 tsp rosemary chopped
6 rosemary sprigs
2 tsp red pepper flakes plus more for serving optional
1 whole free range chicken about 1.4kg
extra-virgin olive oil for drizzling
45 g parmesan finely grated
900ml chicken stock

INSTRUCTIONS
1. Take chicken out of the fridge 1 hour before cooking to allow it to come to room temperature. Temperature in room should be between 20-22℃.
2. Heat oven to 190ºC/fan 170ºC/gas 5.

3. Finely grate 2 teaspoons of zest from the lemons and place into a small bowl. (Save the zested lemon for the drippings.)
4. Stir in the salt, pepper, chopped rosemary and red-pepper flakes. Season the chicken inside and out with salt mixture and set aside. Stuff cavity of chicken with 2 rosemary springs.
5. Place the chicken breast-side down into a deep ovenproof dish with the stock, and 2 of the rosemary springs.
6. Allow to cook for around 1 hour.
7. Remove from the oven, and using tongs take the chicken out of the dish and drain the water.
8. Transfer to a different clean dry dish, drizzle the chicken with the olive oil and place it back into the oven.
9. Increase temperature to 200°C/fan 180ºC/gas 6 for 25 minutes. In the middle of the cooking process sprinkle the chicken with the parmesan cheese. Continue roasting.
10. When cooking is complete the internal temperature should reach 75°C. Let the chicken rest for 5 to 10 minutes then squeeze juice from one of the zested lemons over the chicken.

A3. Vortex recipe for cajun chicken

INGREDIENTS
1.6 kg whole chicken
2 tbsp cajun spice
Salt & pepper

INSTRUCTIONS
1. Pat dry the chicken and combine the cajun spices with the salt and pepper, then rub the spices all over the chicken
2. Select Air Fry and adjust the temperature to 180°C and the time 60 minutes. Preheat Vortex until display indicates Add Food.
3. Spray the air fryer with cooking spray, then place the whole chicken inside.
4. When prompted to Turn Food, turn the chicken over and continue cooking.
5. With 10 minutes left on the timer, open the tray and turn the chicken over again.
6. When the cooking program has finished, use a meat thermometer to check the internal temperature of the chicken is at 75°C. If it isn't quite to temperature put back in the air fryer for a few more minutes.
7. Let the Air Fryer Roast Chicken rest for 5-10 minutes before serving.

A4. Pro-crisp recipe for rosemary and parmesan chicken

INGREDIENTS
2 lemons
3 tsp salt plus more to taste
3 tsp black pepper

2 tsp rosemary chopped
6 rosemary sprigs
2 tsp red pepper flakes plus more for serving optional
1 whole chicken about 1.4kg
extra-virgin olive oil for drizzling
45 g parmesan finely grated
900ml chicken stock

INSTRUCTIONS

1. Finely grate 2 teaspoons of zest from the lemons and place into a small bowl. (Save the zested lemon for the drippings.)
2. Stir in the salt, pepper, chopped rosemary and red-pepper flakes. Season the chicken inside and out with salt mixture and set aside. Stuff cavity of chicken with 2 rosemary springs.
3. Place the chicken breast-side down into the inner pot and the stock, and 2 of the rosemary springs.
4. Select Pressure Cook, and set to High pressure for 20 minutes, followed by Quick Pressure Release.
5. Remove the lid, and using tongs take the chicken out of the inner pot and drain the water.
6. Making sure that your inner pot is dry, place the air fryer basket (or trivet) into the pot, drizzle the chicken with the olive oil and place it into the basket.
7. Using the Air fryer Lid select Roast at 200°C for 25 minutes. In the middle of the cooking process sprinkle the chicken with the parmesan cheese. Continue roasting.
8. When cooking is complete the internal temperature should reach 75°C. Let the chicken rest for 5 to 10 minutes then squeeze juice from one of the zested lemons over the chicken.